Werribee City Infrastructure Planning

Integrated Water Cycle Management

Planning for the productive use of storm water

INTEGRATED STORMWATER MANAGEMENT AT THE WERRIBEE EMPLOYMENT PRECINCT

BONACCI WATER

50 Hoddle Street Abbotsford 3067 Australia
Telephone 03 9418 4000 Facsimile 03 9418 4001

CULLEN CAPITAL

Level 14, 50 Queen Street Melbourne 3000 Australia
Telephone 03 8256 1714

Authors

Dr. Peter Coombes, Mark Colegate, Josh Bairstow and Andrea McGrath

Acknowledgements

The contributions of Alan Cullen from Cullen Capital, Libby Sampson and Germanus Pause to this project are gratefully acknowledged. This project was assisted by the Interagency Water Cycle Management Working Group that included:

Anthony Monaghan from Wyndham City Council
Bill Marks from the Department of Primary Industries
Chris Chesterfield from Melbourne Water Corporation
Clinton Rodda from Southern Rural Water
David Buntine from Port Phillip and Western Port Catchment Management Authority
Greg Aplin from Wyndham City Council
Jessica Davison from the Environment Protection Authority
Libby Sampson from Department of Planning and Community Development (Chair)
Muthu Muthukaruppan from City West Water
Pat Caruso from Southern Rural Water
Paul Byrne from the Growth Area Authority
Peter Rankin from Melbourne Water
Sam Torre from City West Water
Tom Maidment from VicUrban
Victoria Leavold from VicUrban

This project also benefited from review by the Expert Project Review Panel with the following membership:

Sue Holiday: Chair of the Built Environment Industry Innovation Council
Mike Waller: Chair of Sustainability Victoria
Craig Cook: Public finance advisor
Mike Day: Urban Planner – founding partner of Roberts Day

Version Control

Version	Date	Comment
1	12 /10/2009	Preliminary draft reports for discussion and review
2	20/10/2009	Draft final report for discussion
3	4/11/2009	Draft final report
4	31/01/2010	Final report

i. EXECUTIVE SUMMARY

1. This study has provided a compelling argument for innovation at the Werribee Employment Precinct that will incorporate a precinct based infrastructure planning philosophy. It has utilised an integrated systems analysis to examine the water cycle management options for the Precinct. This has allowed an understanding of the reduced requirements for infrastructure generated by different options.

2. A wide range of options for providing water cycle management services for the Werribee Employment Precinct were assessed against the objectives of the Interagency Working Group that included the goal of a exemplar sustainable development.

3. Innovative stormwater management strategies including establishment of local detention basins, bunds to limit the extent of flooding, water sensitive urban design and rainwater harvesting generate considerable reductions in the area of land required for stormwater management.

4. The stormwater management strategies were resilient to the impacts of the potential for climate change which was expected to increase the area of flood inundation in each Option by about 10 ha.

5. An integrated water cycle management (Option K) that includes the use of stormwater and rainwater harvesting, aquifer storage and recovery, water efficient appliances and gardens, and wastewater reuse from a treatment plant located within the Precinct provided the greatest benefits. These benefits included independence from the regional mains water supply, a better net present value that business as usual, a 68% reduction in wastewater discharges from the Precinct – the surplus treated wastewater and stormwater can supply 2.5 GL/yr to the neighbouring areas and the greatest reductions in greenhouse gas emissions (see Figure i).

6. The alternative water cycle management Options were resilient to the impacts of climate change due to reliance on water efficient practices, local water sources and urbanised catchments.

7. This strategy will also improve the environmental impacts of stormwater discharges from the urban catchments in Werribee and improve the viability of the aquifer adjacent to the site.

Introduction

The proposed Werribee Employment Precinct consists of about 925 ha of Crown Land located near Werribee. The vision for the proposed Werribee Employment Precinct is for a city scale development that provides more job opportunities and services closer to where people live to reduce transport congestion in the south western corridor of metropolitan Melbourne. It will be built to 21st century standards with low emissions.

The Department of Planning and Community Development and VicUrban are preparing a development strategy for the proposed Werribee Employment Precinct. Bonacci Water have been commissioned to develop a systems based integrated water cycle management strategy and policy for the project. This report outlines the investigations into setting objectives for water cycle management including stormwater management at the site.

Objectives

Objectives and targets for water management were developed for the Precinct in accordance with the vision for a sustainable development. These objectives represent current best practice and stretch targets for source control, protection of the health and amenity of waterway ecosystems, mitigation of flooding and minimising the impacts on the water cycle. The stretch targets aim to mitigate water cycle impacts to pre-urban levels where possible.

Options

This study examined a range of alternative options for water cycle management at the Werribee Employment Precinct.

- Option A is the base case (BAU) which assumes that mains water will be the sole source of water supply to the Precinct. The BAU case assumes that potable water will be freed up in the Greater Melbourne water supply system by construction of the Wonthaggi desalination plant and the Food Bowl Modernisation project. All sewerage generated by the Precinct will discharge to the Western Trunk Sewer and the site will utilise the existing stormwater management infrastructure with traditional drainage strategies.

- Options B – J consider the use of water efficient appliances and gardens, stormwater and rainwater harvesting, Water Sensitive Urban Design (WSUD), wastewater reuse from local and Precinct scale treatment plants.

- Option K is an integrated water cycle management strategy incorporating most of the above elements. This strategy meets the objectives of the Interagency Working Group and includes treated effluent from a wastewater treatment plant located within the Precinct used for toilet flushing, garden watering and open space irrigation. Class A+ treated effluent will be distributed to households and commercial users via a third pipe distribution network. Rainwater harvested from roofs and treated to appropriate standards will supply laundry, bathroom and hot water demands. All other water demands will be supplied from stormwater stored in the aquifer that is extracted and treated to drinking water standards as required by the development.

Results

The best options reduce demand on regional mains water supplies, minimise sewerage discharges and have a positive net present value, while reducing greenhouse gas emissions in comparison to the Business As Usual (BAU) Option. Option K (Figure i) provided an optimum response to these multiple objectives.

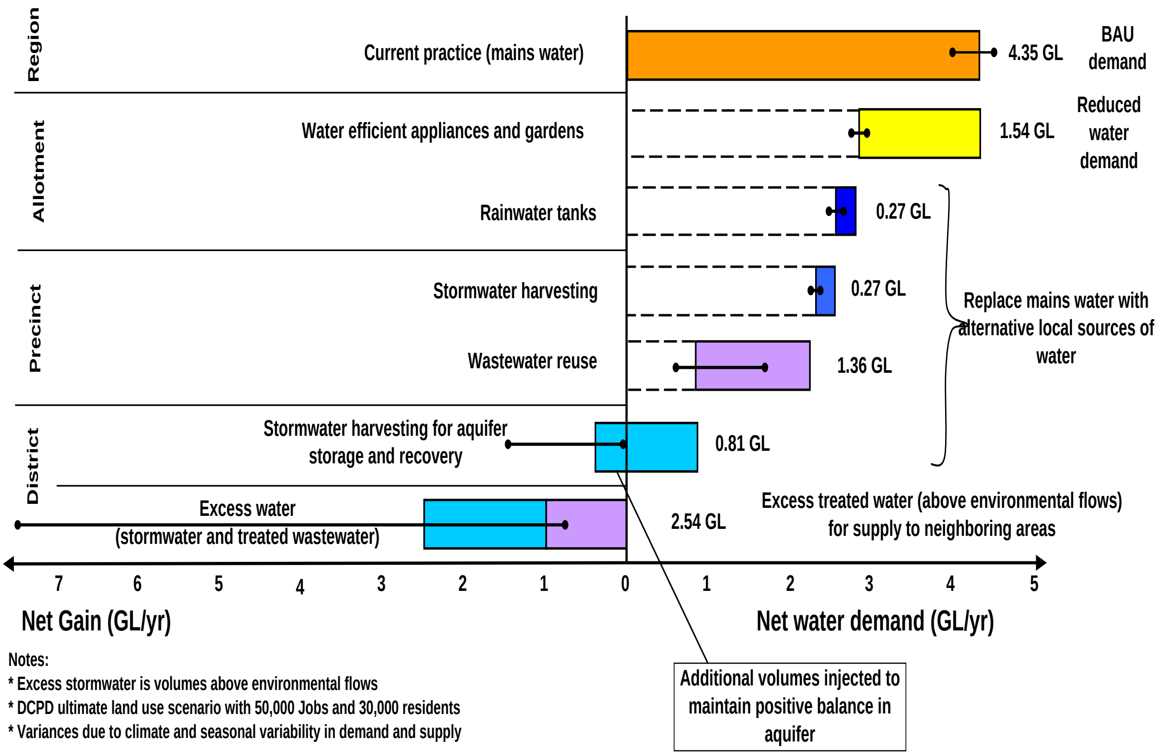

Figure i: Water balance for Option K – the graph highlights the opportunities for the new city to be water positive, generating more water than it uses (local water supply to neighboring areas)

Option K provided a range of performance outcomes that were consistent with the objectives of this study. The Option combines stormwater and rainwater harvesting, water sensitive urban design and water efficient appliances with treated effluent from a wastewater treatment plant located within the Precinct used for toilet flushing, garden watering and open space irrigation. Class A+ treated effluent will be distributed to households and commercial users via a third pipe distribution network. This system will be supplemented by stormwater extracted from the aquifer that is treated to drinking water standards.

Option K was found to be independent of regional mains water supplies, a decrease in sewerage discharges from the Precinct by 68% - this surplus treated wastewater (low salinity) will be supplied to the surrounding areas at an average rate of 1.5 GL/yr, and considerable reductions in the requirement for water and sewerage infrastructure that overwhelm the costs of providing and operating the infrastructure. This option also provided the greatest reduction in greenhouse gas emissions of 78%.

The proposed Werribee Employment Precinct is a unique opportunity to create a Precinct that includes provision of more job opportunities closer to where people live to reduce travel into Melbourne for work and to provide sustainable urban growth.

It is ironic in the apparently dry western region of Melbourne that a sustainable and independent mixed use city is possible because the site has an abundance of available water. The urbanised upper catchments discharge more than 3 GL/yr of stormwater to the Precinct at the moment. The fully developed Werribee Employment Precinct will generate stormwater runoff volumes of between 4 GL/yr and 6.5 GL/yr that have low levels of salinity. The Precinct will also generate wastewater discharges of 3.1 GL/yr. The water demands of the fully developed Precinct of 4.35 GL/yr are considerably less than the combined volumes of stormwater and wastewater generated by the Precinct.

An integrated systems approach to infrastructure planning and design will reduce the requirement for water, sewer and stormwater infrastructure. By planning and designing for the best mix of water management options that include wastewater reuse, rainwater harvesting, demand management and water sensitive urban design of stormwater, regional strategies are not required to provide certainty about future urban water supplies at the Precinct.

The Werribee Employment Precinct can be developed as an exemplar sustainable mixed use Precinct with a minimised carbon footprint by adopting infrastructure planning and design principles that make use of all available water sources from within the development area before relying on large external infrastructure upgrades. A localised infrastructure solution also provides increased flexibility in the timing and rate of development.

In addition, an innovative strategy that incorporates a wastewater treatment plant located within the Precinct and utilised an ASR scheme will allow timely allocation of financial resources and infrastructure to the project.

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Project Context

Urban Development Policy

WEP is the largest undeveloped parcel of publicly owned land in metropolitan Melbourne, comprising 925 hectares of predominantly Crown Land historically managed by the Minister for Agriculture. It is located in Wyndham, one of the fastest growing urban areas in Australia with a population that is expected to reach 400,000 by 2050.

Significant jobs and services are required at WEP to manage the transport congestion consequence of this urban growth and avoid generating employment, social and cultural disadvantage in the west.
In September 2008, the Economic and Sustainable Development Committee endorsed a change in Government policy to facilitate the establishment of a mixed-use employment precinct, with the Minister for Planning becoming the lead Minister and DPCD the lead agency. ESDC requested that the Minister for Planning provide a submission in 2009 that sets out a proposed Development Strategy that builds on the emerging technology precinct to accelerated economic development of the site to provide a larger number of jobs across a wider range of industries and sectors, required for the growing western suburbs.

This project was subsequently announced in Melbourne @ 5 million with comment that the site will provide: "more job opportunities close to where people live so there is less need to travel into the city for work"; and "showcase sustainable design with an emphasis on water, energy and transport efficiency".

During 2009, DPCD led, with support from VicUrban, detailed investigations and preparation of a preliminary Development Strategy. This work involved input from 20 organisations, including relevant Government departments and agencies, such as VicRoads, Melbourne Water, the Growth Areas Authority and Sustainability Victoria and included senior staff from Wyndham City Council. Twelve background technical studies were undertaken, including preliminary contamination and heritage assessments and the preparation of transport, storm water and economic studies.

The work to date clearly confirms the potential and importance of this site and project to the long term development of Melbourne's West. This new urban centre, just 25 km from Melbourne's CBD, will provide local jobs, reduce journey times to work, demonstrate urban development that is resilient to the impacts of climate change and deliver exciting business and investment opportunities. It will be a 'mixed use' city with a range of civic, educational, employment, recreational and residential uses that coexist in the one area.

The development strategy has been reviewed by a Government appointed independent Expert Review Panel who found the site presented a unique opportunity in Victoria, and probably Australia, to deliver a leading example of a mixed use urban centre and that early engagement of the private sector will be critical to delivering the vision for a new 21st century city.

In October 2009, Government endorsed the urban development of the site as a vibrant new city, built to 21st century standards (with low emissions) and a designated Climate Smart Innovation District" to provide "more job opportunities close to where people live" and to "showcase sustainable design".
The project will accelerate economic development of the site to build a city that can eventually accommodate 60,000 jobs and 30,000 residents (in 30 to 50 years time).

The sheer size and complexity of the city scale development is unprecedented in Victoria and has the potential to reshape economic, social and cultural opportunities for Melbourne's south-west, and to become a model for future sustainable urban development.

Government's Superordinate Development Objectives for the Site

1. **Plan for a new city** with the potential to eventually accommodate up to 60,000 jobs and 30,000 residents.
2. **Build the city to 21st Century standards with low emissions** and with an integrated land use, water and transport planning as a blueprint for climate smart urban growth.
3. **Designate the precinct as a 'Climate Smart Innovation District'** – this builds on the concept of an 'Enterprise Zone' that has been used successfully overseas to attract investment to priority development sites, such as London Docklands. In this case the focus would be on attracting businesses and investment in advanced "climate smart" built form technologies and to develop a district that is resilient to climate change, increasing energy prices and scarcity of water

Secretaries Taskforce

The Government has establishment of a DPCD led Secretaries Taskforce supported by a dedicated project directorate, reporting to the Minister for Planning, to oversee the next phase of implementation planning for city scale development of the site until ongoing governance arrangements are determined and established. The work program over the next two years involves:

- Oversee an international competitive process to select the initial private sector joint venture partner(s) with initial registration and expressions of interest to develop a short list of suitable Joint Venture Partner(s) (JVP) in 2010. A more formal request for detailed proposals from the short list is to be undertaken in 2010/11

- Provide advice to Government on the establishment of ongoing governance arrangements (including a fit-for-purpose delivery structure with consideration of the need for a statutory development authority), interim and longer term land management and divestment arrangements and other key issues such as DPI revenue expectations

- Prepare a delivery strategy for Government consideration including a framework plan for city scale development of the site that delivers the endorsed objectives, an integrated (district level) infrastructure delivery plan, a business and investment strategy and seed projects. This work needs to be completed in time to inform the second stage of the process to select a JVP and finalise a JV agreement.

- Coordinate the implementation of Government decisions regarding the above issues until ongoing governance arrangements are determined and established

InterAgency Water Cycle Management Working Group

DPCD is leading an InterAgency Water Cycle Management Working Group in the development of an integrated water cycle management strategy for the site and to coordinate the planning for timely and efficient delivery of "climate change ready" trunk infrastructure for essential services. The InterAgency Water Cycle Management Working Group comprises:

Anthony Monaghan, Manager, Asset Management & Maintenance, Wyndham City Council
Bill Marks, Manager Property Strategy and Governance, Infrastructure and Facilities Management Branch, DPI
Chris Chesterfield, General Manager, Waterways Group, Melbourne Water (Corresponding member)
Clinton Rodda, General Manager, Water Supply, Southern Rural Water (Corresponding member)
David Buntine, Chief Executive, Port Phillip & Westernport Catchment Management Authority, (Corresponding member)
Greg Aplin, Director Economic Development & Planning, Wyndham City Council, (Corresponding member)
Jessica Davidson, EPA
Libby Sampson, Senior Project Manager, Werribee Employment Precinct, DPCD (Chair)

Muthu Muthukaruppan, Manager Water Innovation, Water Solutions, City West Water (Corresponding member)
Pat Caruso, Southern Rural Water
Paul Byrne, Manager, Economic Policy, GAA
Peter Rankin, Manager Development Planning, Melbourne Water
Sam Torre, General Manager, Water Solutions, City West Water (Corresponding member)
Tom Maidment, Development Manager, VicUrban

1.2 Study Brief

Bonacci Water were commissioned by Department of Planning and Community Development to prepare an innovative integrated stormwater management strategy for the site based on rigorous scientific and economic analysis that:

- combines surface water and flood risk mitigation with urban form and infrastructure planning to make the new city resilient to the impacts of climate change (a dual focus on managing the nuisance factor in combination with the productive use of storm water as a scarce resource)
- protects the health and amenity of downstream waterway ecosystems
- increases the resilience of the new city to the impacts of climate change and the severe storm events that are projected to occur under high emissions climate change scenario
- identifies the requisite district scale storm water infrastructure as a platform for a water (net) self sufficient city
- sets objectives for water cycle management, including storm water management, at the site for integrated land use, water and transport planning as a blueprint for climate smart urban growth and planning the delivery of trunk infrastructure the site
- incorporates an objective based planning approach that provides developers with significant flexibility to incorporate the latest approaches and technologies in their Precinct Structure Planning

2 SITE CONTEXT

The location of site within the Melbourne metropolitan region is shown in Figure 2.1.

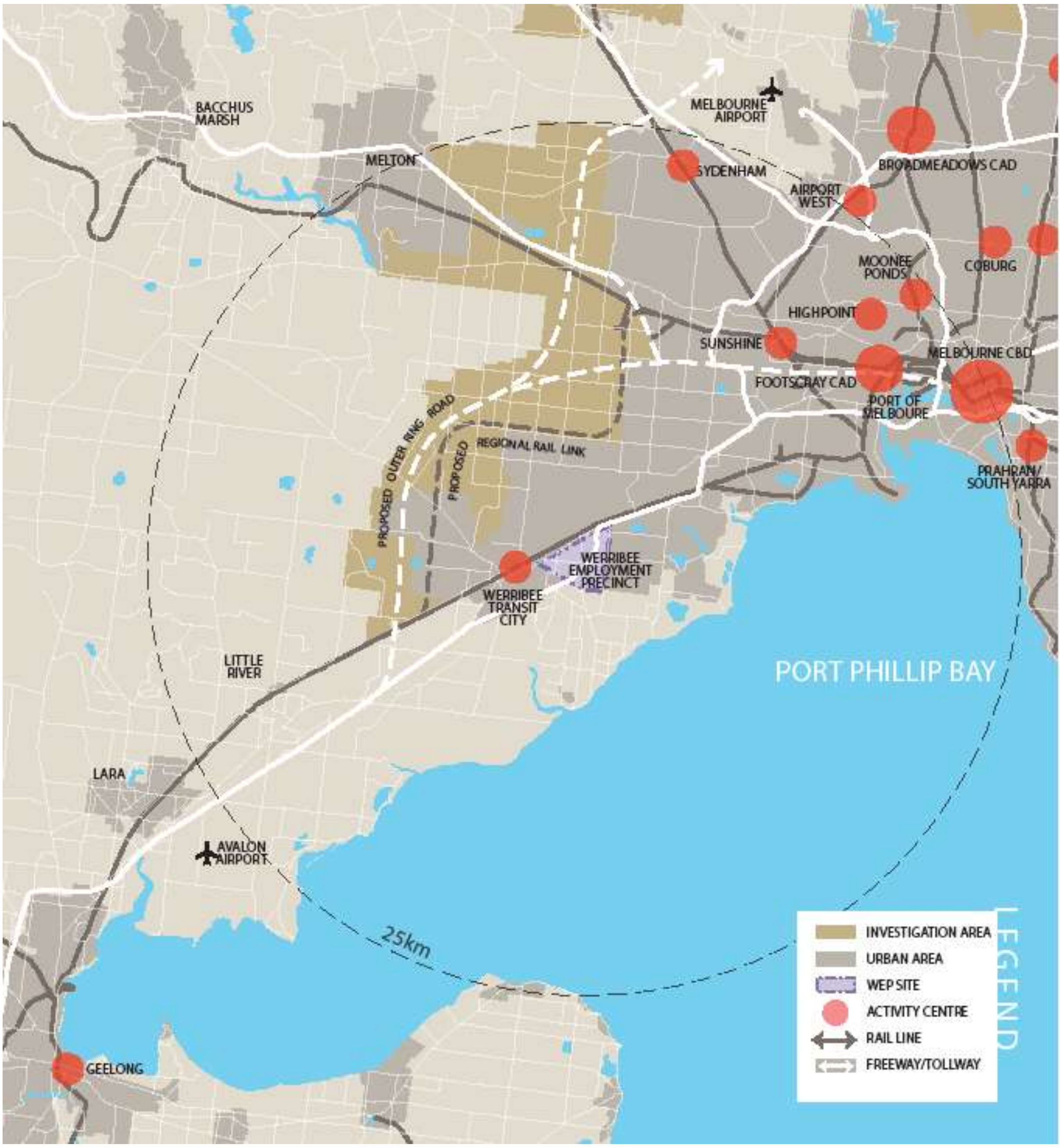

Figure 2.1: The location of the Werribee Employment Precinct with the Melbourne Metropolitan area

The proposed Werribee Employment Precinct consists of about 925 ha of Crown Land located near Werribee (Figure 2.2).

Figure 2.2: Location of the proposed Werribee Employment Precinct

A majority of the developable land area was formerly part of the state research farm. Current land uses include Department of Primary Industry's scientific research and service delivery programs, and research and development by Food Sciences Australia, Melbourne University and Victoria University.

Bonacci Water have been commissioned to develop a systems based integrated water cycle management strategy and policy for the project. This report outlines the investigations into setting objectives for water cycle management including stormwater management at the site.

2.1 Geology

The Werribee Employment Precinct is situated on Werribee River Delta deposits and Newer Volcanic known as the Werribee River Basin[1]. Soil profiles at the site consist of a thin upper layer of windblown and clayey silts (up to 2.1 m thick). A layer of residual basaltic clay (thickness up to 5.2 m) underlays the silt. Weathered basalt is found at depths greater than 0.7 m under the silt and clay layers. Large areas of the site are flat with poor drainage characteristics.

2.2 Groundwater

The site is located above a shallow aquifer (depth: 0 m to 23 m) that is linked to the Werribee Irrigation District (WID)[2]. The aquifer has a surface at about 10 m AHD within the Werribee Employment Precinct and generally flows towards Port Philip Bay and Werribee River. A majority of the aquifer currently has a brackish to saline water quality with total Dissolved Solids readings ranging from 1,170 to 3,270 mg/L. Ground water from this aquifer is unsuitable for irrigation. The quality and volume of groundwater in the aquifer has declined in recent times – note that the WID is currently subject to zero allocation for irrigation.

The ground water surface levels and salinity in the three nearest bores (59528, 145270 and 59522) to the Werribee Employment Precinct are shown in Figure 2.3 and the locations of these bores are shown in Figure 2.4.

[1] GeoAust (2009). Preliminary geotechnical assessment of the Werribee Employment Precinct
[2] SKM (2005). Werribee Irrigation District groundwater investigations

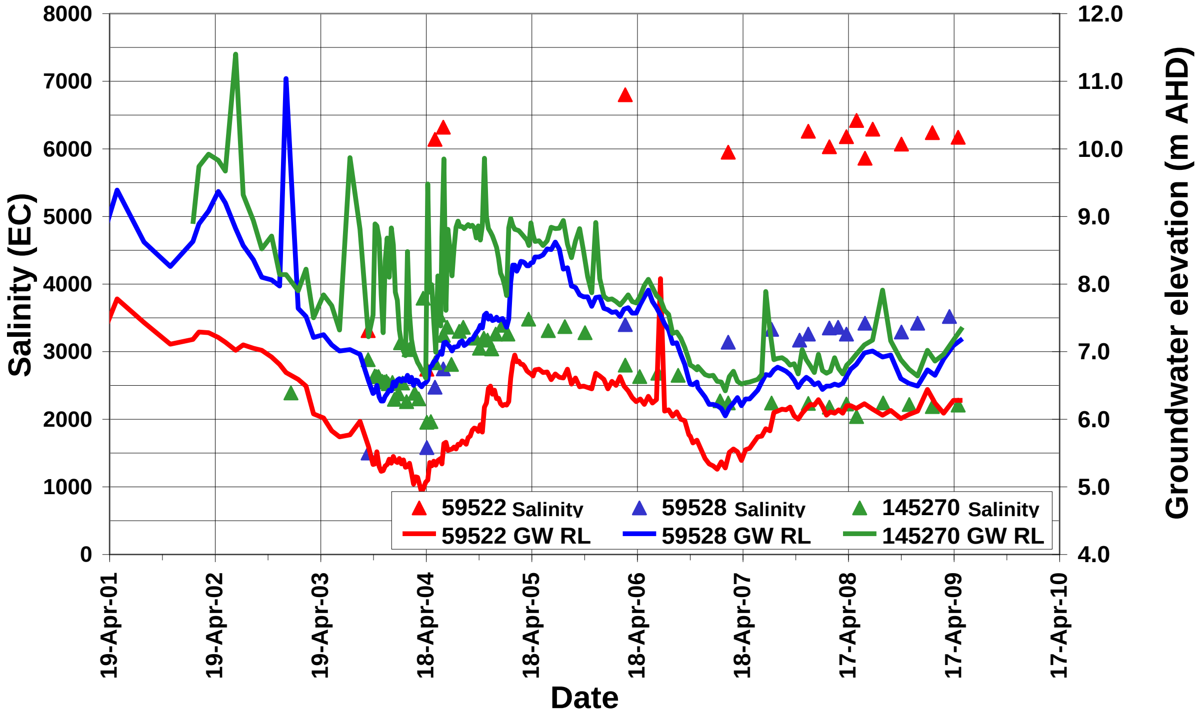

Figure 2.3: Sequence of groundwater surface levels and salinity near the Werribee Employment Precinct – GW RL denotes groundwater surface level

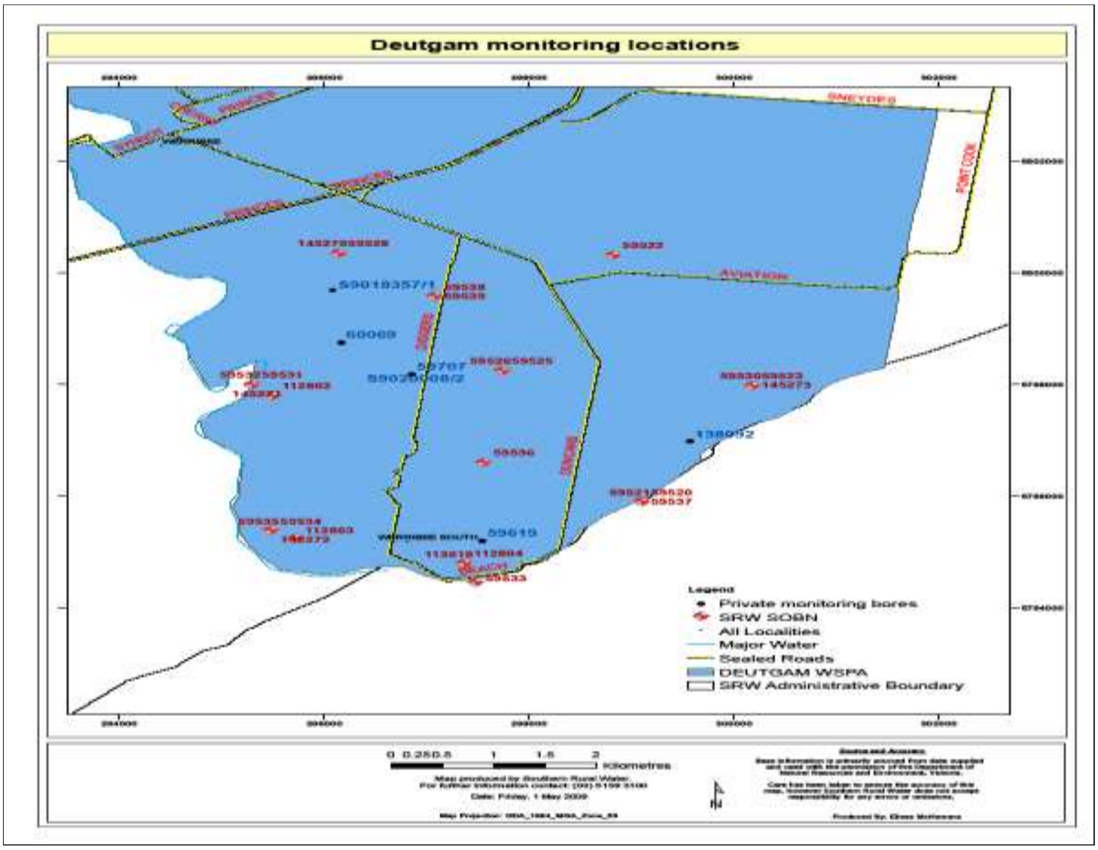

Figure 2.4: Map of bore locations provided by Southern Rural Water

Figure 2.3 shows that ground water surface levels have declined at all locations since April 2001. The salinity levels (as measured using electrical conductivity) at the bore location 59528, which is a similar distance from the coast as the Werribee Employment Precinct, range from 1,500 ms to 3,520 ms. Ground water surface levels are lower and salinity levels greater at locations closer to Port Phillip Bay as shown for bore 59522.

There is potential to inject treated stormwater with lower salinity into the aquifer at the Werribee Employment Precinct in an Aquifer Storage and Recovery (ASR) scheme. This process can improve the salinity levels of the aquifer in the vicinity of the Precinct whilst storing water for use within the Precinct. This process can be successful provided that the balance of recharge to the aquifer and extractions are maintained over a year. Southern Rural Water is responsible for the management of aquifers and licensing water extractions.

2.3 Major infrastructure impacts on the water cycle

The Maltby Bypass passes through the site as shown in Figure 2.2 and the "D1" drain discharges stormwater from Werribee through the site in a north south direction to outlet point A (shown in Figure 2.5). A historical western sewer channel and the newer Western Trunk Sewer are located parallel to the Maltby Bypass which impedes stormwater flows in the D1 drain (Figure 2.5).

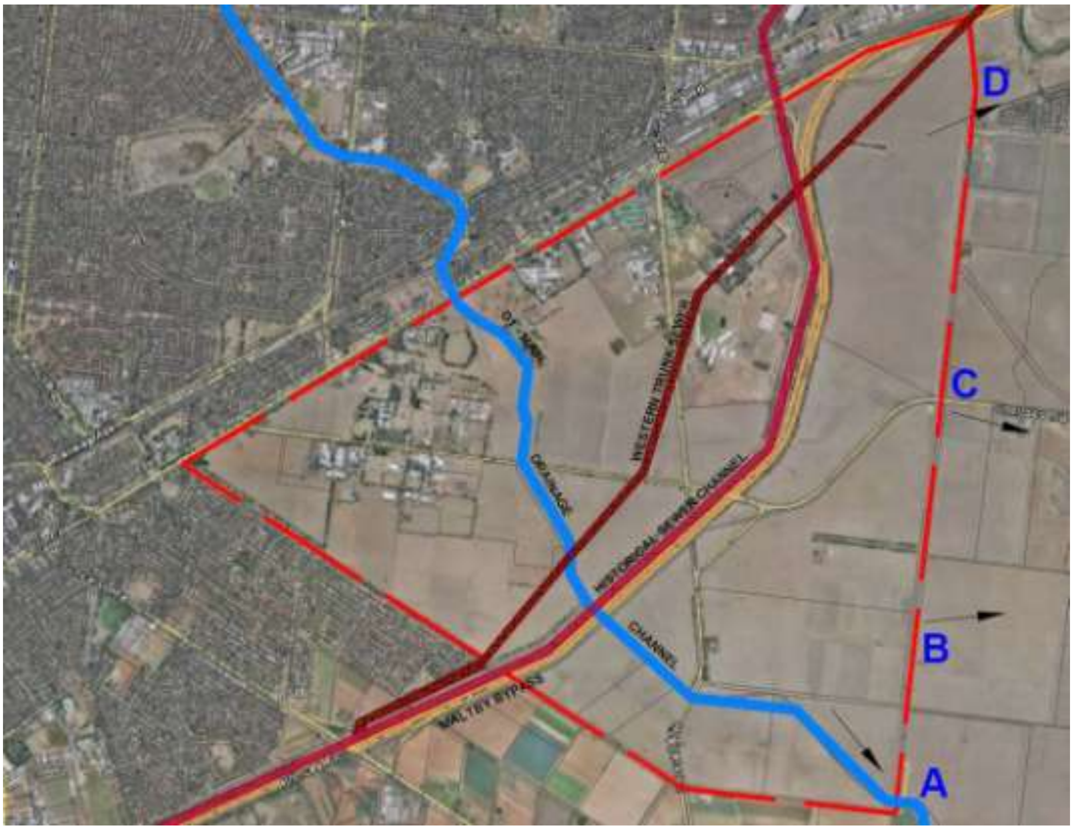

Figure 2.5: Major infrastructure impacts on the water cycle

Melbourne Water's "RB3" detention basin is formed at the intersection of the Western Trunk Sewer and the "D1" drain. At that point the obvert of the sewer conduit is above ground level at about 16 m AHD and the invert of the "D1" drain is at 14 m AHD. Clearly the Western Trunk Sewer is a major impediment to stormwater flows. A siphon (twin 1,800 mm pipes) and a broad crested weir (height of 16.34 AHD and width of 27 m) located at this point allow discharge of stormwater to downstream areas.

Similarly, an embankment surrounding the historical western sewer channel impedes stormwater flows in the "D1" drain downstream of the "RB3" detention basin. Another siphon allows stormwater to pass under the historical sewer channel (discharges of up to 5 m^3/s) and under the Maltby Bypass via a culvert with a maximum capacity of 20.5 m^3/s. Stormwater surcharges from the storage area upstream of the historical sewer channel are likely to enter the channel.

There are currently two Melbourne Water drainage schemes in the vicinity of the Werribee Employment precinct. The Point Cook Development Services Scheme (DSS) 8075 allows stormwater to drain from the Precinct from locations B and C shown in Figure 2.5. Another Melbourne Water Drainage scheme (DSS 135) discharges stormwater towards Skeleton Creek from point D (shown in Figure 2.5).

2.4 Impacts of existing conditions in the upper catchments

The proposed Werribee Employment Precinct is subject to stormwater runoff from a large urbanised catchment (1,015 ha) upstream of the site. Land uses in this catchment include residential housing, shopping centres and road networks. The configuration of stormwater management assets in the upper catchments is shown in Figure 2.6.

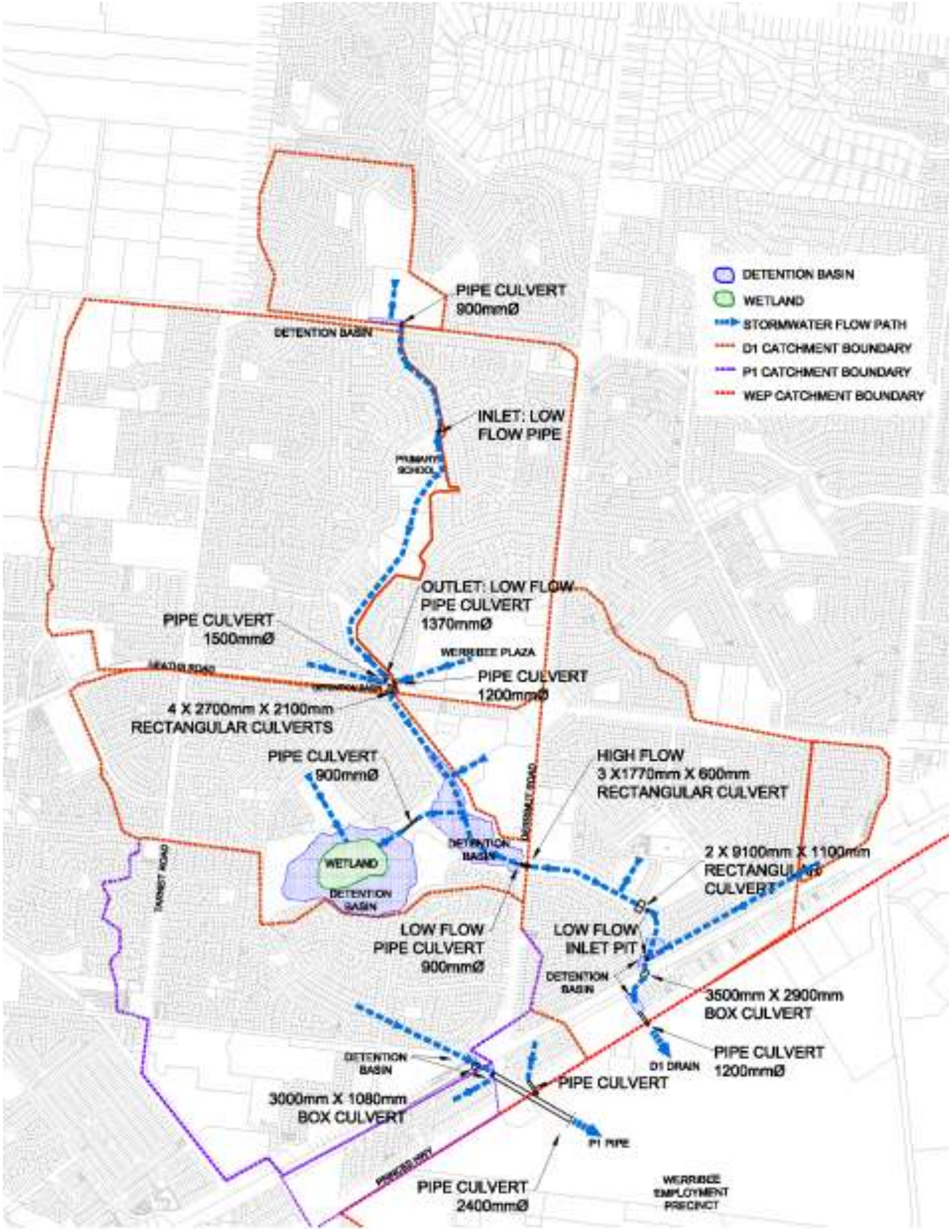

Figure 2.6: The existing stormwater infrastructure in the upper catchments

Figure 2.6 shows that the two different urbanised catchments (denoted as D1 and P1) discharge to the Werribee Employment Precinct. The D1 catchment includes a drainage corridor that discharges to detention basin located below Werribee Plaza that discharges under Derrimut Road towards the Precinct. This catchment also includes a constructed wetland that collects stormwater runoff from a sub-catchment to the east of the D1 drainage corridor before discharging to the detention basin.

The combined storage of the detention basin and constructed wetland does not act to manage all upstream stormwater runoff from the D1 catchment. Field inspections, analysis of the topography and subsequent analysis using two dimensional hydraulic models indicate that the constructed wetland acts as an off-line system from the D1 drainage system that only manages a small part of the catchment. Thus the majority of the stormwater runoff from upstream catchments passes through the smaller online detention basin below Werribee Plaza. Nevertheless, the flat topography of the open space area that contains the detention and wetland systems may allow engineering works to ensure that the combined volumes in the open space is fully utilised to management stormwater runoff.

The increasing impervious areas in the upper catchment have resulted in significant increases in stormwater runoff volumes and peak discharges to the Werribee Employment Precinct over time. The upper catchment also contributes considerable contaminant loads such as suspended solids, phosphorus, nitrogen and litter to the Precinct.

It is expected that infill development will further increase the imperviousness of the upper catchment resulting in larger stormwater runoff volumes and contaminant loads discharging to the site. There is a need for the application of a stormwater management policy in the upper catchments that does not permit increases in peak discharges and contaminant loads.

Responsibility for stormwater management in these catchments has recently passed from Wyndham City Council to Melbourne Water Corporation. It is expected the Melbourne Water Corporation will act as the catchment and waterway manager, whilst Wyndham City Council will continue to management land use and drainage systems within the catchments.

2.5 Climate processes

Australia experiences one of the most variable climate processes on the planet. The extreme natural variation of the continent's climate includes cyclic patterns of droughts and floods throughout recorded history. These variable climatic patterns have resulted in a requirement for additional water cycle infrastructure – for example the capacity of dams supplying Australian cities is more than three times the capacity of dams supplying similar sized cities in Europe and North America.

An understanding of the temporal and spatial variation of climate processes is essential for the development of adequate water cycle management strategies and associated infrastructure. The need to effectively include climate processes in analysis of water resources has increased with the onset of climate change. It is now widely understood that the earth's climate system has been subject to significant warming that will increase the variability of climate processes.[3]

Long term sequences of rainfall at selected locations near Werribee were examined to understand the natural variation of rainfall including the cycle of wet and dry periods which may better describe rainfall processes than speculation about rapid climate change. This phenomenon is known as hydrological persistence.[4] The annual rainfall sequence at Werribee is shown in Figure 2.7.

[3] DSE (2008). Climate change in Victoria: 2008 summary – the Victorian climate change adaptation program.
[4] Whiting J., M. Lambert and A. Metcalf (2006). Identifying persistence in rainfall and streamflow extremes and other hydrological variables. 30th Hydrology and Water Resources Symposium. Engineers Australia. Launceston, Australia.

