USE OF STORMWATER AS AN ALTERNATIVE SUPPLY SOURCE

Thesis submitted in fulfilment of the requirements for the degree of

MASTER OF ENGINEERING

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ABSTRACT

Changing climate, increasing demand for potable water supplies and increased community interest for sustainable use of fresh water sources have resulted in a new focus on water use and sourcing. New sources are being sought, in conjunction with water demand minimisation strategies, to decrease the pressure on existing urban water resources.

At the same time, the management of stormwater is being re-examined with the focus changing from the traditional practice of rapid disposal of stormwater (to reduce the risks of flooding) to utilisation of stormwater as an alternative water supply source. The focus of this thesis is the use of stormwater as an alternative supply source in urban areas at a cluster (or neighbourhood) scale. A decision making framework was developed to assist the adoption of a holistic approach to determining the most appropriate stormwater use scheme option. It was developed as an integrated planning tool to be used in the initial stages of investigating water sourcing and stormwater management ideas.

Due to the time constraints of this project, the focus of the decision making framework was on the technical components (with associated issues) and financial costs. Since additional issues such as environmental, social and economic issues, are crucial to ensure a balanced view is taken in the decision making process, they are included in the process through additional information sources.

Development of the decision making framework considered the following steps:

- Development of stormwater use scheme options based on the technical components and associated issues of collection, storage, treatment, distribution and end use;
- Development of screening tools to screen out infeasible or clearly inferior stormwater use scheme options;

- Development of steps in the decision making framework; and
- Demonstration of the decision making framework through the use of a case study.

The decision making framework consists of eleven steps. The initial six steps of the decision making framework relates to collection and end use issues and are based around matching stormwater runoff to demand and matching stormwater quality to required quality. Steps 7 to 9 of the decision making framework consist of examining and determining feasible storage, treatment and distribution options.

Step 10 of the decision making framework focuses on the integration of the feasible technical options identified in the previous steps, in order to develop stormwater use scheme options. The final step of the decision making framework is to determine costs of the stormwater use scheme options and compare the scheme options on the basis of cost, reliability of supply, quantity of stormwater utilised and end use demands met.

The decision making framework was demonstrated as an easy and practical tool for determining the most appropriate stormwater use scheme through the use of a case study. An existing urban area was chosen as the case study due to the potential for the greater impact in terms of minimising potable water use for non-potable end uses. Feasible collection, storage, distribution, treatment and end use options were determined and integrated into 19 stormwater use schemes. Comparison of all the stormwater use scheme options, as well as the base case with no stormwater use, determined four options as being superior in terms of financial costs, reliability, quantity of stormwater used and end uses met.

The decision making framework was developed based on existing constraints (such as the lack of guidelines directly examining stormwater use) and knowledge, while being flexible enough to include future scientific and practical knowledge, as it becomes available. Recommendations for future development of the decision making framework include expanding this decision making framework to identify the optimum scales of stormwater use schemes. Additionally, an effective yet simple to use costing tool needs to be developed so that all environmental, social and economic costs are determined and actual benefits of stormwater use schemes can be determined.

DECLARATION

I, Carolyn Goonrey, declare that the Master by Research thesis entitled Use of Stormwater as an Alternative Supply Source is no more than 60,000 words in length, exclusive of table, figure, appendices, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Carolyn Goonrey   Date

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ABS	–	Australian Bureau of Statistics
ANZECC	–	Australian and New Zealand Environment and Conservation Council
ARCWS	–	Australian Research Centre for Water in Society
ARMCANZ	–	Agriculture and Resource Management Council of Australia and New Zealand
ASR	–	Aquifer Storage and Recovery
BMP	–	Best Management Practices
BOD	–	Biochemical Oxygen Demand
BOQ	–	Bill of Quantities
CEPA	–	Commonwealth Environment Protection Agency
cfu	–	colony forming units
COD	–	Chemical Oxygen Demand
CRC	–	Cooperative Research Centre
CRCCH	–	Cooperative Research Centre for Catchment Hydrology
CSIRO	–	Commonwealth Scientific and Industrial Research Organisation

EPA	–	Environment Protection Authority (NSW, Victoria etc) or Environmental Protection Agency (Queensland)
FMEA	–	Failure, Mode and Effect Analysis
HACCP	–	Hazard Analysis and Critical Control Point
MCA	–	Multi-criteria analysis
MUSIC	–	Model for Urban Stormwater Improvement Conceptualisation
NFR	–	Non-filtrable residue
NHMRC	–	National Health and Medical Research Council
NRMMC	–	Natural Resource Management Ministerial Council
NTU	–	Nephelometric Turbidity Units
NWQMS	–	National Water Quality Management Strategy
OSD	–	On-Site Detention
SS	–	Suspended Solids
TDS	–	Total Dissolved Solids
TKN	–	Total Kjeldahl Nitrogen
TOC	–	Total Organic Carbon
UV	–	Ultraviolet
VSAP	–	Victorian Stormwater Action Program
WSUD	–	Water Sensitive Urban Design

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Water is one of the basic needs of life. Changing climate, increasing demand for potable water supplies and increased community interest for sustainable use of fresh water sources have resulted in a new focus on water use and sourcing. New sources are being sought, in conjunction with water demand minimisation strategies, to decrease the pressure on mains water supplies.

The management of urban water has always been an important aspect of modern society. Urban water management has generally been divided into different types of water which describe either the use or the location of the water. Generally, water has been classified as water supply for urban or rural water requirements (including drinking, household, agricultural and industrial uses), stormwater for the management of all water runoff in urban areas, and wastewater for the management of household and industrial wastes which are transported with the assistance of water (for example sewage). These water management systems are linked to the different natural water sources such as precipitation (rainfall and snowfall), groundwater, freshwater (including water from rivers or lakes) and ocean water, either as the water source or disposal location.

The focus of urban water supply management has been changing over time. Supply of water to urban areas in Australia has usually been piped to the required location from a distant storage area. To minimise health risks, water may be sourced from dams located in pristine areas where there is minimal risk of contamination. Water can also be sourced from groundwater, rivers, lakes or other water bodies. In all cases, some form of treatment is used to meet drinking water requirements.

While previously new dams or groundwater bores would be considered as the only option for meeting additional water demands, alternative sources are being examined. One alternative water source is using wastewater from the household. This water source may be the total wastewater stream from the household or a separation of the wastewater streams. Household wastewater can be divided into blackwater (sewage), yellow water (urine separation) and greywater (wastewater from the household excluding sewage and sometimes excluding kitchen wastewater). Rainwater captured from roofs is another potential alternative water source.

Stormwater management is one aspect of the urban water resource management, as shown in Figure 1.1. Traditionally stormwater management has involved collection of stormwater and its rapid removal to receiving waters with minimal nuisance, danger or damage to people or property. This practice was adopted to limit the social and economic consequences of flooding in local urban environments. No consideration was given to stormwater as a resource. Furthermore, the receiving water bodies were often adversely affected due to poor quality and increased volume of stormwater. However, in recent times, stormwater has increasingly been considered as a resource due to scarcity of water resources. This view provides opportunities to use stormwater within urban areas and examine the integration between stormwater, wastewater and water supply.