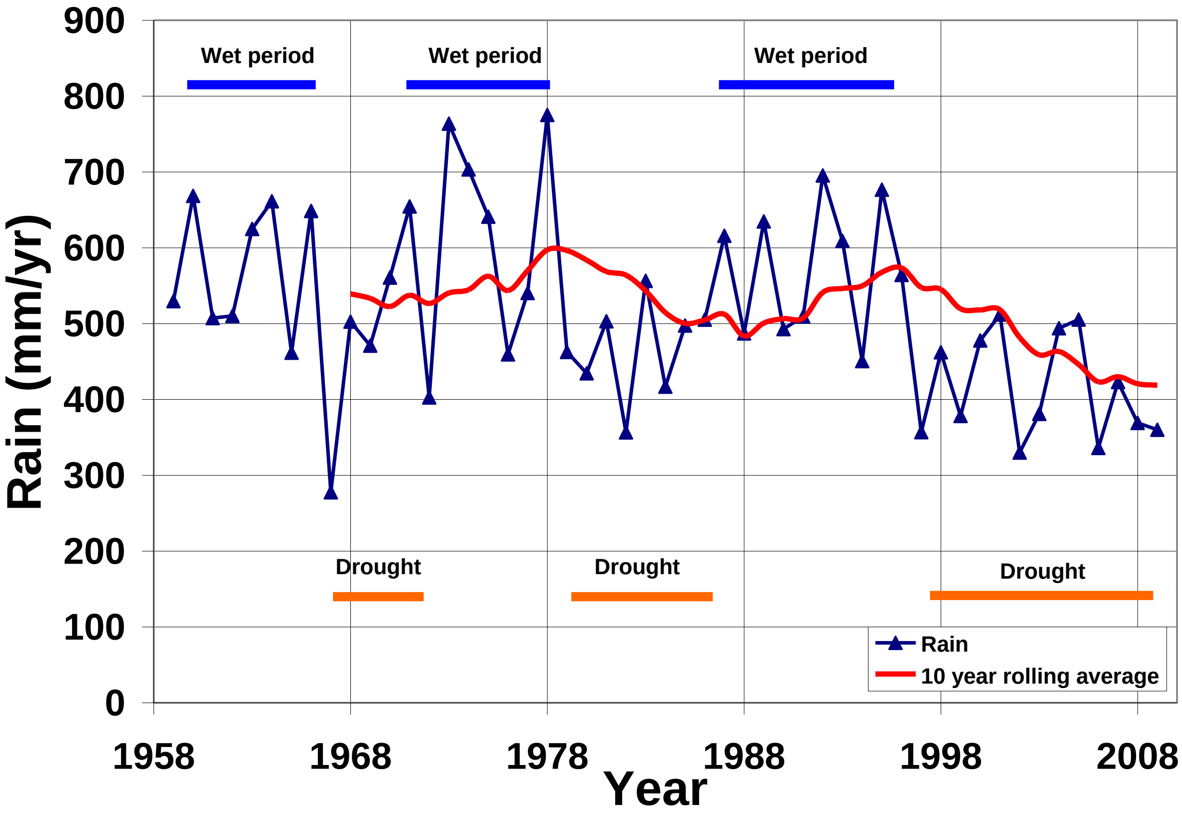

Figure 2.7: Annual rainfall at Werribee

Figure 2.7 shows that the relatively short rainfall record for Werribee includes three drought periods, including the current drought, and three wet periods. Note that the rainfall record includes the decade of highest rainfall (1970s) on record common to most rainfall locations in Australia which in combination with the current drought creates a perception of declining rainfall. The short rainfall record does not provide any certainty about trends in rainfall. The seasonal patterns of rainfall and temperature at Werribee are shown in Figures 2.8 and 2.9 respectively.

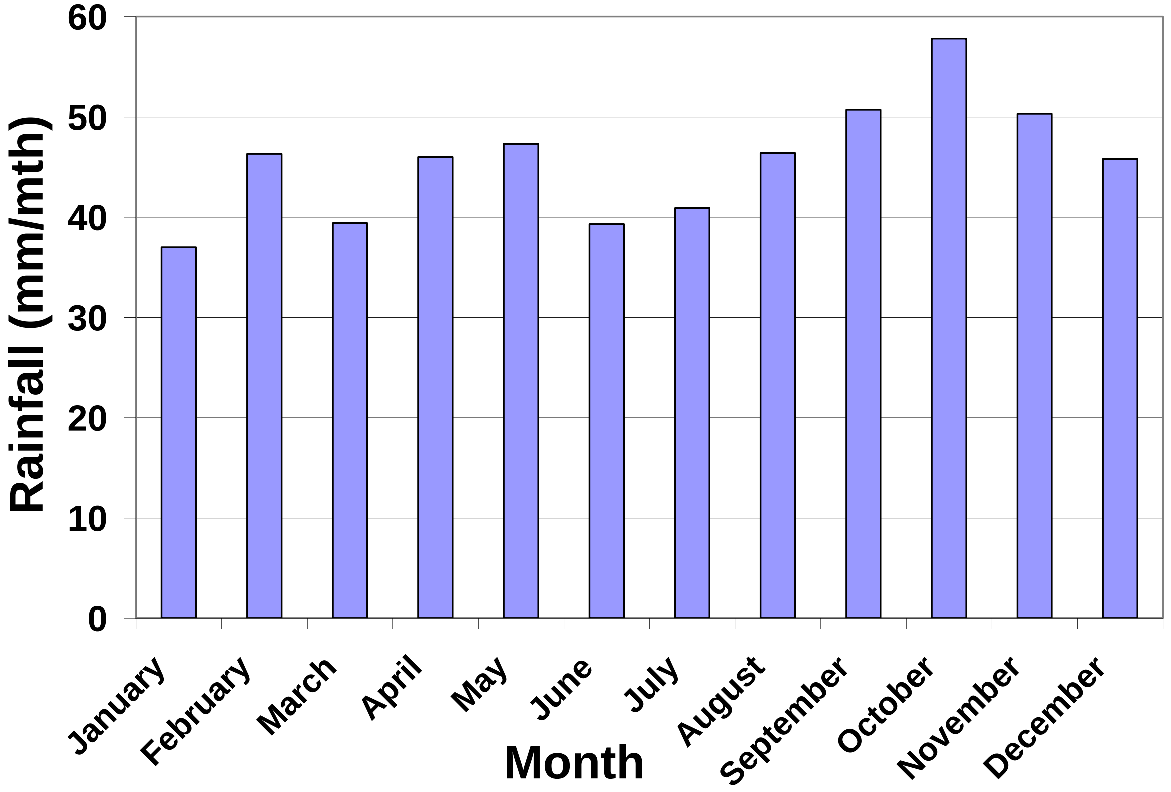

Figure 2.8: Average monthly rainfall at Werribee

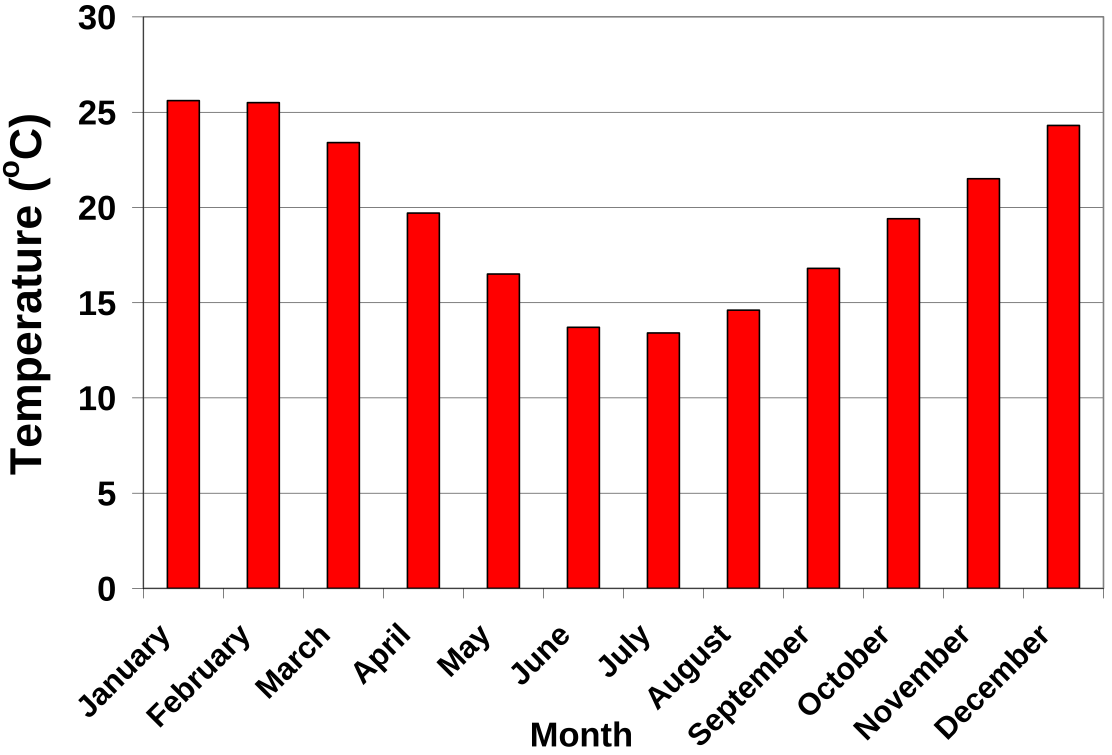

Figure 2.9: Average monthly temperature at Werribee

Figure 2.8 shows that the Werribee area is subject to a relatively even distribution of rainfall throughout the year with higher rainfall during the Spring and Autumn seasons. Figure 2.9 reveals that monthly average temperatures range from greater than 25°C in Summer to less than 14°C in Winter.

The impacts of drought and perhaps climate change on the Werribee area are demonstrated by an increase in temperature by 0.4°C during the last decade (1998 to 2007) in comparison to a thirty year average (1961 to 1990).[5] The region has also been subject to a 14% decrease in annual rainfall during the decade in comparison to the 30 year period (1961 to 1990). However, the 30 year reference period includes the decade of highest rainfall on record. It is likely that the temperature increases in the area represent the impacts of climate change. The longer sequence of annual rainfall at nearby Melton is shown in Figure 2.10 to provide greater certainty about trends in rainfall.

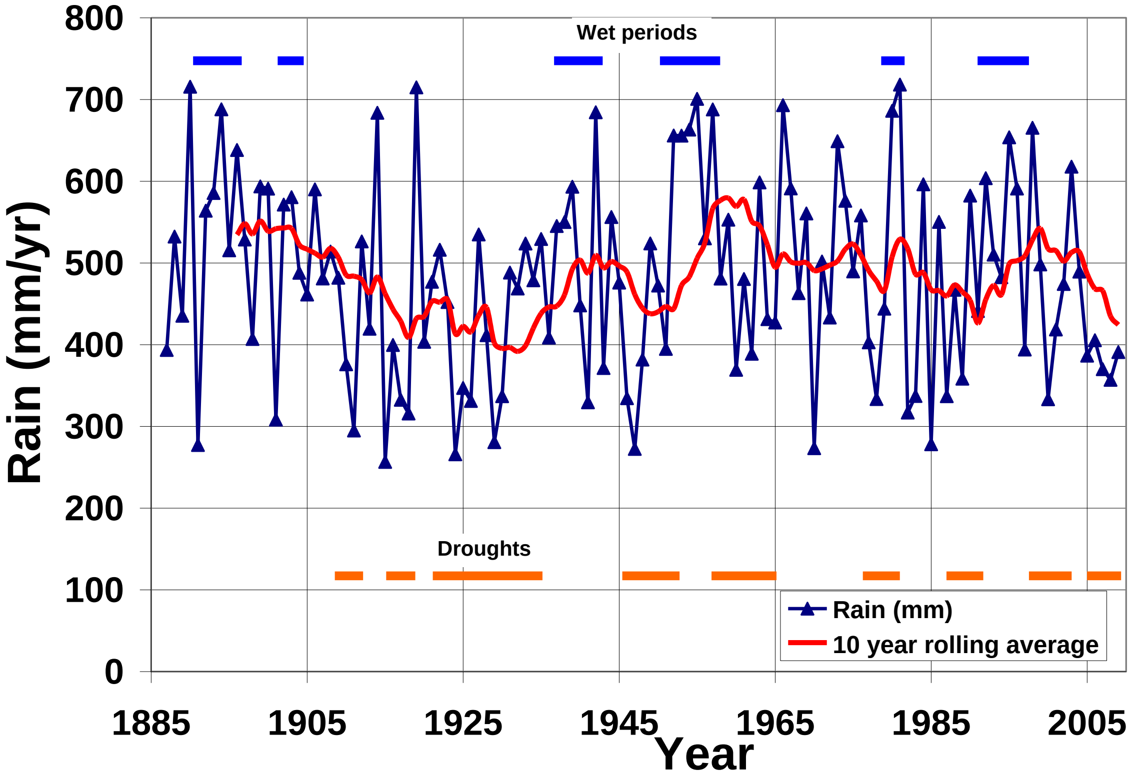

Figure 2.10: The longer annual rainfall sequence at Melton

Figure 2.10 reveals the Melton area was subject to a cycle of higher and lower rainfall periods over a 124 year period. The lower rainfall periods indicate that area has experienced more severe droughts than the current drought. In addition, the rainfall record does not provide evidence of a recent step change to a lower rainfall regime in the record. There is also sufficient rainfall available throughout the record for significant yields from stormwater and rainwater harvesting. The annual rainfall record at Little River which is 18 km south-west of Werribee is shown in Figure 2.11.

[5] DSE (2008). Climate change in Port Phillip and Western Port. The Victorian climate adaptation program.

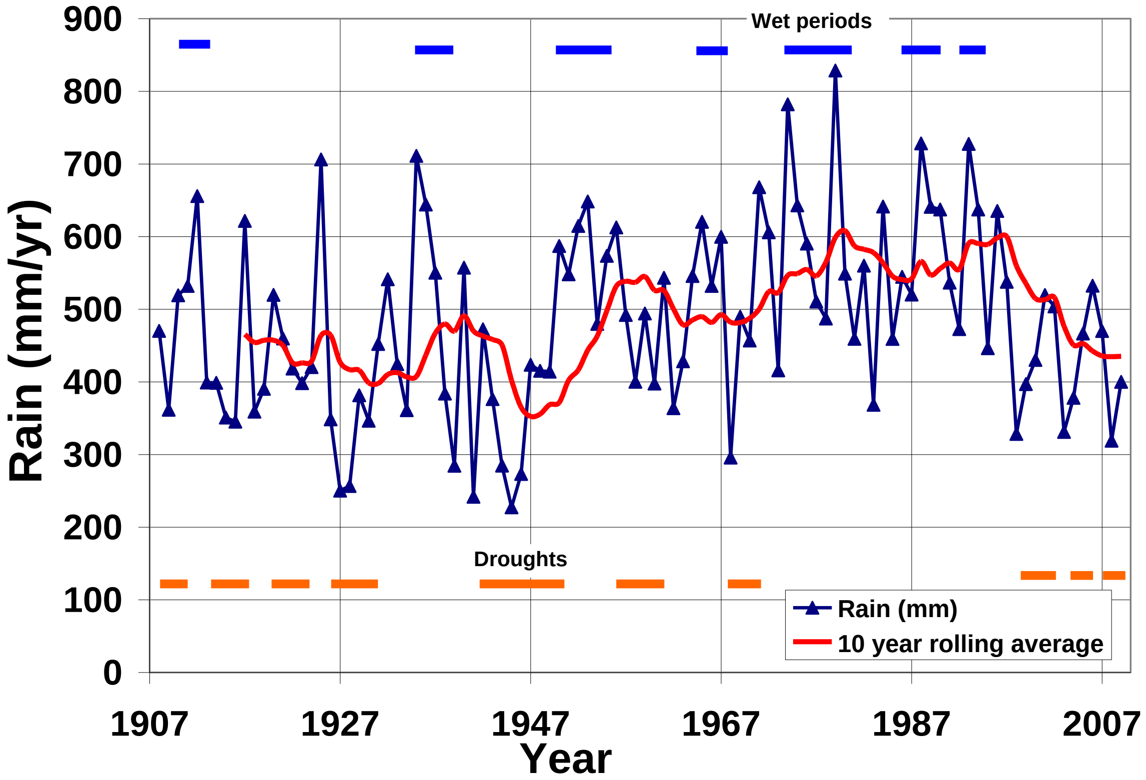

Figure 2.11: The longer sequence of annual rainfall at the Little River

Figure 2.11 reveals the Little River area was subject to a cycle of higher and lower rainfall periods during the 100 year record. The lower rainfall periods during the 1920s and 1940s indicate that area has experienced more severe droughts than the current drought. The rainfall record also does not provide evidence of a recent step change to a lower rainfall regime in the record. There is also sufficient rainfall available throughout the record for significant rainwater stormwater yields from urban catchments.

The longer rainfall records from Little River and Melton demonstrate the natural variability of rainfall in the region. It will be important to incorporate this variability in the analysis of the integrated water cycle management at the Werribee Employment Precinct. This can be achieved by using the most relevant long sequence of rainfall to capture that natural variability of rainfall patterns whilst overlying the expected patterns of climate change.

This approach to analysis of water cycle management strategies for the Werribee Employment Precinct will have the best chance to identify solutions that are resilient to the potential impacts of climate change. The approach captures the uncertainty about the different aspects of climate change – we are fairly certain about increases in temperature but far less certain about impacts on rainfall regimes.

2.6 Security of regional water supplies and relative catchment efficiency

The majority of water supplied to Australian cities has, until been recently, been sourced from rainfall runoff collected from inland catchments. Australia experiences a highly variable climate that has required the construction of large dams to provide a secure water supply to cities. The future reliability of urban water supplies dependent on single centralised sources of water is uncertain due to the combined pressures of population growth, a highly variable climate and the potential for climate change. It is now recognised that multiple sources of water from centralised and decentralised locations in combination with a diverse range of water conservation strategies can increase the resilience and reliability of a city's water supply.[6]

The efficiency of the inland water supply catchments is considerably less than roof and paved catchments in urban areas.[7] It has also been shown that in dry years (rainfall < 500 mm) the annual runoff in water supply catchments is insignificant. In these years water losses to the soil and atmosphere balances most of the rainfall, and as a result water supplies to cities are almost totally dependent on water stored in dams from more bountiful years and from aquifers. In contrast urban catchments, being mostly impervious, only experience small losses at the commencement of each rain event and are able to harvest the majority of rainfall, up until storage overflow. As a result, urban catchments can harvest beneficial volumes of water even during drought years.

This result suggests that rainwater and stormwater harvesting in cities can supplement the performance of dams providing an overall improvement in the resilience of urban water supplies. The concept of relative catchment efficiency is shown in Figures 2.12 and 2.13 using the Thomson catchment suppling Melbourne as an example.[8]

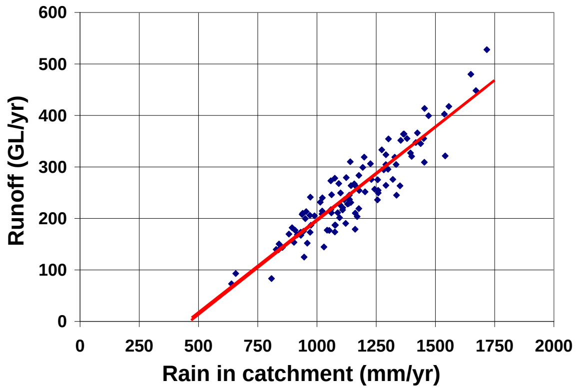

Figure 2.12: Efficiency of Thomson Dam supplying Melbourne

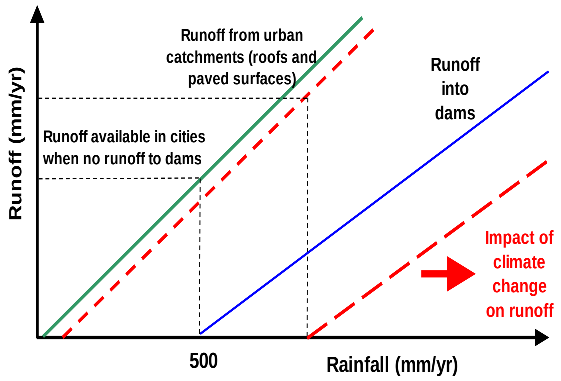

Figure 2.13: Conceptual relative catchment efficiency

Figure 2.12 shows that runoff into Thomson Dam supplying Melbourne diminishes considerably at lower annual rainfall depths to a threshold of no runoff at an annual rainfall of about 500 mm. In Figure 2.13 it is proposed that during years of limited runoff into dams a significant volume of rainwater can be harvested from urban catchments. Urban catchments are expected to have a high relative efficiency for harvesting rainwater and stormwater in comparison to catchments supplying dams. In addition, the impact of climate change is expected to decrease the efficiency of inland water supply catchments relative to catchments within a city.

[6] PMSIEC (2007). Water for our cities – building resilience in a climate of uncertainty. A report by the Prime Minister's Science, Engineering and Innovation Council working group. The Australian Government. Canberra.
[7] Coombes P.J., and G. Kuczera, (2003). Analysis of the performance of rainwater tanks in Australiancapital cities. Proceedings of the 28th International Hydrology and Water Resources Symposium. Wollongong, Australia.
[8] Coombes P.J. and M.E. Barry (2008). The relative efficiency of water supply catchments and rainwater tanks in cities subject to variable climate and the potential for climate change. Australian Journal of Water Resources. Engineers Australia. 12(2)

Relative catchment efficiency

The observed annual rainfall and simulated sequence of runoff into Thomson Dam supplying Melbourne are shown in Figure 2.14.

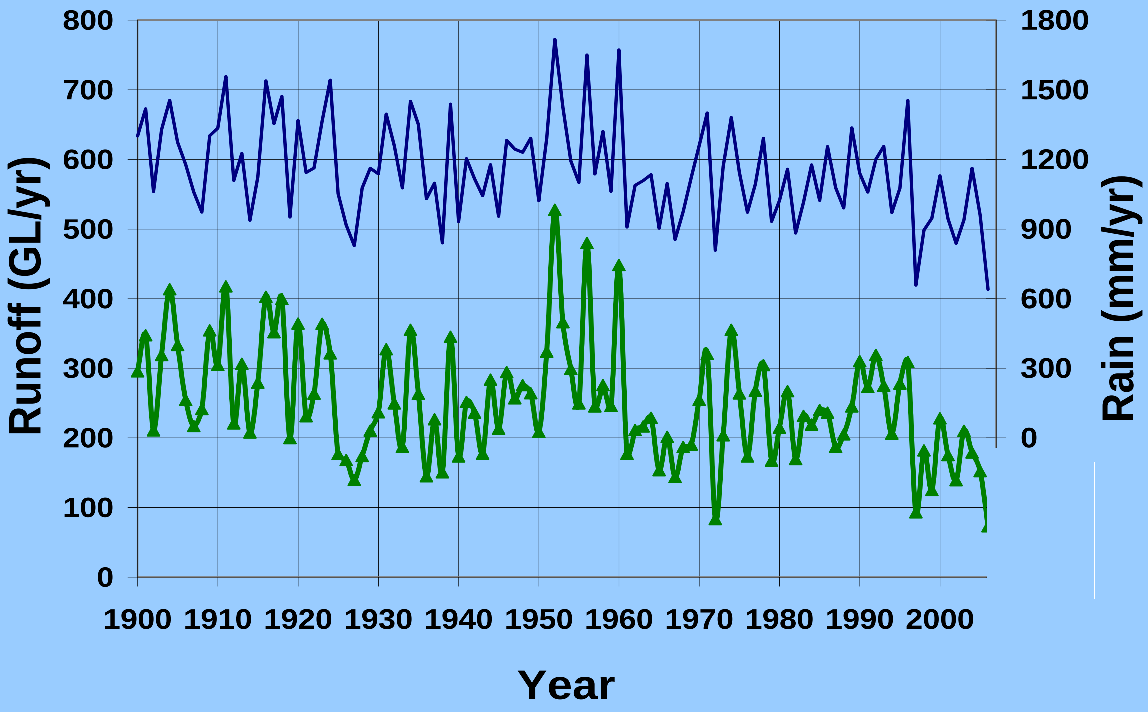

Figure 2.14: Rainfall and runoff sequences at Thomson Dam supplying Melbourne

Figure 2.14 shows that the catchment supplying Thomson Dam is subject to cycles of lower and higher rainfall. The current drought has generated the longest period of low runoff in the record. It is also evident that Thomson catchment may have been subject to a trend to declining runoff during the entire period. The variation in runoff into Thomson Dam supplying Melbourne and yield from 3 kL rainwater tanks in Melbourne is presented in Figure 2.15.

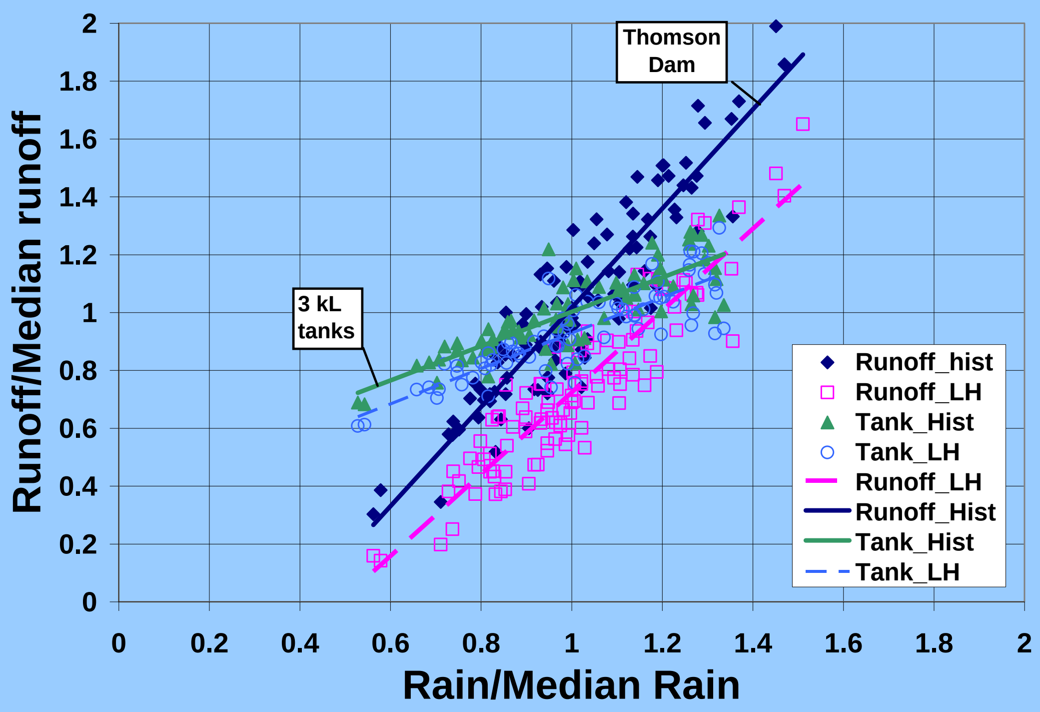

Figure 2.15: Comparative response of catchments and rainwater tanks to climate variation and change in Melbourne

Figure 2.14 reveals that yields from 3 kL rainwater tanks in Melbourne are less dependent on the natural variation in rainfall than runoff into Thomson Dam supplying Melbourne. Median annual rainfall and yield from 3 kL rainwater tanks in Melbourne was 638 mm and 62 kL respectively. Median annual runoff into Thomson Dam from the worst case scenario for climate change in 2030 was 174 GL which represents a 28% reduction in average annual runoff. In contrast median annual yields from rainwater tanks in Melbourne were 58 kL which represents a 7% reduction in yield.

The relative efficiency of traditional water supply catchments and rainwater tanks supplying Melbourne is highlighted by the response to a 50% decrease in median rainfall of an 85% reduction in runoff and a 30% reduction in yield from a 3 kL tank. This may be, at least in part, due to the pervious nature of catchments that generally require significant re-wetting following reduced rainfall in order to generate appreciable runoff. In contrast, rainwater tanks have highly impervious roof catchments and are, therefore, largely immune to the hysteresis exhibited by catchments in runoff generation.

2.7 Greenhouse gas emissions

The planned water future for Greater Melbourne and most Australian capital cities is dependent on high energy strategies including desalination and transport of water across long distances. The full energy costs of augmentation strategies for regional water supplies including desalination and long distance transport of water must be counted. Our plans to mitigate the impacts of climate change must avoid creating further increases in the causes of climate change by the adoption of high energy strategies.

An accurate comparison of energy impacts must assign green energy to all water strategies or assume that all water strategies do not have access to green energy. In either case the energy profiles must be compared to determine the relative requirement for green energy or the relative greenhouse gas emissions. It is expected that greenhouse gas emissions from Greater Melbourne's planned water future will be greater than 4,900 kg/ML. [9]

2.8 Downstream impacts

The Werribee Employment Precinct is situated adjacent to Skeleton Creek and to the north of Werribee River. A majority of stormwater runoff from the site discharges towards Port Philip Bay via the "D1 Drain" and a small proportion of the Precinct discharges towards Skeleton Creek. The "D1 Drain" passes through emerging urban developments and farmlands before discharging to Port Philip Bay near the Point Cook airfield.

Some of the stormwater runoff from the Precinct (discharge points B and C in Figure 2.5) passes through new urban development areas (current being constructed) and remnant brackish wetlands prior to discharging to the "D1 Drain".

Port Philip Bay has been identified as nitrogen limited. Since European settlement the quality of stormwater runoff in waterways discharging to Port Philip Bay has changed significantly due to agricultural, urban and industrial development. Stormwater runoff has been identified as one of the major sources of nitrogen in Port Philip Bay. The Point Cook and Cheetham area of the western shoreline of Port Philip Bay have been identified as a RAMSAR site which supports migratory birds.

---

[9] CSIRO (2008). Water – energy futures for Melbourne: the effect of water strategies, water use and urban form. Kenway S.J., Turner, G.M., Cook, S., and Baynes T. Water for a healthy country flagship report.

It is important to manage the quality and regime of stormwater runoff discharging from the Werribee Catchments and from the Werribee Employment Precinct to protect and enhance the values of the western shores of Port Philip Bay.

3 OBJECTIVES

In accordance with the vision for a sustainable development of the Werribee Employment Precinct objectives and targets for water management are proposed. These objectives represent current best practice and stretch targets for source control, protection of the health and amenity of waterway ecosystems, mitigation of flooding and minimising the impacts on the water cycle (Table 3.1). The stretch targets aim to mitigate water cycle impacts to pre-urban levels where possible.

Table 3.1: Objectives or targets for water cycle management at the Werribee Employment Precinct

Criteria	Objectives or targets	
	Current Practice	**Stretch**
Source Control		
Effective Impervious Areas	Not greater than 30%	Not greater than 5%
Building Form	GreenStar 2	GreenStar 6+
Protecting the health and amenity of waterway ecosystems		
Suspended Solids	80% reduction in average annual urban loads	Maintain average annual loads at pre-urban levels
Total Phosphorus	60% reduction in average annual loads	Maintain average annual loads at pre-urban levels
Total Nitrogen	45% reduction in average annual loads	Maintain average annual loads at pre-urban levels
Litter	70% reduction in average annual loads	No litter discharging to waterways
Flows	Maintain peak discharges from 1.5 ARI storm events at pre-urban levels	Maintain all peak discharges at pre-urban levels
Runoff Days	Limit average annual runoff days to existing levels	Limit average annual runoff days to pre-urban levels
Runoff Volumes	Maintain average annual runoff volumes at existing levels	Maintain average annual runoff volumes at pre-urban levels
Flooding		
Peak stormwater discharges	No worsening compared to existing conditions	No worsening compared to pre-Urban conditions
Water Cycle Management		
Water demands	Reduce demands for mains water by 60% based on 2006 demands	Net self sufficiency
Sewerage discharges	Reduce discharges by 50% based on 2006 sewerage discharges	Net self sufficiency
Salinity	No increase in salinity of waterways and soils	Limit salinity of soils and waterways to pre-urban levels
Energy	No increase in net energy demands in comparison to BAU	No net energy demands
Carbon	No net increase from BAU	Carbon neutral
Climate Change	All water cycle systems resilient when subject to the medium emissions scenario for 2070	All water cycle systems resilient when subject to the high emissions scenario for 2070

The objectives in Table 3.1 include targets for stormwater flow regimes including annual average runoff days and annual average runoff volumes. Targets for stormwater quality include total suspended solids (TSS), total phosphorus (TP), total nitrogen (TN) and litter. The target for total nitrogen, in particular, is important for managing impacts on Port Philip Bay whilst the package of stormwater quality and regime targets aims to protect waterways. Maintenance of 1.5 year average recurrence interval (ARI) storm events at pre-urban levels will protect waterways from erosion and sedimentation.

Objectives for managing building form and limiting effective impervious areas are related to managing stormwater impacts and demands for water at source. Reductions in the effective impervious areas at the allotment or sub-precinct scale will mitigate impacts on waterway health[10].

[10] Walsh C.J. (2004). Protection of instream biota from urban impacts: minimize catchment imperviousness or improve drainage design? Marine and Freshwater Research. 55, 317-326.

Effective impervious area is defined as the impervious area that is directly connected to waterways via stormwater drainage systems.

It is proposed that flooding can be managed by limiting peak stormwater discharges to existing and pre-European conditions.

Reduction of demands for mains water by 60% and discharge of sewerage by 50% in comparison to 2006 levels is a target to drive the water conservation and recycling using current practice. The ultimate objective for water demands and sewerage discharges is net self sufficiency assessed over a 10 year period. Thus net self sufficiency is obtained when mains water demands of the site are balanced by water savings generated by the site.

A salinity target is included to mitigate the increasing salinity of soils and waterways throughout Australia, and in the Werribee region. Urban salinity has the potential to limit the amenity of urban areas whilst creating damage to infrastructure.

Targets for energy and carbon aim for no net increases in comparison to 2006 levels to mitigate the impact of urban development on future climate. The ultimate aim for a carbon neutral development with no increase in net energy demands faces the challenge of minimising impacts of climate change. This action will set an example for future human settlements.

It is also proposed that all water cycle systems at the site are resilient when subject to medium (current practice objective) and high emissions (ultimate objective) scenarios in 2070.

These objectives were endorsed by the members of the InterAgency Working Group to provide direction for this study.

4 STORMWATER MANAGEMENT

A range of stormwater management options were investigated in this study including business as usual (BAU) management and a range of alternatives. All of the following options, other than the pre-European and existing cases, include full development at the Werribee Employment Precinct and upstream catchments with sufficient centralised and decentralised infrastructure to meet either the "current practice" or "stretch" targets defined in Table 3.1. It is expected that all developed options include restoration and/or realignment of the "D1" drain.

Note that this analysis departs from the traditional focus on rapid disposal of stormwater to avoid nuisance from smaller storm events and flood inundation from larger events to an integrated systems approach that also includes stormwater as a valuable resource. Wherever possible the stormwater management options include rainwater and stormwater harvesting.

4.1 Business As Usual with existing stormwater management (BAU_ESM)

The Business As Usual (BAU_ESM) option refers to the fully developed site with existing stormwater infrastructure.

4.2 Option 1: Business as usual (BAU)

This option utilises traditional drainage, the existing "RB3" detention basin on the "D1" drain, and new centralised detention basins, gross pollutant traps (GPT) and constructed wetlands shown in Figure 4.1 to meet the "current practice" and "stretch" targets identified in Table 3.1. This option will also need to operate within the constraints of the historical sewer channel and the western trunk sewer on stormwater connectivity at the site. Note that the obvert of the Western Trunk Sewer is higher than the invert of the D1 drain in this scenario and the only stormwater discharge to the lower reaches of the Werribee Employment Precinct is via the siphon under the historical sewer channel.

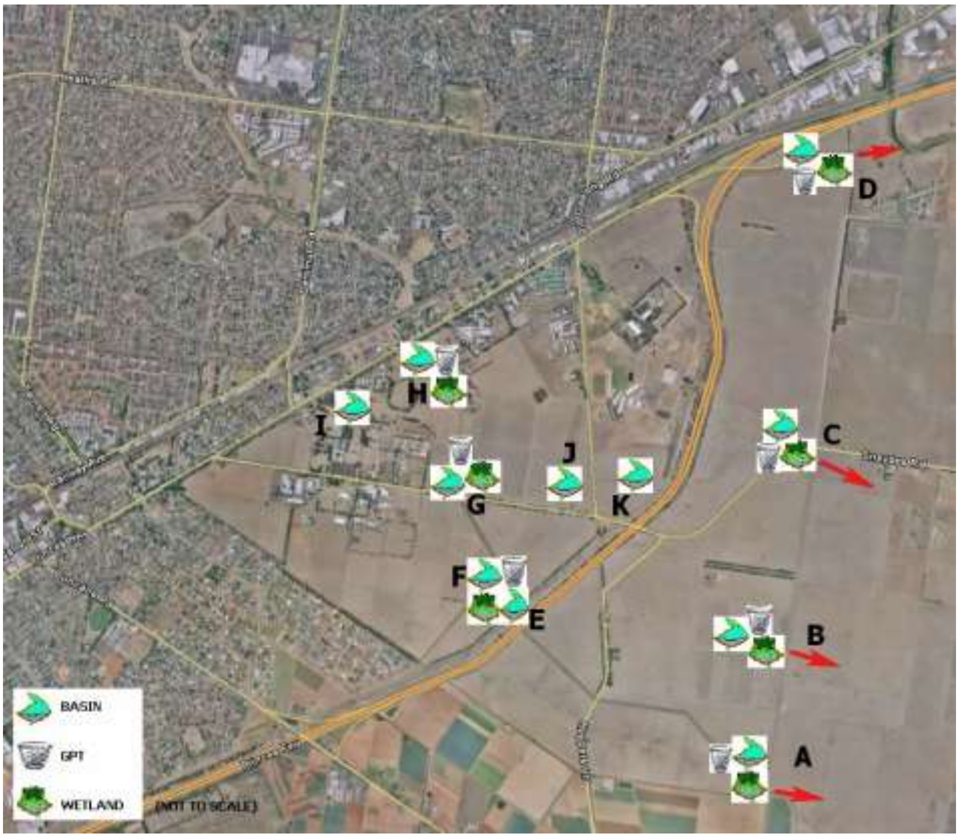

Figure 4.1: Location of detention basins, constructed wetlands and GPTs used in the BAU stormwater management options

4.3 Option 2: Business as Usual with Aqueduct

Option 2 changes the characteristics of the “RB3” detention basin to constrain flooding within a smaller area by use of bunds and includes an aqueduct that bridges the historical sewer channel. The culvert under the Maltby Bypass now acts as the stormwater constraint which allows a maximum discharge under the freeway of 20.5 m^3/s.

4.4 Option 3: Water Sensitive Urban Design (WSUD) with Aqueduct

This option involves creation of precinct scale stormwater management strategies that meet either the “current practice” or “stretch” targets. This option includes WSUD treatment trains of bio-retention facilities and inclusion of defined overland flow paths for control of flood hazards.

Elements of this approach would include swales and bio-retention facilities along appropriate areas of arterial roads such as the medians within dual carriageways, in appropriate suburban streets and public open space. It is assumed that the WSUD systems will be strategically located to reduce the effective impervious areas of the Werribee Employment Precinct.

4.5 Option 3a: Rainwater and Stormwater Harvesting with WSUD and aquaduct

This option incorporates rainwater and stormwater harvesting into the WSUD strategy. Conventional housing will include 5 kL rainwater tanks that collect rainwater from 100 m^2 roof areas for toilet flushing, laundry and for garden watering. It was also assumed that 20,000 L rainwater tanks will collect rainwater from 500 m^2 roof areas of higher density buildings to supply clusters of 10 dwellings. All non-residential areas will also include 50 m^3 of rainwater storage connected to 1,000 m^2 roof areas to supply toilet, outdoor, cooling towers and other non-potable uses per hectare of land area. Each rainwater supply system will include a small first flush device (20 L) and a mains water bypass system for backup during period when water levels in tanks are low.

Rainwater Harvesting: Figure 4.2 shows that the Werribee area has been subject to a number of droughts since 1908 and the current drought may not be the worst on record. Importantly, sufficient annual rainfall is available, even during droughts, to support the reliable annual yields from rainwater tanks. Similarly, Figure 4.3 reveals that the pattern of rainfall in the Werribee area has a relatively even distribution throughout the year which will facilitate a generally reliable seasonal supply of rainwater.

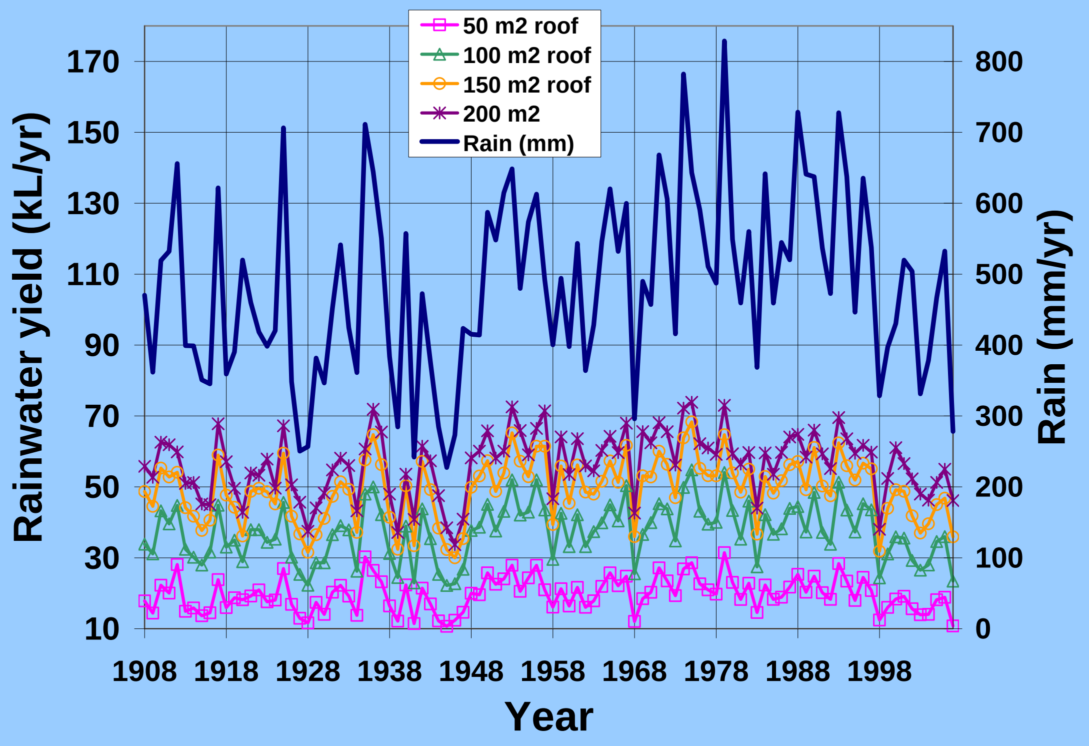

Figure 4.2: Annual rainfall and rainwater yields from 3 kL tanks supplying 2 person households

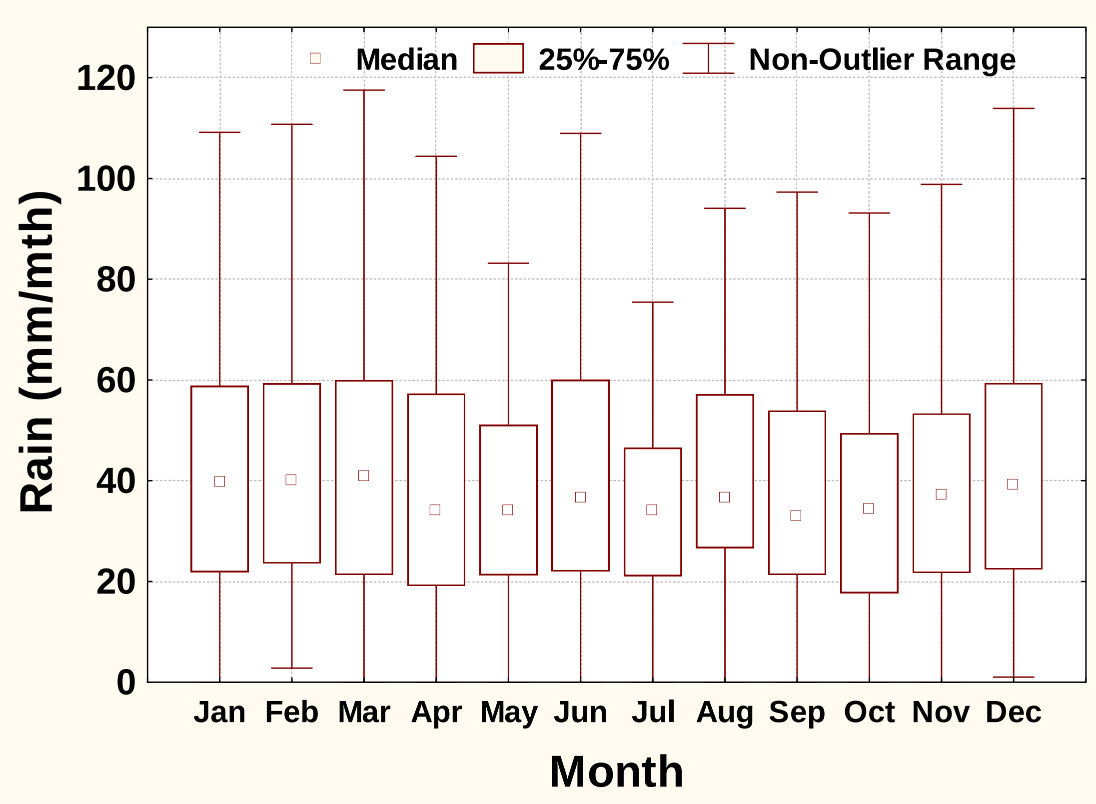

Figure 4.3: Seasonal distribution of rainfall

Investigations into the impacts of climate change on the performance of water resources in Australia has revealed that magnitudes of rainwater yields from tanks in Melbourne were subject to marginal change because the roof surfaces in urban areas are impervious and are, therefore, not subject to the considerable losses that reduce runoff from inland water supply catchments.

4.6 Option 4: Centralised stormwater management with Aqueduct and D1 realignment

This option involves the selection of a new route for the "D1" drain so that the stormwater system can cross the Western Trunk Sewer at a location where the sewer has sufficient depth not to impede the stormwater system and to optimise stormwater connections. This scenario also includes a viaduct over the historical sewer, a centralised treatment train and changes to the characteristics of detention near the Maltby Bypass.

4.7 Option 5: Water Sensitive Urban Design (WSUD) with Aqueduct and D1 realignment

This option involves the selection of a new route for the "D1" drain so that the stormwater system can cross the Western Trunk Sewer at a location where the sewer has sufficient depth not to impede the stormwater system and to optimise stormwater connections. This scenario also includes an aqueduct over the historical sewer, a WSUD treatment train and changes to the characteristics of detention near the Maltby Bypass.

4.8 Option 5a: Rainwater and Stormwater Harvesting with WSUD, realigned waterway and aquaduct

This option incorporates rainwater and stormwater harvesting into Option 5.

4.9 Option 6: Climate Change

Option 6 evaluates the impacts of expected climate change in 2070 on Options 2, 3 and 5 to determine the resilience of the proposed options.

5 INTEGRATED WATER CYCLE MANAGEMENT OPTIONS

A wide range of options were considered to meet whole of water cycle objectives for the project and to complement the options for stormwater management. The options for integrated water cycle management presented in this Section were chosen after consultation with the InterAgency Working Group.

5.1 Option A: Business as Usual (BAU)

Option A is the base case for water cycle management which assumes that mains water will be the sole source of water supply to the Werribee Employment Precinct. The BAU case assumes that additional potable water will be available in the Greater Melbourne water supply system by construction of the Wonthaggi desalination plant and the Food Bowl Modernisation project. It is assumed that all buildings within the Precinct include the equivalent of two star appliances as shown in Table 5.1.

Table 5.1: Characteristics of water efficient appliances in the BAU option

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

This Option was combined with the stormwater Option 1. The magnitude of water flows within the development was assessed using the indicative water network shown in Figure 5.1.

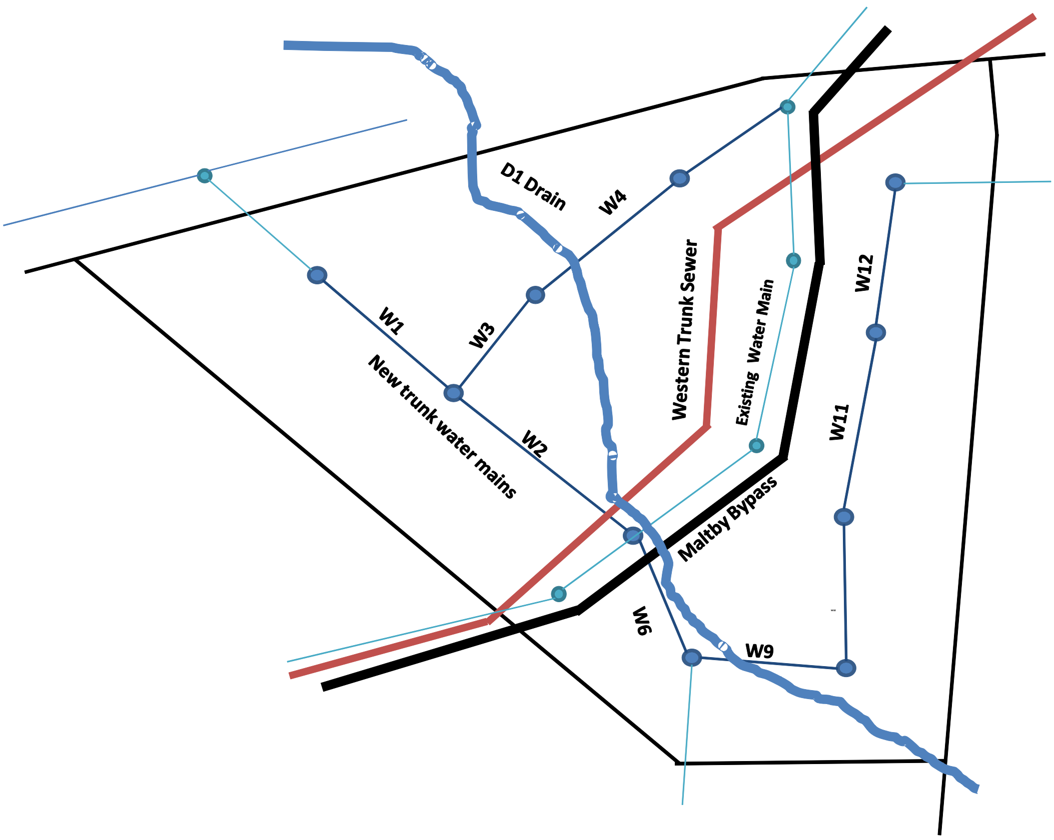

Figure 5.1: Indicative trunk water distribution system used for the analysis of water flows at the Werribee Employment Precinct.

All sewerage from the Werribee Employment Precinct will be directed to the existing Western Trunk Sewer. This will involve the use of rising mains within the development and require significant engineering works to connect to the Western Trunk Sewer. The magnitude of sewerage flows within the development was assessed using the indicative sewerage network shown in Figure 5.2.

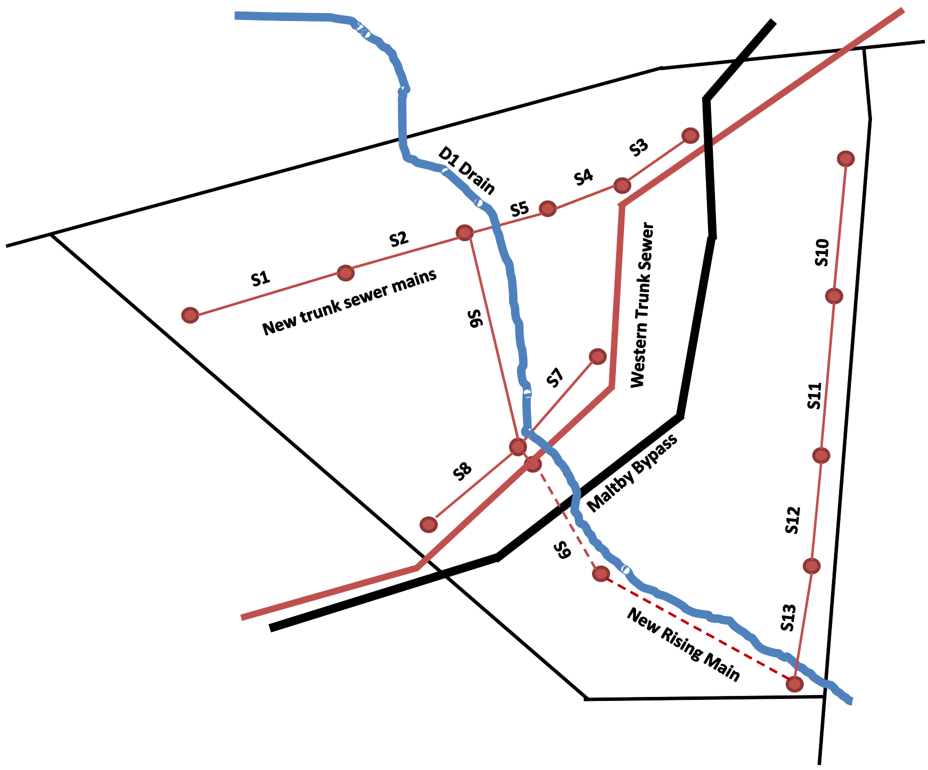

Figure 5.2: Indicative trunk sewerage distribution system used for the analysis of sewerage flows at the Werribee Employment Precinct.

5.2 Option B: Water Efficient Appliances (WEA)

It is assumed that all buildings within the Precinct include the equivalent of six star appliances as shown in Table 5.2.

Table 5.2: Characteristics of water efficient appliances in the BAU option

Appliance	Water use	Reduction (%)
Toilets	4.5/3 Litre flush	10
Taps	4 litres/minute	47
Showers	7 litres/minute	22
Clothes washers	80 litres/wash	38
Outdoor	Low irrigation gardens	50

Water efficient clothes washers are currently adopted in about 8% of Melbourne's households and are expected to reduce laundry water use by 38%. The small proportion of water efficient clothes washers impacting on current water demand trends indicates that adoption in a demand management strategy should produce maximum water savings. This Option was combined with the stormwater Option 2.

Water efficient shower roses have a 52% adoption in Melbourne and are expected to reduce bathroom water use by 22% from current water use patterns. It is expected that the incorporation of water efficient gardens in the Werribee Employment Precinct with support from Council planning policies and a local plant nursery will reduce garden water use by 50%. This strategy has been successfully employed in Multiplex projects in Perth and in Stocklands Projects in Queensland (for example at the Jacobs Ridge development).

5.3 Option C: Rainwater Tanks (RWT) with WEA

Option C evaluates the water cycle management benefits of the use of rainwater tanks for stormwater management in Option 3a as discussed in Section 4.5. Rainwater is used to supply toilet, laundry and outdoor uses. This Option also includes the water efficient strategy outlined in Option B. The stormwater option 3a was included in this Option.

5.4 Option D: Local Wastewater Reuse with WEA

This Option incorporates the use of building or Sub-Precinct scale wastewater treatment plants that supply toilet and outdoor water uses. This strategy will utilise modular membrane bioreactor systems at a range of scales from building to entire Sub-Precinct. These systems are currently available as a complete treatment package. This Option includes the water efficiency strategy outlined in Option B and includes the stormwater Option 3.

5.5 Option E: Local Wastewater Reuse with RWT and WEA

Option E incorporates the local wastewater reuse strategy from Option D with rainwater harvesting for laundry and hot water uses. This Option includes the water efficiency strategy outlined in Option B and includes the stormwater Option 3a.

Analysis of these types of projects that contain integrated infrastructure solutions reveal considerable additional infrastructure savings and benefits at the local scale that has not been directly evaluated in this study.[11] The requirement for water, sewerage and stormwater reticulation infrastructure within the Precinct has been proportioned by the relative magnitude of flows in each system.

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

The author's investigations for these projects have established that use of rainwater in hot water services was a safe and efficient use of rainwater. The rainwater treatment train of a small first flush device, processes of settlement and flocculation in the rainwater storage, the cleansing processes of biofilms on the walls (slime) and on the bottom (sludge) of tanks, and heat death processes in the hot water services form a robust mechanism to deliver rainwater of acceptable quality for household consumption.[12,13]

5.6 Option F: Precinct Scale Wastewater Reuse for Outdoor Uses with WEA

Option F incorporates that use of a Membrane bioreactor (MBR) wastewater treatment plant with ultra-filtration (UF) to service the entire Precinct and supply Class A treated wastewater for outdoor uses via a third pipe network. This Option includes the water efficiency strategy outlined in Option B and includes the stormwater Option 2. The magnitude of flows for wastewater reuse within the development was assessed using the indicative wastewater reuse network shown in Figure 5.3.

[11] WBM (2005). Strategic stormwater study for the Pimpama Coomera Water Futures Strategy. Report for Gold Coast City Council with assistance from Dr. Peter Coombes.

[12] Spinks A.T., R.H. Dunstan, P.J. Coombes, T. Harrison, G. Kuczera, (2006). Heat Inactivation of Pathogenic Bacteria in Water at Sub-boiling Temperatures. Water Research. 40(6). 1326–1332.

[13] Coombes P.J., Hugh Dunstan, Anthony Spinks, Craig Evans and Tracy Harrison (2006). Key Messages from a Decade of Water Quality Research into Roof Collected Rainwater Supplies. 1st National HYDROPOLIS Conference, Perth, Western Australia

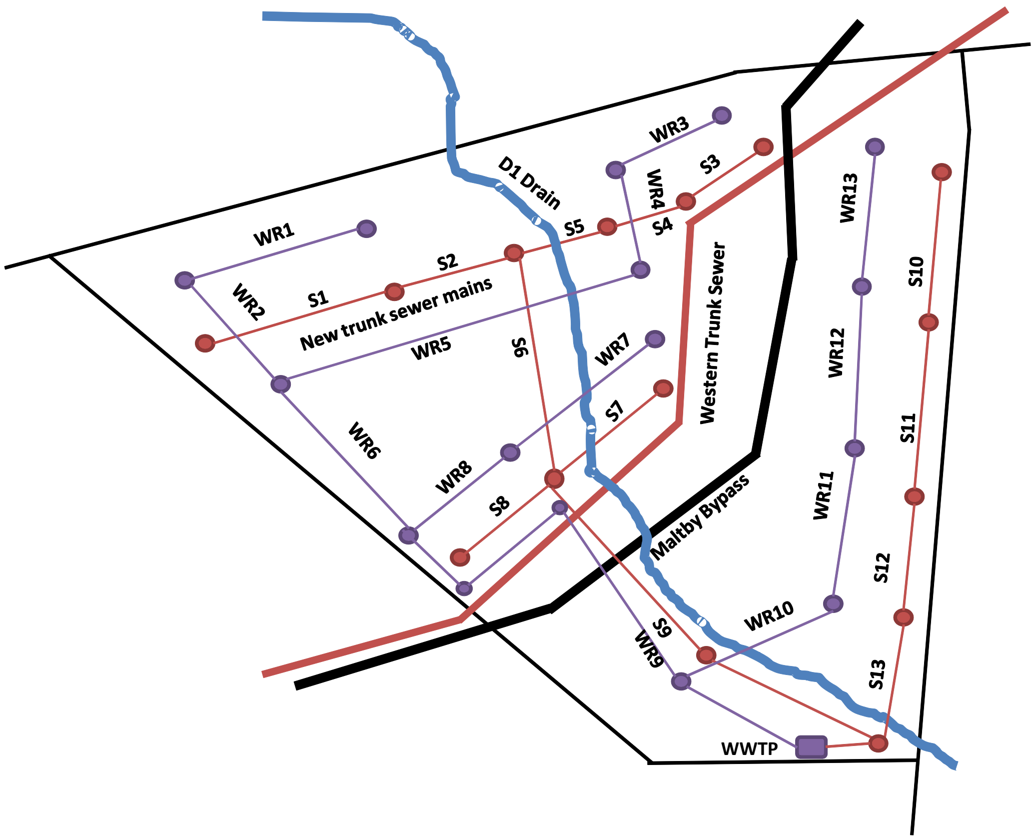

Figure 5.3: Indicative trunk distribution system used for the analysis of wastewater reuse flows at the Werribee Employment Precinct.

5.7 Option G: Precinct Scale Wastewater Reuse for Indoor and Outdoor Uses with WEA

Option G incorporates that use of a Membrane bioreactor (MBR) wastewater treatment plant with ultra-filtration (UF) to service the entire Precinct and supply Class A treated wastewater for toilet flushing and outdoor uses via a third pipe network. This Option includes the water efficiency strategy outlined in Option B and includes the stormwater Option 2.

5.8 Option H: Integrated Water Cycle Management 1

Option H combines the wastewater reuse strategy from Option G and the water efficiency strategy from Option B with rainwater harvesting for laundry and hot water use. Stormwater Option 5a is included in this strategy. This Option is similar to the strategies employed at the Aurora project by VicUrban, at the Pimpama Coomera Water Futures Strategy by Gold Coast City Council and in the Yarrabilba project by Delfin Lendlease.

5.9 Option I: Integrated Water Cycle Management 2

Option I combines the wastewater reuse strategy from Option G and the water efficiency strategy from Option B with rainwater harvesting for laundry, hot water and bathroom use. Stormwater Option 5a is included in this strategy. It is anticipated that rainwater will be treated to drinking water standards using filtration and ultra violet disinfection in this strategy.

5.10 Option J: Aquifer Storage and Recovery (ASR) with WEA and RWT

Option J includes capture of stormwater in a pond for injection via a bore field into the aquifer below the site. Stormwater stored in the aquifer is then extracted and treated to supply toilet flushing and outdoor uses. The water sensitive urban design strategy in Option 5a is used to improve the quality of stormwater prior to injection to the aquifer (Figure 5.4). This Option includes the water efficiency strategy from Option B and rainwater harvesting for laundry and hot water use.

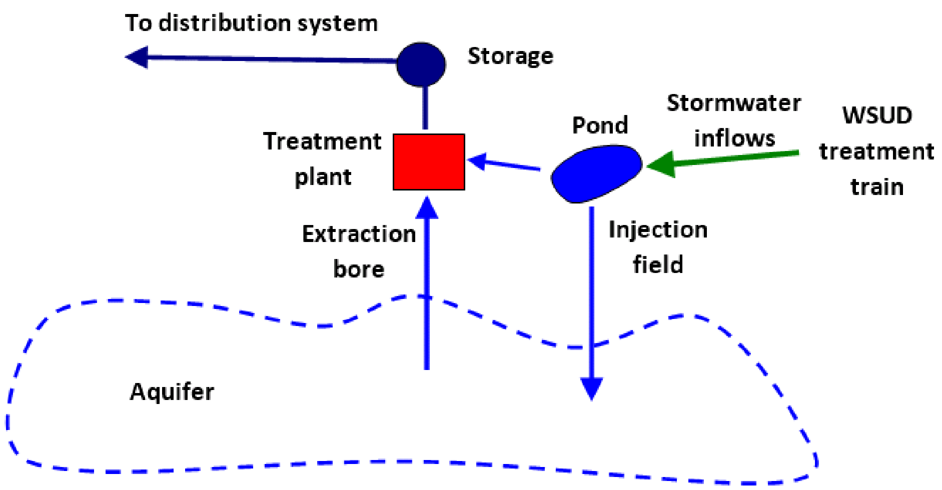

Figure 5.4: Schematic of the aquifer storage and recovery process

The ASR strategy includes a pond with a capacity of 20 ML, an array of bores to inject stormwater into the aquifer, an extraction bore and a water treatment plant. A "working" aquifer storage of 200 ML has been assumed for this study. This strategy will utilise the third pipe network to distribute treated stormwater to end users. The magnitude of flows in the stormwater harvesting system within the development was assessed using the indicative stormwater harvesting network shown in Figure 5.5.

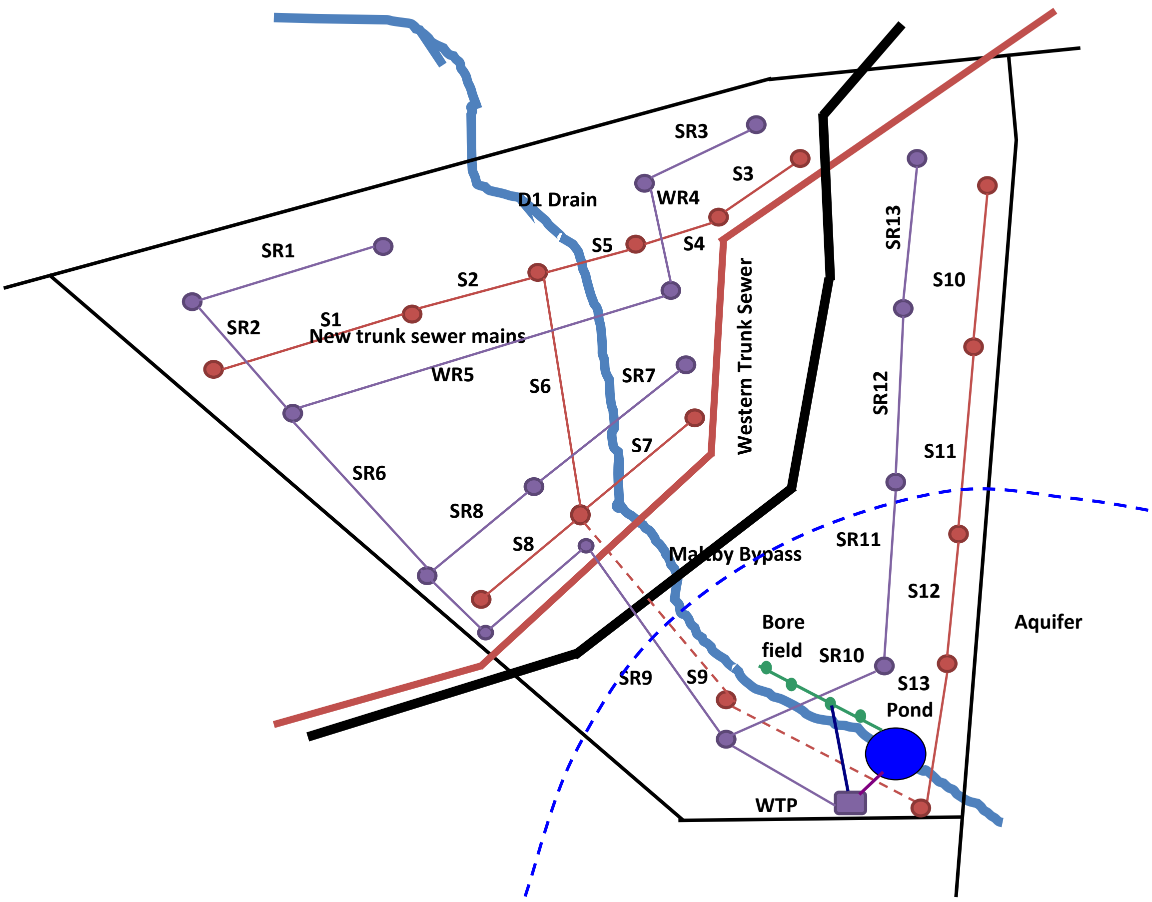

Figure 5.5: Indicative trunk distribution system used for the analysis of flows from the stormwater harvesting system at the Werribee Employment Precinct.

5.11 Option K: Ultimate Integrated Water Cycle Management strategy

Option K is characterised by no water demands from the regional supply and no wastewater discharges to the Western Trunk Sewer. This Option combines the wastewater reuse strategy from Option G and the water efficiency strategy from Option B with rainwater harvesting for laundry, hot water and bathroom use. Stormwater Option 5a is included in this strategy.

It is anticipated that rainwater will be treated to drinking water standards using filtration and ultra violet disinfection in this strategy. Stormwater will be harvested in a pond at the end of a water sensitive urban design treatment train and injected to the aquifer for ultimate recovery and treatment for potable water supply. The magnitude of flows in the stormwater harvesting system within the development was assessed using the indicative stormwater reuse network shown in Figure 5.6.

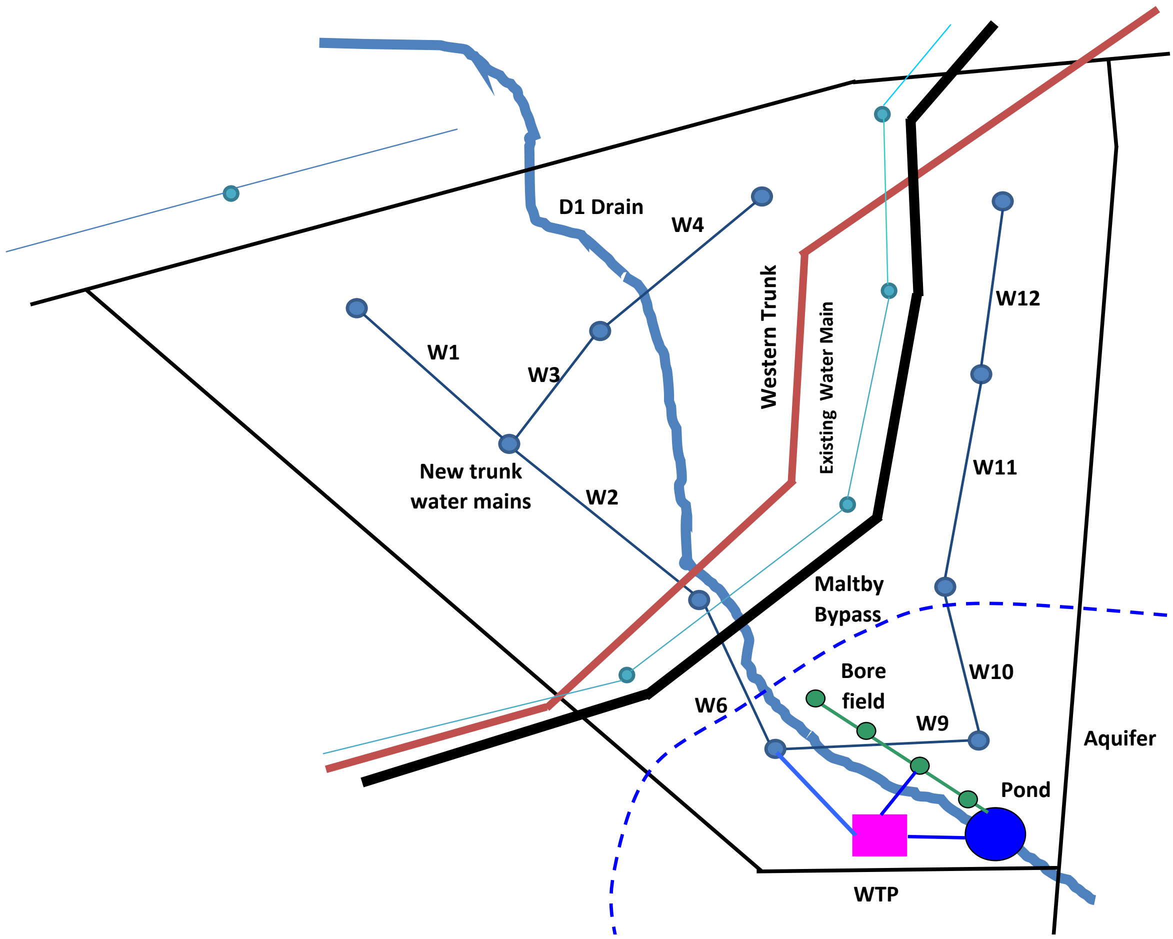

Figure 5.6: Indicative trunk distribution system used for the analysis of flows from the stormwater harvesting system at the Werribee Employment Precinct.

6 METHODS

This study has utilised an integrated systems approach to analysing the performance of a range stormwater and water cycle management options for the Werribee Employment Precinct. This type of analysis is dependent on detailed inputs including topography, sound urban design principles and hydrological design to create an efficient water cycle management strategy.

The topography of the Werribee area was derived from photogrammetry and LiDar data provided by the Department of Sustainability and Environment and augmented with field survey data. The topography, geology and catchments of the area were combined in a digital terrain model (DTM).

A preliminary conceptual development plan for the Precinct was provided by the Department of Planning and Community Development. This allowed assessment of the density of development, proportions of impervious surfaces and water demands. It is important to have an interactive process between urban planners and designers of water cycle systems to disclose the often hidden benefits of integrated water cycle management (IWCM) and water sensitive urban design (WSUD).

This study combined a hydrological model (WUFS) from the University of Newcastle and a two-dimensional hydraulic model (TUFLOW) to analysis the stormwater runoff generated by different options and the extent of flooding. The WUFS model is a variant of ILSAX that utilises the accepted methods and design storm events published in Australian Rainfall and Runoff by Engineers Australia. This model was chosen because it is the only software package that has the capability for robust analysis of integrated stormwater design strategies such as combinations of WSUD and traditional drainage methods.

Analysis of the extent of flooding generated by 100 year average recurrence interval (ARI) storm events was conducted using the hydraulic model TUFLOW that utilised the digital terrain model (DTM) and stormwater runoff hydrographs from each catchment that were generated by the WUFS model. The results from the analysis of flooding were mapped using the vertical mapping functionality provided with the geographical information systems (GIS) software Mapinfo.

This study has undertaken a systems analysis of the Werribee Employment Precinct using linked models. The PURRS model was used to continuously simulate water demands and the performance of lot scale measures (such as water efficient appliances and rainwater tanks) at 6 minute time steps over a 100 year period. The long rainfall record from nearby Little River was utilised rather than the shorter Werribee record to ensure significant droughts are captured in the analysis.

Regional water demand data for the Werribee Employment Precinct was combined with daily rainfall from Little River and evaporation from the Werribee area in the WATHNET model[14]. Performance of the water supply, sewerage disposal and wastewater reuse systems at the different catchments within the Werribee Employment Precinct was simulated at a daily time step.

The WATHNET model is a network linear program for water supply headworks simulation that is a variant of the WASP model originally developed for Melbourne Board of Works and is similar to the REALM model currently used for systems analysis by Melbourne Water. The distribution of stormwater, water, sewerage and recycled water throughout the Werribee Employment Precinct was simulated for a 100 year period.

One thousand climate replicates of this simulation were combined with the potential for climate change to ensure that the probabilities of performance outcomes are understood. This allowed analysis of peak flows in trunk infrastructure and assessment for regional sewerage discharges and water demands. The schematics of the various networks used in this study are shown in Appendix A.

[14] Kuczera, G. (1994). Water supply headworks simulation using network linear programming. *Advances in Engineering Software.* Vol. 14. 55-60.

6.1 Pre-European conditions

Analysis of pre-European conditions included research into the likely historical stormwater flow paths and catchments to establish natural stormwater runoff regimes. These results are used as the basis for comparison to "stretch" targets. The pre-European stormwater catchments are shown in Figure 6.1.

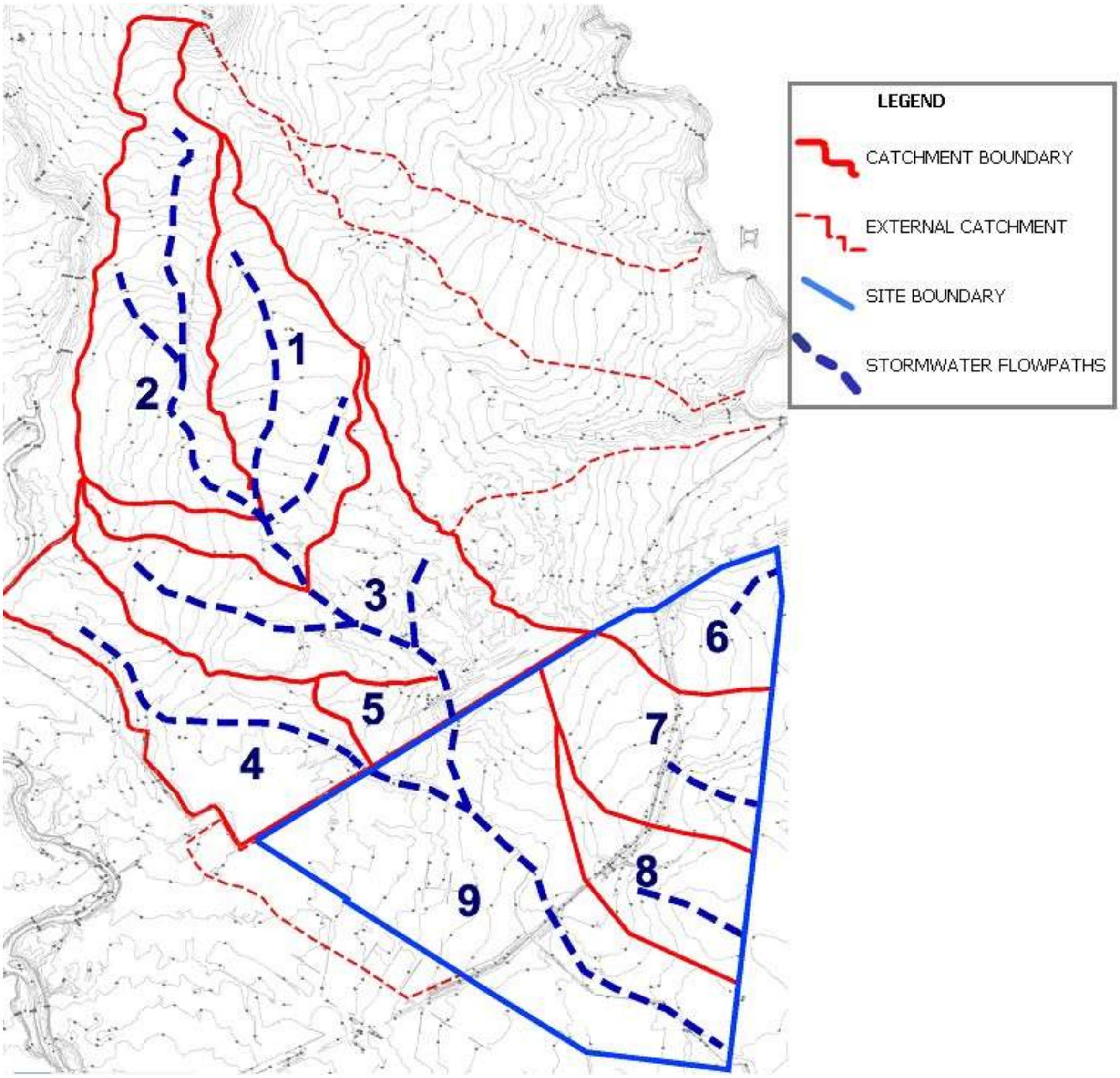

Figure 6.1: Pre-European stormwater catchments used in the analysis

The areas of each of the pre-European catchments used in the analysis are shown in Table 6.1.

Table 6.1: Areas of pre-European catchments

Catchment	Area (ha)
1	164.3
2	269.4
3	179
4	224.6
5	12.9
6	92.2
7	266.7
8	109
9	433

6.2 Existing Conditions

Urbanisation of the upper catchments and associated drainage systems has changed the extent of the catchments as shown in Figure 6.2. Plans of stormwater drainage infrastructure provided by Wyndham City Council were used to define the urban catchments. The construction of the Maltby Bypass, the historical western sewer and the newer western trunk sewer has also changed the extent of stormwater catchments within the proposed Werribee Employment Precinct.

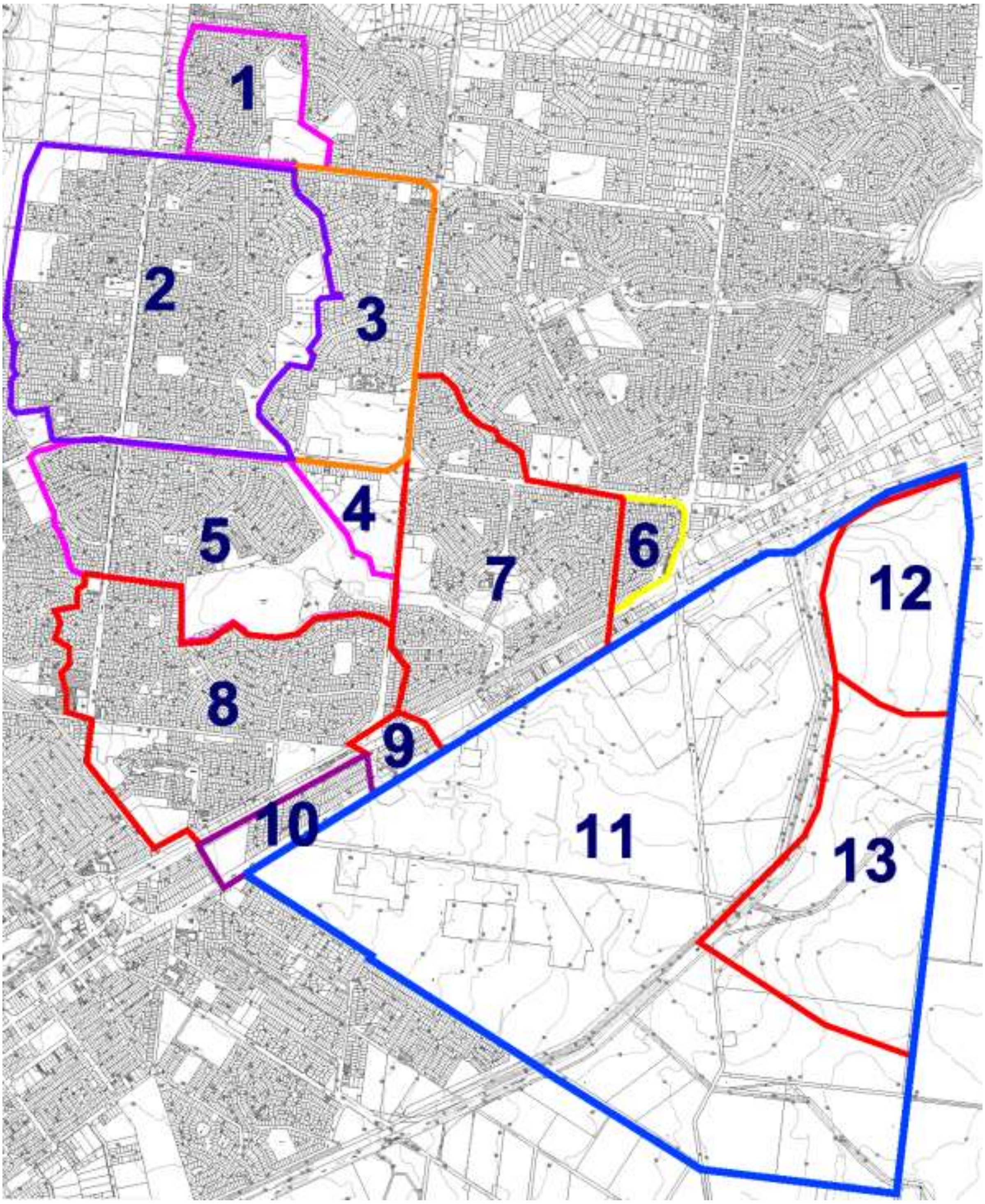

Figure 6.2: Existing urbanised stormwater catchments used in this study

The areas of the existing urbanised catchments used in this study are shown in Table 6.2.

Table 6.2: Urbanised stormwater catchments

Catchment	Area (ha)
1	51.9
2	233.4
3	113.4
4	21.7
5	158.3
6	17.3
7	182.3
8	197.7
9	12.9
10	26.4
11	617.4
12	70.1
13	202.8

Investigation of the existing conditions included analysis of stormwater runoff and flooding regimes. Results from this analysis form the basis for comparison to "current practice" targets.

6.3 DPCD's developed Precinct scenario

The draft Precinct plan shown in Figure 6.3 provided by the Department of Planning and Community Development[15] was utilised to inform the developed options for the Werribee Employment Precinct. Note that this precinct plan may not be the final planning outcome for the site and is only utilised as an indicative plan for water cycle management (see Appendix F for the draft report).

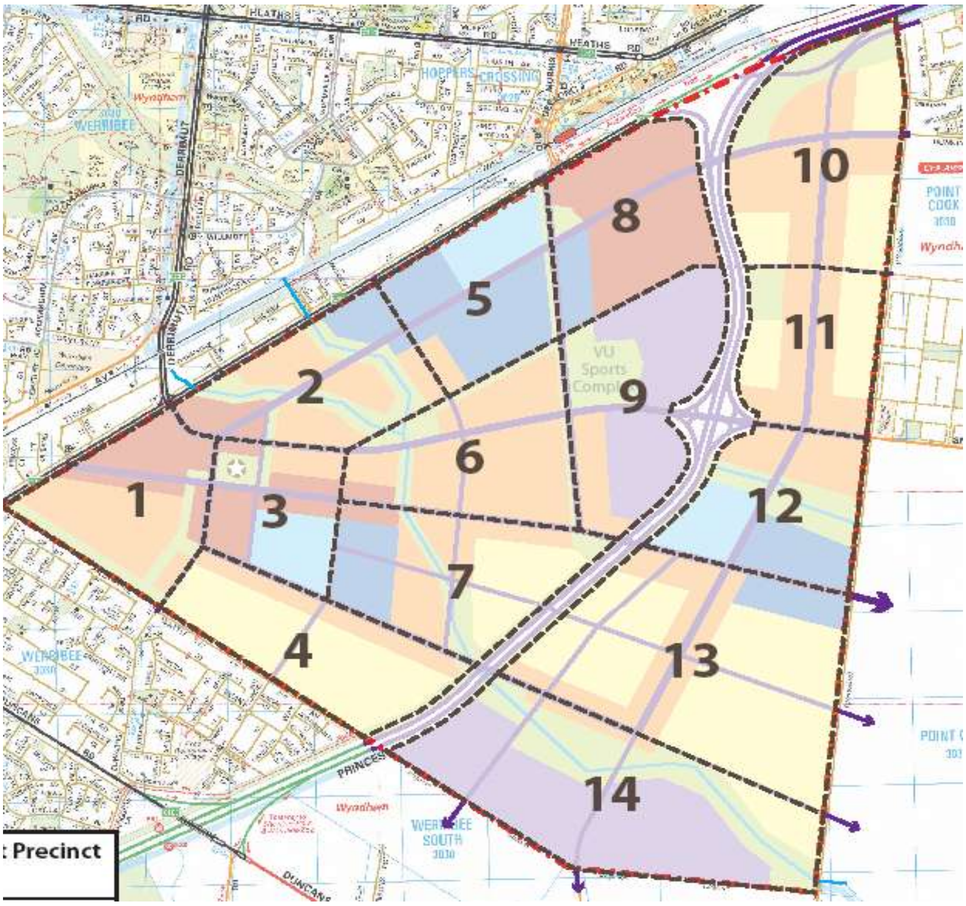

Figure 6.3: Indicative draft precinct structure plan used in the analysis

[15] DPCD (2009). Werribee Employment Precinct – preliminary employment and household projections.

Although the structure plan shown in Figure 6.3 is only an indication of the final development it does present locations for the Sub-Precincts (1 to 14) that are consistent with the topography and existing infrastructure at the site.

Development of the proposed Werribee Employment Precinct will increase the proportion of impervious surfaces within the site and the magnitude stormwater discharges from each of the 14 Sub-Precincts shown in Figure 6.3. The proportions of impervious surfaces for each land use shown in Table 6.3 were adopted for this study.

Table 6.3: Proportions of impervious surfaces versus land use

Land use	**Proportion of impervious surfaces (%)**
Commercial	80
Health	80
Education	50
Industrial	90
Public Open Space	10
Conventional housing	70
Mix use development	80
Medium density housing	80
High density housing	90

The analysis has not utilised all of the estimations of the proportions of impervious surfaces for each land use provided by Melbourne Water.[16] These estimates of fraction imperviousness appear to be low in the context of a trend in reduced lot sizes and national practice, and appear to have been derived from the practice of using discrete Rational Method assumptions for design of urban drainage systems. The use of Rational Method estimations for design of stormwater management facilities is not recommended to the Werribee Employment Precinct.