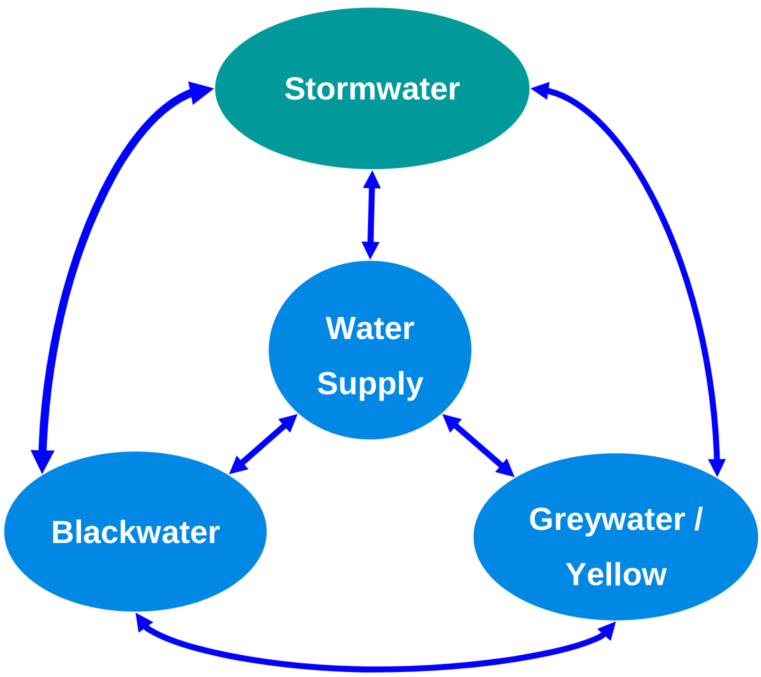


Figure 1.1 Integration of Stormwater as Part of Urban Water Resource Management

1.2 AIMS AND SCOPE OF THE STUDY

This thesis examines the potential to utilise stormwater as an alternative supply source in urban areas at a cluster (or neighbourhood / regional) scale. Using stormwater as an alternative supply source is still a relatively new idea and as such, there are a number of gaps in research related to stormwater use. One of the major gaps identified during the literature review (Section 2.3.6) is that the research to date has failed to develop a holistic approach to stormwater use schemes. This research gap provided an opportunity to conduct research into integration of the issues required to identify the most appropriate stormwater use scheme. In order to fill this research gap, a number of aims were identified. The main aims of this research project are to:

- Set up a decision making framework to investigate the viability of potential scheme options where stormwater can be used as an alternative supply source;
- Determine the most appropriate scheme option for the study site using the decision making framework; and
- Test this methodology using a case study located in an existing urban area.

The focus of this thesis has been the use of stormwater in urban areas at a cluster or neighbourhood / regional scale, as shown in Figure 1.2. Cluster scale use of stormwater in urban areas has been defined for this thesis to include individual residential and community irrigation use with the collection, storage, treatment and management of that stormwater use at a community or cluster scale. As such, technology such as rainwater tanks on individual properties was not examined, except as a means to store the communally collected and managed stormwater at the individual household.

Use of stormwater at lot or individual residential / commercial property level was not examined as part of this thesis since it was considered to be more appropriate as a separate project. However, where lot scale technology and research is relevant to cluster scale use of stormwater, these issues have been examined as part of the review of the literature. Additionally, some of the issues discussed in this thesis are equally applicable to use of stormwater at a lot or individual residential / commercial property level.

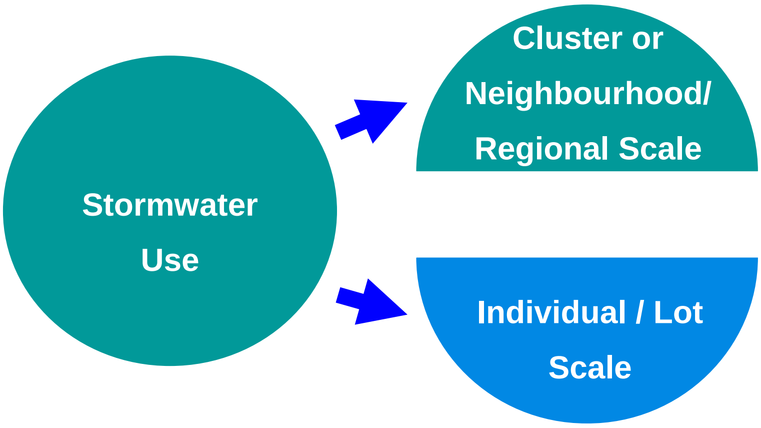


Figure 1.2 Research Focus

Industrial or other municipal water use demands may provide additional potential opportunities to use stormwater. However, industrial or other municipal uses have only been examined within this thesis on the periphery as it was determined that examination of industrial uses is more appropriate at an individual or lot scale, rather than as a cluster scale which is the focus of this thesis. There is scope to examine industrial uses within the decision making framework through including industrial demand within the community scale irrigation end use.

There may be a vast number of potential opportunities for utilising blackwater and greywater either individually as in combination with stormwater. Since there has previously been a tendency to overlook stormwater use in urban areas, this thesis focused on the potential of stormwater use. Therefore, the opportunities for blackwater and greywater use are acknowledged but have not been examined as part of this thesis. This also ensured a manageable amount of work could be undertaken within the time limits of this thesis and research.

1.3 METHODOLOGY IN BRIEF

A decision making framework was developed in this thesis to identify the most appropriate stormwater use scheme option for stormwater use schemes in urban areas. In order to analyse potential stormwater use schemes, a matrix of possible stormwater use scheme options was developed. Through the development of the possible options, it became apparent that the number of stormwater use scheme options was very large. Examination of all of these scheme options would be time consuming. Therefore, screening tools were developed to decrease the number requiring analysis. Inferior or infeasible options were initially screened out as not being relevant for any study site, based on current social, environmental and economic knowledge. Additional screening was based on technical issues, as well as social, environmental and economic issues. Additional screening was implemented as part of the decision making framework and was implemented on a case-by-case basis specific to the study site.

The decision making framework was developed taking into account technical components and associated issues. Due to time constraints of the project, environmental, social and economic issues were only examined briefly. The technical components were collection, storage, treatment, distribution and end use options and associated issues. The decision making framework was divided into steps that focused on examining the relevant issues for each technical component, and identifying feasible component options. The final two steps of the decision making framework were developed to integrate, examine and compare the feasible component options and associated issues.

The decision making framework was then demonstrated through the use of a case study. An existing urban area was the focus of the case study as existing urban areas could potentially have a larger impact on water demand and sustainability issues than greenfield (or new residential development) areas. This is due to the number of houses that are in existing urban areas compared to new development areas.

1.4 SIGNIFICANCE OF THE RESEARCH

This research project is of direct relevance to the engineering community, the environment and society in general. While it has been recognised within the research and residential developer community that stormwater use has the potential to replace mains water, the approach used to determine the most appropriate stormwater use scheme is still relatively haphazard. There has been no integrated approach in decision making and practical implementation has often preceded sound scientific research. This research project is to assist developers, council workers and decision makers to take into account a holistic view of water management and stormwater use.

Sustainable use of water, one of our most precious resources, and the holistic view of water management and water issues is rising in profile. In particular, water policy is becoming more important and at the forefront of governmental attention. This research project is of direct relevance to new initiatives announced by the Victorian Government Department of Sustainability and Environment (2003a), which shows the change of governmental view towards management of the entire water cycle, including stormwater use opportunities. One of the proposed outcomes was *"that the potential for integrating increased stormwater harvesting into the future planning processes be investigated*" (Department of Sustainability and Environment Victoria, 2003a, p. 3).

Specifically, the Victorian Government Office of the Premier (2004) announced $10 million in funding over two years towards investigating and demonstrating stormwater use, focusing on collection, storage and water quality improvement issues. The stormwater use decision making framework described in this thesis can be directly applied to assist in the implementation of these stormwater use scheme initiatives.

1.5 OUTLINE OF THE THESIS

Chapter 1 provided an overview of the thesis and the importance of urban water resource management. The aims of the research project and a brief methodology were also described in Chapter 1.

Chapter 2 provides a review of the literature in relation to stormwater management and using stormwater as an alternative water supply source. The progression of stormwater management from traditional management ideas to current and future stormwater management, including stormwater utilisation, is described. The technical aspects of stormwater management as they relate to stormwater utilisation are then discussed, followed by a description of the benefits of stormwater use and barriers to implementation of stormwater. Finally, the research gaps identified in relation to stormwater use are presented.