6.4 Water Demands

Analysis using the Sub-Precincts shown in Figure 6.3 provides a reasonable indication of potential land uses that allows evaluation of various water cycle management strategies. The land use categories and areas of each Sub-Precinct analysed in this report are shown in Table 6.4.

Table 6.4: Indicative land uses and areas for each Sub-Precinct

Sub-precinct	**Land area (ha)**						
	Commerce	**Mixed Use**	**Health**	**Education**	**Industry**	**Residential**	**Open Space**
1	16.7	24	-	-	-	-	6.2
2	7.4	22.9	-	7.5	-	-	15.7
3	14	4.3	13.1	-	-	-	4.9
4	-	10.7	-	-	-	40	2.2
5	-	2.4	13	30.5	-	2.8	2.8
6	2	44.5	-	-	-	-	9.9
7	2	21.1	-	11.3	-	15.9	7.7
8	42.1	-	-	8	-	-	1.8
9	-	6.5	-	-	43	-	15.1
10	-	29.3	-	-	-	31.7	11.2
11	-	21.7	-	-	-	22	5.1
12	-	13	13.4	13.7	-	-	14
13	-	26.6	-	5.9	-	75.7	3
14	-	3	-	-	66.7	8.7	30.5
Total	**84.2**	**230**	**39.5**	**76.9**	**109.7**	**196.8**	**130.1**

[16] Melbourne Water (2004). MUSIC input parameters

The information presented in Table 6.4 was used to develop water demands for each Sub-Precinct and to inform the stormwater management and water cycle management strategies for the Precinct.

Water use information for a range of business categories shown in Table 6.5 was derived from CLUE (Census of Land Use and Employment) data that was combined with summaries of water use categories for 2000 to 2008 provided by Yarra Valley Water and previous reports by Bonacci Water.[17,18] This information was used to determine water demands for each Sub-Precinct.

Table 6.5: Water use categories derived from census data

Category	Water use (L/day/ha)
Transport & Logistics	1,500
Food & Beverages	100,700
Light Commercial	16,200
Sales & Distribution	16,200
Warehousing and Storage	1,500
Office	15,800
Nurseries and Flower Production	19,900
Education	25,500
Accommodation	12,200
Retail	18,700
Health	20,900

Water demands for detached dwellings (average: 227 kL/yr) and for units (average: 159 kL/yr) in the Wyndham area derived by Bonacci Water[19] from postcode water use data provided by Department of Sustainability and Environment (DSE) were also utilised to determine water demands for each Sub-Precinct. It was also assumed that 30% and 5% of water demands for detached and unit dwellings respectively are for outdoor use. Potential water demands and sewerage discharges for each fully developed Sub-Precinct are shown in Table 6.6.

Table 6.6: Water demands and sewerage discharges for Sub-Precincts

Sub-Precincts	Water demands and sewerage discharges (kL/day)		
	Indoor	**Outdoor**	**Sewerage**
1	511	49	416
2	465	75	350
3	570	75	445
4	398	129	243
5	644	67	519
6	560	57	452
7	524	82	398
8	660	48	551
9	1,537	62	1,328
10	565	134	388
11	401	51	315
12	568	60	457
13	901	216	617
14	2,358	141	1,995
Total	**10,663**	**1,248**	**8,474**

[17] Bonacci Water (2008). Responsible water use at Armstrong Creek. Report for City of Greater Geelong.
[18] Bonacci Water (2008). Responsible water use at Armstrong Creek West. Report for the Carter Group.
[19] Bonacci Water (2008). Rainwater Tank Evaluation Study for Greater Melbourne. Report for the Department of Sustainability and Environment

The estimated average water demands and sewerage discharges for the fully developed Werribee Employment Precinct of 4,348 ML/yr and 3,092 ML/yr were derived from Table 6.6. These water demands and sewerage discharges were used as the basis for analysis of water cycle management at the Precinct.

6.5 Stormwater quality

A comparative analysis of stormwater quality at key locations within the Werribee Employment Precinct has been conducted. This analysis of stormwater quality was integrated with the hydrological simulations. Four key reference locations at Skeleton Creek (D) and Hacketts Road (A, B and C) were nominated for assessment of stormwater quality targets (see Figure 2.5). The configurations of the stormwater networks used in this analysis are shown in Appendix C.

Analysis of the impacts of urban development on waterway ecosystem health was conducted using the continuous simulation model MUSIC from eWater CRC and the hydrological model. The MUSIC model was used to analyse and assess the environmental benefits of each stormwater management option in regards to:

- Stormwater quality,
    - Total Suspended Solids
    - Total Phosphorus
    - Total Nitrogen
    - Gross Pollutants
- Average annual volumes, and
- Frequency of stormwater runoff as indicated by average annual runoff days.

Stormwater quality measures were designed using MUSIC to meet "current practice" and "stretch" stormwater quality targets described in Section 2. The hydrological model was used to determine a no worsening of stormwater peak discharges for 1 and 2 year ARI storm events to protect waterways from erosion and sedimentation. These design parameters serve the dual purpose of protecting waterway health and improving the amenity of waterways. Two rainfall records were utilised in the analysis of stormwater quality to account for different climate regimes in the area as shown in Table 6.7.

Table 6.7: Rainfall records used in the analysis of stormwater quality and flows

Record	Start date	End date	Annual rainfall (mm/yr)	Length (years)
Werribee	7/05/1968	29/06/1980	586	12
Drome Paddock	1/01/1998	20/04/2009	388	10

The 6 minute rainfall record from Werribee is normally used in analysis of stormwater management in the Werribee area but this record represents a decade of the highest rainfall on record. In order to capture lower rainfall regimes a 6 minute rainfall from nearby Drome Paddock (see Figure 6.4) provided by Melbourne Water was also used to analysis stormwater management strategies.

Figure 6.4: Location of Drome Paddock continuous rainfall gauge

6.6 Topography and existing infrastructure

The topography of the Werribee area was derived from photogrammetry and LiDar data provided by the Department of Sustainability and Environment and augmented with field survey data. The topography, geology and catchments of the area were combined in a digital terrain model (DTM).

This information was analysed using the 12D civil design package and Mapinfo Vertical Mapper to create a DTM with 5 metre grid spacing for the site. A fine grid of topographical information was required to adequately capture the variable terrain and low lying areas. Continuous elevation strings were included in the model to account for significant features including road structures, channels and embankments.

Details of existing stormwater infrastructure (including culverts, wetlands and detention basins) in the Werribee Employment Precinct and in the surrounding Werribee catchments were sourced from Wyndham City Council, the Department of Sustainability and Environment, and from the infrastructure report prepared by ARUP. Additional information to complete the understanding of existing infrastructure and conditions was obtained from field inspections. The digital terrain model of the Werribee Employment Precinct is shown in Figure 6.5.

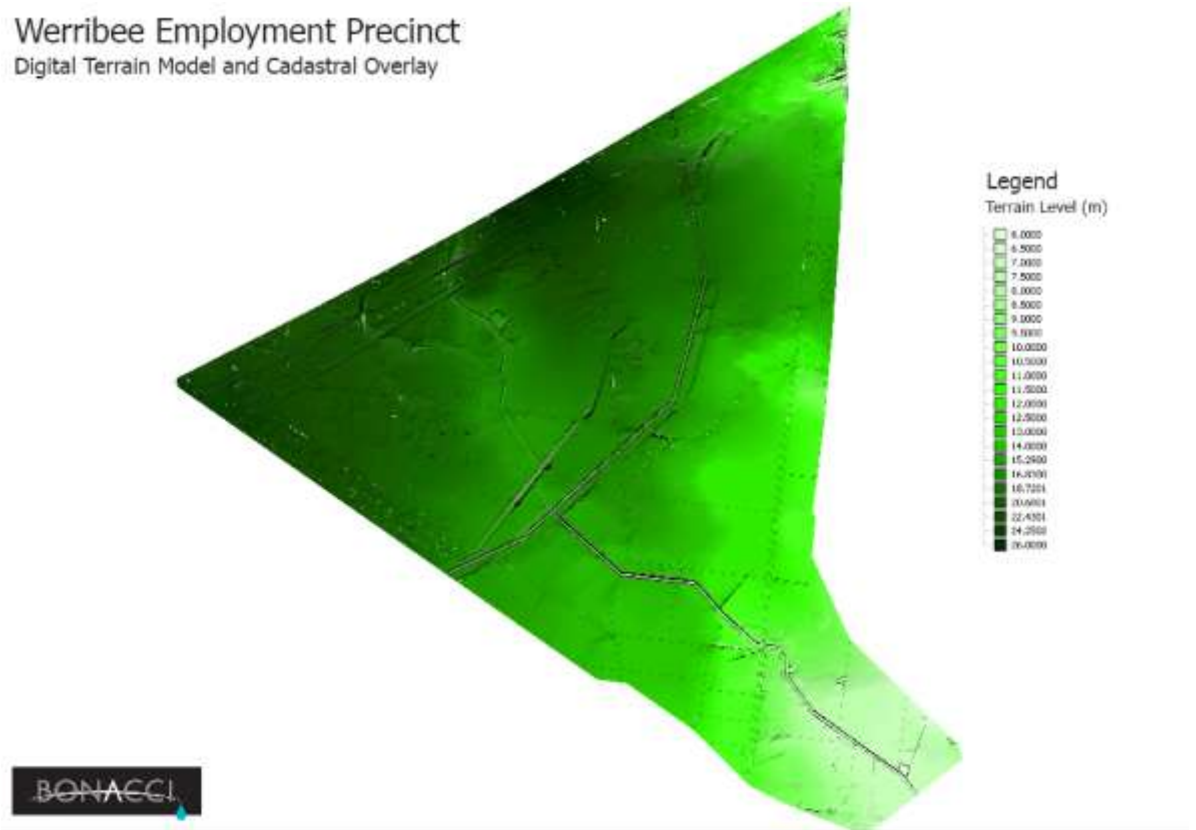

Figure 6.5: Digital terrain model (DTM) of the Werribee Employment Precinct

6.7 Hydrology

It was an objective for this study that the development should not significantly change the stormwater runoff and quality aspects of the existing stormwater catchments. The assessment of the stormwater runoff characteristics of the site in the existing and developed states was undertaken using WUFS (Water Urban Flow Simulator) developed at the University of Newcastle.[20] The stormwater networks utilised in this analysis are shown in Appendix A.

The WUFS program is the only reliable analysis tool available to industry that can compare traditional drainage solutions to water sensitive urban design solutions or analyse combinations of both. The WUFS software was until recently freely available to industry from the website www.eng.newcastle.edu.au/~cegak in a similar mode to the availability of ILSAX. Note that both ILSAX and WUFS are freeware that are recommended for research and investigation purposes. WUFS has been developed from the ILSAX algorithms. The more simplistic Rational Method calculations were not employed in this study (other than for calibration purposes) because this type of method does not account for the volumes of rainfall in storm events and the range of initial conditions that impact on stormwater runoff.

Using the WUFS model, the stormwater catchments shown in Figure 3.1 and 3.2, and design storm parameters from Australian Rainfall and Runoff[21] the performance of the stormwater catchments was analysed. The intensity frequency duration (IFD) data used in the hydrology model to simulate the performance is shown in Table 6.8.

The WUFS model was calibrated to peak discharges in the pre-European option derived using the Rational Method at key locations within the Werribee Employment Precinct. The expected changes in

[20] Kuczera, G., Williams, B., Binning, P. and Lambert, M., (2000). An education web site for free water engineering software. 3rd International Hydrology and Water Resources Symposium. Institution of Engineers Australia. Perth. Western Australia. 1048 – 1053.

[21] IEAust., (2001). Australian rainfall and runoff: a guide to flood estimation. Vols. 1 and 2. The Institution of Engineers, Australia.

rainfall intensity due to climate change have also been included in this analysis.

Table 6.8: IFD data for the Werribee Employment Precinct

ARI (years)	Rainfall intensity (mm/hour) for a given duration (hours)		
	1	12	72
2	18	3.5	0.9
50	38	7	2

Design storms were generated for all storm durations using a skew of 0.38 and temporal pattern region 1 as defined from Australian Rainfall and Runoff.

6.8 Hydraulics

The extent of flooding from the fully developed Precinct was evaluated by employing outputs from the hydrological model in the two dimensional hydraulic model TUFLOW which utilised the digital terrain model (DTM) to analyse stormwater flows throughout the area. Results from the analysis were mapped using the thematic mapping processes in MapInfo.

TUFLOW is a one-dimensional (1d) and two-dimensional (2d) flood and tide simulation package. It simulates the complex hydrodynamics of floods and tides using the full 1d St. Venant equations and the full 2d free-surface shallow water equations. The hydraulic model TUFLOW simulates:

- A range of flooding considerations from major rivers to complex overland and piped urban flows;
- estuarine and coastal tide hydraulics; and
- inundation from storm tides.

TUFLOW combines both 1d and 2d equations within the same analysis. The 1d components include system assets such as streams, culverts and drainage reticulation whilst 2d components primarily include overland flows across the terrain model. The inputs and outputs from TUFLOW are specifically linked to GIS systems and can be interfaced with a number of Graphical User Interfaces (GUI's). The results from this analysis are shown in Appendix E.

6.9 Water balance

Regional water demand data for the site was combined with daily rainfall from Little River and evaporation from the Werribee area in the stochastic Water Headworks Network (WATHNET) software [22]. The integrated water cycle networks used in this analysis are provided in Appendix C.

Performance of the water supply, stormwater flows, sewerage disposal and wastewater reuse systems at the different catchments within the Werribee Employment Precinct was simulated at a daily time step over a 100 year period that includes many significant droughts. The Werribee and Little River rainfall records are compared in Figure 6.6.

[22] Kuczera, G. (1994). Water supply headworks simulation using network linear programming. *Advances in Engineering Software.* Vol. 14. 55-60.

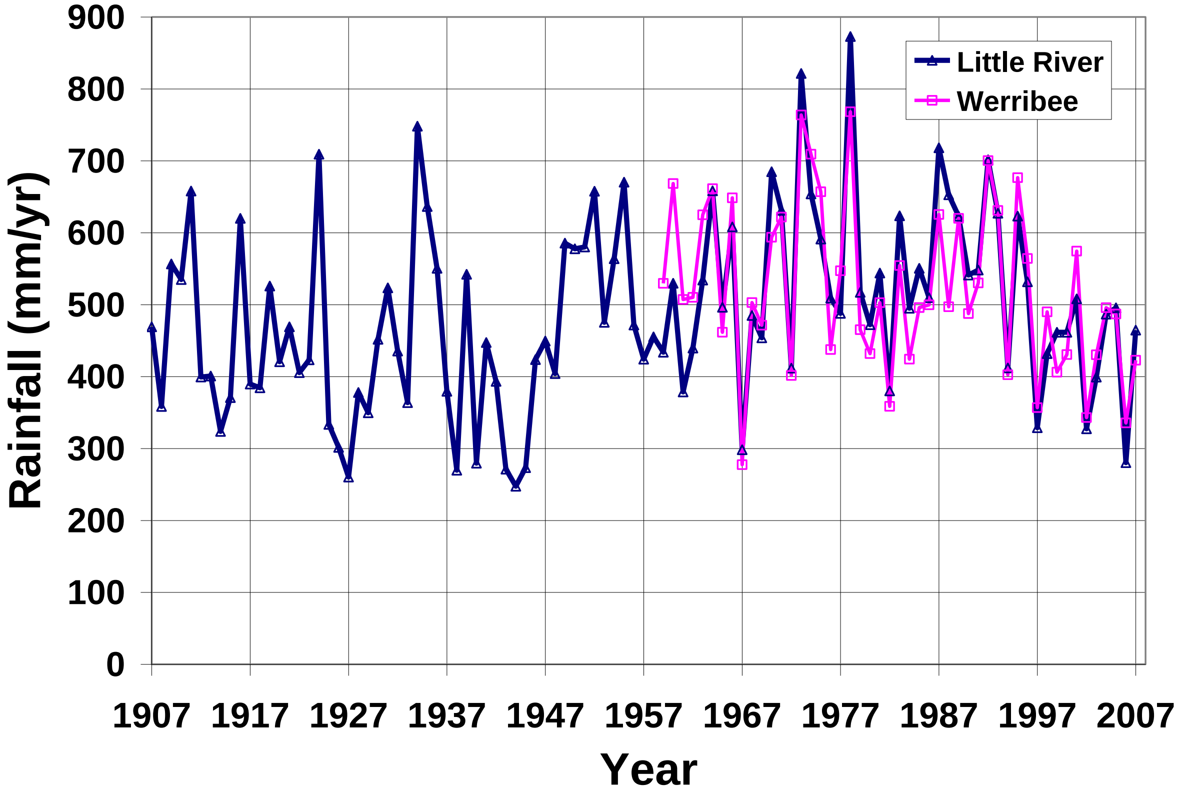

Figure 6.6: Rainfall records for Werribee and Little River

Figure 6.6 shows that the longer rainfall record from Little River (average annual rainfall of 488 mm) compares adequately to the shorter rainfall record from Werribee (average annual rainfall of 523 mm). Note that the longer rainfall record includes more significant droughts than the current drought. The expected changes in temperature and rainfall in response to climate change were included in analysis of water balances in this study.

6.10 Local water balance and water use

The PURRS model was utilised to derive water use and the performance of rainwater harvesting and water efficient appliances. A schematic of the basic processes in the PURRS (Probabilistic Urban Rainwater and wastewater Reuse Simulator) model is shown in Figure 6.7. The rainfall input to the model can be from pluviograph rainfall data, the DRIP (Disaggregated Rectangular Intensity Pulse) event rainfall model or the synthetic pluviograph rainfall generator. The synthetic pluviograph rainfall generator can be used to create a rainfall pluviograph record from daily rainfall at locations where incomplete or no pluviograph data is available. A more complete description of the PURRS model is provided by Coombes[23].

The rainfall falling on roof areas discharges to a first flush device and if the capacity of the roof gutter system is exceeded, rainfall also overflows from the roof gutter system to impervious areas as shown in Figure 6.8. Rainwater is then routed through the first flush device to a rainwater tank. Water is drawn from the rainwater tank for household uses (such as laundry, toilet and outdoor uses) and, if the water level in the rainwater tank is below a set minimum level, the tank is topped up with mains water at a nominated rate or mains water is used to supply all household uses. Mains water is used to supply all household uses not sourced from the rainwater tank and to supplement the rainwater tank supply. The rainwater tank overflows can be directed to an infiltration trench, an on-site detention tank, a stormwater tank or the street drainage system.

---

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

Rain falling on impervious areas can be directed to pervious areas, an on-site detention tank or the street drainage system. Rain falling on pervious areas can infiltrate to the soil and can discharge to the atmosphere via evapotranspiration, an on-site detention tank or the street drainage system.

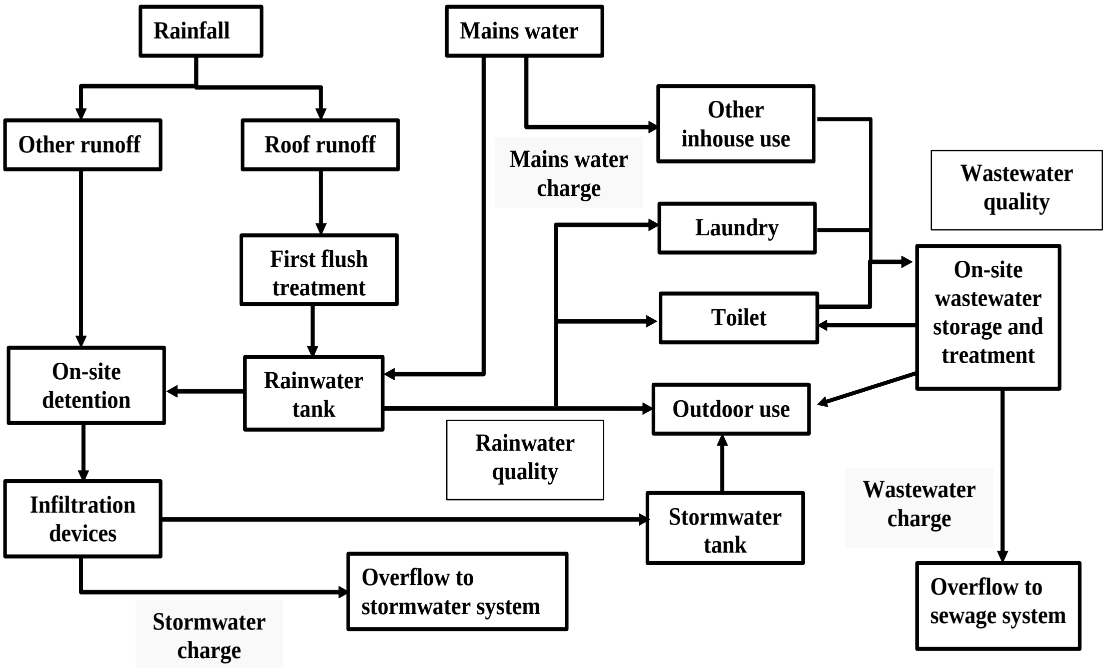

Figure 6.7: Schematic of the basic processes in the PURRS water balance model

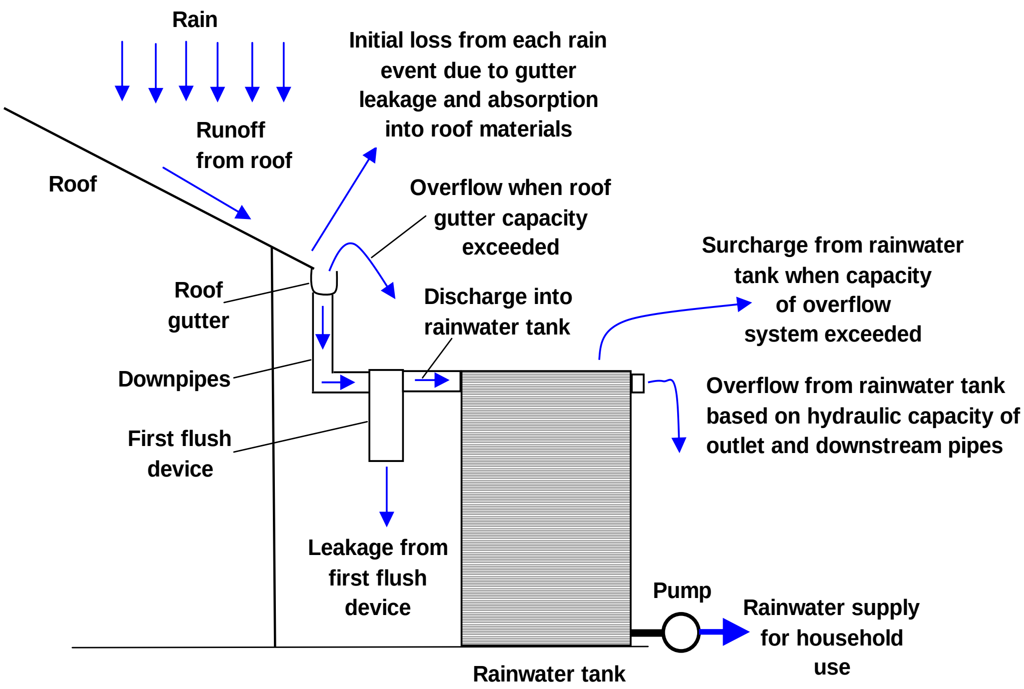

Figure 6.8: Schematic of the roof runoff to rainwater tank processes in PURRS

An importance advance in the simulation of roof runoff process as shown in Figure 6.8 has been included in the PURRS model. The roof runoff processes used in the model do not include arbitrary initial and continuing losses because these processes may be adequate for stormwater runoff from rural or urban catchments but are not relevant to rainwater harvesting from roofs. Roof systems are relatively impervious and are not subject to significant evapotransporation or infiltration losses. More accurately, these systems are subject to losses that are based on leakage from roof gutter systems and overflows from roof gutter systems when the capacity of gutters and downpipes is exceeded. The arbitrary use of inappropriate initial and continuing losses in analysis of domestic rainwater harvesting creates considerable errors.

Monitoring studies by the author has revealed that initial gutter losses range from the first 0 to 0.8 mm of roof runoff with the average initial gutter losses being about 0.5 mm.[24] This study has employed an initial gutter loss of 0.5 mm.

6.10.1 Diurnal Pattern of Indoor and Outdoor Water Use

In order to determine indoor and outdoor water use at short time steps in a water balance model a diurnal water use pattern is required. A diurnal water use pattern was adopted from previous studies into the performance of rainwater tanks for use in the PURRS Model. The adopted diurnal water use pattern for a household is shown in Figure 6.9.

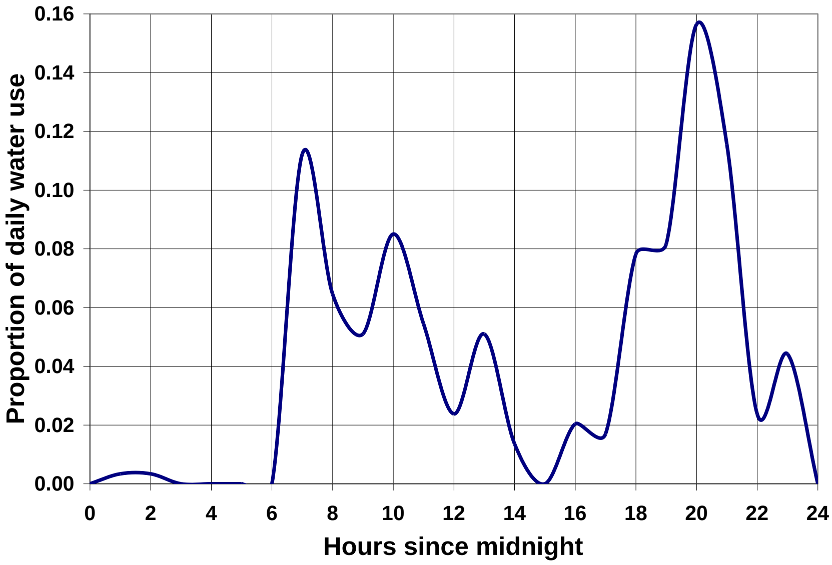

Figure 6.9: The diurnal water use pattern at a household

The diurnal water use pattern shown in Figure 6.9 have been transformed into a normalised water use (cumulative use/daily use) versus normalised time relationship (Figure 6.10) to enable the PURRS model to determine diurnal indoor and outdoor water use patterns.

[24] Coombes P.J., (2002). Rainwater tanks revisited – new opportunities for urban water cycle management. PhD thesis. University of Newcastle. Australia.

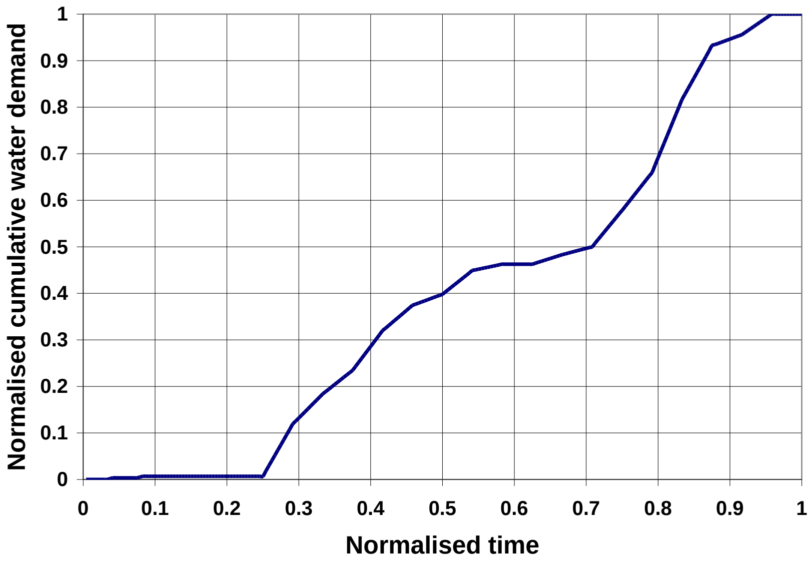

Figure 6.10: Normalised diurnal water use pattern used in the PURRS model

The PURRS model calculates water consumption at six-minute intervals using indoor and outdoor water use patterns established for a particular location, daily water demand algorithms and the normalised diurnal water use pattern shown in Figure 6.10.

6.10.2 The Outdoor Water Use Model

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

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

During a day with rainfall there is a smaller probability of water use and the volume of water used is dependent on the rainfall depth. There is a chance of outdoor water use when people perceive rainfall depth to be insignificant and, conversely, when rainfall depth is perceived to be large there will be no outdoor water use. When that rainfall depth is sufficiently high, people may not use water outside of the house for a number of days. These behavioural considerations have been formalised into a probabilistic framework by Coombes [25] that drives the daily simulation of outdoor water use. This climatic behavioural simulation approach is used in the PURRS model.

Outdoor water use in public open space and on non-residential properties was derived from an average annual irrigation demand of 12 mm/week that was dependent on rainfall, temperature and cumulative dry days.

6.10.3 Indoor water end uses

Simulation of daily indoor uses in the PURRS model are based on the values estimated using the values derived in Table 6.1 and 6.2, the diurnal patterns provided in Figure 6.10 and a distribution of indoor water uses into kitchen, laundry, toilet, bathroom and hot water uses presented in Table 5.3. In this study has modified the distribution of indoor water uses reported by Roberts[26], Bonacci

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

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

Water[27] and Greenstar rating tools [28] for use in PURRS as shown in Table 6.9.

Table 6.9: Proportion of water end uses for different land uses

End use	Proportion of water end uses (%)				
	Residential	Commercial	Industrial	Education	Health
Kitchen	10	12	12	5	10
Laundry	21	2	2	5	10
Toilet	18	64	64	80	34
Bathroom	24	8	8	5	36
Hot water	27	14	14	5	10

6.10.4 Configuration of rainwater storages and supply

Two different mains water back up processes to supplement rainwater supply from rainwater tanks are evaluated in this study, employing either mains water top up or mains water bypass systems. The configuration of the rainwater tanks with mains water top up systems used in this study is shown in Figure 6.11.

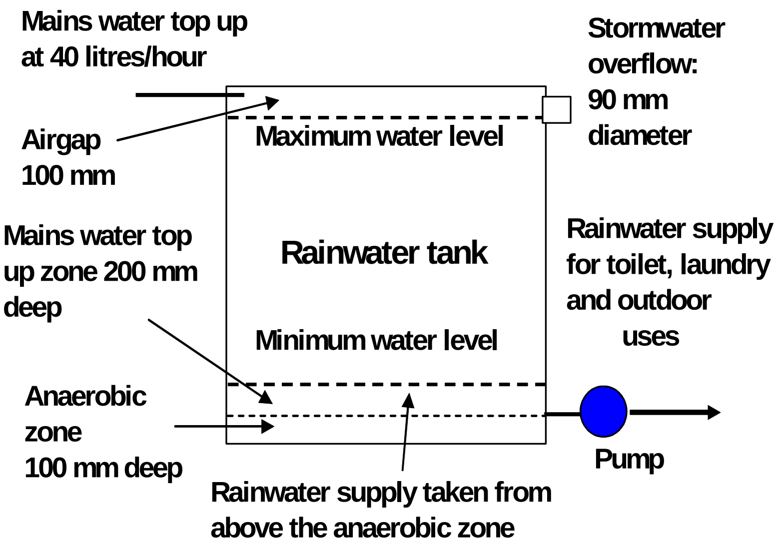

Figure 6.11: Configuration of a rainwater tank with mains water trickle top up

Figure 6.11 shows that rainwater stored in the tank is used to supply domestic toilet, laundry and outdoor water uses. Runoff from roof surfaces passes through a first flush device with a capacity of 20 litres and into the rainwater tank. Whenever water levels in the rainwater tanks are drawn below a depth of 300 mm, the tanks were topped up with mains water at a rate of 40 litres/hour. In the mains water bypass scenario, mains water is supplied to households for toilet, laundry and outdoor uses when water levels in rainwater tanks reach a depth of 300 mm.

6.11 Climate change

This study has adopted climate change scenarios derived by CSIRO[29] from recent IPCC[30] summaries of global climate models. The high emissions scenario has been adopted to account for the continuing growth in global emissions. Expected seasonal changes in temperature and rainfall will have a moderate impact on analysis of water balances including rainwater and stormwater

[27] Bonacci Water (2008). Rainwater tank evaluation study for Greater Melbourne. Report for Department of Sustainability and Environment.
[28] www.gbca.org.au/greenstar/ratingtools. Website of the Green Building Council
[29] CSIRO (2007). Climate change in Australia. www.climatechangeinaustralia.com.au
[30] IPCC (2007). Fourth assessment report. www.ipcc.ch

harvesting, and stormwater quality. The climate change scenarios shown in Table 6.10 were used in the analysis of water balances.

Table 6.10: Estimated changes in temperature from the high emissions scenario

Season	Change in temperature (°C)		Change in rainfall (%)	
	2030	2070	2030	2070
Spring	+0.8	+2.6	-7	-21
Summer	+0.9	+3.0	-2	-7
Autumn	+0.8	+2.6	-2	-5
Winter	+0.7	+2.1	-4	-11

The potential for climate change is expected increase rainfall intensity and have a significant impact on flooding at the site. The expected seasonal changes in rainfall intensity shown in Table 6.11 have been included in the analysis.

Table 6.11: Estimated changes in rainfall intensity

Season	Change in rainfall intensity (%)	
	2030	2070
Spring	+0.6	+7.4
Summer	+2.7	+16.3
Autumn	+1.1	+7.0
Winter	+2.3	+17.0

The maximum increase in rainfall intensity of 17% in 2070 has been derived from Table 6.11 and used in the hydrological analysis of flooding. The minimum height at the site is greater than 8 m above mean sea level and is, therefore, unlikely to be inundated by increased sea levels and stormwater surges resulting from climate change.

6.12 Assumptions about trunk infrastructure

The indicative requirement for trunk infrastructure including water, sewerage, recycled water and rising mains has been determined in this study. It was also assumed that storages will cost $0.2 m/ML, connection to the Western Trunk Sewer will cost $0.2 m and connection to the regional water network will cost $0.05 m. The estimated costs to install pumping stations are presented in Table 6.12.

Table 6.12: Installation costs of pumping stations

Flow rate (L/sec)	Cost ($m)
50	0.5
120	0.9
175	1.3
640	1.8
860	2.6

Trunk mains were sized using the 95th percentile daily flow and a peak factor of 2.5. The estimated costs to install trunk mains are shown in Table 6.13.

Table 6.13: Costs of water, sewer and recycled water mains

Diameter (mm)	Cost ($/m)
100	65
150	75
225	85
300	100
375	110
450	125
Installation	130

The assumed costs of sewer rising mains are presented in Table 6.14.

Table 6.14: Costs of sewer rising mains

Diameter (100 mm)	Cost ($/m)
225	95
300	110
375	120
Installation	130

The unit costs shown in Tables 6.12, 6.13 and 6.14 were used in the economic analysis of the Options.

6.13 Economics

The economic performance of each option was evaluated from a whole of society perspective. A net present value (NPV) of each option was determined using a 20 year horizon, an average discount rate of 6.5% and an average inflation rate of 3%. These values have been adopted following advice from the Victorian Treasury. A timeline to full development of 20 years was also assumed for this analysis. The inputs and outputs of the economic analysis are shown in Appendix D.

This study has assumed that the Werribee Employment Precinct is an independent entity and the different water cycle management Options will have varying levels of dependence on the surrounding regional water cycle infrastructure networks and resources. This dependence can be represented by the impact of each Option on deferring the next augmentation of the regional water supply and sewerage treatment systems. The estimated values for augmenting the regional water and sewerage system are shown in Table 6.15.

Table 6.15: Values used to estimate annualised cost of augmentation

Criteria	Desalination plant	Wastewater treatment plant
Capacity (ML/yr)	120,000	18,250
Installation ($m)	5,000	300
Management ($m/yr)	50	3
Operation ($m/yr)	130.2	39.6
Replacement ($m/yr)	100	6

Stormwater management Options for the site will also manage the contaminant loads from the upstream developed catchment. The annualised values of deferring the augmentation of water and sewerage infrastructure, and managing contaminant loads from upstream catchments and impacts on Port Phillip Bay as represented by nitrogen loads are shown in Table 6.16. This study has, therefore, adopted a value for reduction in discharges of nitrogen of $47.55/kg of nitrogen from recent studies[31]. This approach is consistent with the approach employed by Melbourne Water Corporation to value the benefits of reduced discharges of nitrogen to the environment.[32]

Table 6.16: Annualised values of deferred augmentation, managing contaminant loads from upstream catchments and impact on Port Phillip Bay

Item	**Annual value of deferral**
Water ($/ML)	8,125
Sewerage ($/ML)	488
Nitrogen ($/tonne)	4,755

Results from Table 6.16 are included in the economic analysis to account for the impacts of the various Options for the Werribee Employment Precinct on the security of regional resources. The additional impact on the operating costs of regional water and sewerage infrastructure of $380/ML and $491/ML, respectively, was derived from the National performance report 2006 – 2007: urban water utilities.33 These annualised augmentation and operation costs have been included in the economic analysis to represent the impact of the Werribee Employment Precinct on regional systems.

The costs to provide stormwater management infrastructure CAPsw ($ m) at year t have been derived as:

$$CAPsw_t = NL_t\left(\frac{SW}{SW_{BAU}}\right).RC + LV_t + DB_t + CW_t + RWT_t + BRT_t + SR_t + GPT_t \quad \text{........................(1)}$$

where NL is the number of lots, SW is the stormwater flows in the Option, SW_{BAU} is the stormwater flows in the base case (BAU), RC is the cost of street drainage infrastructure ($ m), LV is value of land occupied by stormwater infrastructure ($ m), DB is the cost of detention basins ($ m), CW is the costs of constructed wetlands ($ m), RWT is the cost of rainwater tanks ($ m), BRT is the cost of providing bio-retention facilities ($ m), SR is the restoration costs of the D1 drain ($ m) and GPT is the cost of gross pollutant traps ($ m).

The operating costs of the stormwater management options OPsw ($ m) were estimated as follows:

$$OPsw_t = 0.01\left(\frac{SW}{SW_{BAU}}\right).RC_t + 0.04DB_t + 0.06BRT_t + CWop_t - 0.0011N_t \quad \text{....................................(2)}$$

where CWop is the cost of maintaining constructed wetlands ($ m) and N is the value of nitrogen ($ m/tonne).

The costs to provide water cycle infrastructure CAPwc ($ m) at time t were:

$$CAPwc_t = NL_t\left(\frac{WAT}{WAT_{BAU}}WR + \frac{SEW}{SEW_{BAU}}SR\right) + TI_t + WWTP_t + WWR_t + SWR_t + ASR_t + SWTP_t + WEA_t \quad \text{................................(3)}$$

where WAT are the water flows in each Option, WATBAU are the water flows in the base case, SR is the cost of water reticulation, SEW is sewerage flows in each Options, SEWBAU is the sewerage flows in the base case, SR is cost of sewer reticulation, TI is the cost of trunk infrastructure ($ m), WWR is the cost of wastewater reuse infrastructure ($ m), SWR is the cost of stormwater harvesting infrastructure ($ m), ASR is the cost of infrastructure for aquifer storage and recovery ($ m), SWTP is the cost of a stormwater treatment plant ($ m) and WEA is the differential costs of installing more efficient appliances.

[31] Gray S., and N. Booker (2002). Contaminant flows in urban residential water systems. Urban Water. 4. 331-346.
[32] Melbourne Water (2006). Stormwater quality offsets – a guide to developers
[33] NWC (2008). National performance report 2006 – 2007: urban water utilities. Australian Government National Water Commission and Water Services Association of Australia.

The operating costs of water cycle infrastructure OPwc (S m) at time t were:

$$OPwc = 0.01\left(NL_t \frac{WAT}{WAT_{BAU}} WR + NL_t \frac{SEW}{SEW_{BAU}} SR + TI_t + WWR_t + SWR_t \right) +$$
$$TC(WWTP_t + SWTP_t) + MW(RWaug + RWop) + MS(RSaug + RSop) \quad \text{.................................(4)}$$

where TC is the treatment cost ($ m), MW is mains water demand (ML/yr), RWaug is the annualised augmentation cost of the regional water supply ($ m), RWop is the operating cost of the regional water supply ($ m), MS is sewerage discharges to the Western Trunk Sewer (ML/yr), RSaug is the augmentation cost of the regional sewerage system ($ m) and RSop is the operating cost of the regional sewerage system ($ m).

Equations 1, 2, 3 and 4 were combined in the economic analysis of the stormwater and water cycle management options for the Werribee Employment Precinct. The analysis also included sources of revenue from headworks, service and usage charges in accordance with the most recent ruling from the Essential Services Commission. [34] These values are shown in Table 6.17.

Table 6.17: Sources of revenue utilised in this analysis

Criteria	Water	Sewerage	Reuse
Headworks ($/property)	1,100	1,100	
Headworks with reuse ($/property)	550	1,100	1,100
Residential service changes ($/property)	126	134	20
Non-residential service charges ($/property)	184	238	20
Usage ($/kL)	1.2	1.34	1.02

6.14 Energy use and greenhouse gas emissions

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

This study has evaluated the energy uses of key water cycle infrastructure to assess the impacts of each Option on greenhouse gas emissions. The translation factor of 1.22 kg CO_2 for each kWh of energy use for Victoria published by the Department of Climate Change was utilised in this analysis.[35]

The pumping energy of various elements of trunk infrastructure in the various Options was determined to be 700 kWh for each ML of water flows. The energy use of the regional wastewater system was estimated from the National Performance Report 2006 – 2007 to be 264 kWh for each ML for wastewater discharge.

Greenhouse gas emissions GHG were summed over the analysis period using the following equation:

$$GHG = 1.22\sum TIe + WTe + RWTe + RMe + RWWe_t - \Delta WEAe \quad \text{..(5)}$$

where TIe is the pumping energy from trunk infrastructure, WTe is the energy use for treating stormwater and wastewater, RWTe is the energy use from the rainwater harvesting systems, RMe is the energy use of the regional mains water supply, RWWe is the energy use of the regional wastewater system and ΔWEAe is the reduction in energy use, in comparison to the base case, of water efficient appliances.

Equation 5 was used to compare the greenhouse emissions of each Option.

[34] Essential Services Commission (2008). 2008 water price review. City West Water determination 1 July 2008 – 30 June 2009.
[35] Department of Climate Change (2009). National Greenhouse Account Factors

6.15 Costs and related assumptions

The installation costs of detention basins, constructed wetlands and Gross Pollutant Traps (GPTs) used in this study were $\$35/m^3$, $\$95/m^3$ and $\$2,000/m^3/s$ respectively.[36] Annual operation and maintenance costs employed in this study sourced from a range of industry publications for detention basins, wetlands and GPTs were 4% of installation cost, $11,000/ha and 5% of installation cost respectively.[37]

This study has defined net land value as the sale price of fully serviced conventional allotments less the land and infrastructure costs. Net land values were considered to be $500,000 per hectare.

A conceptual design of the aqueduct includes a 7 metre wide channel with a length of 14 metres that bridges the historical sewer channel (Figure 6.12). The aqueduct will include piers to anchor the structure and bunds to direct stormwater into the channel. The estimated construction cost of the aqueduct is $300,000.

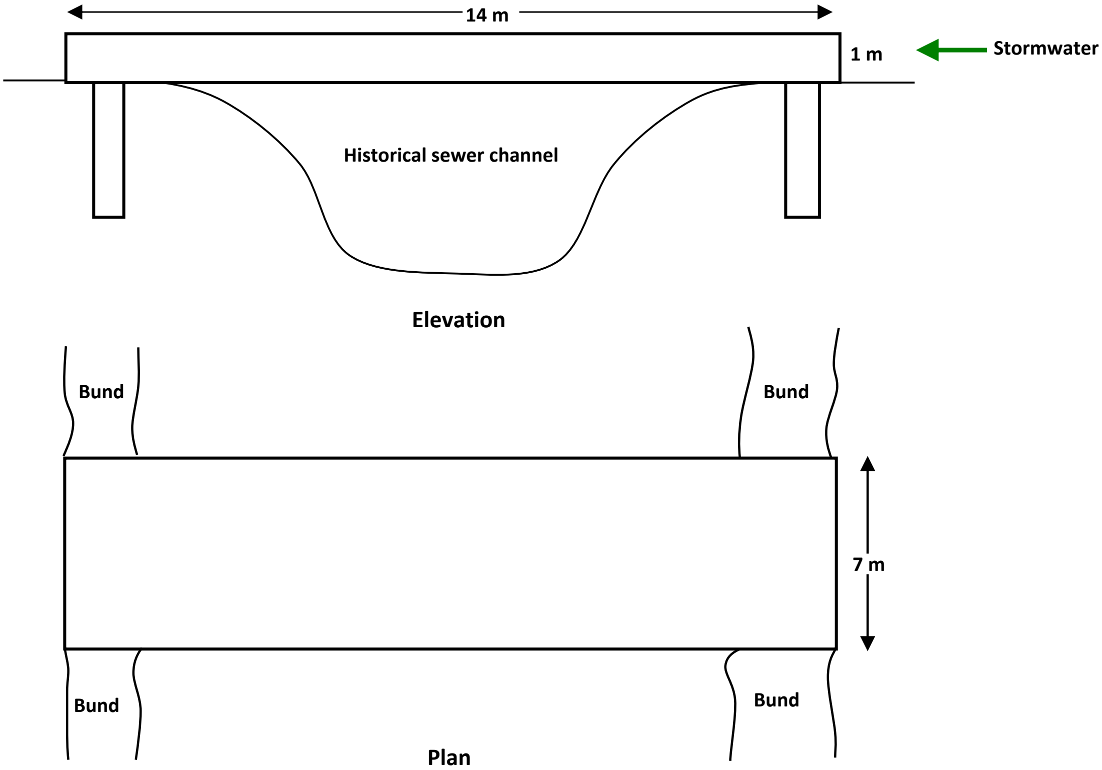

Figure 6.12: Conceptual design of stormwater aqueduct

The installation costs of the bio-retention strategies were assumed to be $\$150/m^3$ of storage. Operation and maintenance costs of 4% of installation costs were adopted. Incremental renewal and adaptation expenses of 2% of installation costs were used in this study.

The average cost to install 5,000 L rainwater tanks to supply household laundry, toilet and outdoor uses of $3,055 was sourced from recent research into the rainwater industry.[38] This research has established that the use of the most common rainwater pumps (0.45 kWh) in a mains water bypass

[36] Bayley M.L., and D. Newton (2007). Water quality and maintenance costs of constructed water bodies in urban areas of South East Queensland. Rainwater and Urban Design Conference. Engineers Australia. Sydney.
[37] Taylor A.C., (2005). Work undertaken to develop a lifecycle costing module for the CRC for Catchment Hydrology's MUSIC model. CRC for Catchment Hydrology. Melbourne. Victoria
[38] Coombes P.J (2007). Energy and economic impacts of rainwater tanks on the operation of regional water systems. Australian Journal of Water Resources. 11(2). 177-191.

configuration will consume 1,068 kWh/ML of rainwater supply. On average, household rainwater pumps will have a design life of 10 years and a replacement cost of $450.

An average cost of $6,500 was determined for the full installation of 20,000 L rainwater harvesting systems supplying higher density dwelling clusters. The replacement cost of these pumps was deemed to $950. Installation of rainwater harvesting systems on non-residential land was determined to be $14,500 per hectare with pump replacement costs of $2,190 per hectare.

It was assumed that street scale water, sewer and stormwater infrastructure would cost $3,500/lot, $4,100/lot and $3,000/lot respectively. The cost of trunk infrastructure servicing the Precinct was also derived from hydraulic analysis of each Option.

It is expected that local wastewater treatment plants will cost about $5 m/ML of daily treatment capacity with treatment costs of $1,085/ML. The energy use of these MBR plants was estimated to be 1,570 kWh/ML. It was assumed that the cost of a Precinct scale MBR plant would be $3 m/ML of daily capacity and the plant will have a treatment cost of $1,085/ML.

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

Installation of water efficient clothes washers is expected to reduce energy use by 3.5 kWh/ML of water saved.[39] Energy savings of 6.4 kWh/ML of water saved area expected. The water efficient appliances have design lives of about 10 years. This study estimated the residual cost of installing a water efficient clothes washer to be $100 and $60 for a water efficient shower head. The residual cost is the difference between purchasing non-water efficient and water efficient appliances. Current water use patterns will include the water savings from Water efficient 6/3 L flush toilets that are installed in over 85% of Melbourne households. Installation of 4.5/3 flush toilets is expected to reduce water use for toilet flushing by 20% at an additional cost of $70.

The capital cost of the ASR system was assumed to be $5 m. The capital and operating costs of the water treatment plant used to treat stormwater to drinking water standards were considered to be similar to the costs of the MBR_UF wastewater treatment plants – installation costs of $3 m/ML of daily capacity and operating costs of $1,085/ML.

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

7 STORMWATER RESULTS

The results of the analysis of stormwater management options are presented in this section.

Pre-European conditions

The peak stormwater discharges derived for each of the outlets shown in Figure 2.2 using the Rational Method are shown in Table 7.1.

Table 7.1: Pre-European peak discharges from the Precinct

ARI	Peak stormwater discharges at key locations (m^3/s)				AMC
	A	B	C	D	
1	2.9	0.3	0.7	0.3	3.9
2	4.8	0.5	1.1	0.4	2.9
5	7.7	0.8	1.8	0.7	2.5
10	10.1	1.0	2.4	0.9	2.3
20	13.3	1.4	3.1	1.2	2
50	17.9	1.8	4.2	1.6	1.6
100	22.4	2.3	5.3	2.0	1.1

Table 7.1 also reveals the antecedent moisture conditions (AMC) used to calibrate the WUFS model to Rational Method calculations for each ARI. Stormwater runoff quality and regimes for the pre-European catchments are shown in Table 7.2 and 7.3.

Table 7.2: Stormwater runoff quality and regimes from catchments in pre-European conditions (using Werribee Data)

Location	Flow (ML/yr)	TSS (kg/yr)	TP (kg/yr)	TN (kg/yr)	GP (kg/yr)
A	1,580	112,000	116	1,590	0
B	137	10,900	11	128	0
C	337	23,300	25	318	0
D	116	9,150	10	114	0

Table 7.2 shows that, using the Werribee rainfall data, the estimated average annual natural stormwater discharges from the Werribee Employment precinct total 2,170 ML/yr.

Table 7.3: Stormwater runoff quality and regimes from catchments in pre-European conditions (Drome Paddock data)

Location	Flow (ML/yr)	TSS (kg/yr)	TP (kg/yr)	TN (kg/yr)	GP (kg/yr)
A	783	51,700	55	726	0
B	68	4,390	5	62	0
C	166	11,000	12	155	0
D	57	3,820	4	53	0

Table 7.3 shows that, using the Drome Paddock rainfall data, the estimated average annual natural stormwater discharges from the Werribee Employment precinct total 1,014 ML/yr.

Existing Conditions

The peak stormwater discharges derived for each of the outlet shown in Figure 1.2 for existing conditions are shown in Table 7.4.

Table 7.4: Existing peak discharges from the Precinct

ARI	Peak stormwater discharges at key locations (m^3/s)			
	A	B	C	D
1	10.95	0.45	0.86	0.49
2	13.54	0.64	1.21	0.68
5	17.23	0.87	1.61	0.93
10	20.79	1.15	2.03	1.21
20	25.27	1.53	2.54	1.55
50	31.52	2.03	3.36	2.02
100	35.99	2.19	3.55	2.12

Table 7.4 reveals that peak discharges from the Werribee Employment Precinct in existing conditions has increased considerably over natural conditions. The extent of flooding in the existing catchment from 100 year ARI storm events is shown in Figure 7.1.

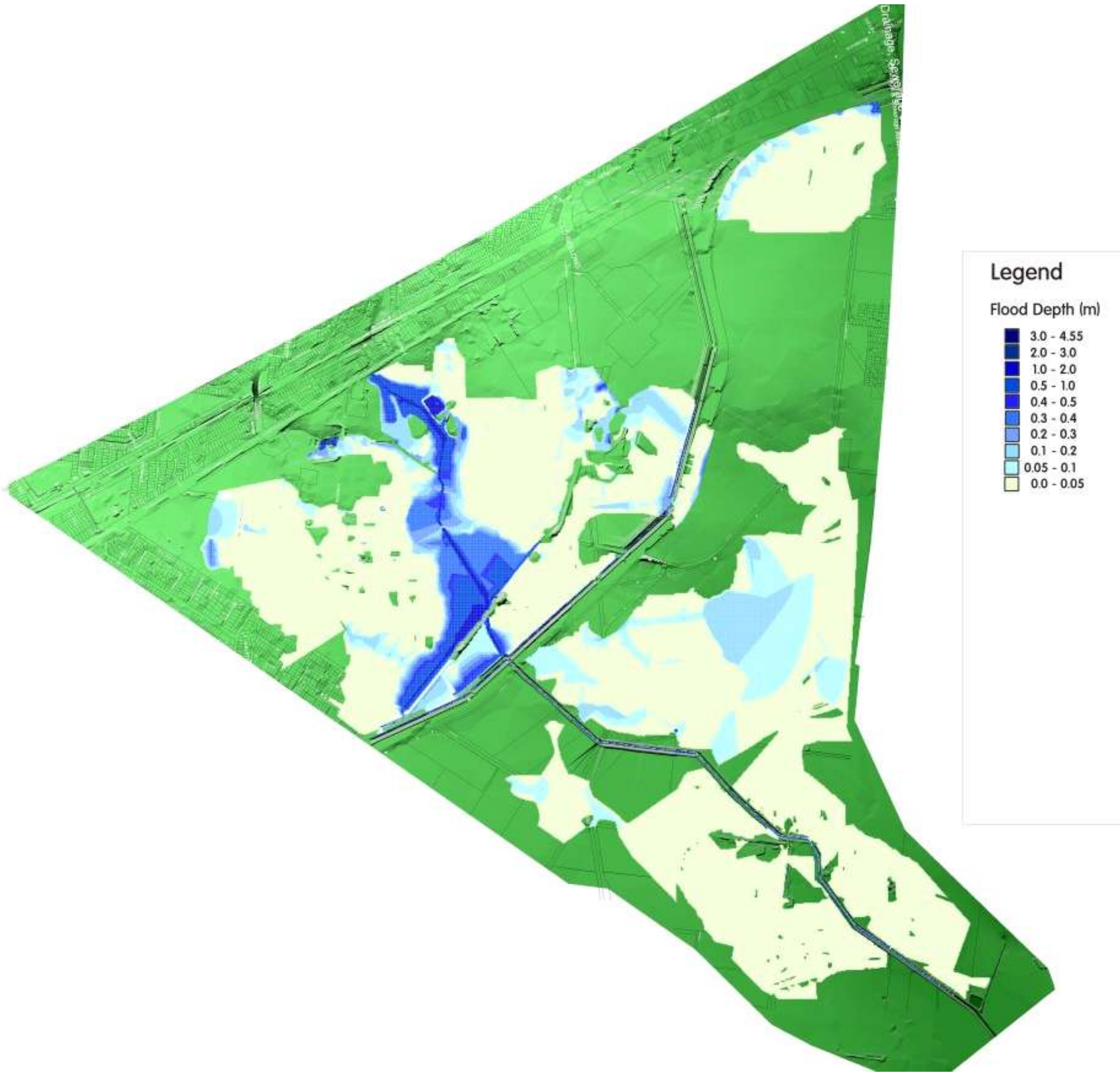

Figure 7.1: The extent of flooding from 100 year ARI storm events at the Werribee Employment precinct subject to existing conditions

Figure 7.1 reveals considerable extent of flooding in the “D1” drain upstream of the Western Trunk Sewer and in the east of the Precinct. The extent of land area inundated by flooding, area with flood depths greater than 50 mm and greater than 100 mm, subject to existing conditions, are shown in Table 7.5 below.

Table 7.5: Flood areas for Existing conditions

Criteria	Extent	Depth > 50 mm	Depth > 100 mm
Existing Flood Areas (ha)	605	140	90

Stormwater runoff quality and regimes for the existing catchments are shown in Table 7.6 and 7.7.

Table 7.6: Stormwater runoff quality and regimes from catchments in existing conditions (Werribee Data)

Location	Flow (ML/yr)	TSS (kg/yr)	TP (kg/yr)	TN (kg/yr)	GP (kg/yr)
A	3,110	640,000	1,310	9,230	113,000
B	51	9,680	27	179	0
C	75	14,000	39	270	0
D	44	7,990	22	163	0

Table 7.6 shows that the average annual stormwater discharges from the Precinct subject to existing conditions is 3,280 ML/yr and that the upstream catchments contribute considerable loads of litter, nutrients and suspended solids.

Table 7.7: Stormwater runoff quality and regimes from catchments in existing conditions (Drome Paddock Data)

Location	Flow (ML/yr)	TSS (kg/yr)	TP (kg/yr)	TN (kg/yr)	GP (kg/yr)
A	2,870	605,000	1,230	8,630	102,000
B	48	10,200	28	186	0
C	71	14,200	38	275	0
D	41	8,040	22	155	0

Table 7.7 shows that the average annual stormwater discharge from the Precinct subject to existing conditions is 3,030 ML/yr. The lower rainfall regime in the Drome Paddock rainfall record has produced small reductions in annual average stormwater runoff volumes and contaminant loads.

Developed catchments with existing stormwater management

The impact of urban development on stormwater runoff in the Werribee Employment Precinct is presented in this section. Peak stormwater discharges derived for each of the outlets shown in Figure 2.2 are shown in Table 7.8.

Table 7.8: Peak stormwater discharges from the Precinct

ARI	Peak stormwater discharges at key locations (m^3/s)				
	Sewer	A	B	C	D
1	4.83	5.35	3.33	2.40	0.88
2	13.76	6.81	4.56	3.24	1.25
5	24.96	9.4	6.44	4.74	1.74
10	30.94	11.53	7.56	5.73	2.13
20	40.97	14.38	9.31	7.11	2.65
50	58.98	18.05	11.3	8.89	3.36
100	71.85	21.03	13.4	10.46	3.88

Table 7.8 reveals significant increases in peak stormwater discharges from the fully developed Werribee Employment Precinct with existing stormwater management in comparison to natural and existing conditions. A significant quantity of stormwater enters the historical sewer. The extent of flooding in this option is shown in Figure 7.2.

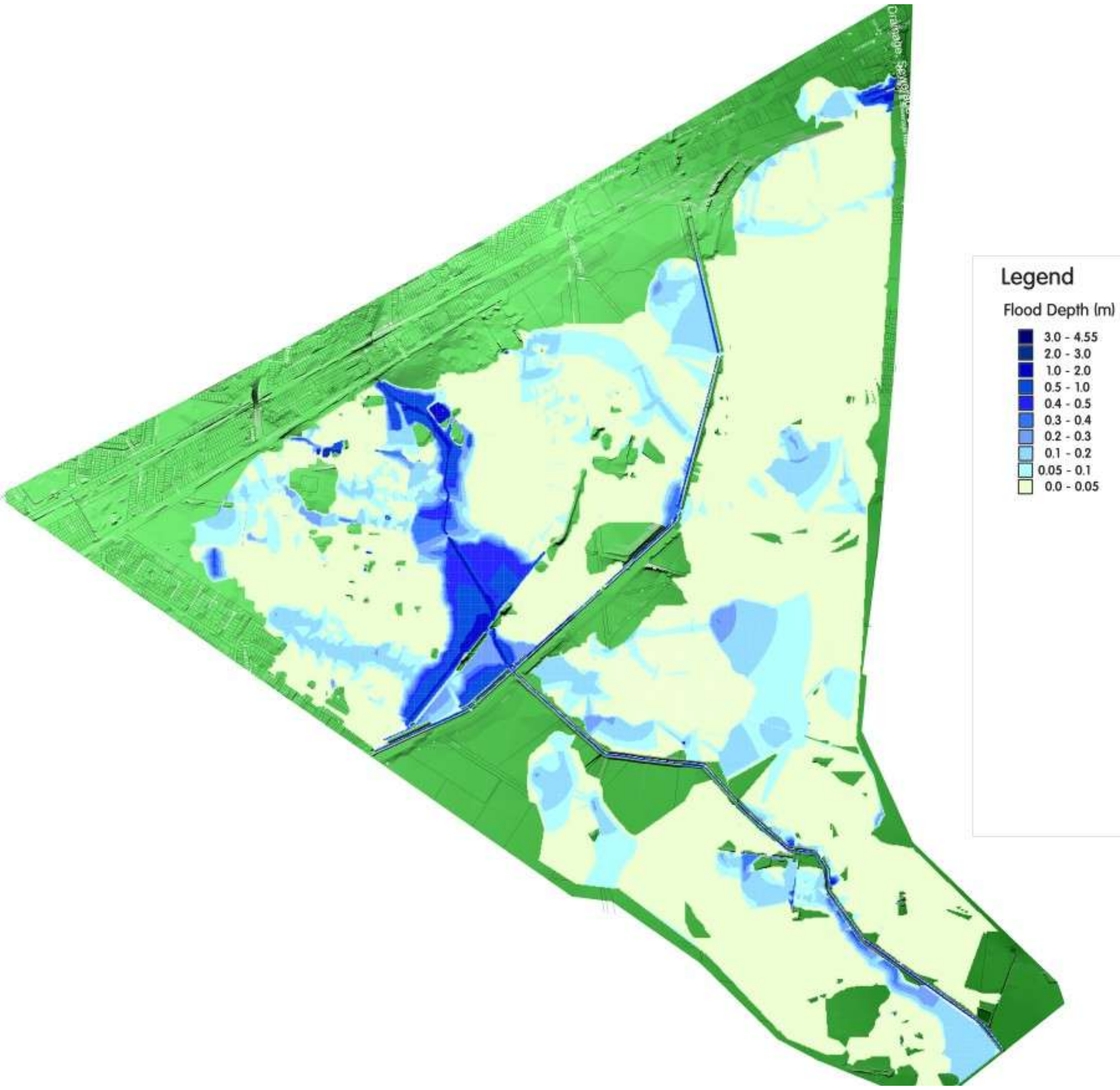

Figure 7.2: The extent of flooding from 100 year ARI storm events at the developed Werribee Employment precinct

Figure 7.2 reveals significant flooding in the "D1" drain and throughout the Precinct, particularly north of the Maltby By-Pass along the "D1" drain alignment. Full development of the WEP and utilisation of the existing stormwater management system results in the changes in the extent of flooding shown in Table 7.9.

Table 7.9: Developed (BAU) Flood Areas

Criteria	**Extent**	**Depth > 50mm**	**Depth > 100mm**
BAU Flood Areas (ha)	690	250	144
Difference to Existing (%)	+15%	+80%	+60%

Development of the Werribee Employment Precinct has the potential to double the extent of flooding in the Precinct. Stormwater runoff quality and regimes for the developed catchments using rainfall from Werribee are shown in Table 7.10.

Table 7.10: Stormwater runoff quality and regimes from catchments in developed conditions using rainfall from Werribee

Location	Flow (ML/yr)	TSS (kg/yr)	TP (kg/yr)	TN (kg/yr)	GP (kg/yr)
A	5,820	1,200,000	2,370	16,500	208,000
B	593	115,000	240	1,640	20,900
C	175	36,300	71	485	6,170
D	249	47,500	95	698	8,600

Table 7.10 shows that the average annual stormwater runoff volumes from the fully developed Werribee Employment Precinct was 6,837 ML/yr. Stormwater runoff quality and regimes from the developed catchments using rainfall from Drome Paddock are shown in Table 7.11.

Table 7.11: Stormwater runoff quality and regimes from catchments in developed conditions using rainfall from Drome Paddock

Location	Flow (ML/yr)	TSS (kg/yr)	TP (kg/yr)	TN (kg/yr)	GP (kg/yr)
A	3,650	750,000	1,480	10,400	140,000
B	373	75,300	152	1,050	14,100
C	110	22,500	45	310	4,150
D	156	30,700	63	436	5,780

Table 7.11 shows that average annual stormwater runoff volumes from developed conditions from the fully developed Werribee Employment Precinct generated by rainfall from Drome Paddock was 4,289 ML/yr. The lower rainfall depths in the Drome Paddock rainfall record have resulted in a 37% reduction in stormwater runoff.

To ensure that "Best Practice" objectives for stormwater management were achieved for the Precinct a centralised treatment system was developed for Options 1, 2 and 4 and a decentralised system was developed of Options 3 and 5. Detention basins, wetlands and bio-retention swales were designed and strategically located to enable effective management of stormwater.

Option 1

The peak stormwater discharges derived for each of the outlet shown in Figure 2.2 for the developed case in Option 1 are shown in Table 7.11 and 7.12 for stormwater management facilities designed to meet Pre-European and Existing conditions respectively.

Table 7.11: Peak discharges from a stormwater management system designed to meet pre-European conditions

ARI	Peak stormwater discharges at key locations (m^3/s)			
	A	B	C	D
1	4.68	0.15	0.97	0.24
2	6.55	0.23	1.44	0.33
5	9.21	0.49	2.09	0.45
10	10.3	0.8	2.79	0.66
20	14.1	1.11	3.44	1.06
50	17.68	1.78	4.25	1.55
100	20.69	2.14	5.3	1.93

Table 7.12: Peak stormwater discharges from a stormwater management system designed to meet best practice guidelines

ARI	**Peak stormwater discharges at key locations (m³/s)**			
	A	**B**	**C**	**D**
1	10.95	0.45	0.86	0.49
2	13.54	0.64	1.21	0.68
5	17.23	0.87	1.61	0.93
10	20.79	1.15	2.03	1.21
20	25.27	1.53	2.54	1.55
50	31.52	2.03	3.36	2.02
100	35.99	2.19	3.55	2.12

Note that the higher peak discharges at location C are generated by pre-European conditions in comparison to existing conditions because the catchments have been altered by urbanisation. The Maltby bypass and the historical sewer channel divides catchments in the existing state which diverts stormwater flows to point A which would otherwise discharge to point C in the pre-European state. The extent of flooding in Option 1 from 100 year ARI storm events and the impact of the stormwater management strategy is clearly shown in Figure 7.3.

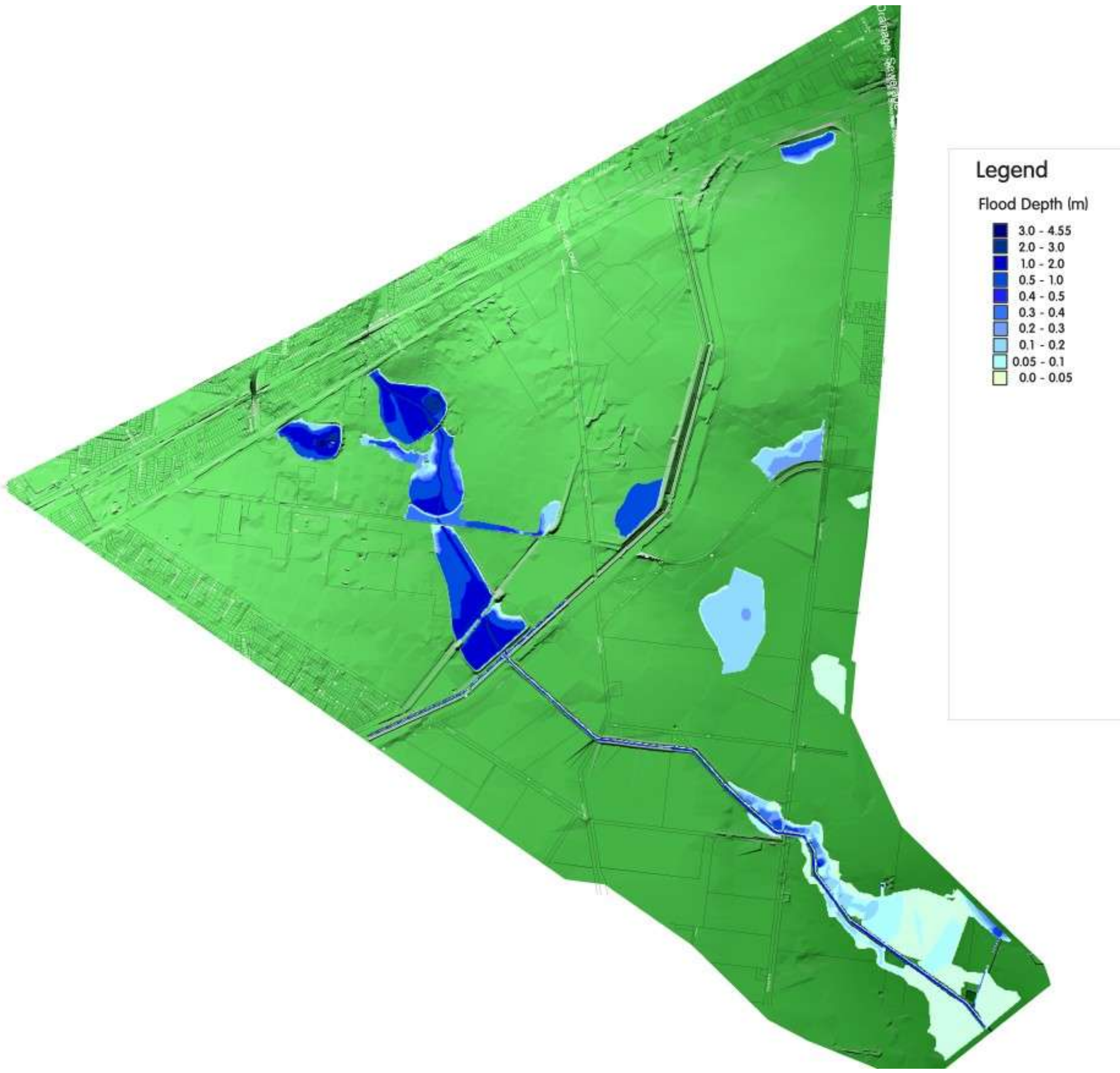

Figure 7.3: The extent of flooding from 100 year ARI storm events for Option 1 at the Werribee Employment precinct

The area of flood inundation is compared to existing conditions in Table 7.13.

Table 7.13: Extent of flood inundation in Option 1

Criteria	Extent	Depth > 50mm	Depth > 100mm
Option 1 Flood Areas (ha)	84.78	80.86	78.22
Difference to Existing (%)	-85.99	-42.24	-13.09
Difference to BAU (%)	-87.71	-67.66	-45.68

Figure 7.13 reveals reduced flooding in the "D1" drain and throughout the Precinct in comparison to existing conditions. Option 1 has significantly mitigated the impact of development of the Werribee Employment Precinct on flooding from 100 year ARI storm events.

Figure 7.4 shows that Options 1, 2 and 3 incorporate a majority of the existing drainage infrastructure, the existing "RB3" detention basin on the "D1" drain and new centralised detention basins throughout the Precinct.

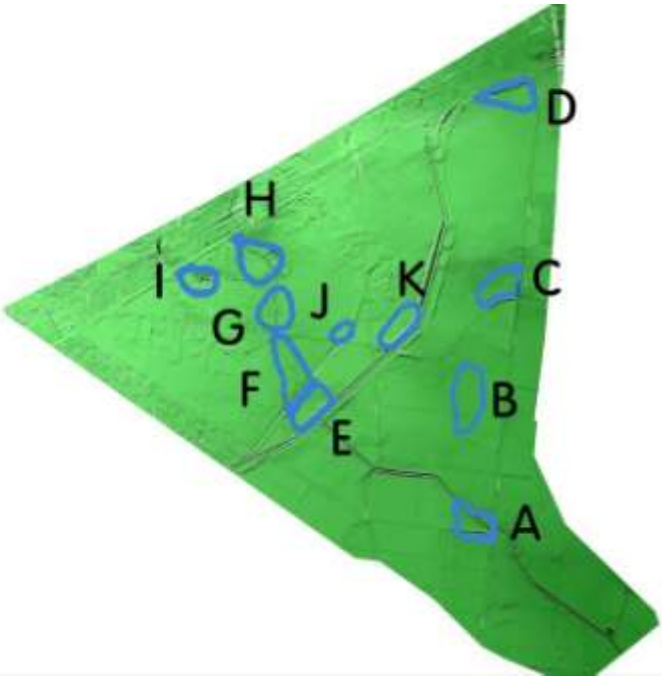

Figure 7.4: Detention Basin configuration for Options 1, 2 and 3.

The size of the detention basins required to meet the objectives for stormwater management using rainfall data from Werribee and Drome Paddock is shown in Tables 7.14.

Table 7.14: Size of detention basins required for Option 1

Location	Area (ha)
A	3.45
B	14.64
C	5.53
D	4.63
E	7.28
F	11.42
G	10.27
H	10.61
I	4.92
J	1.47
K	4.67
Total	**78.89**

The centralised management strategies of Options 1 and 2 require constructed wetlands to meet "Best Practice" guidelines or Pre-European objectives. The required areas of constructed wetlands to meet "Best Practice" and pre-European objectives are identified in Tables 7.15 and 7.16 respectively.

Table 7.15: Size of constructed wetlands to meet "Best Practice" objectives in Option 1

Discharge location	**Wetland**	**Werribee area (m²)**	**Drome area (m²)**
A	1	50,000	15,000
	2	40,000	15,000
	3	60,000	30,000
	4	21,000	-
B	5	26,000	32,000
C	6	18,000	17,000
D	7	20,000	21,000
Total area	**m²**	**235,000**	**130,000**
	Ha	**23.5**	**13.0**

Table 7.16: Size of constructed wetlands to meet Pre-European objectives in Option 1

Discharge point	**Wetland**	**Werribee area (m²)**	**Drome area (m²)**
A	1	500,000	442,000
	2	500,000	400,000
	3	550,000	300,000
	4	150,000	200,000
B	5	150,000	137,500
	5a	130,000	130,000
	5b	150,000	120,000
C	6	6,650	19,250
D	7	200,000	240,000
Total area	**m²**	**2,336,650**	**1,988,750**
	Ha	**234**	**199**

Table 7.16 reveals that a dramatic increase in areas of constructed wetlands is required to return stormwater quality discharging from the Precinct to pre-European conditions.

Figure 7.5 shows the location of constructed wetlands in Options 1 and 2 that incorporates a centralised management system along the existing "D1" alignment.

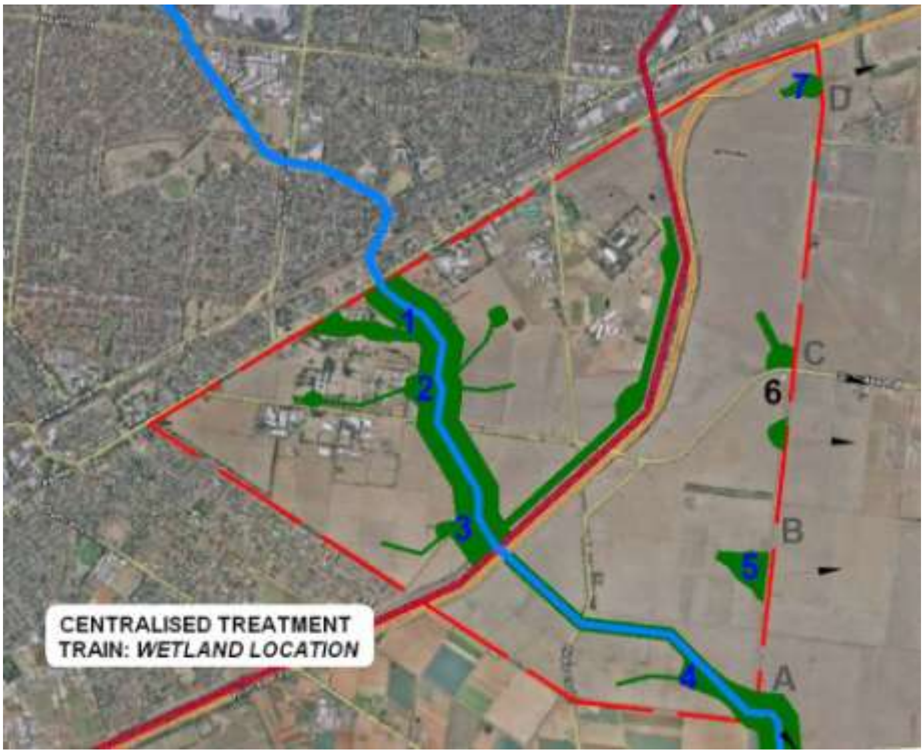

Figure 7.5: Wetland locations for Options 1, and 2.

The characteristics of stormwater runoff at each of the four discharge locations A, B, C and D are shown for both the Werribee and Drome rainfall data sets in Tables 6.16 and 6.17 respectively.

Table 7.17: Stormwater discharge characteristics to meet "Best Practice" guidelines for Option 1. (using Werribee rainfall data)

Location A			
Criteria	**Sources**	**Residual Load**	**Reduction (%)**
Flow (ML/yr)	5,820	5,540	5
Total Suspended Solids (kg/yr)	1,190,000	24,600	98
Total Phosphorus (kg/yr)	2,400	471	80
Total Nitrogen (kg/yr)	16,800	9,260	45
Gross Pollutants (kg/yr)	208,000	0	100
Location B			
Flow (ML/yr)	593	577	3
Total Suspended Solids (kg/yr)	117,000	4,190	96
Total Phosphorus (kg/yr)	234	57	76
Total Nitrogen (kg/yr)	1,600	879	45
Gross Pollutants (kg/yr)	20,900	0	100
Location C			
Flow (ML/yr)	175	166	5
Total Suspended Solids (kg/yr)	34,100	1,380	96
Total Phosphorus (kg/yr)	69	15	78
Total Nitrogen (kg/yr)	477	263	45
Gross Pollutants (kg/yr)	6,170	0	100
Location D			
Flow (ML/yr)	249	238	4
Total Suspended Solids (kg/yr)	48,900	1,840	96
Total Phosphorus (kg/yr)	97	21	78
Total Nitrogen (kg/yr)	673	372	45
Gross Pollutants (kg/yr)	8,600	0	100

Table 7.18: Stormwater discharge characteristics to meet "Best Practice" guidelines for Option 1. (using Drome rainfall data)

Location A			
Criteria	**Sources**	**Residual Load**	**Reduction (%)**
Flow (ML/yr)	3,650	3,520	3
Total Suspended Solids (kg/yr)	748,000	130,000	83
Total Phosphorus (kg/yr)	1,480	516	65
Total Nitrogen (kg/yr)	10,400	5,710	45
Gross Pollutants (kg/yr)	140,000	10,600	92
Location B			
Flow (ML/yr)	373	361	3
Total Suspended Solids (kg/yr)	75,600	2,320	97
Total Phosphorus (kg/yr)	152	33	78
Total Nitrogen (kg/yr)	1,050	579	45
Gross Pollutants (kg/yr)	14,100	0	100
Location C			
Flow (ML/yr)	110	106	4
Total Suspended Solids (kg/yr)	22,100	660	97
Total Phosphorus (kg/yr)	44	8	81
Total Nitrogen (kg/yr)	309	170	45
Gross Pollutants (kg/yr)	4,150	0	100
Location D			
Flow (ML/yr)	156	150	4
Total Suspended Solids (kg/yr)	30,500	936	97
Total Phosphorus (kg/yr)	61	12	81
Total Nitrogen (kg/yr)	437	239	45
Gross Pollutants (kg/yr)	5,780	0	100

The annual average stormwater runoff volumes from Option 1 will range 6,521 ML to 4,137 ML.

Option 2

The extent of flooding from 100 year ARI storm events for stormwater Option 2 is shown in Figure 7.6.

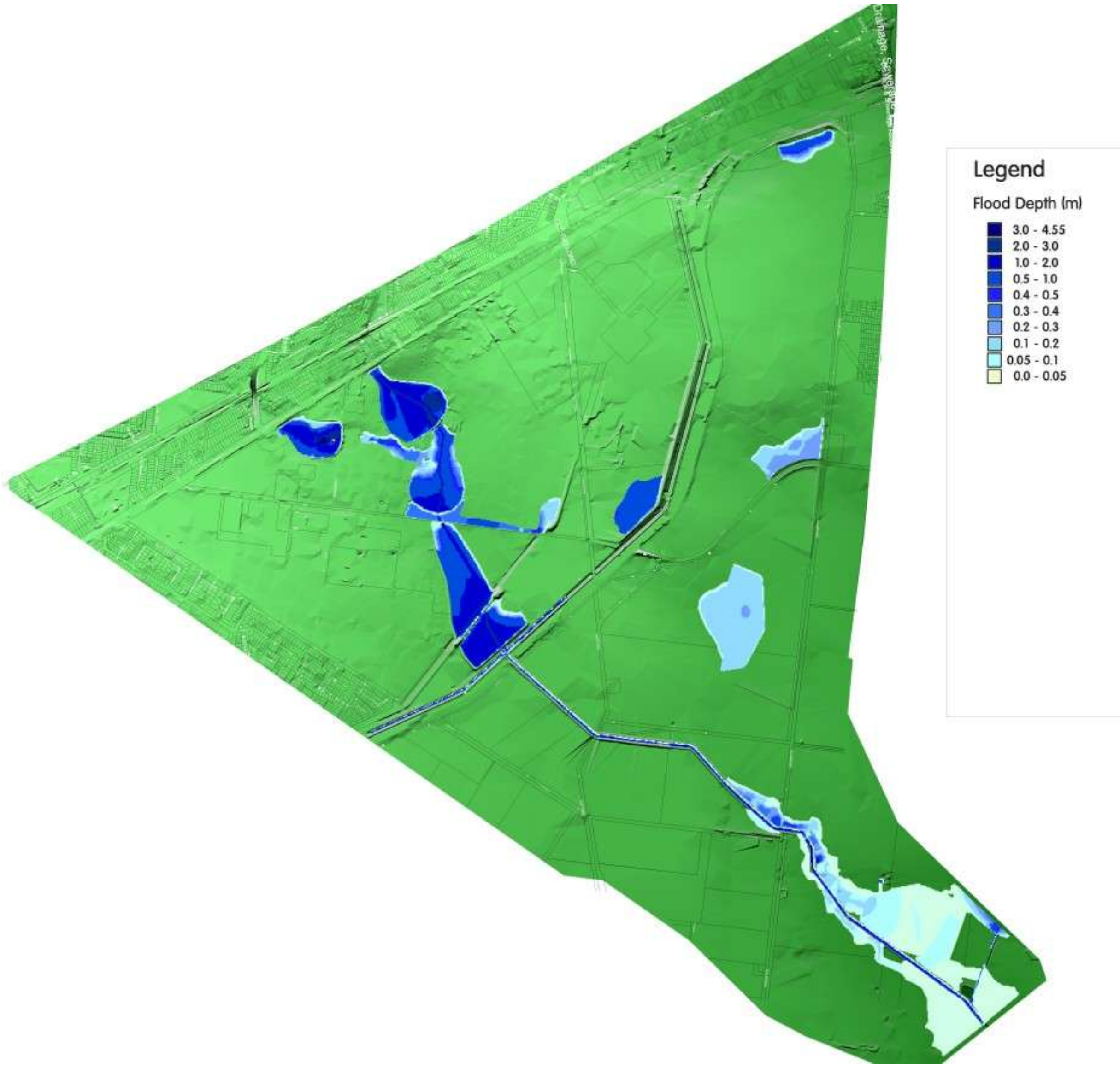

Figure 7.6: The extent of flooding from 100 year ARI storm events for Option 2 at the Werribee Employment precinct

The areas of inundation from flooding and comparison to existing conditions are shown in Table 7.19.

Table 7.19: Extent of flooding for Option 2

Criteria	Extent	Depth > 50mm	Depth > 100mm
Extent (ha)	84.04	79.48	74.92
Difference to Existing (%)	-86.11	-43.23	-16.76
Difference to BAU (%)	-87.82	-68.21	-47.97

The stormwater management strategy in Option 2 has mitigated the impact of the fully developed Werribee Employment Precinct on flooding from 100 year ARI storm events.

The detention basins required for Option 2 to meet the objectives for stormwater management is shown in Table 7.20.

Table 7.20: Size of detention basins in Option 2

Location	Area (ha)
A	3.45
B	14.64
C	5.53
D	4.63
E	6.54
F	11.19
G	10.27
H	10.61
I	4.92
J	1.47
K	4.67
Total	**77.92**

The stormwater management strategy in Option 2 reduced the requirement for stormwater detention. The sizes of constructed wetlands required for Option 2 are the same as required for Option 1.

Option 3

The extent of flooding in Option 3 generated by 100 year ARI storm events is shown in Figure 7.7.

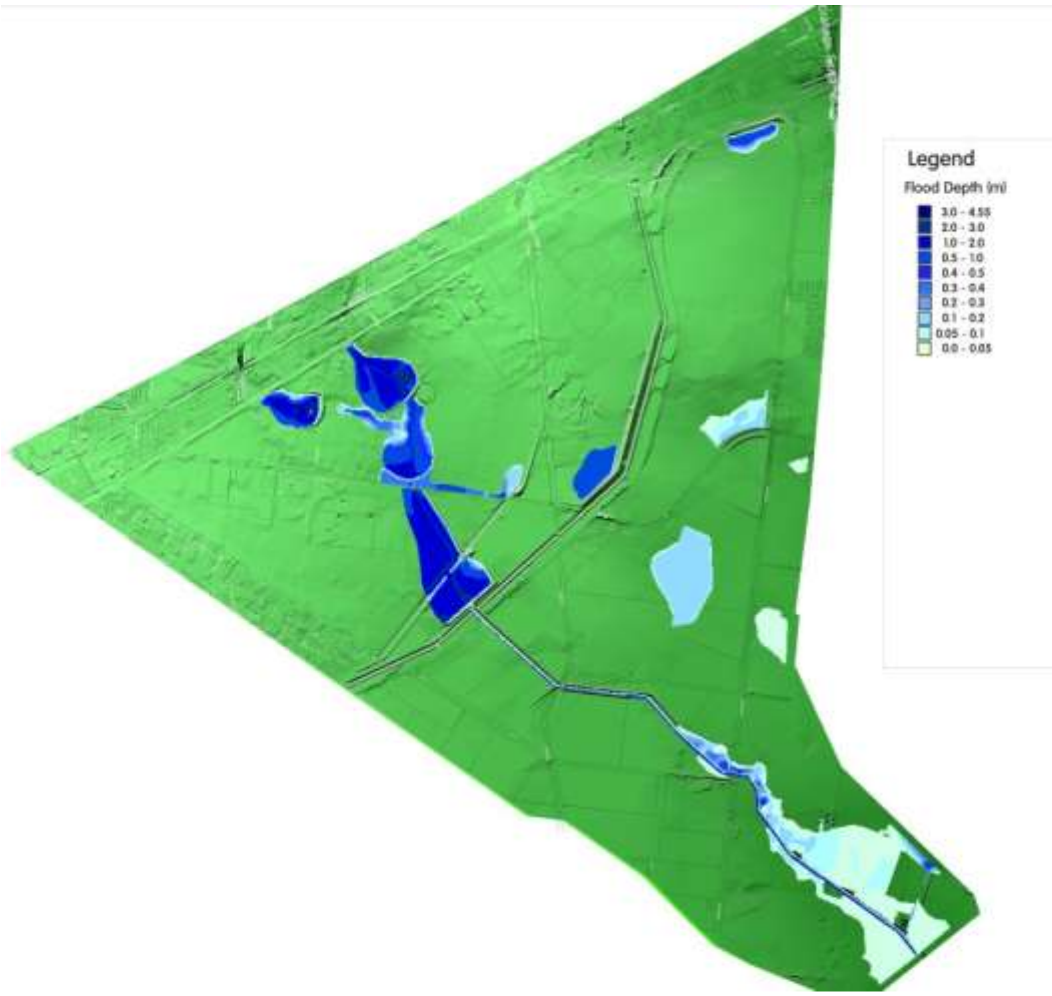

Figure 7.7: The extent of flooding from 100 year ARI storm events for Option 3 at the Werribee Employment precinct

The areas of inundation from flooding and comparison to existing conditions are shown in Table 7.21 below.