In order to examine stormwater use schemes in an integrated manner, a decision making framework was developed. Chapter 3 provides an overview of the issues relevant to the decision making framework. Issues include determining feasible stormwater use scheme options, screening out infeasible options, as well as an overview of the technical components and issues that need to be examined in order to identify the most appropriate stormwater use scheme for the study site.

The technical components and issues which were briefly discussed in Chapter 3 are described in detail in Chapter 4. Analysis of the decision making framework and how this framework relates to the integration of the technical components of a stormwater use scheme are presented in Chapter 4. The steps in this framework are described, as well as methodologies to analyse storage, treatment, distribution and collection options and to determine the feasible options for the study site.

Chapter 5 presents the case study that was used to demonstrate the decision making framework. The application of the framework to an existing urban area and demonstration of the integration of the technical components is described Chapter 5.

A summary of the work conducted and the conclusions arisen from this work is provided in Chapter 6. Recommendations for future work, based on the findings of this research project, are also presented in Chapter 6.

CHAPTER 2

STORMWATER MANAGEMENT PRACTICES

2.1 INTRODUCTION

Traditionally stormwater management has involved collection of stormwater and its rapid removal to receiving waters with minimal nuisance, danger or damage. This practice was adopted to limit the social and economic consequences of flooding in local urban environments. No consideration was given to stormwater as a resource. Furthermore, the receiving water bodies were often adversely affected due to poor quality and increased volume of stormwater. However, in recent times, stormwater has increasingly been considered as a resource due to scarcity of water resources. This view provides opportunities to use stormwater within urban areas.

This chapter reviews the current worldwide practices in and impediments to using stormwater as an alternative supply source at a cluster or neighbourhood / regional scale. Past, current and emerging stormwater management practices are examined. Discussion of collection, treatment, storage and distribution issues is presented. These issues have a reasonable amount of qualitative research in relation to current urban stormwater management. However, they have usually not been considered in an integrated manner and not in the context of using stormwater as an alternative water supply source. Finally, in the context of the benefits and possible barriers to using stormwater as an alternative water source, Chapter 2 examines and defines the gaps in research and opportunities for further development. Discussions relating to the implementation impediments for using stormwater as a resource are focused on Australia.

Figure 2.1 demonstrates the progress and future directions of stormwater management. The bold lines represent the areas of direct relevance to using stormwater as an alternative supply source in this research project. The thin lines represent the areas which have been examined as background information. As shown in Figure 2.1, this research project and the review of the literature focuses on using stormwater as an alternative supply source within urban areas and is limited to use of stormwater at a cluster or neighbourhood / regional scale. Use of stormwater at lot or individual residential / commercial property level is not examined in this research project (Section 1.1). Nevertheless, some of the issues discussed in this chapter are equally applicable to use of stormwater at a lot or individual residential / commercial property level.

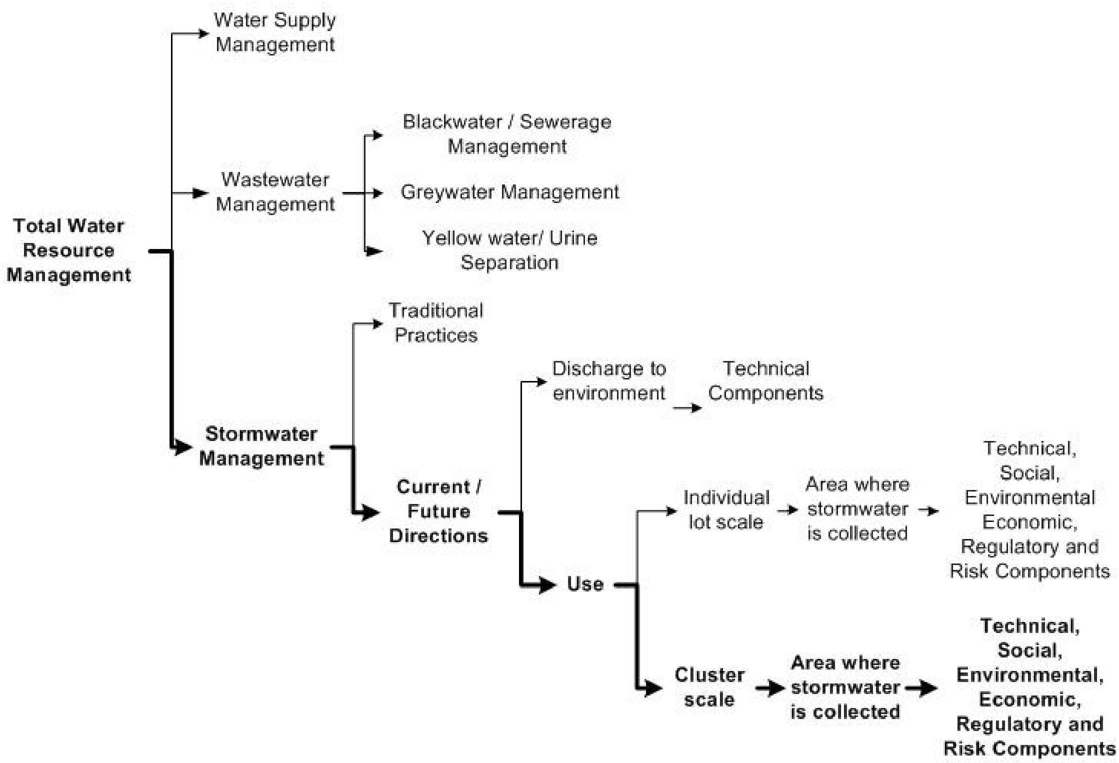


Figure 2.1 Past and Emerging Stormwater Management

For the purpose of this research project, the nomenclature *'use'* of stormwater will be used rather than the normal classification *'reuse'* of stormwater. Stormwater collected in an urban area has fallen as rain without being utilised, and therefore can only be *used* rather than *reused*. This is in contrast to wastewater where the water has already been used to transport the wastes and is then reused after treatment. The nomenclature reinforces the idea that stormwater should be seen as a resource to be used instead of waste to be disposed of.

2.2 PAST STORMWATER MANAGEMENT PRACTICE

Stormwater management involves the control of water that runs off urban surfaces from precipitation. To gain a greater understanding of current stormwater management practices and to explain some of the difficulties in developing and implementing new ideas in this field, past practices have been examined in this section. These practices are especially relevant since the traditional stormwater management system is still the main system in use today. Stormwater management has generally been managed separately from water supply. Stormwater may be managed in combination with wastewater or managed separately, as in Australia.

The Commonwealth Environment Protection Agency (1993), Mouritz (2000), Environment Australia (2002a) and Shipton and Mitchell (2002) provide comprehensive summaries of past stormwater management practices and how these past practices relate to the change in attitude so that stormwater can be viewed as a resource rather than a waste to be disposed of quickly and efficiently.

Stormwater management has traditionally been concerned with protection of people and properties from stormwater and flooding. With the increase in urban development and associated increase in impervious surfaces, stormwater management became even more important to ensure adequate drainage. In a natural environment, rain is dispersed through infiltration into the ground and vegetation absorption, with as little as 2% of the rain becoming surface runoff in an area with good ground cover (Commonwealth Environment Protection Agency, 1993). This compares to as much as 98-100% of the rain becoming surface runoff in a built-up environment. These increased flows with quicker flow travel times can cause more frequent and larger floods, if not controlled or managed properly. The focus on flooding and drainage is demonstrated by the fact that stormwater management was traditionally referred to as urban drainage.

Because the main stormwater concern was to minimise the possibility of flooding, traditional stormwater management practices have dealt with the construction of concrete pipes, culverts and concrete lined open drains to transport stormwater as quickly and efficiently away from the source and urban areas to a local water body (such as a river, creek or directly to the ocean for disposal). Collection of the stormwater has been through inlet structures from roads, fields and impervious surfaces or roof collection and downpipes from houses and buildings. Detention basins have been used to temporarily store the stormwater before disposal during large storm events, so that the distribution system is not overwhelmed with the quantity of flow. It is only in recent times that stormwater management practices have moved to focus on replicating natural environments.