Table 7.21: Extent of flooding in Option 3

Criteria	**Extent**	**Depth > 50mm**	**Depth > 100mm**
Extent (ha)	82.66	78.31	74.91
Difference to Existing (%)	-86.34	-44.06	-16.77
Difference to BAU (%)	-88.02	-68.68	-47.98

The WSUD strategy has significantly reduced the extent of flooding. The size of the detention basins and bio-retention facilities in Option 3 required to meet the objectives for stormwater management are shown in Tables 7.22 and 7.23 respectively.

Table 7.22: Area of detention basins in required for Option 3

Location	**Area (ha)**
A	2.82
B	14.12
C	4.90
D	1.39
E	5.87
F	10.74
G	9.93
H	10.64
I	3.05
J	1.44
K	4.91
Total	**69.81**

Table 7.23: Area of bio-retention facilities required to meet "Best Practice" objectives in Option 3

Discharge location	**Sub-precinct**	**Werribee area (m²)**	**Drome area (m²)**
A	1	900	1,200
	2	2,900	4,000
	3	750	900
	4	900	1,200
	5	180	300
	6	720	1,200
	7	1,200	1,650
	8	300	500
	9	750	1,250
	13	750	1,050
	14	150	525
B	12	3,000	5,250
C	11	960	2,010
D	10	1,440	2,550
Total area	**m²**	**14,900**	**23,585**
	Ha	**1.49**	**2.36**

Option 3 did not require the use of constructed wetlands to meet best practice guidelines for stormwater quality. The use of gross pollutant traps (GPT) and bio-retention facilities have provided the necessary improvement in stormwater quality. The characteristics of stormwater runoff from Option 3 to meet "Best Practice" guidelines using Werribee and Drome Paddock rainfall data are shown in Tables 7.24 and 7.25 respectively.

Table 7.24: Characteristics of Option 3 to meet "Best Practice" guidelines. (using Werribee Data)

Location A			
Criteria	**Sources**	**Residual Load**	**Reduction (%)**
Flow (ML/yr)	5,820	5,560	5
Total Suspended Solids (kg/yr)	1,160,000	59,900	95
Total Phosphorus (kg/yr)	2,300	548	76
Total Nitrogen (kg/yr)	16,600	9,130	45
Gross Pollutants (kg/yr)	208,000	5,100	98
Location B			
Flow (ML/yr)	593	523	12
Total Suspended Solids (kg/yr)	117,000	6,880	94
Total Phosphorus (kg/yr)	234	65	72
Total Nitrogen (kg/yr)	1,600	720	45
Gross Pollutants (kg/yr)	20,900	0	100
Location C			
Flow (ML/yr)	175	154	12
Total Suspended Solids (kg/yr)	34,100	2,280	93
Total Phosphorus (kg/yr)	69	19	73
Total Nitrogen (kg/yr)	477	263	45
Gross Pollutants (kg/yr)	6,170	0	100
Location D			
Flow (ML/yr)	249	215	14
Total Suspended Solids (kg/yr)	48,900	3,430	93
Total Phosphorus (kg/yr)	97	27	72
Total Nitrogen (kg/yr)	673	370	45
Gross Pollutants (kg/yr)	8,600	0	100

Table 7.25: Characteristics of Option 3 to meet "Best Practice" guidelines. (using Drome Data)

Location A			
Criteria	**Sources**	**Residual Load**	**Reduction (%)**
Flow (ML/yr)	3,650	3,504	4
Total Suspended Solids (kg/yr)	750,000	40,900	95
Total Phosphorus (kg/yr)	1,480	389	74
Total Nitrogen (kg/yr)	10,300	4,635	45
Gross Pollutants (kg/yr)	140,000	3,420	98
Location B			
Flow (ML/yr)	373	305	18
Total Suspended Solids (kg/yr)	74,800	4,600	94
Total Phosphorus (kg/yr)	151	44	71
Total Nitrogen (kg/yr)	1,050	580	45
Gross Pollutants (kg/yr)	14,100	0	100
Location C			
Flow (ML/yr)	110	90	18
Total Suspended Solids (kg/yr)	22,100	1,350	94
Total Phosphorus (kg/yr)	45	13	72
Total Nitrogen (kg/yr)	307	169	45
Gross Pollutants (kg/yr)	4,150	0	100
Location D			
Flow (ML/yr)	156	127	19
Total Suspended Solids (kg/yr)	30,700	2,010	94
Total Phosphorus (kg/yr)	62	18	71
Total Nitrogen (kg/yr)	441	244	45
Gross Pollutants (kg/yr)	5,780	0	100

The annual average stormwater runoff volumes from Option 3 will range 6,452 ML to 4,026 ML. The characteristics of stormwater runoff from Option 3 to meet "Pre-European" guidelines using Werribee and Drome Paddock rainfall data are shown in Tables 7.26 and 7.27 respectively.

Table 7.26: Size of bio-retention facilities required in Option 3 to meet pre-European objectives

Discharge location	**Sub-precinct**	**Werribee (m^2)**	**Drome (m^2)**
A	1	1,800	1,800
	2	23,000	23,000
	3	1,350	1,350
	4	1,800	1,800
	5	540	540
	6	2,160	2,160
	7	4,350	3,750
	8	2,000	1,600
	9	5,000	4,000
	13	2,100	3,300
	14	825	825
B	12	180,000	123,750
C	11	396	2,865
D	10	31,250	39,750
Total area	**m^2**	**256,571**	**210,490**
	Ha	**26**	**21**

Table 7.27: Size of constructed wetlands in Option 3 required to meet "pre-European" objectives

Discharge location	**Wetland**	**Werribee area (m^2)**	**Drome area (m^2)**
A	1	450,000	135,000
	2	450,000	168,750
	3	475,000	237,500
	4	150,000	150,000
Total area	**m^2**	**1,525,000**	**691,250**
	Ha	**153**	**69**

Tables 7.26 and 7.27 show that constructed wetlands and additional bio-retention facilities are required to meet pre-European objectives. The magnitude of stormwater quality improvement facilities required to achieve best practice and pre-European objectives is greater for the Werribee rainfall data whilst the use of rainfall data from Drome Paddock generated relatively less requirement for stormwater quality improvement facilities. A requirement to meet pre-European objectives for stormwater runoff will need a dramatic increase in the magnitude of stormwater quality facilities.

Option 3a

This Option combines the WSUD approach in Option 3 with rainwater and stormwater harvesting within each Sub-Precinct. This Option reduces the magnitude of stormwater runoff from each Sub-Precinct as source.

The extent of inundation from flooding in Option 3a from 100 year ARI storm events is shown in Figure 7.8.

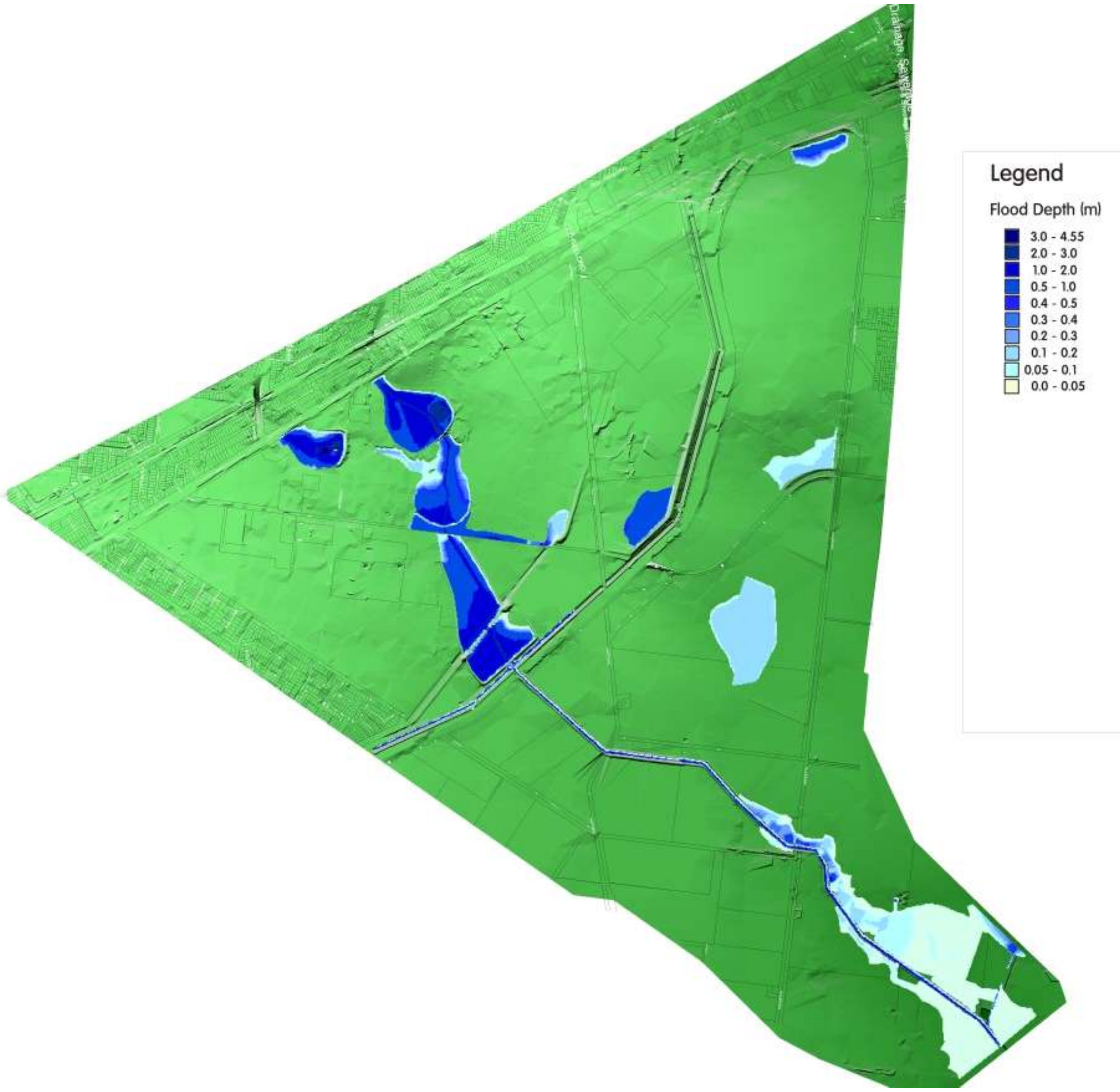

Figure 7.8: The extent of flooding from 100 year ARI storm events for Option 3 with rainwater and stormwater harvesting at the Werribee Employment precinct.

The areas of inundation from flooding and comparison to existing conditions are shown in Table 7.28 below.

Table 7.28: Areas of inundation from flooding in Option 3a

Criteria	Extent	Depth > 50mm	Depth > 100mm
Extent (ha)	81.03	77.14	73.17
Difference to Existing (%)	-86.61	-44.90	-18.70
Difference to BAU (%)	-88.26	-69.14	-49.19

Table 7.28 shows that the WSUD strategy that includes rainwater and stormwater harvesting has provided significant reductions in flood inundation.

The areas of stormwater quality facilities located within each Sub-Precinct to meet 'best practice' objectives are shown in Table 7.29.

Table 7.29: Size of bio-retention facilities required in Option 3a to meet "best Practice" objectives

Discharge location	Sub-precinct	Werribee area (m²)	Drome area (m²)
A	1	600	1,200
	2	1,600	5,550
	3	450	450
	4	300	600
	5	120	300
	6	480	1,200
	7	720	1,050
	8	180	400
	9	450	1,000
	13	450	900
	14	450	150
B	12	1,590	3,000
C	11	510	1,140
D	10	630	1,440
Total area	**m²**	**8,530**	**18,380**
	Ha	**0.85**	**1.84**

Table 7.29 shows that inclusion of the rainwater and stormwater harvesting in the WSUD strategy reduces the requirement for bio-retention facilities within each Sub-Precinct. The magnitude of the stormwater quality facilities required to meet pre-European objectives are similar to Option 3.

Option 4

Options 4 and 5 incorporate the majority of the existing drainage infrastructure, a new alignment for the D1 drain and new centralised detention basins along the new alignment as shown in Figure 7.9.

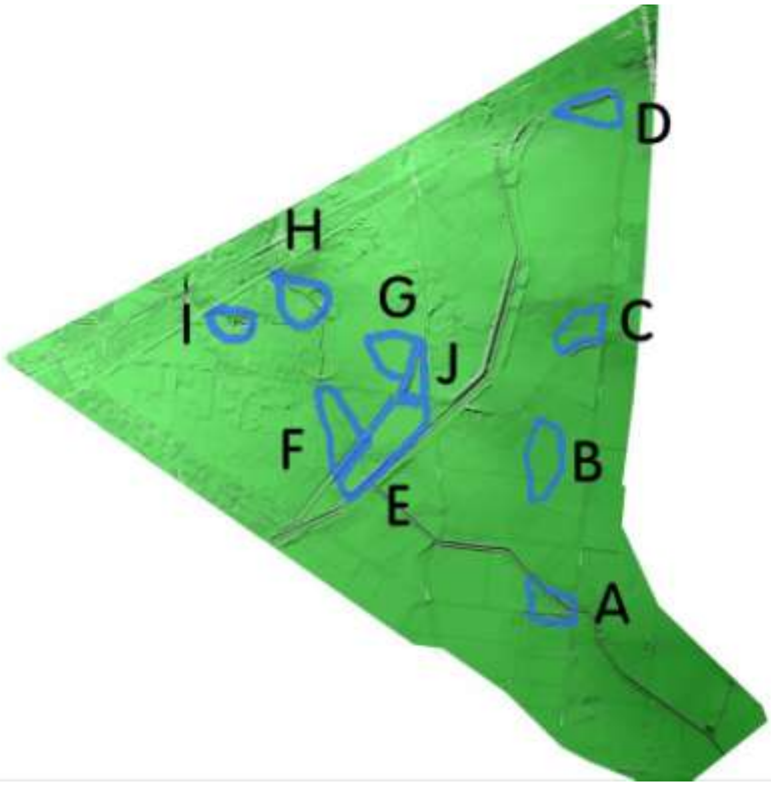

Figure 7.9: Configuration of detention basins for Options 4 and 5.

The extent of inundation from flooding generated in Option 4 by 100 year ARI storm events is shown in Figure 7.10.

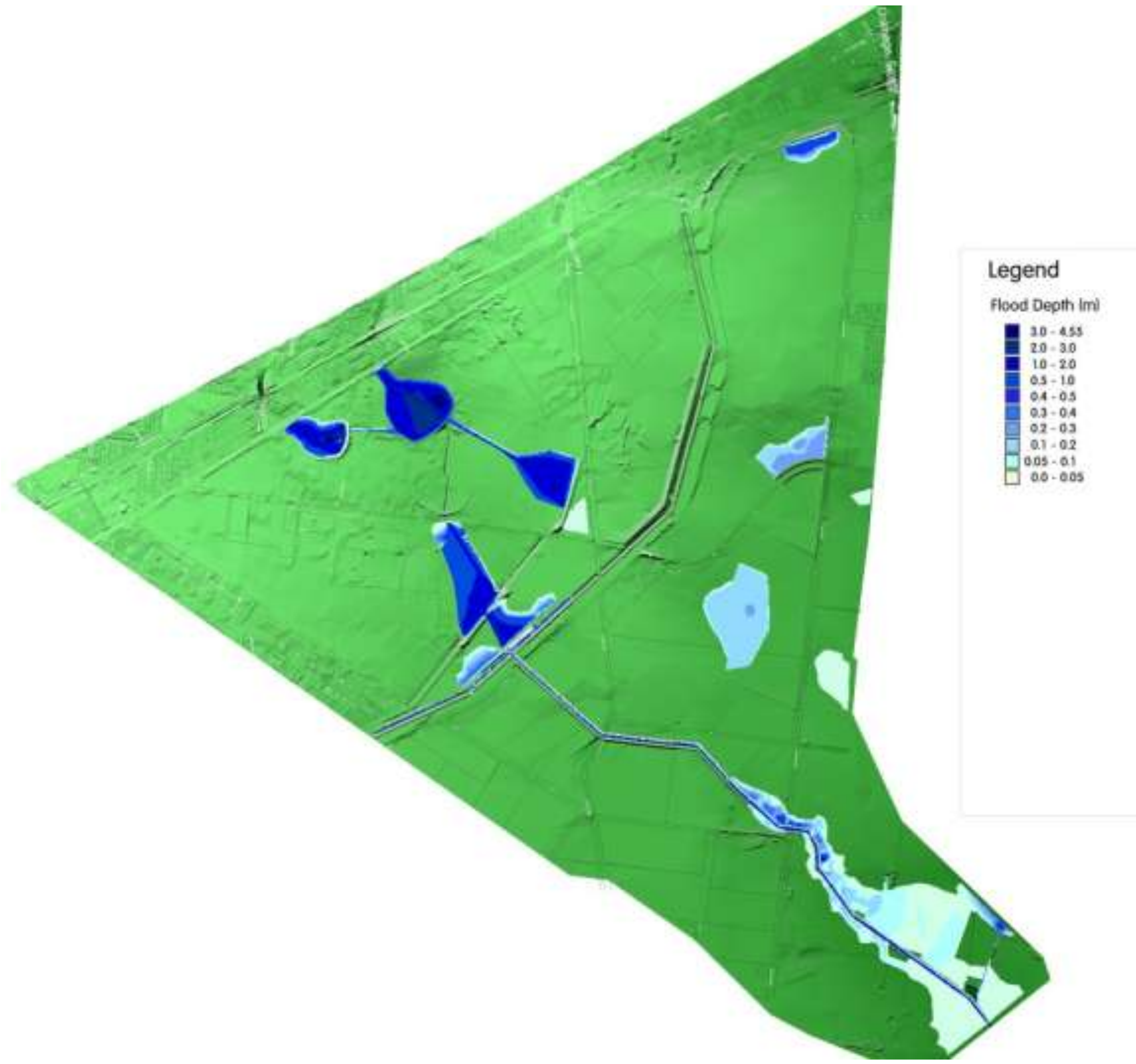

Figure 7.10: The extent of flooding from 100 year ARI storm events in Option 4 at the Werribee Employment precinct

The area of flooding inundation and the comparison to existing conditions are shown in Table 6.29 below.

Table 7.30: Areas of flood inundation in Option 4

Criteria	**Extent**	**Depth > 50mm**	**Depth > 100mm**
Extent of flooding (ha)	72.47	66.52	64.24
Difference to Existing (%)	-88.02	-52.49	-28.62
Difference to BAU (%)	-89.50	-73.39	-55.39

Option 4 has produced considerable reductions in the extent of flooding at the Werribee Employment Precinct. The areas of detention basins required for Option 4 to meet the objectives for stormwater management are shown in Table 7.31.

Table 7.31: Size of detention basins in Option 4

Location	Area (ha)
A	2.26
B	13.9
C	4.86
D	2.47
E	3.12
F	10.43
G	6.75
H	10.7
I	5.3
J	0
Total	**59.79**

The stormwater management strategy in Option 4 significantly reduced the requirement for stormwater detention. The restriction of the siphon crossing the large western sewer pipeline can be avoided by realigning the D1 drain with centralised detention basins. The discharge point remains at the historical sewer channel crossing adjacent to the bridge in the Maltby Bypass. The requirement for constructed wetlands is similar to Option 1.

Figure 7.11 shows the location of constructed wetlands for Option 4 that incorporates a centralised system along the realignment of the "D1" drain.

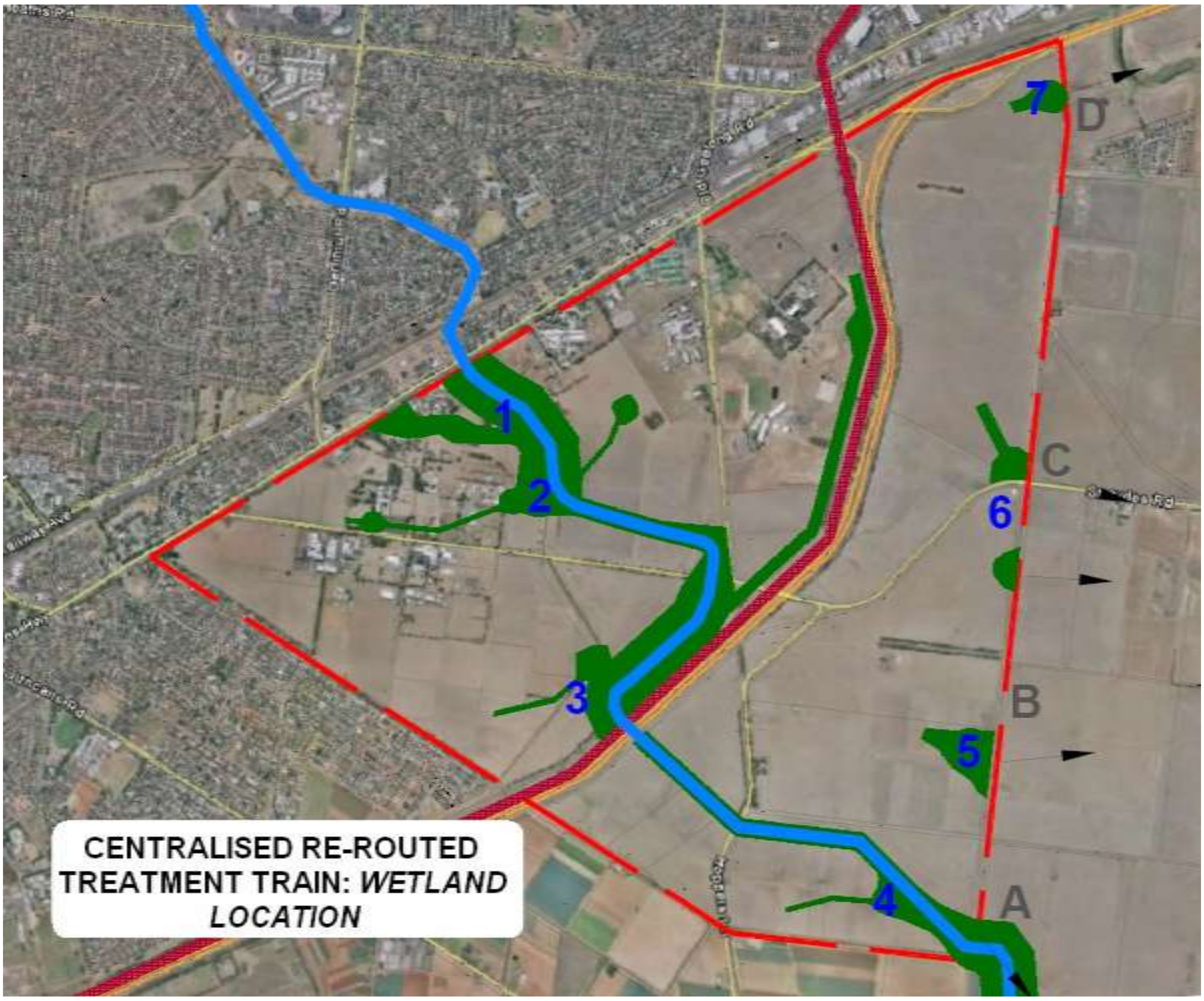

Figure 7.11: Locations of constructed wetlands in Option 4.

Option 5

The extent of inundation from flooding generated in Option 5 by 100 year ARI storm events is shown in Figure 7.12.

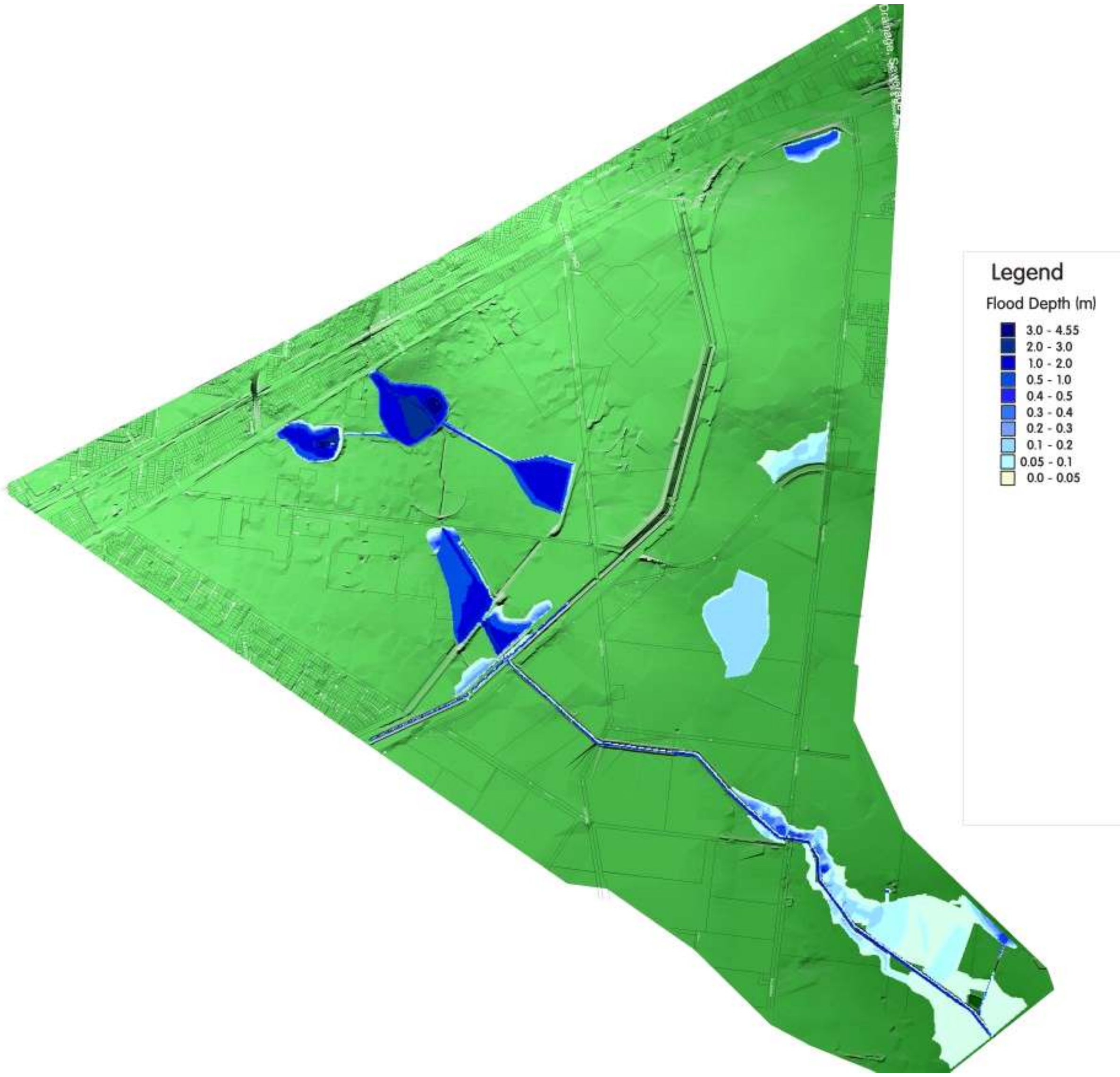

Figure 7.12: The extent of flooding generated by 100 year ARI storm events in Option 5 at the Werribee Employment precinct

The area of inundation from flooding and comparison to existing conditions is shown in Table 7.32 below.

Table 7.32: Option 5 Flood Areas

Criteria	Extent	Depth > 50mm	Depth > 100mm
Extent of flooding (ha)	71.39	66.49	62.24
Difference to Existing (%)	-88.20	-52.51	-30.84
Difference to BAU (%)	-89.65	-73.40	-56.78

The stormwater management strategy in Option 5 has mitigated the extent of flooding from 100 year ARI storm events. The detention basins required for Option 5 to meet the objectives for stormwater management are shown in Table 7.33. The bio-retention facilities required for Option 5 is the same as Option 3.

Table 7.33: Size of detention basins required for Option 5

Location	Area (ha)
A	2.72
B	6.52
C	6.70
D	1.10
E	4.13
F	6.48
G	7.79
H	11.15
I	2.22
J	1.62
Total	**50.43**

Table 7.33 shows that a combination of the realigned D1 drain and a WSUD strategy has significantly reduced the requirement for detention basins.

Option 5a

Option 5a combined Option 5 with rainwater and stormwater harvesting in each Sub-Precinct. This reduces the magnitude of stormwater runoff from each Sub-Precinct. The extent of flooding in Option 5a from 100 year ARI storm events is shown in Figure 7.13.

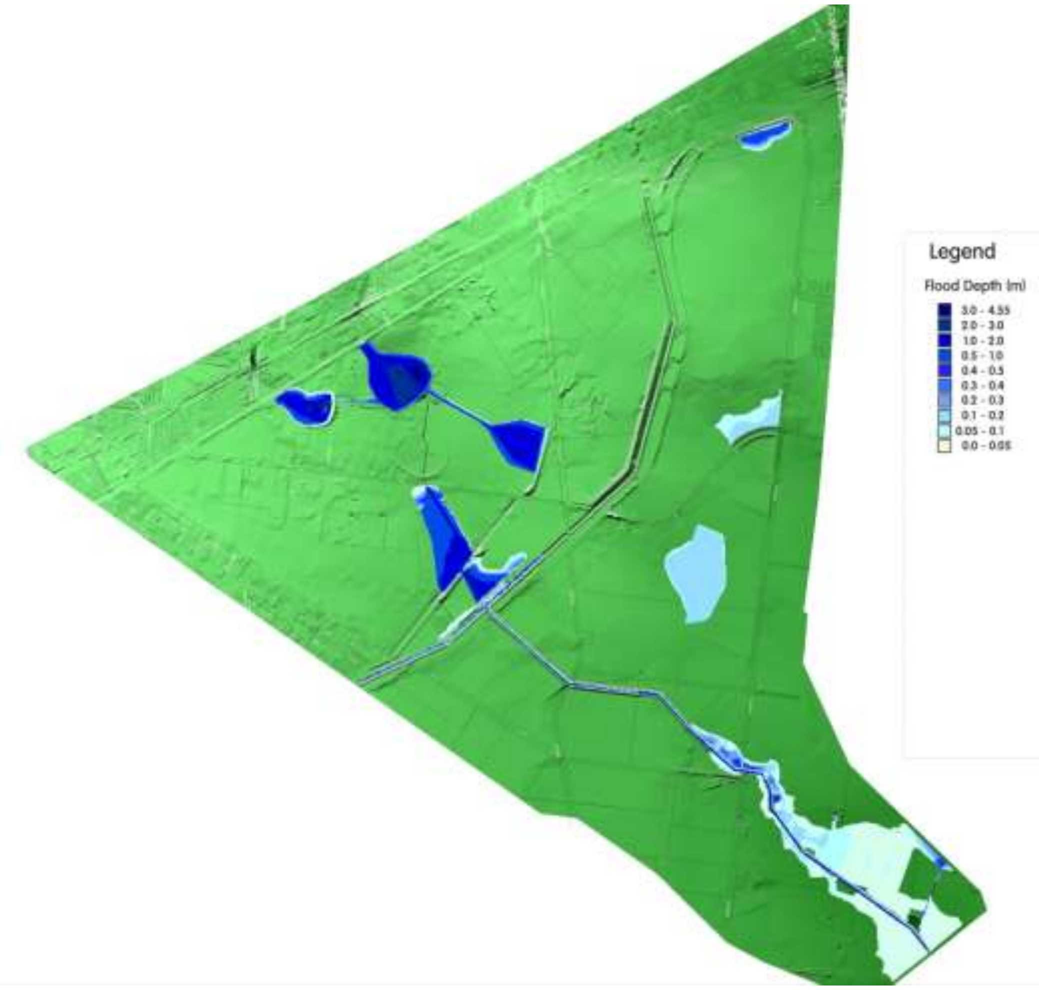

Figure 7.13: The extent of flooding from 100 year ARI storm events for Option 5 with rainwater and stormwater harvesting at the Werribee Employment precinct

The area of inundation from flooding and comparison to existing conditions is shown in Table 7.34 below.

Table 7.34: Area of flood inundation in Option 5a

Criteria	Extent	Depth > 50mm	Depth > 100mm
Extent of flooding (ha)	71.34	64.99	61.33
Difference to Existing (%)	-88.21	-53.58	-31.86
Difference to BAU (%)	-89.66	-74	-57.41

The magnitudes of bio-retention facilities required in each Sub-Precinct to achieve 'best practice' objectives are shown in Table 7.35.

Table 7.35: Size of bio-retention facilities required in Option 5a to meet "Best Practice" objectives.

Discharge location	Sub-Precinct	Werribee area (m^2)	Drome area (m^2)
A	1	600	1,200
	2	1,600	5,550
	3	450	450
	4	300	600
	5	120	300
	6	480	1,200
	7	720	1,050
	8	180	400
	9	450	1,000
	13	450	900
	14	450	150
B	12	1,590	3,000
C	11	510	1,140
D	10	630	1,440
Total	**m^2**	**8,530**	**18,380**
	Ha	**0.85**	**1.84**

The characteristics of stormwater runoff from Option 5a that achieve best practice objectives are shown in Tables 7.36 and 7.37 respectively.

Table 7.36: Characteristics of stormwater runoff from Option 5a. (using Werribee rainfall)

Location A			
Criteria	**Sources**	**Residual Load**	**Reduction (%)**
Flow (ML/yr)	5,650	5,250	7
Total Suspended Solids (kg/yr)	1,160,000	60,100	95
Total Phosphorus (kg/yr)	2,300	550	76
Total Nitrogen (kg/yr)	16,000	8,820	45
Gross Pollutants (kg/yr)	201,000	5,100	98
Location B			
Flow (ML/yr)	554	450	19
Total Suspended Solids (kg/yr)	113,000	6,200	95
Total Phosphorus (kg/yr)	227	67	70
Total Nitrogen (kg/yr)	1,580	870	45
Gross Pollutants (kg/yr)	19,400	0	100
Location C			
Flow (ML/yr)	164	131	20
Total Suspended Solids (kg/yr)	32,600	2,030	94
Total Phosphorus (kg/yr)	65	19	72
Total Nitrogen (kg/yr)	445	245	45
Gross Pollutants (kg/yr)	5,720	0	100
Location D			
Flow (ML/yr)	233	189	19
Total Suspended Solids (kg/yr)	46,900	2,350	95
Total Phosphorus (kg/yr)	93	25	73
Total Nitrogen (kg/yr)	649	357	45
Gross Pollutants (kg/yr)	7,980	0	100

Table 7.37: Characteristics of stormwater runoff for Option 5a. (using Drome rainfall)

Location A			
Criteria	**Sources**	**Residual Load**	**Reduction (%)**
Flow (ML/yr)	3,380	3,120	8
Total Suspended Solids (kg/yr)	459,000	39,400	91
Total Phosphorus (kg/yr)	1,010	332	67
Total Nitrogen (kg/yr)	7,627	5,260	45
Gross Pollutants (kg/yr)	261,000	3,460	99
Location B			
Flow (ML/yr)	345	264	24
Total Suspended Solids (kg/yr)	69,300	3,720	95
Total Phosphorus (kg/yr)	140	42	70
Total Nitrogen (kg/yr)	978	540	45
Gross Pollutants (kg/yr)	13,100	0	100
Location C			
Flow (ML/yr)	102	78	23
Total Suspended Solids (kg/yr)	20,500	973	95
Total Phosphorus (kg/yr)	41	12	71
Total Nitrogen (kg/yr)	289	159	45
Gross Pollutants (kg/yr)	3,850	0	100
Location D			
Flow (ML/yr)	144	111	23
Total Suspended Solids (kg/yr)	28,700	1,460	95
Total Phosphorus (kg/yr)	58	17	70
Total Nitrogen (kg/yr)	401	221	45
Gross Pollutants (kg/yr)	5,370	0	100

The annual average stormwater runoff volumes from Option 5a will range 6,020 ML to 3,573 ML. The magnitude of bio-retention facilities and constructed wetlands required to meet pre-European objectives are shown in Tables 7.39 and 7.40, respectively, for Werribee and Drome Paddock rainfall data.

Table 7.39: Size of bio-retention facilities required to meet Pre-European discharges in Option 5a.

Discharge location	Sub-Precinct	Werribee area (m²)	Drome area (m²)
A	1	1,800	1,800
	2	11,000	23,000
	3	1,200	1,350
	4	1,200	1,800
	5	540	540
	6	2,160	2,160
	7	4,200	3,750
	8	2,000	1,600
	9	5,000	4,000
	13	2,100	3,300
	14	825	825
B	12	135,000	123,750
C	11	2,100	2,865
D	10	18,000	39,750
Total area	**m²**	**185,295**	**210,490**
	Ha	**18.53**	**21.05**

Table 7.40: Size of constructed wetlands to meet pre-European objectives in Options 5a

Discharge location	Wetland	Werribee area (m²)	Drome area (m²)
A	1	450,000	135,000
	2	450,000	168,750
	3	450,000	237,500
	4	75,000	150,000
Total area	**m²**	**1,425,000**	**691,250**
	ha	**142.5**	**69**

Option 6

The potential impact of climate change in 2070 was analysed by assuming a 17% increase in rainfall intensity.

Option 2 with Climate Change

The extent of flooding in Option 2 generated by 100 year ARI storm events and expected climate change in 2070 is shown in Figure 7.14.

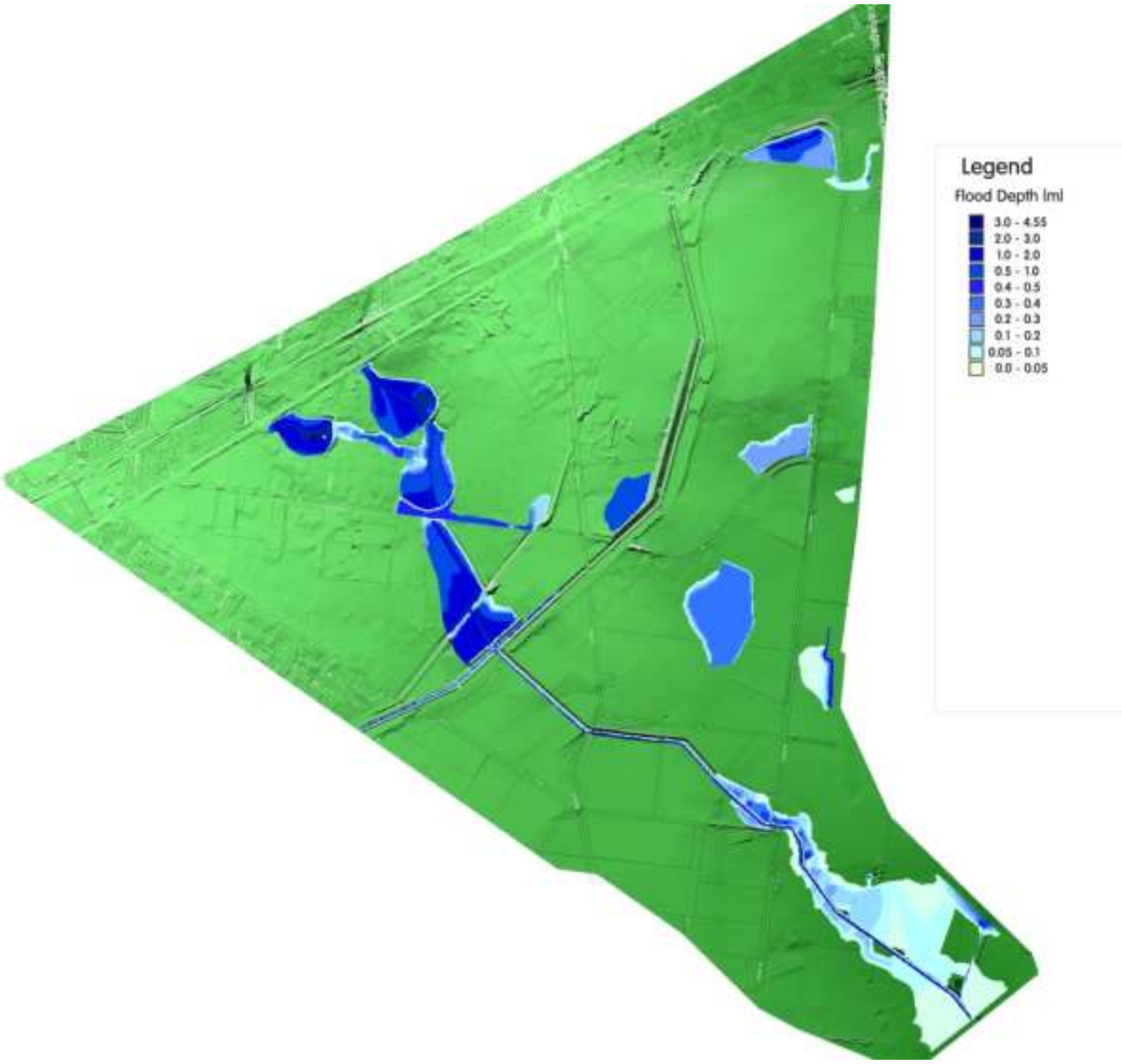

Figure 7.14: Extent of flooding in Option 2 generated by 100 year ARI storm events and expected climate change in 2070.

Figure 7.14 shows that expected climate change will increase the extent of flooding in Option 2. The area of inundation from flooding and comparison to existing conditions is shown in Table 7.41.

Table 7.41: Areas of flood inundation in Option 2 subject to climate change

Criteria	Extent	Depth > 50mm	Depth > 100mm
Extent of flooding (ha)	92.7	88.1	86.12
Difference to Existing (%)	-84.68	-37.07	-4.31
Difference to BAU (%)	-86.57	-64.76	-40.19

Table 7.41 shows that expected climate change will increase the extent of flooding by over 11 ha for the flood depths greater than 100 mm. Nevertheless, the strategy continues to provide a reduction in the extent of flooding in comparison to existing conditions.

Option 3 with Climate Change

The extent of flooding in Option 3 generated by 100 year ARI storm events and expected climate change in 2070 is shown in Figure 7.15.