The Australian Rainfall and Runoff (Institution of Engineers Australia, 1987) provides guidelines for management of flooding from stormwater. It is a comprehensive design guide to ensure flooding is minimised, and properties and people are protected from flooding.

In the mid 1980s the public raised concerns about the pollution of the waterways, mainly because litter and rubbish entering the creeks and streams became more noticeable. This resulted in stormwater management practices aimed at improving the quality of the stormwater before disposal into natural waterways, with stormwater management now including treatment as well as collection, transport, storage and disposal (Pitrans, 1993). Treatment methods were concerned mainly with removing gross pollutants such as litter, and with the use of detention basins both to remove suspended solids and to provide storage for flood protection.

2.3 CURRENT AND FUTURE DIRECTIONS OF STORMWATER MANAGEMENT PRACTICE

2.3.1 DISPOSAL TO THE ENVIRONMENT

With increasing awareness of stormwater quality issues, a new approach to stormwater management has developed throughout Australia as well as overseas. This approach has resulted in a number of different management ideas with the underlying principle of treating stormwater to a suitable standard before either release into the environment or use as an alternative supply source.

Best Management Practice (BMP), Water Sensitive Urban Design (WSUD) and Integrated Water Management have been developed to manage stormwater prior to disposal to the environment and improve water quality. These practices are also aimed at examining stormwater in terms of the total urban water cycle and developing sustainable practices. In line with the push to examine quality as well as quantity, a draft version of Australian Runoff Quality was launched in June 2003 as a complimentary guide to Australian Rainfall and Runoff (Wong, 2003).

In more recent times stormwater Best Management Practices (BMPs) have been in use around the world including Australia, the United States and Europe. Structural and non-structural treatment methods are applied to reduce the impacts of stormwater on receiving bodies. Stormwater BMPs were initially developed as a method to improve the stormwater quality prior to disposal rather than prior to use. Urbonas (1994) provides a good summary of the removal efficiencies of stormwater BMPs, as well as describing the range of measures available. These range from public education programs to raise awareness and reduce pollutants such as litter and oils from industrial sources, to structural measures to capture or treat the stormwater before disposal into the receiving water body. Andoh and Declerck (1997) state that it can be advantageous to control pollutants at the source using BMPs. This is because source control results in minimised costs compared to large stormwater treatment measures applied at the end of the line. While BMPs can be adapted to stormwater use schemes, the focus of past, current and proposed BMP research is on stormwater quality improvement prior to disposal to the environment rather than use as an alternative supply source.

The concept of Water Sensitive Urban Design (WSUD) began in Western Australia in the late eighties and is based on minimising the impact of urban developments on the natural environment and water system, and managing the total urban water cycle. Hedgecock and Mouritz (1993) state that a group of interested individuals set up a group in Perth, Australia, that initiated the ideas and basis of WSUD. This group discussed and researched the benefits and practicalities of implementing WSUD. While the basic principles of WSUD are about management of the entire water cycle including water, sewage and stormwater, the Victorian Stormwater Committee (1999) have shown the focus for implementation of WSUD in Melbourne has been on stormwater design to minimise impacts on receiving water bodies, rather than on the whole water cycle and the interaction between all of the water areas. A limitation of these guidelines is that solutions to manage stormwater have been developed without examining solutions to manage water supply shortages. Thus using stormwater as an alternative supply source has been overlooked.

WSUD principles when applied to stormwater management, focus on integrating stormwater management into the landscape; minimising impervious areas to increase infiltration; maximising local on-site retention; efficient stormwater treatment to protect the receiving water bodies; (re)use of stormwater; and using stormwater beneficially for environmental and cultural benefits. The practicalities and effectiveness of implementing WSUD has been demonstrated at Lynbrook Estate in Melbourne (Lloyd et al., 2002). A shortcoming of this study was that the potential for using stormwater as a resource was minimal, although there has been small-scale irrigation of local red gums. Instead, the focus of the project was on stormwater quality improvement. While demonstrating the effectiveness of WSUD is very important, future demonstration projects should include larger scale use of stormwater as a resource.

As well as providing a comprehensive review of WSUD projects around Australia and overseas, Shipton and Mitchell (2002) examine WSUD technologies, including a number of technologies whose main or secondary purpose is to use stormwater as a water supply source. This study is useful in that the entire water cycle is examined and the application of WSUD as a design tool for stormwater use schemes is clearly demonstrated. In particular, the authors list the issues that need to be considered for selecting a water service. These issues are very relevant to stormwater use schemes and can be included in the decision making process for selecting a stormwater use scheme.

The emerging stormwater management practice has required a new approach to management of all of the water systems. Integrated stormwater, wastewater and water supply management systems are being developed in order to explore ways to use and effectively manage all of these water resources (Mouritz, 2000). Integrated Water Management is similar to WUSD in that it examines the multiple functions of water resources as a whole, including natural functions, in-situ uses and withdrawals of water. Stormwater, sewage, groundwater and fresh water are managed in an integrated manner. When stormwater management is examined in terms of the total urban water cycle, the focus shifts from examining only flood protection measures to also examine the impact of stormwater on the surrounding environment and opportunities to use stormwater as a substitute for non-potable uses of water (Apostolidis, 2004; Lawrence et al., 1999; Marsalek, 1990; Palmer et al., 2000; Phillips et al., 2002; Schmitt, 1996).

Many of the abovementioned studies examining BMPs, WSUD and Integrated Water Management did not focus on using stormwater as an alternative supply source. The potential for using stormwater as a resource was not fully developed or realised. However, the management practices and tools developed as part of these new approaches can be adapted for stormwater use schemes, in particular treatment of the stormwater prior to use. Additionally, examination of stormwater in the context of the total urban water cycle has produced new opportunities for using stormwater.

2.3.2 STORMWATER USE

The Commonwealth Environment Protection Agency (1993) brought the issues of utilising stormwater and considering it as a resource rather than a problem to the forefront of community, government and stormwater industry discussions. Dowsett (1994) continued to develop these ideas in the public forum. While both papers presented the idea that stormwater has the potential to replace mains water, details of how this could proceed were minimal. The focus of these papers was on stormwater storage, treatment and quality improvement, aiming to emphasise use of stormwater for its recreational and aesthetic value, rather than as a water supply source. Although promotion of using stormwater (as well as wastewater reuse) was noted, both papers suggested that planning for this outcome should begin, but was not a priority. In fact, it was noted that “neither the NSW Environment Protection Authority (EPA) nor the Sydney Water Board sees any urgency to plan for the reuse of stormwater” (Dowsett, 1994, p.6).

The changing climate, increasing demand for potable water supplies and increased community interest for sustainable use of fresh water sources have resulted in a new focus on water use and sourcing. Other sources are being sought, in conjunction with water demand minimisation strategies, to decrease the pressure on mains water supplies. The development of new sources for mains water supplies has the additional benefit of postponing the need to build new dams or water headworks with the associated costs and environmental and other concerns.

Non-potable uses of water include irrigation, car washing, toilet flushing, hot water systems and clothes washing. As there may be human consumption of the water from taps in the kitchen, bathroom or showers, potable quality water is normally required for these areas (Coombes et al., 2003). All of the non-potable uses of water, and possibly the potable uses of water in the future, have the potential to be sourced from other areas such as stormwater, rainwater tanks, treated wastewater or a combination of these. Potential sites for commercial use of stormwater are wide and varied, and depend upon the type of industry, local site conditions and current water uses.

One of the main opportunities for stormwater being examined as an alternative source to replace potable water is that the quantity of stormwater discarded each year in cities around Australia is approximately equivalent to the quantity of mains water supplied to these cities each year (CEPA, 1993). Additionally, an average household uses more than 50% of mains water for purposes which do not require a potable quality of water. Another motivation for using stormwater as a supply source is to reduce the impact of pollution on receiving water bodies.