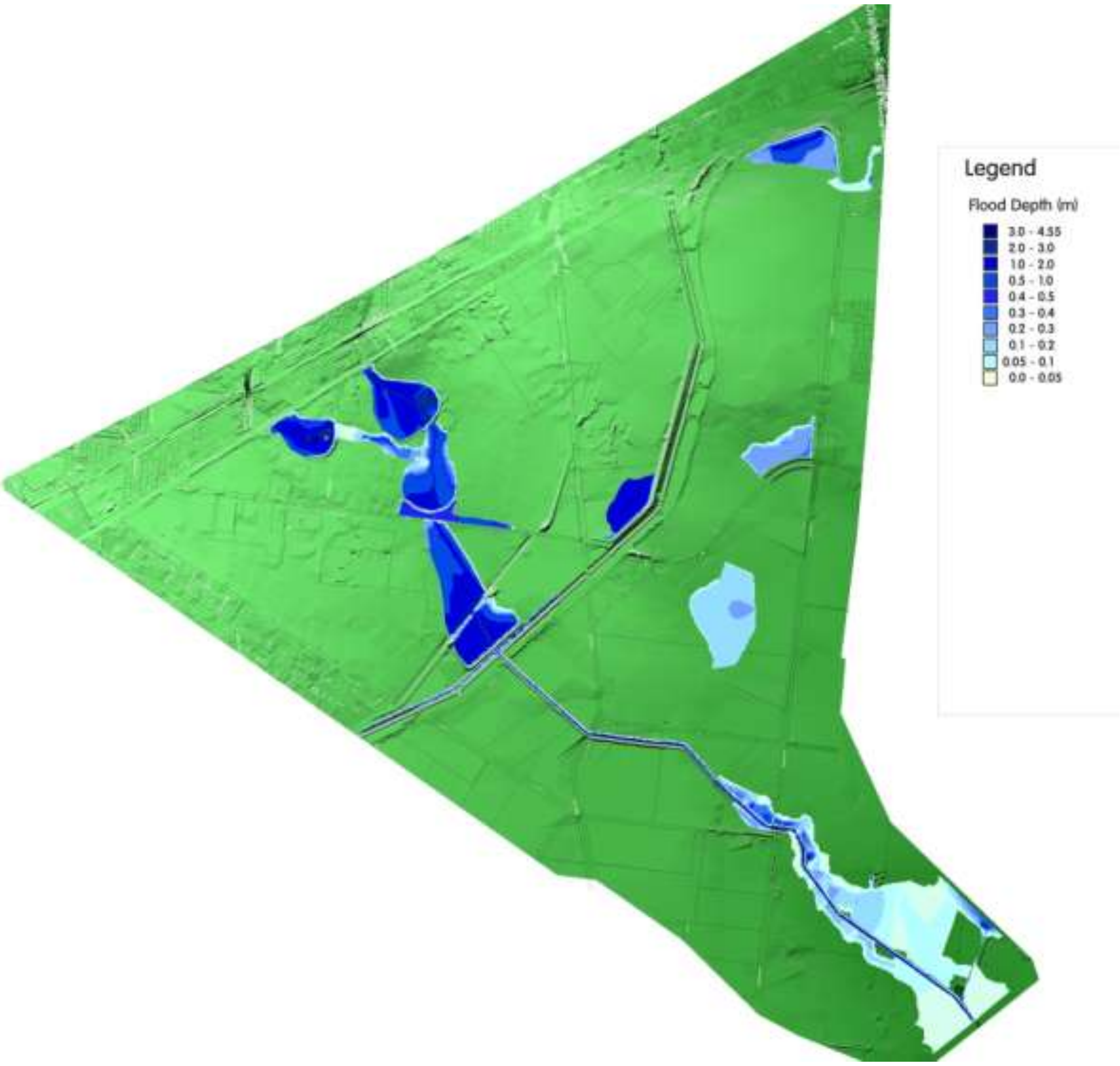

Figure 7.15: Extent of flooding in Option 3 generated by 100 year ARI storm events and expected climate change in 2070.

Figure 7.15 shows that expected climate change will increase the extent of flooding in Option 3. The area of inundation from flooding and comparison to existing conditions is shown in Table 7.42.

Table 7.42: Area of flood inundation in Option 3 with impacts of climate change

Criteria	**Extent**	**Depth > 50mm**	**Depth > 100mm**
Extent of flooding (ha)	90.48	86.61	84.75
Difference to Existing (%)	-85.04	-38.14	-5.83
Difference to BAU (%)	-86.89	-65.36	-41.15

Table 7.42 shows that expected climate change will increase the extent of flooding by over 10 ha for the flood depths greater than 100 mm. Nevertheless, the strategy continues to provide a reduction in the extent of flooding in comparison to existing conditions.

Option 5 with Climate Change

The extent of flooding in Option 5 generated by 100 year ARI storm events and expected climate change in 2070 is shown in Figure 7.16.

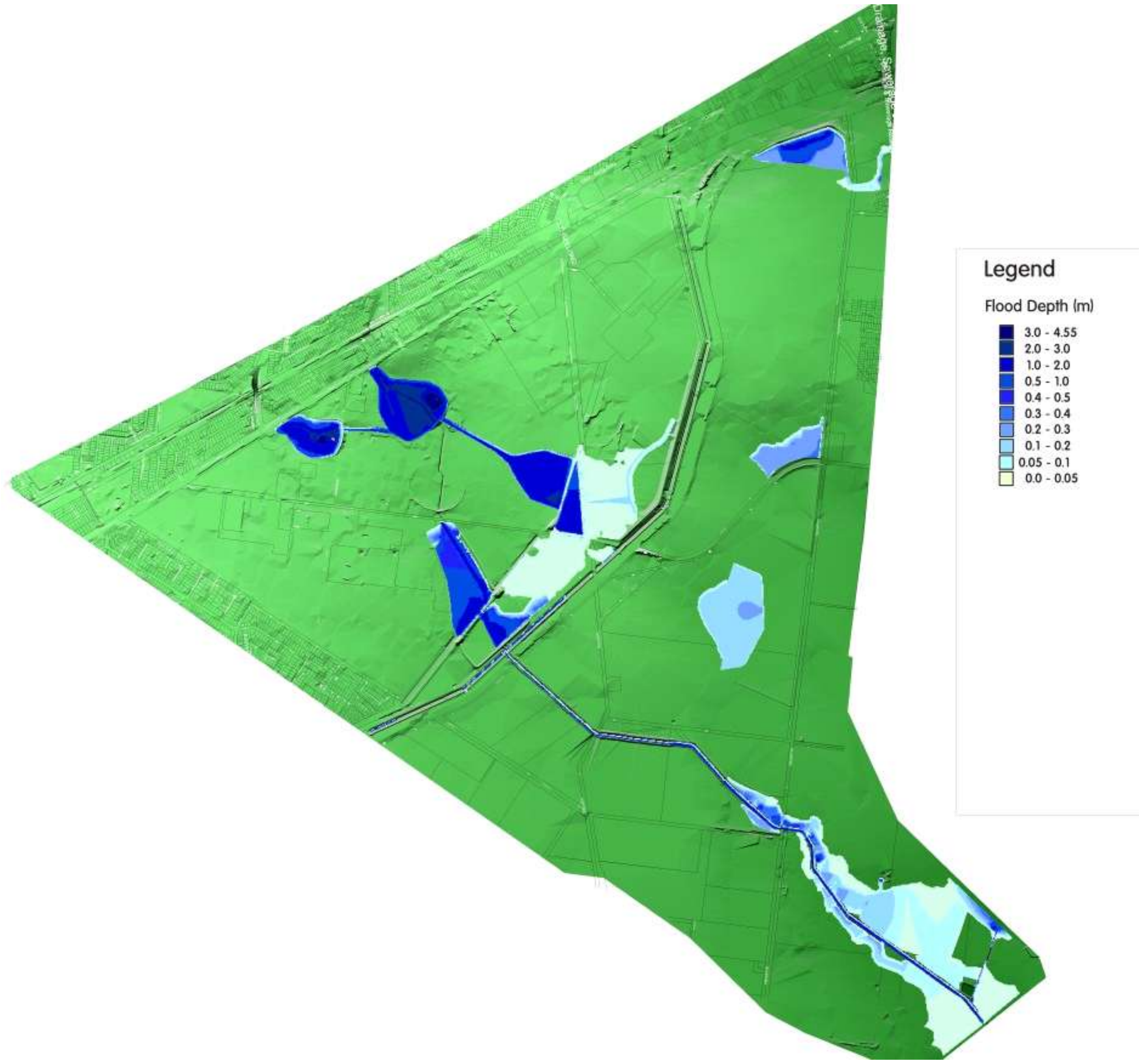

Figure 7.16: Extent of flooding in Option 5 generated by 100 year ARI storm events and expected climate change in 2070.

Figure 7.16 shows that expected climate change will increase the extent of flooding in Option 5. The area of inundation from flooding and comparison to existing conditions is shown in Table 7.43.

Table 7.43: Area of flood inundation in Option 5 with the impacts of climate change

Criteria	**Extent**	**Depth > 50mm**	**Depth > 100mm**
Extent of flooding (ha)	105.93	77.86	74.77
Difference to Existing (%)	-82.49	-44.39	-16.92
Difference to BAU (%)	-84.65	-68.86	-48.08

Table 7.43 shows that expected climate change will increase the extent of flooding by over 12 ha for the flood depths greater than 100 mm. However, the strategy continues to provide a significant reduction in the extent of flooding in comparison to existing conditions.

7.12 Option K

Option K includes Option 5a in a Precinct scale stormwater harvesting strategy. The strategy will generate average annual stormwater runoff volumes of 5,100 ML and 3,043 ML from the Werribee and Drome Paddock rainfall records respectively. The strategy will also generate average annual nitrogen loads of 7,932 kg and 3,999 kg from the Werribee and Drome Paddock rainfall records respectively.

7.13 Summary of Stormwater Results

The areas of inundation by flooding at depths greater than 100 mm for each Option are summarised in Figure 7.17 and Table 7.44.

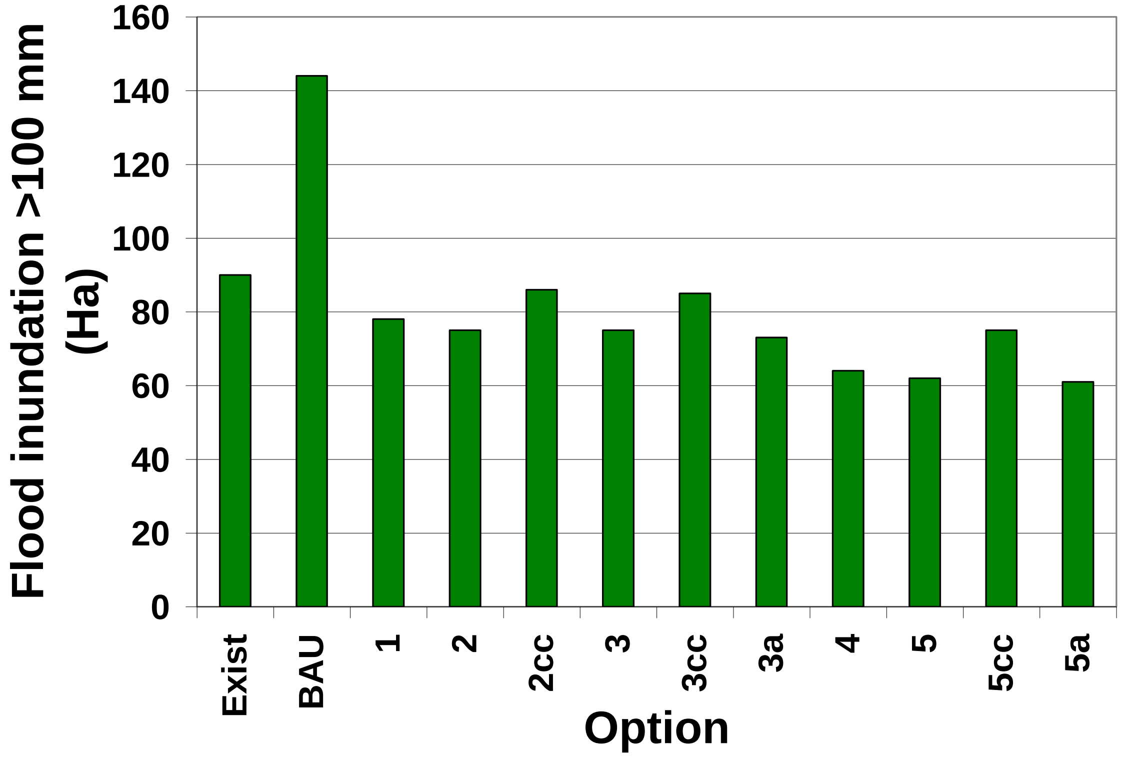

Figure 7.17: Summary of flood inundation at depths greater than 100 mm for each Option.

Figure 7.17 show that all of the alternative Options decrease the extent of flooding at the Werribee Employment Precinct in comparison to the Existing and BAU cases. Options that include WSUD and rainwater harvesting further decrease the extent of flooding. Realignment of the D1 drain has significant impact on reducing the extent of flooding and the impact of the potential for climate change increases the extent of flood inundation.

Table 7.44: Summary of flood inundation at depths greater than 100 mm for each Option

Option	Area (ha)
Exist	90
BAU	144
1	78
2	75
2cc	86
3	75
3cc	85
3a	73
4	64
5	62
5cc	75
5a	61

Table 7.44 shows that the extent of inundation from flooding ranges from 61 ha to 78 ha for the alternative Options. The potential impacts of climate change will increase the extent of flooding from each Option. However, the increases in the extent of flooding remain less than the Existing case. The proposed stormwater management Options are resilient to climate change. The average annual stormwater runoff volumes from each Option are summarised in Figure 7.18 and Table 7.45.

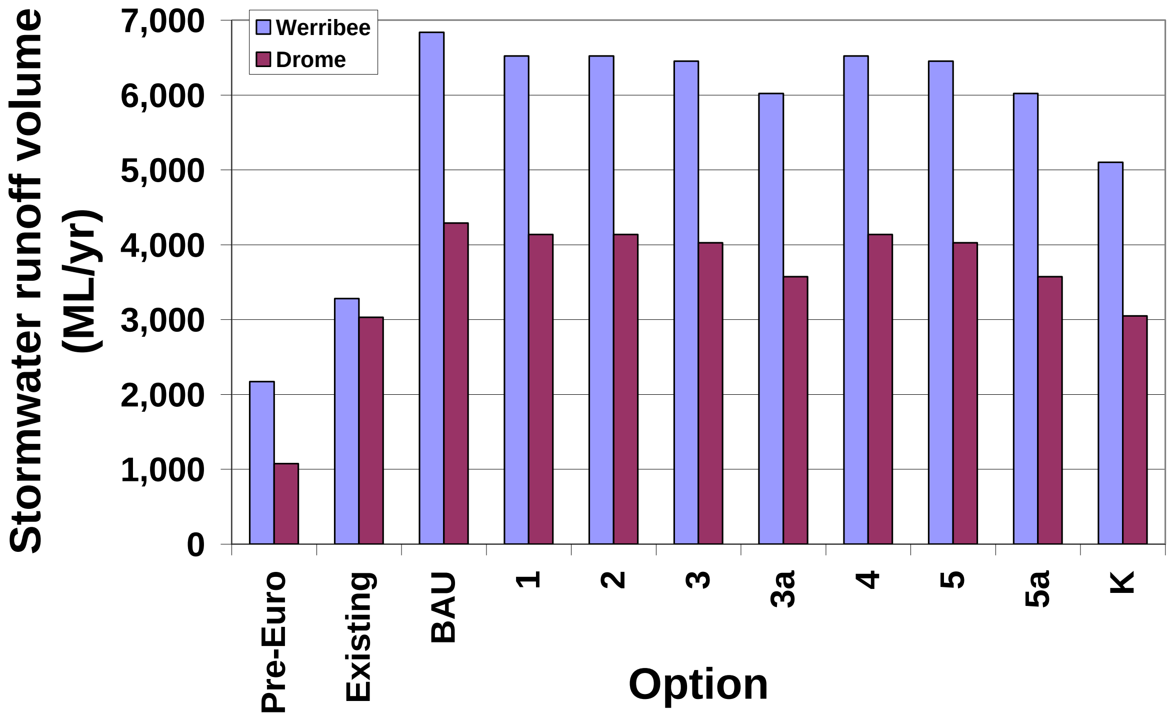

Figure 7.18: Summary of average annual stormwater runoff volumes discharging from each Option.

Figure 7.18 reveals that Options 3a and 5a that include WSUD and rainwater harvesting provide significant reductions in stormwater runoff volumes from the BAU Option. The greatest reductions in stormwater runoff volumes were generated by Option K that includes Precinct scale stormwater harvesting, rainwater harvesting and WSUD strategies. Note that only Option K was able to return average annual stormwater runoff volumes to existing levels using rainfall with lower annual rainfall depths from the Drome Paddock record. Analysis using the Werribee rainfall record that has higher rainfall depths was not about to reduce stormwater runoff volumes to existing levels.

Table 7.45: Summary of average annual stormwater runoff volumes discharging from each Option.

	Runoff Volume (ML/yr)	
Option	**Werribee**	**Drome**
Pre-European	2,170	1,074
Existing	3,280	3,030
BAU	6,837	4,289
1	6,521	4,137
2	6,521	4,137
3	6,452	4,026
3a	6,020	3,573
4	6,521	4,137
5	6,452	4,026
5a	6,020	3,573
K	5,100	3,048

Table 7.45 also reveals that the stormwater management Options did not reduce average annual stormwater runoff volumes to less that pre-European runoff volumes. The proposed Options will not reduce environmental flows in the waterways. The average annual nitrogen loads discharging from each Option are summarised in Figure 7.19 and Table 7.46.

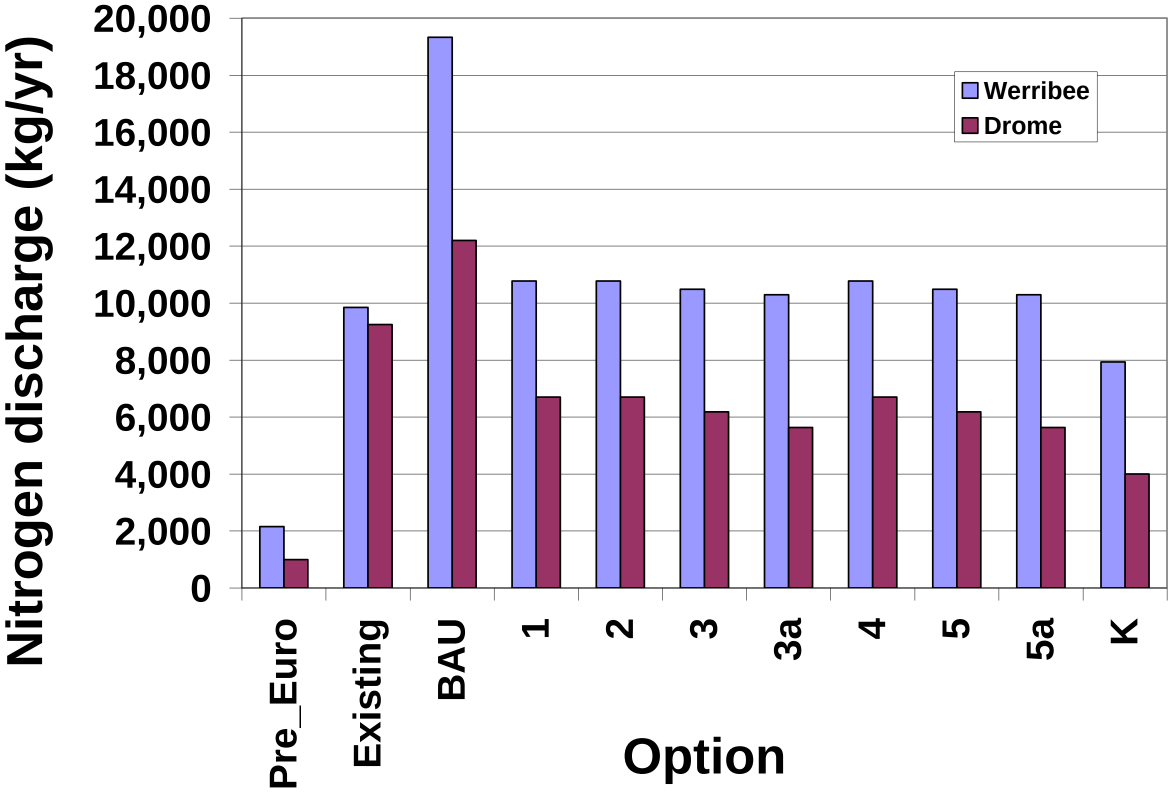

Figure 7.19: Summary of average annual nitrogen loads discharging from each Option.

Figure 7.19 shows that all Options reduce nitrogen loads discharging from the site to levels less than the existing and BAU Options for analysis using rainfall from the Drome Paddock record. Analysis using the Werribee rainfall record reveals that all Options generate reduced nitrogen loads in comparison to the BAU Option and only Option K reduces nitrogen loads to levels less than the Existing case. None of the Options was able to reduce nitrogen loads to less than pre-European levels.

Table 7.46: Summary of average annual nitrogen loads discharging from each Option.

	Nitrogen load (kg/yr)	
Option	**Werribee**	**Drome**
Pre-European	2,150	996
Existing	9,842	9,246
BAU	19,323	12,196
1	10,774	6,698
2	10,774	6,698
3	10,483	6,180
3a	10,292	5,628
4	10,774	6,698
5	10,483	6,180
5a	10,292	5,628
K	7,932	3,999

8 WATER BALANCE RESULTS

The average daily mains water demands for each Option at the Werribee Employment Precinct are shown in Figure 8.1.

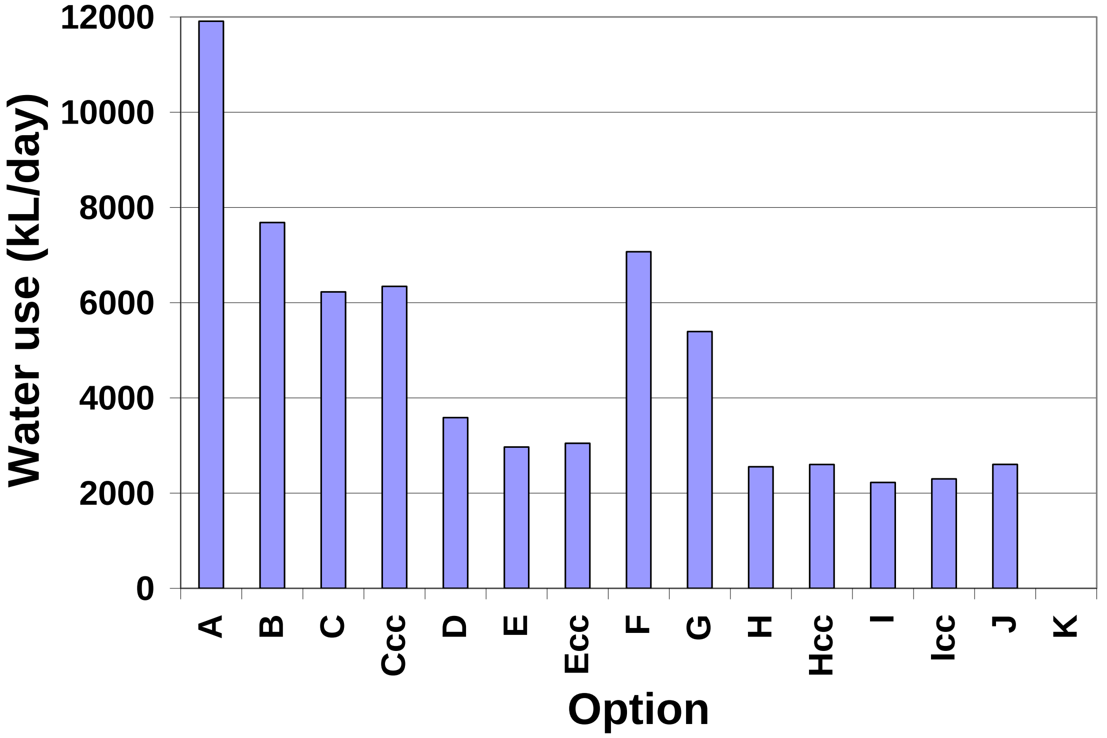

Figure 8.1: Average daily mains water demands for each Option at the Werribee Employment Precinct.

Figure 8.1 shows the average daily volume of mains water required from the regional water supply system for each Option. The variation of daily water demands for each Option is shown in Table 8.1.

Table 8.1: Variation in daily water demands from each Option

	Water demand (kL/day)			Reduction (%)
Option	**Average**	**95th ile**	**5th ile**	**Ave: (95th , 5th)**
A	11,911	13,469	10,351	-
B	7,682	8,527	6,867	36 (28, 42)
C	6,226	7,860	4,736	48 (34, 60)
Ccc	6,342	7,966	4,884	47 (33, 59)
D	3,586	4,177	3,172	70 (65, 73)
E	2,968	4,245	2,125	75 (64, 82)
Ecc	3,046	4,331	2,156	74 (64, 82)
F	7,069	7,531	6,466	41 (37, 46)
G	5,394	5,772	5,003	55 (52, 58)
H	2,553	3,123	2,222	79 (74, 81)
Hcc	2,600	3,164	2,283	78 (74, 81)
I	2,299	3,010	1,710	81 (75, 86)
Icc	2,223	2,961	1,636	81 (73, 81)
J	2,604	3,196	2,251	78 (73, 81)
K	0	0	0	100 (100, 100)

Table 8.1 shows the resilience of each strategy by presenting the average, 95th and 5th percentile daily water demands for the Precinct. The reductions in mains water demands generated by Option B that includes 6 star water efficient appliances and water efficient gardens ranges from 28% to 42%.

Option C that combines rainwater tanks to supply laundry, toilet and outdoor uses with water efficient appliances and gardens provides reductions in mains water demands that vary from 34% to 60%. This variation in decreased mains water demands represents the natural variation in local rainfall. The impact of climate change on this scenario is to reduce the magnitude of reductions in mains water demands by only 1%. This result is consistent with research that shows that rainwater harvesting strategies in cities were resilient to the impacts of climate change.[40]

A combination of local wastewater treatment plants within each Sub-Precinct to supply toilet and outdoor uses with the water efficient strategy from Option B in Option D generated reductions in mains water demands that range from 65% to 73%.

Option E includes wastewater reuse from local plants, water efficient appliances and gardens, and rainwater harvesting for laundry and hot water uses to provide decreased demands for mains water that range from 64% to 82%. Option E was also shown to be resilient to the impacts of climate change.

The Precinct scale wastewater reuse for outdoor uses with water efficient appliances and gardens in Option F generated reductions in mains water demands that ranged from 37% to 46%. Whilst Option G that also supplies toilet flushing with treated wastewater from the Precinct scale reuse system provides decreases in mains water demands that range from 52% to 58%.

The integrated water cycle management strategy in Options H involved use of recycled wastewater from the Precinct scale system for toilet and outdoor uses, water efficient appliances and gardens, and rainwater harvesting for laundry and hot water uses reduced mains water demands from 74% to 81%. Climate change will have negligible impact on Option H.

The use of combined strategies produces considerable reductions in average annual mains water demands. Option I adds the use of rainwater harvesting for bathroom uses to Option H and provides reductions in mains water demands ranging from 75% to 86%. Climate change produces small increases in the range of mains water demands.

Option J uses harvests stormwater in a aquifer storage and recovery (ASR) scheme to supply outdoor and toilet uses, includes water efficient appliances and gardens, and rainwater harvesting for laundry and hot water uses generates reductions in mains water demands ranging from 73% to 81%.

Option K harvests stormwater from an ASR scheme to replace mains water demands for kitchen and drinking uses, and to supplement the wastewater and rainwater supplies in Option I. This Option does not require mains water from the regional water supply and is resilient to the impacts of climate change. The performance of the section of the aquifer used for the ASR strategy is shown in Figure 8.2.

[40] Coombes P.J., and M.E. Barry (2008). Climate change, efficiency of water supply catchments and integrated water cycle management in Australia. Australian Journal of Water Resources. Engineers Australia.

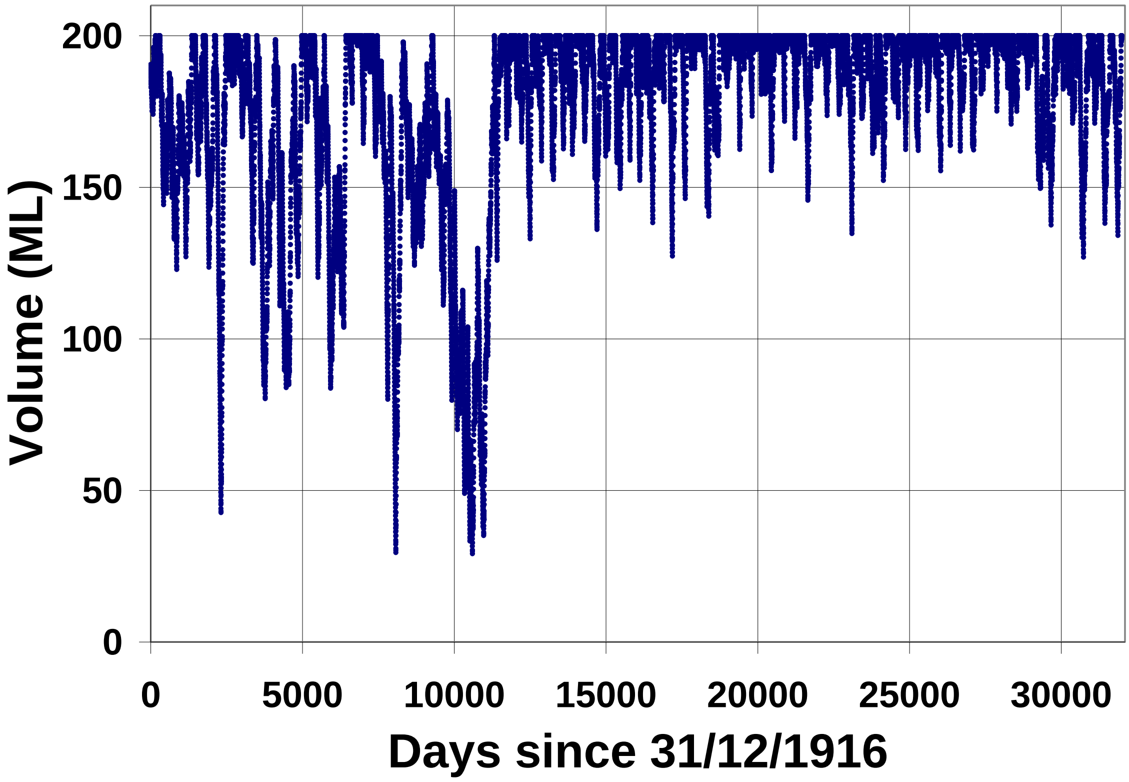

Figure 8.2: Performance of the aquifer storage in Option K.

Figure 8.2 shows that the aquifer storage in Option K was able to provide a secure water sources throughout the climate sequence that incorporated climate change impacts including during the most severe drought during the 1936 to 1948 period. The stormwater harvesting strategy and ASR strategy was resilient because the urban catchments supply the strategy are not subject to the same losses as inland catchments supplying dams and storage in the aquifer eliminates the considerable impacts of evaporation.

The average daily surplus of wastewater from each Option is shown in Figure 8.3. The options that do not include Precinct scale wastewater treatment (Options A, B, C, D, E and J) discharge wastewater to the Western Trunk Sewer whilst the remainder of the Options provide "surplus" treated wastewater to the surrounding irrigation district.

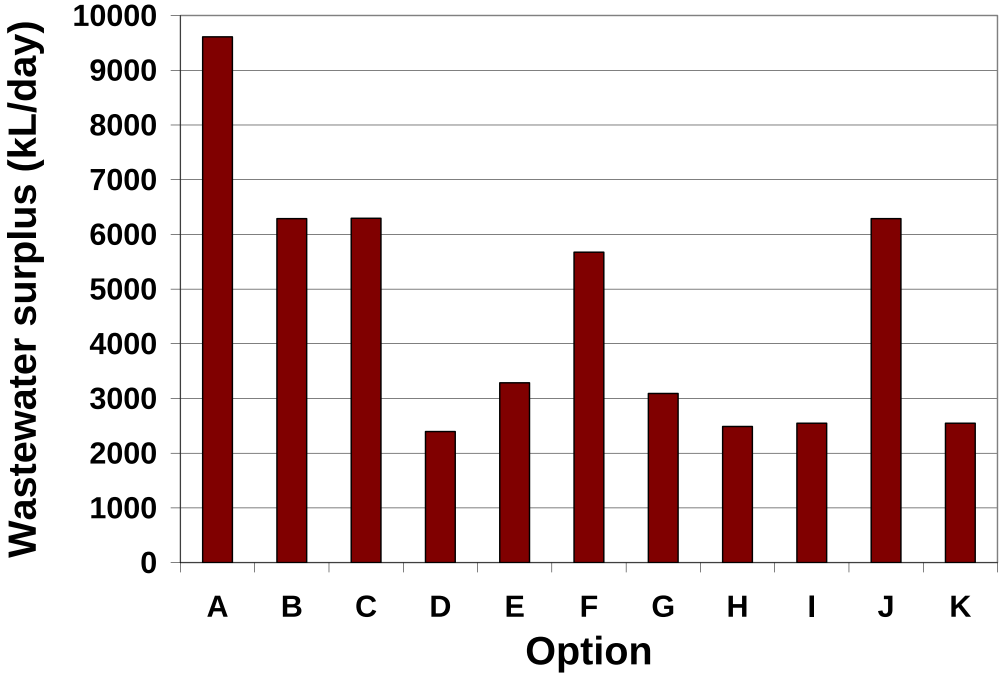

Figure 8.3: Average daily sewerage discharges from the Werribee Employment Precinct.

Figure 8.3 reveals that most of the water management options provide significant reductions in wastewater discharges to the Western Trunk Sewer. The variation of daily wastewater discharges for each Option is shown in Table 8.2.

Table 8.2: Variation in daily sewerage discharges from the Precinct

	Wastewater surplus (kL/day)			Reduction (%)
Option	**Average**	**95^{th} ile**	**5^{th} ile**	**Ave: 95^{th} , 5^{th}**
A	9,610	8,762	8,762	-
B	6,287	6,728	5,704	35 (30, 41)
C	6,293	6,728	5,720	35 (30, 41)
D	2,396	2,748	1,975	75 (71, 79)
E	3,286	3,682	2,776	75 (71, 79)
F	5,674	6,705	4,551	41 (30, 53)
G	3,092	4,494	1,479	68 (53, 85)
H	2,488	3,298	1,623	74 (61, 85)
I	2,547	3,718	1,403	73 (61, 85)
J	6,287	6,728	5,704	35 (30, 41)
K	2,547	3,718	1,403	73 (61, 85)

Table 8.2 shows the variation in wastewater discharges from each strategy by presenting the average, 95^{th} and 5^{th} percentile wastewater surpluses for the Precinct. Reductions in wastewater discharges to the Western Trunk Sewer from Option B that includes water efficient appliances ranges from 30% to 41%. Similar wastewater discharges were simulated for Option C that included rainwater harvesting and from Option J that does not include reuse of wastewater.

Option D that includes local wastewater treatment and reuse, and water efficient appliances reduces wastewater discharges to the Western Trunk Sewer from 71% to 79%. Option E also includes rainwater harvesting which provides a similar reduction in wastewater discharges.

The discharges of wastewater from Option F that utilise a centralised reuse system for outdoor uses are reduced from 30% to 53%. Whilst also supplying toilets in Option G provides reductions in wastewater discharges ranging from 53% to 85%.

Options H, I and K that include use of a Precinct scale wastewater reuse system for toilet and outdoor uses, and water efficient appliances provide similar reductions in wastewater discharges ranging from 61% to 85%.

Options F to K will provide an average of 2,547 kL/day to 5,674 kL/day of treated wastewater to the surrounding irrigation district. This treated wastewater will have low levels of salinity (300 mg/L to 500 mg/L) in comparison the salinity of the wastewater in the Western Trunk Sewer and the Deutgam Aquifer.

The injection of treated stormwater from Option K into the Aquifer will also improve the salinity of ground water in the nearby aquifer. This strategy in combination with an adequate water sharing plan could assist in restoring the aquifer over time. The integrated water cycle networks used in this analysis are shown in Appendix C.

9 ECONOMIC RESULTS

The economic performance of each Option was evaluated from a whole of society perspective. A net present value of each Option was determined using a 20 year horizon, a 6.5% discount rate and an inflation rate of 3%. This analysis has included all water cycle management asset values and operating costs. The analysis includes revenue earned from centralised water and sewerage services including headworks and connection fees. The deterioration of infrastructure has not been included. The net installation and lifecycle costs used in this study are summarised in Appendix D. The net present values of the Options are shown in Figure 9.1.

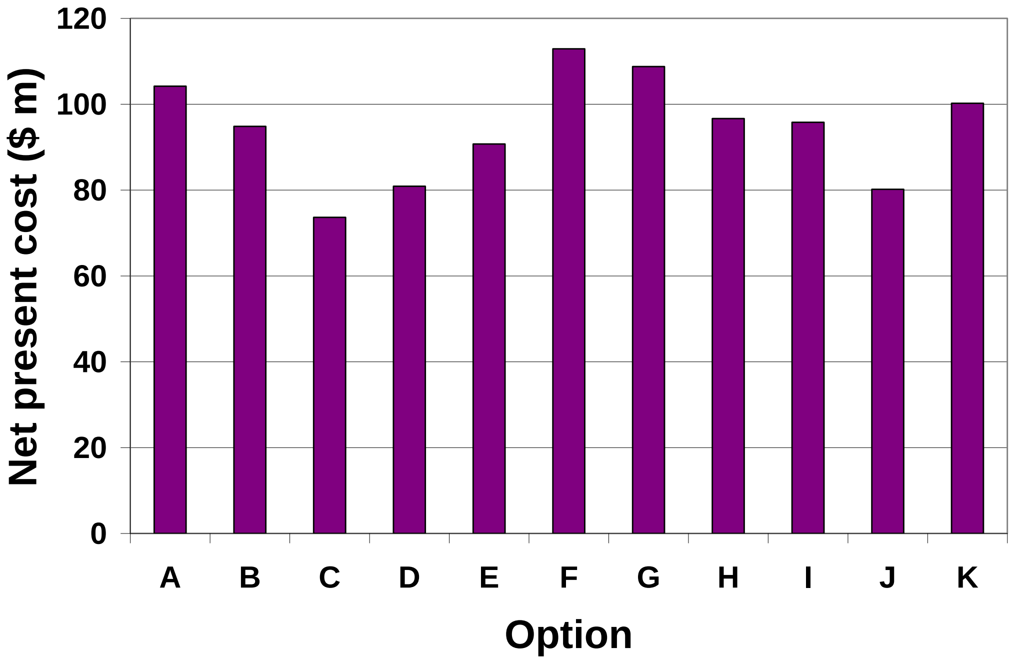

Figure 9.1: The net present costs of the Options.

Figure 9.1 shows that Options F and G that include Precinct scale wastewater reuse, and water efficient appliances and gardens have higher net present costs than the base case Option A. The costs of providing and operating the wastewater reuse infrastructure in Options F and G overwhelm the benefits derived from water savings and reductions in the requirement for water and sewerage infrastructure. All other Options produce smaller net present costs than the base case.

The lowest net present costs are attributed to Option C that includes rainwater harvesting, and water efficient appliances and gardens. In this Option, a reduction in the land required for stormwater management, in demands for mains water, for stormwater and water supply infrastructure overwhelm the costs of rainwater harvesting strategy to provide considerable reductions in net present costs.

Option D that includes local wastewater reuse and Option J that combines Precinct scale stormwater harvesting, rainwater harvesting, water efficient appliances and gardens generate similar net present costs. Option E that incorporates local integrated water cycle management strategies – reuse of wastewater, rainwater harvesting, water efficient appliances and gardens provides the next lowest net present cost. Note that the local strategies reduce the revenue sourced from centralised services. However, this effect is balanced by a reduced requirement for infrastructure and associated operating costs.

Options H, I and K that combine integrated water cycle management at different scales including local rainwater harvesting and water efficient appliances with Precinct scale wastewater reuse and stormwater harvesting produces lower net present costs than the base case. Although these options generate higher net present costs than some of the other alternative Options they also provide the highest levels of reduced dependence on regional water resources. In particular, Option K will be independent of regional water and sewerage infrastructure.

It is important to note that this analysis has also included the costs of providing and operating street scale infrastructure (water, sewerage, stormwater and recycled water reticulation) that is normally provided by land developers at the development phase and then operated by water utilities and local government. The net present cost per equivalent allotment for each Option at the Werribee Employment Precinct is shown in Figure 9.2.

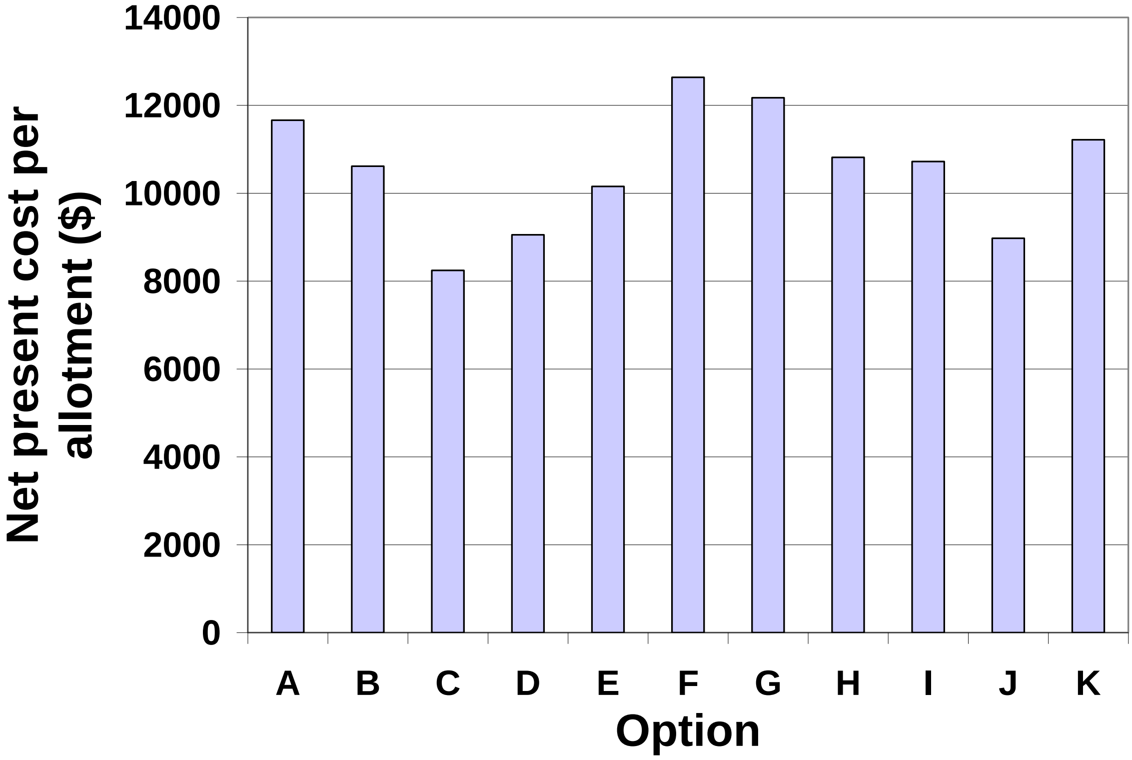

Figure 9.2: Net present cost per allotment for each Option.