The integrated management of all water resources has resulted in demands being met by water sources not previously considered, such as stormwater. In Hervey Bay, Queensland, sewer wastewater which is recycled and used for irrigation is being supplemented with stormwater. The stormwater is temporarily stored in a detention basin and then pumped into the sewer system during the night when the sewer flow is low (Weeks et al., 2000). Similarly, in Brighton, Tasmania, additional infrastructure was constructed to redirect stormwater from a large stormwater drain and wastewater from the Bridgewater Wastewater Treatment Plant, into separate treatment areas and then to be used for irrigation (Environment Australia, 2002b).

2.3.3 TECHNICAL FEASIBILITY

To examine the potential for using stormwater as an alternative water supply source, research investigating the technical components of stormwater use schemes has been reviewed. Technical components include collection, treatment, storage and distribution methods, as shown in Figure 2.2. Research and analysis have usually focused only on one or two of the technical issues in any given study and have failed to develop a holistic approach to stormwater use. There is a vast amount of research into treatment and storage of stormwater, but very little on distribution and collection. More importantly, how these issues relate to using stormwater for a beneficial end use is often not incorporated into the research project.

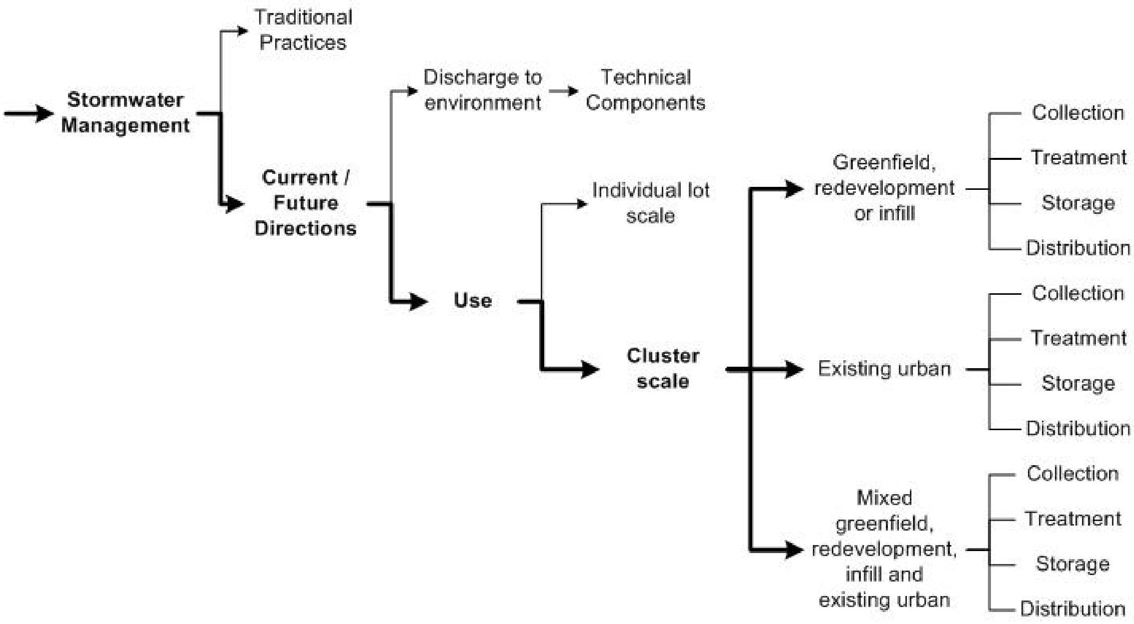


Figure 2.2 Details of Technical Components in Emerging Stormwater Management

Most of the technical components required for implementation of a stormwater use scheme are already available and are based on sound research and practice. However, not all of the research relating to these technical components is focused towards using stormwater as a resource. They have nonetheless been included in the review of the literature to assist in understanding why stormwater utilisation has not been fully examined and to discuss what is required to deal with possible barriers to the implementation of stormwater use schemes.

Hatt et al. (2004) provides a comprehensive analysis of stormwater use schemes that have been implemented in Australia as well as a number of international case studies. The integration between the technical components of a stormwater use scheme is also examined. Due to stormwater utilisation still being relatively new, the details provided in Hatt et al. (2004) and links to verified treatment or implementation system information is limited. The details of technology performance and lessons learnt from the implemented schemes needs to be further disseminated in the public domain.

2.3.3.1 COLLECTION

The quality and quantity of stormwater are highly variable, depending on the area from which it has been collected (Mudgway et al., 1997). Collection methods include traditional gutter and pipe networks or more recent developments such as infiltration trenches. Infiltration trenches can be located in median strips or in reserves to collect stormwater runoff from a number of residential lots. Bekele and Argue (1994) provide a number of examples where infiltration trenches have been used to collect stormwater on a cluster scale in South Australia. This includes the New Brompton Estate, University of South Australia car park retrofit, the Unley project and the Whyalla retrofit. These projects were linked with aquifer storage and recovery to utilise the stormwater for irrigation purposes.

Research into stormwater collection on a cluster scale in an existing urban area has generally been limited to examination of stormwater mixed with wastewater. Otherwise strict planning and control measures are required. The latter is the case in Singapore. Lim and Lim (1998) describe how industrial activities were excluded from a catchment area to ensure an acceptable quality of water was collected and to minimise required treatment and costs. Collection methods were also designed to match the high intensity rainfall

Examination of different stormwater collection areas and associated water qualities can lead to minimisation of treatment measures and implementation costs. Argue and Pezzaniti (1999) stated that collection of stormwater from a low use carpark did not require as much treatment as stormwater collected from a residential road with higher traffic use.

Pollutants on a road or roof surface are dislodged and accumulate in stormwater during medium to large size storm events. The initial flow collects and transports the majority of pollutants and is classified as ‘first flush’ (NSW EPA 2002). This initial first flush normally has a much higher pollutant concentration than the remainder of the storm runoff. However, first flush does not occur in all instances. Coombes et al. (2000a) found that when the first flush was collected and stored, the quality of the stored water became acceptable for use due to dilution of the pollutants from additional stormwater flows. The quality also improved over time due to settling of the pollutants. However, there is often no consistency between storm events and first flush effects, with a number of case studies not achieving sufficient water quality to be used without disinfection (Gardner et al., 2004).

2.3.3.2 TREATMENT

The amount of treatment necessary for using stormwater as an alternative supply source depends on the final water quality required. This can be obtained from existing guidelines or regulations. Once the quality that needs to be achieved for a certain end use is known, the amount of treatment required can be determined. Since stormwater treatment measures have been in practice around the world for a number of years now, there is a vast amount of literature examining stormwater treatment options and performance. The limitation of these studies is that the focus is on stormwater quality improvement prior to discharge into water bodies rather than prior to use. However, the treatment options available can generally be adapted to stormwater use schemes.

As there are a number of stormwater treatment methods available, documents summarising the available stormwater treatment options have been published. For example, the Victorian Stormwater Committee (1999) and Ecological Engineering et al. (2004) provide comprehensive guidelines on the available stormwater treatment methods and associated performances. The shortcoming of these guidelines is that secondary functions such as storage potential or applications in a stormwater use scheme were neglected. In addition, a holistic approach to stormwater management was not examined. That is, the impact and integration of different treatment measures with stormwater collection, distribution and storage issues were not examined.

New treatment methods that take into account collection and storage issues have been developed. Commercial paving products that act as both a treatment and a storage measure have been designed for application in stormwater use schemes. The Manly Council, in a highly urbanised area in Sydney, implemented a project with Atlantis paving to treat and use stormwater for watering the heritage listed Norfolk Island Pines in the area (Atlantis Corporation, 2000). Permeable pavements were also used to treat and store stormwater for toilet flushing in a Youth Hostel in the UK (Pratt, 1999).

Other ways in which to produce high quality stormwater for use have included using hot water systems as a form of pasteurisation. In Figtree Place, a new housing development in Newcastle, NSW, rainwater is collected and stored in community based rainwater tanks. Testing of tank-supplied hot water systems, which were operating between 50°C and 65°C, indicated that the water was compliant with the Australian Drinking Water

Guidelines (Coombes et al., 1999). This is believed to be due to pasteurisation and tyndallization. Although it was not the main focus of the study the authors also demonstrated how examination of all components of a stormwater use scheme in an integrated manner resulted in more effective systems in terms of both costs and utilisation. As noted by the authors, the processes which produced this high quality water replicated what was reported in Benenson (1995). While the viability of using hot water systems in isolation for treatment of rainwater has not yet been verified, projects such as the Aurora development project in Melbourne, Australia, plan to implement rainwater utilisation with high temperature treatment through the hot water system with the addition of ultraviolet disinfection (Coomes Consulting Group, 2003).

2.3.3.3 STORAGE

Traditional stormwater management practices use storage as a flood protection measure. Only recently, some of the existing stormwater storage systems have been examined to convert the system from minimising flooding to using stormwater as a resource. The Kogarah Municipal Council in NSW demonstrated how a stormwater use scheme could be used for flood control, water conservation and minimisation of water pollution on downstream water bodies (Kogarah Municipal Council, 2002).

In some cases, high expenses associated with constructing underground storage tanks, or high land costs and space restrictions for aboveground storage tanks, limit the feasibility of using storage tanks. In these cases, aquifer storage may be a viable alternative. Aquifer storage is commonly practised around the world in cluster scale stormwater use schemes. South Australia has a number of established and new projects which inject stormwater into aquifers for storage and recovery for irrigation and other uses (South Australian Department of Water Land and Biodiversity Conservation, 2002). While some of these systems are naturally occurring, such as an aquifer storage and recovery system that has been in place for over 100 years at Mount Gambier, most systems are designed with pumps for injection and recovery (Dillon et al., 1997).

Use of stormwater to recharge the natural groundwater has also been found to be a sustainable solution to the problems of water sourcing in Atlantis, South Africa (Tredoux et al., 1999). The Victorian Government Office of the Premier (2004) is also proposing to investigate the feasibility of introducing Aquifer Storage and Recovery in

Melbourne for urban stormwater use. Despite these successful examples, it is recognised that aquifer storage and recovery may not be suitable in all situations. Deep aquifers may result in injection and extraction being too expensive. The high post extraction treatment costs associated with aquifers containing poor quality groundwater may also limit the feasibility of aquifer storage and recovery.

The size of a storage tank is dependent upon the water demand, rainfall pattern and capture potential, as well as site and cost constraints. A compromise is normally required between the area available for storage and the storage required to meet the water demand. This compromise is demonstrated at the new Inkerman Oasis development in the City of Port Phillip, Melbourne, Victoria. To meet all potential toilet flushing and irrigation demand at this site, a 660 kL tank would be required. However, due to architectural requirements and site constraints, only one 45 kL tank was designed (Port Phillip City Council, 2002). In some cases, the temporal and spatial variability between stormwater runoff and end use demand may mean that some end uses cannot be met due to excessive storage requirements (Mitchell et al., 2002a)

2.3.3.4 DISTRIBUTION

Although distribution of the stormwater, from the source to the final end use, is a very important component of a stormwater use scheme, most literature has not focused on distribution options. When distribution was considered, it was generally for schemes where both treated stormwater and wastewater were distributed for use, rather than examination of distribution options for stormwater only. The benefits of a distribution system which also acts as a treatment system are often overlooked. Traditional distribution networks will have minimal effect on the stormwater quality, but sustainable stormwater practices may improve the stormwater quality. Water Sensitive Urban Design practices, which are usually implemented as collection systems, may be adapted to the distribution network. Grassed swales and infiltration trenches constructed as a distribution system act as filters and capture sediments, suspended solids and attached pollutants.

The current attitude towards stormwater distribution, as well as wastewater and greywater distribution, is to construct a system that is separate from the existing potable water supply distribution system. One prevalent view, such as that of Melbourne Water

Corporation (Ireland, 2002), is that the high quality potable water distribution system to the household should be maintained. This means alternative sources such as stormwater, greywater and wastewater should be used only to replace non-potable uses.

To maintain both a potable water supply and supply of water for non-potable uses, a dual pipe system has been examined and implemented in a number of areas. The focus in the literature for dual pipe systems has either been only on treated wastewater distributed in the second pipe, or treated stormwater in combination with treated wastewater. In the Netherlands, preliminary studies have shown that the additional costs due to a dual pipe system for distribution back to the household would be economically feasible. Savings were due to smaller wastewater treatment systems being required to treat smaller volumes of wastewater. The separated stormwater or greywater was then treated with cheaper systems prior to (re)use (Dirkzwager, 1997).

In new residential areas where the infrastructure is to be constructed, a dual pipe distribution system is more feasible than in existing development areas. MacCormick (1995) assumed that the water in the second pipe of a dual pipe system would be for external and fire fighting uses only. Therefore smaller pipes would be required for the potable network. The dual pipe system was estimated to cost only 40% more than a single pipe distribution system if the second pipe was placed in the same trench as the first pipe. In the same manner, the pricing of combined recycled wastewater and stormwater distributed in a dual pipe system in Mawson Lakes, South Australia was determined to be $0.88/kL compared to potable water supply of $1.12/kL for residences and $0.91/kL for open space irrigation (Gardner et al., 2001).

The Department of Sustainability and Environment Victoria (2003b) reported that implementation of a dual pipe system for supply of water in existing residential areas is not practical due to the expense and magnitude of work required. However, this approach has not taken into account the possible cost reduction if the dual pipe system was implemented as part of the general maintenance, upgrade and retrofitting of existing services.

2.3.4 BENEFITS OR MOTIVATORS OF STORMWATER USE

The major benefits for using stormwater as an alternative supply source are reduced potable water supply demands, delay in construction of water supply headworks or dams, reduction in downstream pipe and channel sizing due to reduced peak flow in some cases and reduction in pollutants being disposed to natural water bodies (Hatt et al., 2004). When stormwater is used to supply different domestic demands such as flushing toilets, outdoor and hot water use, the constant draw down can ensure that there is sufficient space remaining in storage facilities to capture roof or road runoff. This ensures flood control measures are maintained.

An example of the length of time that headworks construction could be delayed is provided by studies for the Lower Hunter Region and Central Coast Region of New South Wales. Delays of up to 34 years for the Lower Hunter Region and a minimum delay of 28 years up to no requirement for new headworks in the Central Coast Region were determined with the implementation of rainwater tanks (Coombes et al., 2002). This study used two cluster scale scenarios that represented typical cluster scale development in the region. However, the study did not take into account larger cluster scale stormwater use schemes or a variety of rainwater tank sizes.

Rozis and Rahman (2002) determined that life cycle costs of Water Sensitive Urban Design (WSUD) technologies, that may also be applied in a stormwater use scheme, are higher than traditional stormwater management methods due to higher maintenance and operation costs. However, Rozis and Rahman also identified that these costs are offset by the benefit to water quality improvement, aesthetics and improvement of the natural water bodies and urban environments.

Economies of scale can be used to overcome financial costs currently limiting the implementation of stormwater use schemes. Regular maintenance and monitoring are generally not dependent upon the quantity of water being used so that a larger area included in the stormwater use scheme would reduce the unit cost. Additionally, the costs of supplying dual reticulation infrastructure to a large new area can be compensated for by savings in pipe sizes to supply potable water (Phillips and Maher, 1995; WBM Oceanics Australia, 1999). Conversely, Coombes et al. (2000b) determined that it was economically feasible to retrofit a small number of existing houses with rainwater tanks, compared to the traditional way of providing water supply.

ARCWS (1999) found that around 90% of the public in Perth supported the use of stormwater or wastewater for community or household irrigation, toilet flushing and fire fighting, if the water is treated to a suitable quality. There was slightly stronger support for stormwater use rather than wastewater reuse on household gardens. The public attitude then decreased to 70% support for stormwater use in the laundry, 50% for stormwater use in the bathroom and 30% for stormwater as a potable source. There is much more acceptance of recycled water for potable use in the USA and UK. The Water Resources Strategy Committee for the Melbourne Area (2002) also found that there was public support for new initiatives including using stormwater as an alternative supply source.