Figure 9.2 reveals that the net present cost/allotment ranges from $8,243/allotment for Option C to $12,636/allotment for Option F. All of the alternative Options compare well to the net present cost of the base case of $11,661/allotment.

10 GREENHOUSE GAS EMISSIONS

The greenhouse gas emissions from the alternative Options are compared to emissions from Option A in Figure 10.1.

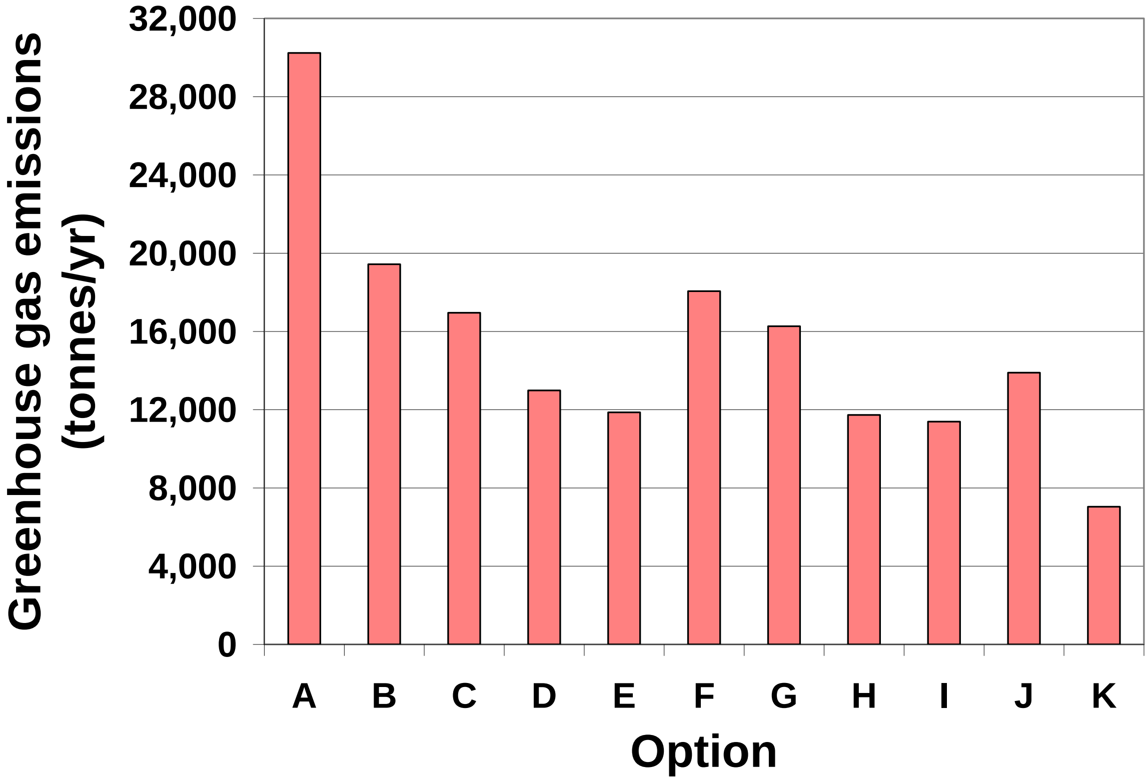

Figure 10.1: Greenhouse gas emissions for each Option

Figure 10.1 reveals that the base case Option A that is reliant on regional water supply and wastewater treatment generates the highest annual greenhouse gas emissions. Option K that is independent of the regional water and sewerage resources contribute the lowest greenhouse gas emissions.

All alternative Options produce significant reductions in greenhouse gas emissions in comparison to Option A. The Options using water efficient appliances and gardens (B), combinations of rainwater tanks, water efficient appliances and gardens (C), and integrated water cycle management (D, E, H, I, J and K) produce large reductions in greenhouse gas emissions.

The diminished greenhouse gas emissions in the alterative options are generated by reductions in mains water demands, use of water efficient appliances and reductions in sewerage discharges. Higher levels of independence from regional water cycle systems generate greater reductions in greenhouse gas emissions.

Strategies that integrate local sources of water (rainwater, stormwater and wastewater) and water efficient appliances reduce the energy requirement of water strategies thereby reducing greenhouse gas emissions. The reductions in greenhouse emissions in comparison to the base case are shown in Figure 10.2.

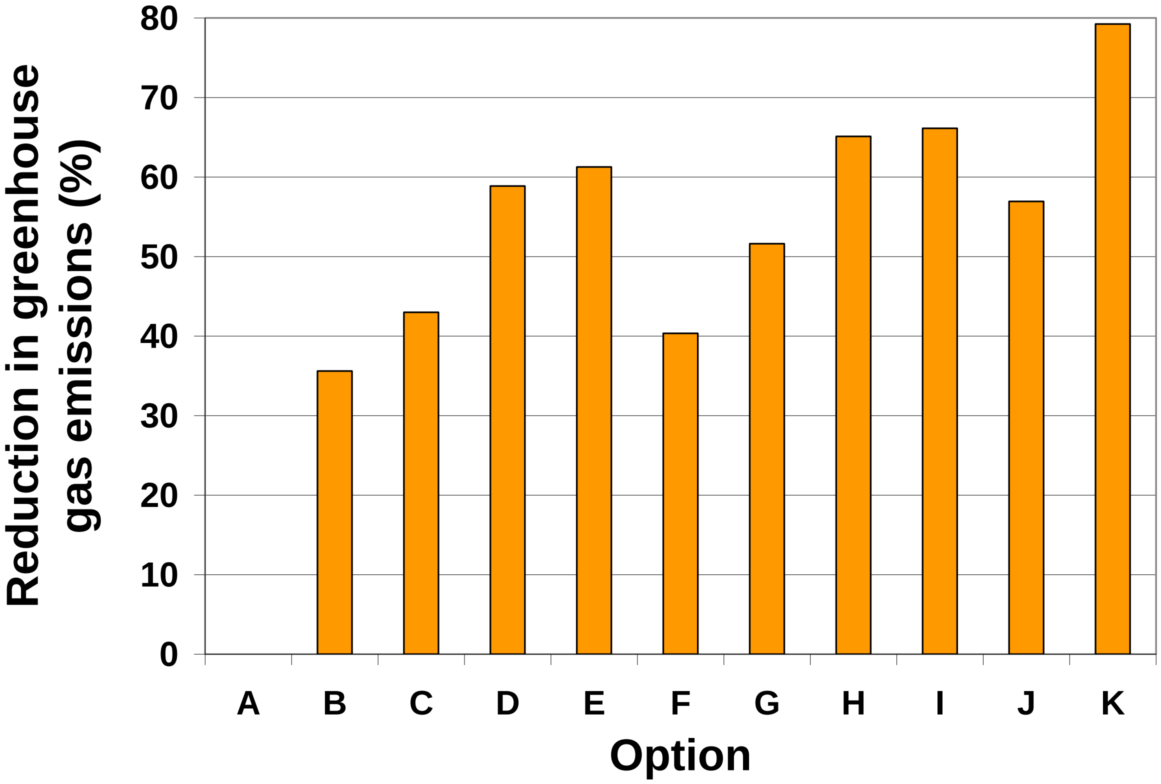

Figure 10.2: Reductions in greenhouse gas emissions generated by the alternative Options

Figure 10.2 shows that reductions in greenhouse gas emissions range from 36% for Option B to 78% for Option K. The highest reductions in greenhouse gas emissions are generated by the integrated water cycle management strategies Options D, E, H, I, J and K.

11 DISCUSSION

This study has utilised a detailed systems analysis to explore water cycle management options for the Werribee Employment Precinct. This process has involved the integration of water balance, water cycle network, hydrology, hydraulic and water quality models at sufficient detail to reveal the wide range of opportunities available for the Precinct. Ongoing feedback from the Interagency working group has assisted with assigning objectives.

11.1 Multi-criteria analysis

A selection of key results from this study were combined in a preliminary multi-criteria analysis that utilises the percentage changes in mains water demand, sewerage discharges, stormwater runoff volumes, greenhouse gas emissions, net present values, nitrogen loads and areas of flood inundation from each Option. Weights were not assigned to each criterion in this study. This decision is consistent with the author's concerns that the subjective application of weights in multi-criteria analysis can add considerable bias to the results.

The multi-criteria analysis is shown in Table 11.1. It can be seen by the range of the criteria shown in Table 10.1 that reductions in mains water demands and sewerage discharges have the highest natural weighting that appears to adequately represent a desire for the development to achieve independence from regional water supplies. The natural weightings for greenhouse gas emissions, nitrogen loads and stormwater runoff volumes represent the objective for global and local sustainability at the Werribee Employment Precinct.

Table 11.1: Preliminary multi-criteria analysis of results from the simulations

	Reduction from the base case for each criterion (%)							
Option	**Water**	**Sewer**	**Stormwater runoff**	**GHG**	**NPV**	**Nitrogen**	**Flood area**	**Preliminary Rank**
B	36	35	4	36	9	45	46	10
C	48	35	17	44	29	54	49	7
D	70	75	6	57	22	49	48	5
E	75	66	17	61	13	54	49	4
F	41	41	6	40	-8	49	48	9
G	55	68	6	46	-4	49	48	8
H	79	74	17	61	7	54	58	3
I	81	73	17	62	8	54	58	2
J	78	35	17	54	23	54	58	6
K	100	73	29	77	4	67	58	1

Table 11.1 shows that the integrated water cycle management option that utilises wastewater treatment plants for wastewater reuse within the Precinct and aquifer storage and recovery (ASR) has the highest ranking (Option K). This option includes use of water efficient appliances and gardens, rainwater tanks to supply laundry, hot water and bathroom uses, wastewater reuse for toilet, outdoor and open space water use, and a water sensitive urban design strategy.

This option integrates a high level of stormwater management, reduction in water demands and sewerage discharges with a reduced requirement for infrastructure. This solution is consistent with the infrastructure strategies developed for the Aurora project by VicUrban, the Gold Coast Pimpama Coomera Water Futures Strategy and the Yarrabilba development.[41]

Option B that employs water efficient appliances, regional mains water supplies and sewerage

[41] Barry M.E., A. McAlister and P.J. Coombes (2004). A Three-Tier Approach to Urban Water Cycle Modelling in South East Queensland. Municipal and Local Government Engineers Association. Warwick. Queensland.

treatment with traditional drainage systems has the lowest ranking.

11.2 Systems analysis

This study has carried out detailed systems analysis of a range of integrated strategies from a high level planning perspective. It has used indicative trunk infrastructure networks to assess that likely infrastructure trade offs within the Werribee Employment Precinct using a network linear analysis of each system.

A detailed hydraulic analysis has not been conducted to further analyse each of the infrastructure strategies and detailed designs have not been carried out. It is expected that detailed design and subsequent analysis of the development will reveal even greater benefits that discussed in this study. This was the outcome for the Pimpama Coomera project.[42]

This study has utilised the considerable detail and integrated analysis required to understand the actual performance of integrated water cycle management strategies. It is important that further studies and subsequent designs of integrated water cycle management strategies for the Precinct continue to use the necessary details and systems analysis demonstrated in this study. Use of average assumptions and discrete analysis methods will not lead to improved understanding of the opportunities provided in this study.

11.3 Business models for the timely delivery of infrastructure

This study has evaluated alternative water cycle management options from a whole of community perspective and found that Options B, C, D, E, H, I, J and K have better net present values than the Business As Usual (BAU) Option. These Options include rainwater tanks, Water Sensitive Urban Design, water efficient appliances and gardens, and wastewater reuse. The costs and benefits of these Options are provided by different elements in the community.

It is noteworthy that the community and developers have a high value for their gardens and the prospect of a green Precinct. In addition land developers and financiers have a high value for flexible and timely delivery of infrastructure. Delays and uncertainty of about delivery of infrastructure generate considerable holding costs in the land development industry which are passed on to homeowners. These values have not been captured in the economic analysis.

11.4 Stormwater management

This study has identified strategies that provide substantial reductions in the extent of flooding at the Werribee Employment Precinct.

11.4.1 Flooding

This study has found that employment of innovative stormwater management approaches including water sensitive urban design (WSUD) will reduce the extent of flooding at the Precinct. This was achieved by a range of measures including the use of bunds to constrain the extent of flood inundation across the flat terrain from the RB3 "detention basin", additional stormwater detention upstream of the existing RB3 "detention basin", source control measures within the Precinct and redirection of the D1 Drain to eliminate the height constraint created by the Western Trunk Sewer.

However it is important to highlight that the potential for flooding in the Precinct is dominated by relatively unmitigated stormwater discharges from the developed upper catchments within Wyndham City Council area. The application of additional measures to mitigate peak stormwater discharges from the upper catchments will have profound impacts on improving the risk of major flooding in the Werribee Employment Precinct.

[42] WBM (2003). Pimpama Coomera Water Futures Masterplan – strategic stormwater planning study. Gold Coast Water.

Nevertheless, this study has identified that the proposed alternative Options will be subject to flood inundation ranging from 78 ha to 61 ha (including area required for detention basins) which is a considerable improvement from the 140 ha flood inundation associated with the BAU scenario. The impact of expected climate change in 2070 is to increase flood inundation by about 10 ha for each Option.

The analysis has revealed the need to increase the height of Sneydes Road in the vicinity of the D1 Drain to eliminate the risk of unacceptable flood inundation across the road. The proposed realignment of the D1 Drain will need to be carefully planned to avoid a return to flooding along the original alignment. This can be achieved by filling of the old D1 Drain and careful urban planning – the original route for the drain could become a linear park.

11.4.2 Peak stormwater discharges

The proposed alternative Options for stormwater management were able to reduce peak stormwater discharges to Existing and Pre-European levels at all outlets. Stormwater management strategies were assisted in not exceeding Pre-European peak discharges by the changed configurations of the catchments and barrier created the historical western sewer and the Maltby Bypass. Excess peak stormwater discharges currently discharge to the historical sewer.

11.4.3 Stormwater quality

Analysis of various indicators of stormwater quality and environmental impacts revealed that alternative Options were able to meet the current "best practice" stormwater guidelines. The performance of the stormwater quality measures was dependent on the magnitude of rainfall within the rainfall records used in the analysis. The Drome Paddock record had a lower rainfall regime which resulted in a requirement for less stormwater quality infrastructure.

The alternative Options were able to mitigate stormwater runoff volumes to less than existing conditions for the Drome Paddock rainfall and close to existing conditions for the Werribee rainfall record. Similarly, the alternative Options were able to reduce nitrogen loads discharging from the Precinct in comparison to BAU and to Existing conditions using Drome rainfall.

It was not possible to reduce stormwater runoff volumes or nitrogen loads to Pre-European levels without a dramatic increase in the areas of constructed wetlands and bio-retention (Constructed wetlands: 175 ha to 69 ha; bio-retention: 18 ha to 26 ha). This is a ten fold increase in requirement for stormwater quality infrastructure. This requirement was generated by the unmitigated nitrogen loads discharging from the developed upper catchment to the precinct. Clearly additional stormwater quality measures in the upper catchment will assist the efforts to manage stormwater quality within the Precinct.

11.5 Council approvals

This study has revealed that use of decentralised Water Sensitive Urban Design (WSUD) allows considerable flexibility and opportunities for the Precinct whilst producing a high level of stormwater management. However, the benefits of strategies are dependent on City of Wyndham's capacity to understand and approve innovative stormwater management approaches in a reasonable time frame.

11.6 Integrated water cycle management

The most resilient Options for Integrated Water Cycle Management (IWCM) at the Werribee Employment involve multiple local sources of water and water efficient appliances. These strategies were resilient to the expected impacts of climate change and reduced dependent on regional water resources and infrastructure.

These strategies build on the knowledge that the volumes of water discharged from urban areas is greater than the volume of water imported for a range of uses. Thus the use of locally available water and reducing water demands using water efficiency measures is a significant opportunity.

11.6.1 Water efficient appliances and gardens

Use of water efficient appliances (6 star) and low water use gardens produces large reductions in water use with associated diminished requirement for water and sewerage trunk infrastructure. Ideally, water efficient appliances and gardens would be mandated for the Werribee Employment Precinct.

These initiatives would apply at the land development and building phase of the project. For example land developers can choose to establish water efficient landscaping and builders can include the highest acceptable levels of water efficient appliances in buildings. However, the maximum benefits from water efficiency would be achieved by the certainty provided by a mandate of a minimum level of water efficiency throughout the Precinct by the State government.

11.6.2 Rainwater harvesting and water sensitive urban design

Rainwater harvesting systems will be provided at the building phase and the bio-retention facilities will be established at the land development phase of the project. The benefits from installing rainwater tanks and bio-retention facilities, derived from reducing the requirement for detention basins, constructed wetlands and land area, accrue to the land developer. However, utilisation of these benefits is dependent on City of Wyndham and Melbourne Water accepting that decentralised WSUD approaches can down size the requirement for regional stormwater facilities.

The operating benefits of rainwater tanks accrue to both the owners of allotments (water savings and lifecycle costs), the Council (improved stormwater regime and reduced maintenance of stormwater infrastructure) and to City West Water (reduced costs of treating and delivering mains water). The operating benefits of the bio-retention facilities accrue to Council. These benefits are derived from reducing the maintenance requirements for detention basins, constructed wetlands and GPTs.

An equitable business model for provision of rainwater tanks and bio-retention facilities will be dependent on the transfer of a proportion of the benefits from the land developer to the home owner and the Council. Part of the avoided costs of providing stormwater infrastructure can be contributed to the Infrastructure Contribution Plan that will fund provision of rainwater tanks and early maintenance of bio-retention facilities. The avoided costs of purchasing mains water can be a proxy for transferring benefits of mains water savings from City West Water to the homeowner.

Rainwater tanks can be mandated using a Section 173 agreement or similar that could release funds to homeowners or builders for approved rainwater harvesting designs. Alternatively, rainwater tanks could be provided by the developer as a part of the required stormwater infrastructure solution. Bio-retention facilities will be provided by the land developer and can be required in Melbourne Water and Council's stormwater planning documents.

11.6.3 Wastewater reuse

Option D utilises wastewater treatment plants at the building or Sub-Precinct scale, whilst Options F, H, I and K involves the provision of treated wastewater from a Precinct scale wastewater treatment plant via a third pipe distribution system. These Options are increasingly viable due to the advances in modular technologies for wastewater treatment that utilise membrane bioreactors, ultrafiltration and disinfection. The modular technology has reduced costs and energy use (< 900 kWh/ML) whilst increasing flexibility of a strategy.

An example of the benefits of modern modular strategies is that wastewater treatment capacity can be funded and provided as required in response to urban growth pressures. This is an important departure from the current inflexible model of infrastructure provision that requires substantial initial investment to purchase the majority of infrastructure capacity prior to development.

In addition, the Options with a Precinct scale wastewater treatment plant (F, H, I and K) can provide highly treated effluent to the nearby irrigation district. Importantly, the use of wastewater from within the Precinct will have a low salt content (300 mg/L to 500 mg/L) in comparison to the wastewater from the Western Trunk Sewer. Direct use of this excess treated wastewater that has a low concentration of salt is infinitely more feasible than trying to dilute the high concentrations of salt from the Western Trunk Sewer.

11.6.4 Stormwater harvesting with aquifer storage and recovery (ASR)

The stormwater runoff regimes from the upper catchments create a range of challenges for the Precinct and the significant opportunity for stormwater harvesting. Similarly the salinity of ground water in the aquifer underlying the Precinct has presented challenges to surrounding irrigators. Nevertheless, a combination of a WSUD treatment train and injection of harvested stormwater into the aquifer will improve the salinity of water in aquifer enabling recovery of that water for later use in the Precinct. This outcome has been achieved by a range of applied research projects including Figtree Place.[43]

Injection of treated stormwater with low salinity to the aquifer will, over time, create a fresh water envelope in the aquifer adjacent to the Precinct. This process will improve the quality and availability of ground water in the aquifer for use at a later time. Our preliminary investigations indicate that the early establishment of the ASR scheme and a managed extraction process will provide sufficient fresh water for Option K and improve the viability of the aquifer.

It is expected that the ASR strategy will require a local water sharing plan that allows the aquifer to recover and then ensures that the quality and quantity of water in the aquifer is maintained over an annual cycle. This will involve establishing a capped extraction agreement for the Precinct and surrounding irrigators. Note that extractions of water for irrigation from the Werribee River and the aquifer are not permitted at the moment. A new local water sharing plan would include use of excess treated wastewater with low salt levels from the Precinct and the long term availability of surplus ground water from the aquifer.

[43] Coombes (2002). Rainwater tanks revisited – new opportunities for urban water cycle management. PhD Thesis. University of Newcastle. Callaghan Australia.

12 CONCLUSIONS AND RECOMMENDATIONS

The proposed Werribee Employment Precinct is a unique opportunity to create a Precinct that includes provision of more job opportunities closer to where people live to reduce travel into Melbourne for work and to provide sustainable urban growth.

It is ironic in the apparently dry western region of Melbourne a sustainable and independent mixed use city is possible because the site has an abundance of available water. The urbanised upper catchments discharge more than 3 GL/yr to the Precinct at the moment. The fully developed Werribee Employment Precinct will generate stormwater runoff volumes of between 4 GL/yr and 6.5 GL/yr that have low levels of salinity. The Precinct will also generate wastewater discharges of 8.5 GL/yr. The water demands of the fully developed Precinct of 10.7 GL/yr are considerably less than the combined volumes of stormwater and wastewater generated by the Precinct.

An integrated systems approach to infrastructure planning and design will reduce the requirement for water, sewer and stormwater infrastructure. By planning and designing for the best mix of water management options that include wastewater reuse, rainwater harvesting, demand management and water sensitive urban design of stormwater, regional strategies are not required to provide certainty about future urban water supplies at the precinct.

The Werribee Employment Precinct can be developed as an exemplar sustainable mixed use Precinct with a minimised carbon footprint by adopting infrastructure planning and design principles that make use of all available water sources from within the development area before relying on large external infrastructure upgrades. A localised infrastructure solution also provides increased flexibility in the timing and rate of development.

Option K provided a range of performance outcomes that were consistent with the objectives of this study. The Option combines stormwater and rainwater harvesting, water sensitive urban design and water efficient appliances with treated effluent from a wastewater treatment plant located within the Precinct used for toilet flushing, garden watering and open space irrigation. Class A+ treated effluent will be distributed to households and commercial users via a third pipe distribution network. This system will be supplemented by stormwater extracted from the aquifer that is treated to drinking water standards (Figure 12.1).

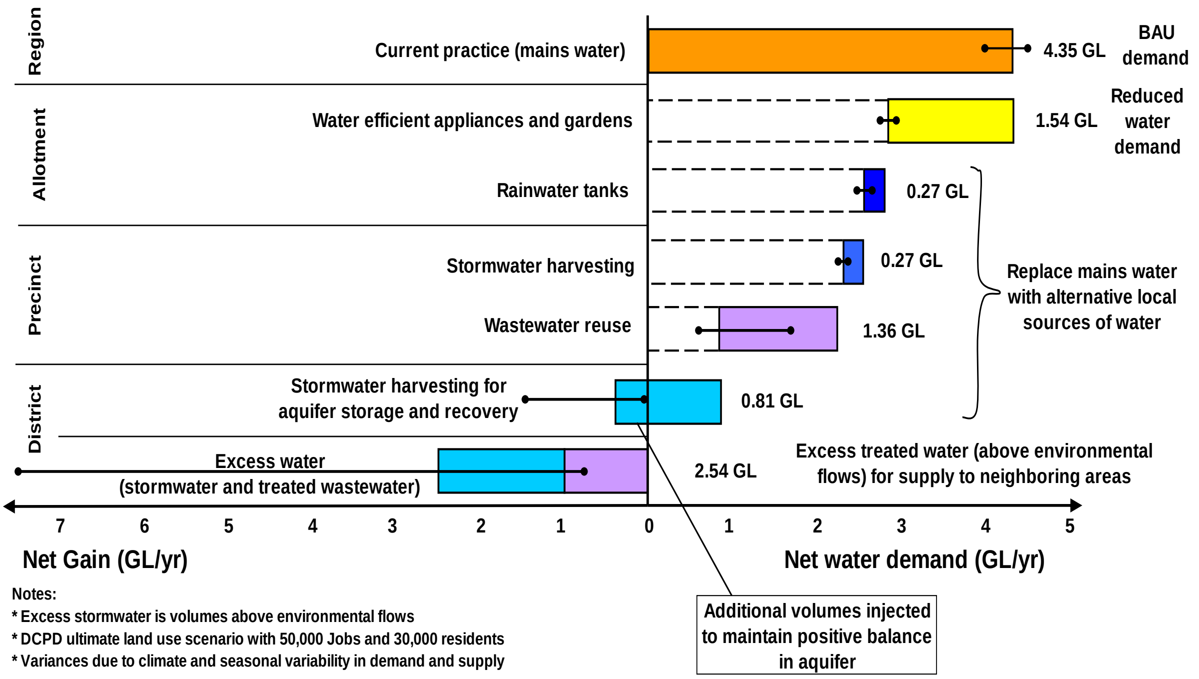

Figure 12.1: Water balance from Option K

Option K was found to be independent of regional mains water supplies, a decrease in sewerage discharges from the Precinct by 68% - this surplus treated wastewater (low salinity) will be supplied to the nearby areas at a rate of 1.5 GL/yr, and considerable reductions in the requirement for water and sewerage infrastructure that overwhelm the costs of providing and operating the infrastructure. This option also provided the greatest reduction in greenhouse gas emissions of 78%.

In addition, an innovative strategy that incorporates a wastewater treatment plant located within the Precinct and utilised an ASR scheme will allow timely allocation of financial resources and infrastructure to the project.

The recommended Option K includes strategies (See Figure 12.1) that operate at different spatial and temporal scales. At the district scale strategy includes restoration of the D1 Drain and ASR scheme. The Precinct scale includes wastewater reuse, rainwater and stormwater harvesting and WSUD solutions, and the allotment scale incorporates water efficient buildings and rainwater harvesting. This strategy allows for objective driven strategies that allow flexibility of solution and timing.

Appendix A: Stormwater networks used in the analysis using design storms

Appendix B: Stormwater networks used in the analysis of stormwater quality

Appendix C: Networks used in the analysis of integrated water cycle management

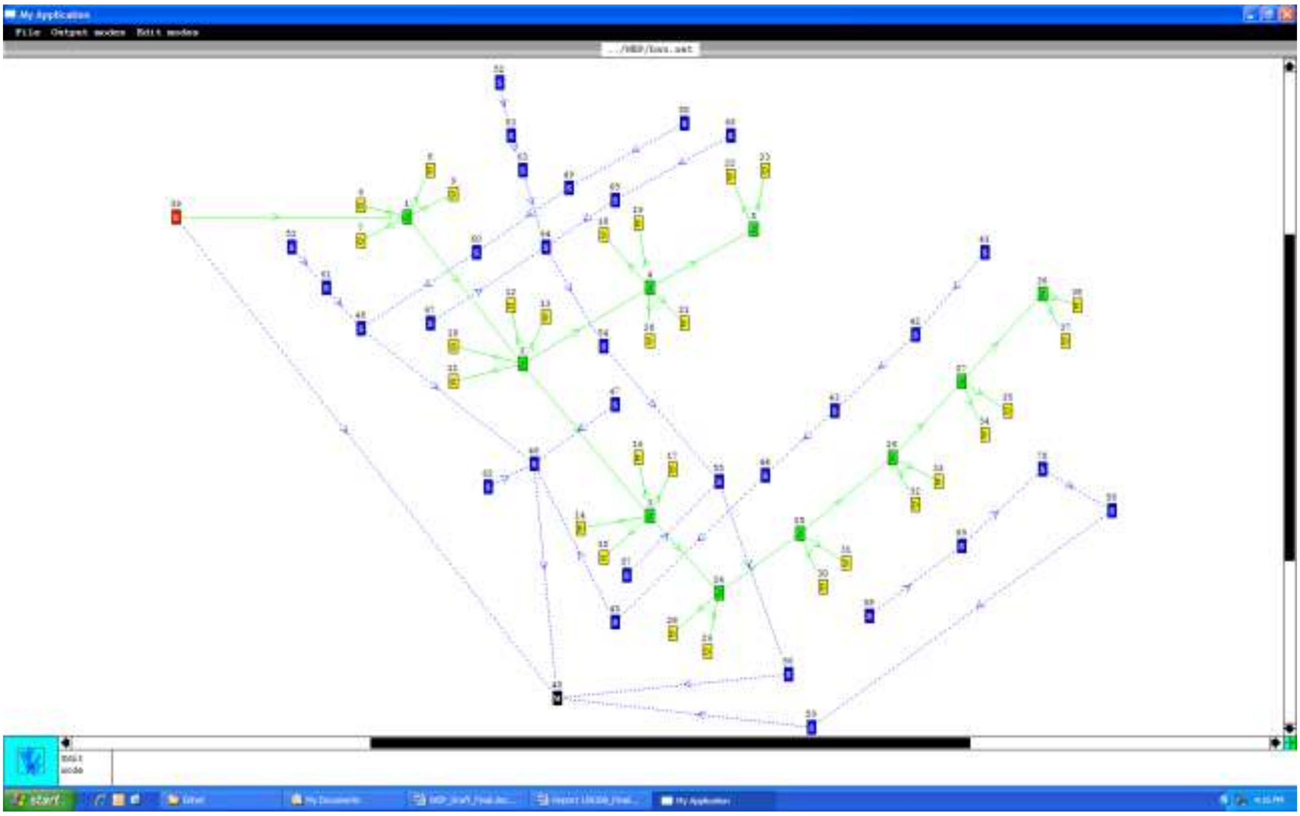

Figure C.1: The BAU network

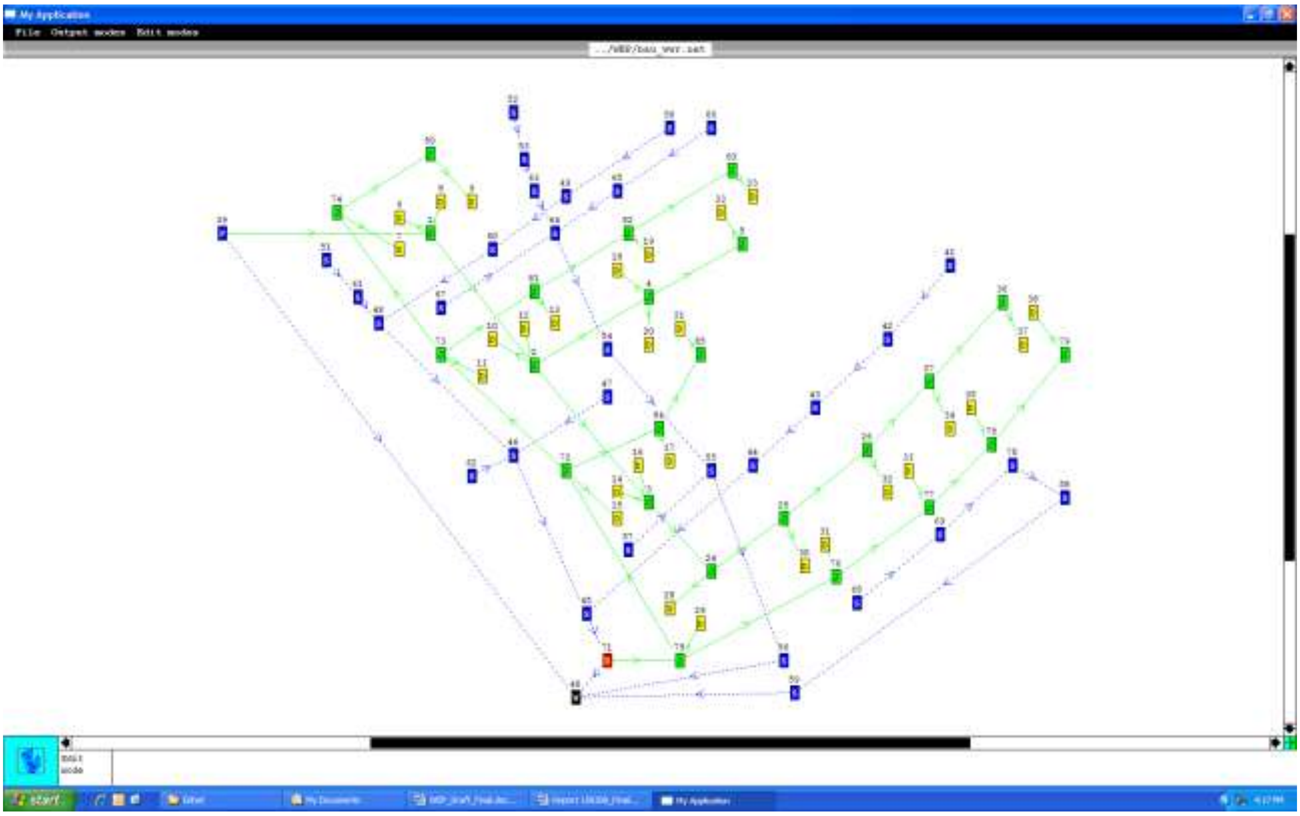

Figure C.2: The network that includes wastewater reuse via a third pipe system

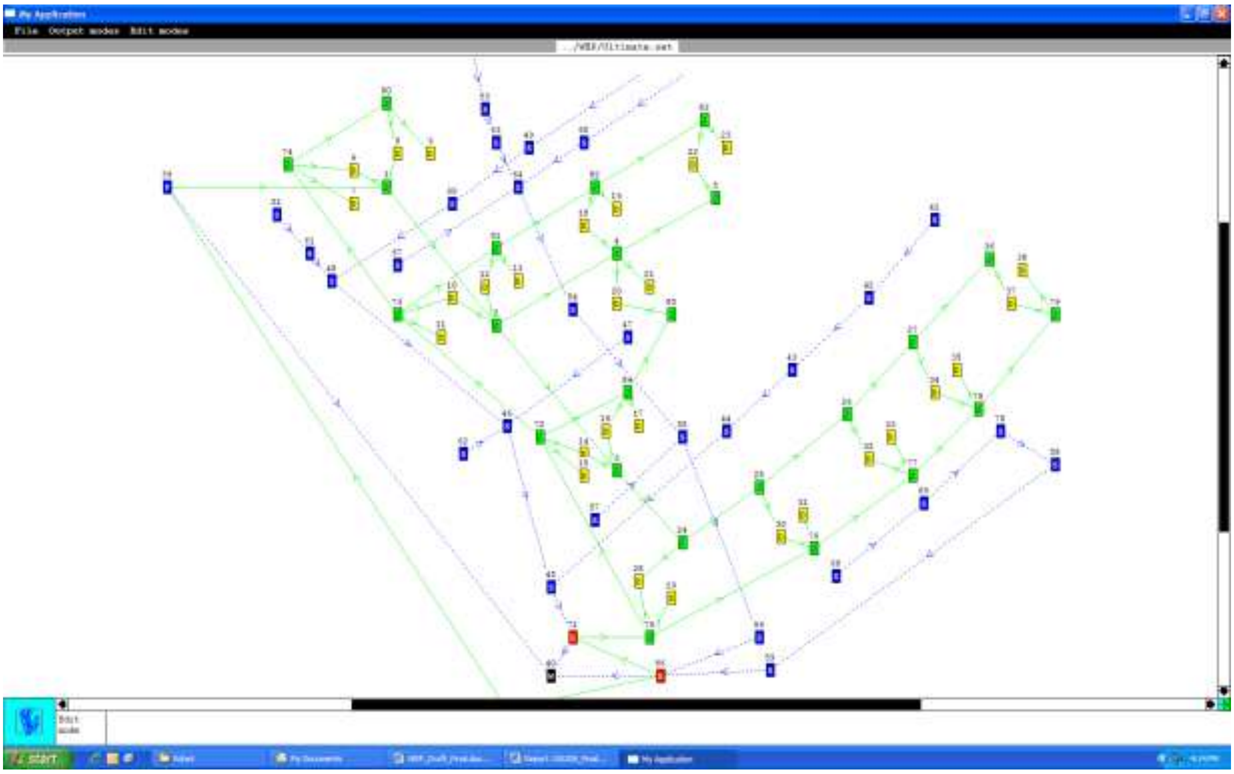

Figure C.3: The network that includes stormwater harvesting, ASR and wastewater reuse via a third pipe system

Appendix D: economic data

Table D.1: Capital costs for each Option

Year	Capital costs ($ m) for each Option										
	A	B	C	D	E	F	G	H	I	J	K
1	98.3	95.3	69.8	70.7	71.1	91.8	91.8	81.3	81.2	70.6	92.7
2	6.1	5.0	5.6	5.8	7.0	7.7	7.5	7.8	7.8	7.2	7.6
3	6.1	5.0	5.6	5.8	7.0	7.7	7.5	7.8	7.8	7.2	7.6
4	6.1	5.0	5.6	5.8	7.0	7.7	7.5	7.8	7.8	7.2	7.6
5	6.1	5.0	5.6	5.8	7.0	7.7	7.5	7.8	7.8	7.2	7.6
6	6.1	5.0	5.6	5.8	7.0	7.7	7.5	7.8	7.8	7.2	7.6
7	6.1	5.0	5.6	5.8	7.0	7.7	7.5	7.8	7.8	7.2	7.6
8	6.1	5.0	5.6	5.8	7.0	7.7	7.5	7.8	7.8	7.2	7.6
9	6.1	5.0	5.6	5.8	7.0	7.7	7.5	7.8	7.8	7.2	7.6
10	6.1	5.0	5.6	5.8	7.0	7.7	7.5	7.8	7.8	7.2	7.6
11	6.1	5.0	5.6	5.8	7.0	7.7	7.5	7.8	7.8	7.2	7.6
12	6.1	5.0	5.6	5.8	7.0	7.7	7.5	7.8	7.8	7.2	7.6
13	6.1	5.0	5.6	5.8	7.0	7.7	7.5	7.8	7.8	7.2	7.6
14	6.1	5.0	5.6	5.8	7.0	7.7	7.5	7.8	7.8	7.2	7.6
15	6.1	5.0	5.6	5.8	7.0	7.7	7.5	7.8	7.8	7.2	7.6
16	6.1	5.0	5.6	5.8	7.0	7.7	7.5	7.8	7.8	7.2	7.6
17	6.1	5.0	5.6	5.8	7.0	7.7	7.5	7.8	7.8	7.2	7.6
18	6.1	5.0	5.6	5.8	7.0	7.7	7.5	7.8	7.8	7.2	7.6
19	6.1	5.0	5.6	5.8	7.0	7.7	7.5	7.8	7.8	7.2	7.6
20	6.1	5.0	5.6	5.8	7.0	7.7	7.5	7.8	7.8	7.2	7.6

Table D.2: Operation and maintenance costs for each Option

Year	Operation and maintenance costs ($ M) for each Option										
	A	B	C	D	E	F	G	H	I	J	K
1	1.6	1.4	1.0	0.9	0.9	1.1	1.1	0.7	0.7	0.7	0.7
2	2.0	1.7	1.2	1.1	1.0	1.5	1.4	1.0	0.9	0.9	1.0
3	2.4	2.0	1.5	1.3	1.2	1.9	1.8	1.2	1.2	1.2	1.2
4	2.9	2.3	1.8	1.5	1.4	2.2	2.1	1.5	1.4	1.4	1.4
5	3.3	2.6	2.0	1.7	1.6	2.6	2.4	1.7	1.7	1.6	1.7
6	3.8	2.9	2.3	1.8	1.7	3.0	2.7	2.0	1.9	1.8	1.9
7	4.2	3.2	2.5	2.0	1.9	3.4	3.1	2.2	2.1	2.1	2.1
8	4.6	3.5	2.8	2.2	2.1	3.7	3.4	2.5	2.4	2.3	2.4
9	5.1	3.7	3.1	2.4	2.2	4.1	3.7	2.7	2.6	2.5	2.6
10	5.5	4.0	3.3	2.6	2.4	4.5	4.1	2.9	2.9	2.7	2.8
11	5.9	4.3	3.6	2.8	2.6	4.8	4.4	3.2	3.2	3.0	3.1
12	6.4	4.6	3.9	2.9	2.8	5.2	4.7	3.5	3.5	3.3	3.4
13	6.8	4.9	4.2	3.1	3.1	5.6	5.1	3.8	3.7	3.5	3.7
14	7.2	5.2	4.6	3.3	3.3	6.0	5.4	4.1	4.0	3.8	4.0
15	7.7	5.5	4.9	3.5	3.5	6.3	5.7	4.4	4.3	4.1	4.2
16	8.1	5.8	5.2	3.7	3.7	6.7	6.1	4.7	4.6	4.4	4.5
17	8.5	6.1	5.5	3.9	3.9	7.1	6.4	5.0	4.9	4.6	4.8
18	9.0	6.4	5.8	4.1	4.2	7.5	6.7	5.3	5.2	4.9	5.1
19	9.4	6.6	6.1	4.2	4.4	7.8	7.1	5.6	5.5	5.2	5.4
20	9.8	6.9	6.4	4.4	4.6	8.2	7.4	5.9	5.8	5.5	5.7

Table D.3: Revenue generated by each Option

Year	Revenue ($ m) generated by each Option										
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
1	1.9	1.8	1.7	1.6	1.6	2.0	1.9	1.9	1.9	2.0	1.8
2	2.9	2.5	2.5	2.2	2.1	2.8	2.6	2.5	2.5	2.7	2.3
3	3.8	3.3	3.2	2.8	2.7	3.5	3.3	3.2	3.2	3.4	2.9
4	4.8	4.1	4.0	3.4	3.3	4.3	4.0	3.8	3.8	4.2	3.4
5	5.8	4.9	4.7	4.0	3.9	5.1	4.7	4.5	4.5	4.9	3.9
6	6.7	5.7	5.5	4.6	4.5	5.9	5.4	5.1	5.1	5.6	4.5
7	7.7	6.4	6.2	5.1	5.1	6.6	6.2	5.8	5.8	6.4	5.0
8	8.6	7.2	7.0	5.7	5.6	7.4	6.9	6.4	6.4	7.1	5.6
9	9.6	8.0	7.7	6.3	6.2	8.2	7.6	7.1	7.1	7.9	6.1
10	10.5	8.8	8.5	6.9	6.8	8.9	8.3	7.7	7.8	8.6	6.6
11	11.5	9.6	9.2	7.5	7.4	9.7	9.0	8.4	8.4	9.3	7.2
12	12.4	10.3	10.0	8.1	8.0	10.5	9.7	9.1	9.1	10.1	7.7
13	13.4	11.1	10.7	8.7	8.5	11.3	10.4	9.7	9.7	10.8	8.3
14	14.3	11.9	11.5	9.3	9.1	12.0	11.1	10.4	10.4	11.5	8.8
15	15.3	12.7	12.2	9.9	9.7	12.8	11.8	11.0	11.0	12.3	9.3
16	16.2	13.5	13.0	10.5	10.3	13.6	12.5	11.7	11.7	13.0	9.9
17	17.2	14.2	13.7	11.1	10.9	14.3	13.2	12.3	12.3	13.7	10.4
18	18.2	15.0	14.4	11.7	11.5	15.1	13.9	13.0	13.0	14.5	11.0
19	19.1	15.8	15.2	12.3	12.0	15.9	14.6	13.6	13.6	15.2	11.5
20	20.1	16.6	15.9	12.9	12.6	16.7	15.3	14.3	14.3	16.0	12.1

Appendix E: Extent of flood inundation

Appendix F: WERRIBEE EMPLOYMENT PRECINCT - Preliminary Employment and Household Projections Report 18 February 2009