For a stormwater use scheme to be effective in a new development area, there needs to be support not only from the public but also from developers. While developers are usually wary about constructing non-traditional systems, especially if costs seem to be higher, they have found that wetlands and other stormwater management systems have a positive effect on land and property prices. Premium prices can be charged for land and developments with water views or frontage, more than covering the additional construction costs (Young, 2000).

A number of projects demonstrating the feasibility of stormwater use schemes have been constructed. Since it is more economical, and the necessary components of a stormwater use scheme are easier to develop as part of the initial design and construction, there are more studies examining collection of stormwater in a greenfield or redevelopment area than in an existing urban area. These include Figtree Place in New South Wales (Coombes et al., 2000c), Mawson Lakes in South Australia (Gardner et al., 2001), New Haven Village also in South Australia (Downton and Fulton, 2001) and Inkerman Oasis in Victoria (Port Phillip City Council, 2002).

In conjunction with examining sourcing options, public education on water conservation practices is being implemented. Pepperdine (1995) recognised that while water conservation schemes can be quite effective, total water demand and domestic consumption is generally only contained rather than decreased, due to the increase in population. Therefore, using stormwater as an alternative supply source needs to be implemented in conjunction with water conservation practices.

2.3.5 BARRIERS TO STORMWATER USE

Although the current social climate seems to be one of acceptance and encouragement of stormwater use initiatives, the rate of implementation is still very limited. This can be seen by the rate of lot scale stormwater use, with a limited number of households in Melbourne using rainwater tanks for storage and recycling of stormwater (Department of Sustainability and Environment Victoria, 2003b). Although authorities and governments encourage stormwater use initiatives, there are still a number of impediments and perceived problems to the implementation of these initiatives.

Economics has often been a limiting factor in implementation of new ideas and designs. Many cost comparison studies have determined that possible stormwater use schemes were more expensive than the traditional water mains supply and stormwater disposal system, and therefore these schemes were not implemented. For example, Phillips and Maher (1995) determined the life cycle costs of a stormwater use scheme in Sydney at an equivalent water cost of 121¢/kL, compared to the water main price of 65¢/kL. Additionally, Baker and Cartwright (1994) determined that on a price basis, it was more cost effective to obtain irrigation water from the existing potable water supply, since environmental and social benefits of utilising stormwater were difficult to price.

The method of comparing stormwater use scheme life cycle costs to the mains water unit price is biased towards existing traditional water supply and stormwater disposal systems. This is due to social and environmental costs and factors being ignored. These factors include savings due to reduction in water supply infrastructure, sediment loads and associated cleaning of the waterways (WBM Oceanics Australia, 1999). Additionally, the price charged for mains water does not reflect the actual cost of supplying that water. It does not include initial construction and implementation costs, government subsidies and future asset maintenance and replacement costs (Environment Australia, 2002a). A tiered pricing structure for mains water which is to be implemented by the Victorian Government begins to provide a more realistic basis for the price of water and place responsibility on water users for the amount of water that they use (Department of Sustainability and Environment Victoria, 2004).

A less biased economic analysis method was demonstrated by McAlister (2000). According to this method, the new scheme costs would be compared to the theoretical case that the infrastructure was at capacity and the conventional demand needed to be supplied by constructing new traditional infrastructure.

Life cycle costing is another alternative for assessing financial viability of stormwater use schemes. Taylor (2003) identified a lack of consistency in recording life cycle costing information and developed data sheets to assist recording life cycle information. This report was further developed by Taylor (2004) who compiled life cycle costing information for stormwater best management practice technologies. Taylor (2004) is a very useful reference for estimating life cycle costs for technologies that can be implemented in a stormwater use scheme.

The use of life cycle cost assessment determined that some alternative water sourcing options were cost comparable to the traditional water supply and disposal system for a greenfield site in Brisbane (Mitchell et al., 2002b). Additionally, the alternative water sourcing options provided benefits of water minimisation and sustainability as well as social and environmental benefits that were not quantified.

Lloyd et al. (2001) summarised the perceived impediments and opportunities in water sensitive urban design in Australia. These impediments include a lack of tools or knowledge to assess or implement projects. Also the spread of information about treatment efficiency is not in an easily accessible location or format. Ecological Engineering et al. (2004) developed a draft Water Sensitive Urban Design (WSUD) technical manual, to assist in detailed design of stormwater management systems utilising WSUD practices. While Ecological Engineering et al. (2004) has gone some way to tackling the barrier of a lack of easy access to tools or knowledge, sample costing tables and information is not included. Additionally, stormwater utilisation is only mentioned briefly through aquifer storage and recovery or rainwater tanks.

In addition to economics and lack of information for decision makers, quality and health concerns are a barrier to implementation of stormwater use schemes. Sinclair (2002) stated concerns relating to rainwater tanks and roofwater include microbiological risks, bacteria or protozoa from animals walking on the roof, and airborne emissions from vehicles or local industries. Quality concerns with stormwater include concentration of heavy metals (Boller, 1997) as well as litter, oil, pesticides, dissolved and suspended particles, organic wastes and biological contaminants (EPA Victoria, 1997).

Many health and water authorities in Australia, particularly on the eastern coast, also have health concerns about the acceptability of roofwater or stormwater for medium to high quality uses, such as showering or clothes washing. However, there is lack of research to either prove or disprove this view. Coombes and Kuczera (2001) stated that the original motivation for pushing health quality concerns relating to rainwater tanks was related more to revenue raising and compelling the public to use mains water supply in the 1800s in order to ensure economic viability of the new water authorities.

The lack of guidelines or standards has also been a barrier to implementation of stormwater use schemes. Most of the guidelines relating to stormwater quality are focused on treatment before disposal, rather than use. Otherwise, the guidelines are focused on wastewater reuse. One guideline which begins to fill this gap is Dillon and Pavelic (1996). Some issues dealt with in these guidelines, such as processes within the aquifer providing limited treatment of the injected water, are specific to aquifer storage and recovery. Therefore additional research is needed to develop guidelines and required water qualities for stormwater stored by other methods prior to use. Stormwater reuse and recycling guidelines based on a risk management approach are proposed to be developed in 2005 and should reduce this barrier (CRC for Water Quality and Treatment, 2003). Additionally, recycled water guidelines have begun to identify stormwater as a possible source of recycled water, for example Queensland Government Environmental Protection Authority (2003).

Where guidelines are available, they are not enforced and stormwater or wastewater use schemes are regulated by agreements with local health authorities rather than legal obligations to enforceable guidelines or standards. This results in uncertainties about the practical and legal implications of implementing a stormwater use scheme

(Mitchell et al., 1999). However, Moore (2003) recommends that guidelines should be complied with and measures to minimise the possibility of reclaimed water being used for non-intended end uses should be put in place in order to minimise legal liability risks.

While there are many environmental and social reasons for implementing stormwater use projects, some studies have found that the incentive for implementing these projects is not yet sufficient. Mikkelsen et al. (1999) determined at the time of their study that collection of rainwater on a large scale, rather than an individual basis, was not economically or environmentally recommended for Denmark. This in part was because there were no water shortages and therefore no demand for sourcing new water supplies. This is in contrast to many areas around the world today, including parts of Australia. McLean (2003) determined that stormwater utilisation would not be examined further for a proposed development in Melbourne, Australia, as the priority of the project was the management of wastewater within the development.

2.3.6 FUTURE RESEARCH NEEDS

Attitudes are already changing to examine stormwater as a resource rather than treating stormwater as a problem. To continue the momentum for effective and sustainable management of stormwater, long-term planning and thorough and relevant research are required. Using stormwater as an alternative supply source is still a relatively new concept and as such, there are a number of gaps where further research is required.

Although there is public support for stormwater use schemes, one gap identified during the literature review is the lack of implementation and monitoring of projects demonstrating the feasibility of stormwater use schemes. Demonstration projects are necessary to either verify the feasibility of stormwater use schemes or identify areas of concerns where additional research is required. Due to the time constraints of this research project and expected construction and completion dates of some of the proposed stormwater use schemes in Victoria, this gap was not examined as part of this research project.

Another gap is the lack of practical guidelines to demonstrate how stormwater use schemes can be implemented and assist governmental bodies to assess stormwater use schemes. However, documents such as Ecological Engineering et al. (2004) begin to bridge this gap.

As there is currently a lack of evidence related to health concerns and stormwater or rainwater consumption, further research should be conducted, with the aim of determining the potential for using stormwater as a potable supply source. One aim of this research could be to produce guidelines for either potable or non-potable end uses. This in turn could be used to determine the amount of treatment required and associated costs. This gap will partly be filled with research being undertaken by the Cooperative Research Centre for Water Quality into water quality from rainwater tanks.

The focus for implementation of stormwater use schemes has generally been in greenfield, new development, infill or redevelopment sites. This has meant there is a gap in the research examining the opportunities for using stormwater in an existing urban area, particularly as this has the potential to impact greatly on water sourcing and sustainability issues. This research could incorporate future planning issues and examine the potential for stormwater use schemes to replace or complement existing infrastructure as part of the normal maintenance routine.

The current development of stormwater management plans for each city council in Melbourne presents an opportunity for research into incorporating stormwater use into the stormwater management plans, especially as most of the councils have only examined stormwater quality and have neglected stormwater use. A case study could be developed to include stormwater use schemes in an existing stormwater management plan. This research is likely to raise a number of different issues and constraints for existing urban areas such as storage and treatment methods for sites with limited area available.

The potential for using sewer-mining technologies or small scale on-site effluent treatment systems to treat stormwater is another area where future research could be conducted. Adapting the existing literature related to sewer mining could be examined for collection of stormwater either from existing pipes or storage facilities.

The final major gap identified during the literature review is that the research to date has failed to develop a holistic approach to stormwater use schemes. That is, specific components of a stormwater use scheme are not examined in an integrated way, to identify the best option for stormwater use schemes. Hatt et al. (2004) proposed an outline of a framework for developing and assessing stormwater utilisation systems which is similar to the decision making framework developed and presented in this thesis. The decision support framework that was outlined but not described in detail in Hatt et al. (2004) consisted of problem definition, selection and combination of appropriate technical components, development of scenarios based on sustainability and examination of costs.

2.4 SUMMARY AND CONCLUSIONS

Stormwater management practices have developed from a focus on flood protection and improving stormwater quality prior to disposal to the new focus of examining stormwater as a resource to be utilised rather than disposed. While there are many methods for storage of stormwater, the literature is generally silent on how to adapt these storage systems for use in a stormwater use scheme. Although distribution of stormwater is an important component of a stormwater use scheme, again, much of the literature does not cover distribution options. When distribution has been considered, it was generally for a combined stormwater and wastewater utilisation scheme, rather than an examination of distribution options for stormwater alone.

One of the main barriers to implementation of stormwater use schemes has been the bias of economic analysis methods which compare life cycle costs of the scheme to the unit price of mains water. However, new methods are being developed and promoted to include environmental and social benefits and provide a more balanced economic analysis method for cost comparison on options. Another barrier is considered to be the lack of implementation and monitoring of stormwater use schemes, even though the current social climate has been found to be one of acceptance and encouragement of stormwater use initiatives. Additional impediments and perceived problems include health concerns for potable use of stormwater, uncertain design requirements in certain areas around Australia, intermittent stormwater supply and economic viability.

The major benefits of using stormwater as an alternative supply source are the reduced potable water supply demands, delay in constructing new water supply headworks or dams, decreased stormwater infrastructure requirements and reduction in pollutants being disposed to natural water bodies. The levels of public support, as well as the positive effect on land and property prices for implementation of sustainable stormwater management practices are additional benefits.

During this thesis, the lack of publicly available information became very apparent. The information that commercial organisations have, such as costing tables of stormwater use technologies, is not available to the public because of commercial in-confidence. The lack of guidelines has also limited the amount of work that can be completed within the timeframe of this thesis. To develop these ideas even further, it is important that this information is easily accessible and available in the public domain. Until more information is in the public domain, the effectiveness of the decision making framework developed as part of this thesis has limitations. However, this framework is important to progress the work, knowledge and understanding towards utilising stormwater as well as providing the available information in an easily accessible format.

CHAPTER 3

OVERVIEW OF A STORMWATER USE SCHEME

3.1 INTRODUCTION

A decision making framework was developed in this study to investigate the viability of potential stormwater use scheme options and to determine the most appropriate scheme option based on a holistic approach to decision making. This framework was based on utilising stormwater at a cluster or neighbourhood / regional scale. This framework takes into account the current knowledge relating to stormwater use, as described in Sections 2.3.2 to 2.3.6.

The basic components that are used in the decision making framework and an overview of the framework is described in this chapter. This chapter initially presents the development of possible stormwater use schemes that can be implemented with a focus on technical issues. Screening tools that were used to screen out infeasible stormwater use options are then described. This is followed by an overview of the technical components as they directly relate to using stormwater as a resource. More detailed information about the technical components and associated issues and the format of the decision making framework is provided in Chapter 4.

3.2 FOCUS OF DECISION MAKING FRAMEWORK

A lack of information and research meant that there has been limited implementation of stormwater use schemes. The decision making framework identified information related to stormwater use that is available in order to provide access to this information. Additionally, an existing urban area was targeted as the case study in order to research the potential opportunities and constraints for using stormwater in existing urban areas. This aimed to overcome the research gap identified as minimal research into the potential to use stormwater in existing urban areas (Section 2.3.6)

While this study endeavoured to overcome some of the research gaps identified in Section 2.3.6, the work that could be conducted was restricted due to time constraints of this research project and the timeframe of work being completed external to this study. For example, the timeline for completing stormwater use guidelines was outside the timeframe of this research project and the guidelines could therefore not be integrated into the decision making framework. The framework developed in this study incorporated research that was available, while being flexible enough to develop further as new ideas, attitudes, information and guidelines become available.

3.3 STORMWATER USE SCHEME OPTIONS

Within each stormwater use scheme, there are a number of required components so that stormwater could be collected and utilised, while meeting quality and quantity requirements. The possible stormwater use scheme options were generated based on the technical components and associated issues, prior to determining feasible stormwater use schemes. While social, environmental and economic issues have been considered and are described in Section 4.5, this study focused on the technical aspects of a stormwater use scheme (Section 1.3).

3.3.1 GENERATION OF STORMWATER USE SCHEME OPTIONS

To generate the possible stormwater use scheme options, a simplistic tree diagram was developed. This diagram was based on the following technical components and associated issues:

- Type of urban area where stormwater and/or roofwater is collected;
- Type of water collected;
- Storage and treatment options;
- Distribution options;
- End use location compared to the collection or catchment area; and
- End uses.

A baseline case, where there is no stormwater use, was also generated for each type of urban area. In an existing urban area, the baseline case is to determine the replacement or retrofitting costs for new infrastructure replacing existing infrastructure. This approach takes into account total costs rather than comparing supply prices against the water mains unit price. In a redevelopment or greenfield area, the baseline case assumes the infrastructure requirements are the traditional practice of all mains supplied water and disposal of stormwater with no stormwater use.

Figure 3.1 shows a section of the diagram with generated possible stormwater use schemes. The entire diagram is shown as Figures A.1 to A.3 in Appendix A. While an indication of all the possible stormwater use scheme options is shown in Figures A.1 to A.3, these diagrams do not show all possible options. A complete diagram would require expansion of all storage and treatment options, as well as all combinations of alternative water sources provided to all different end uses. Figures A.1 to A.3 were constructed on the basis that end uses requiring lower water quality would be met first with alternative water sources before using water from the centralised potable water supply.

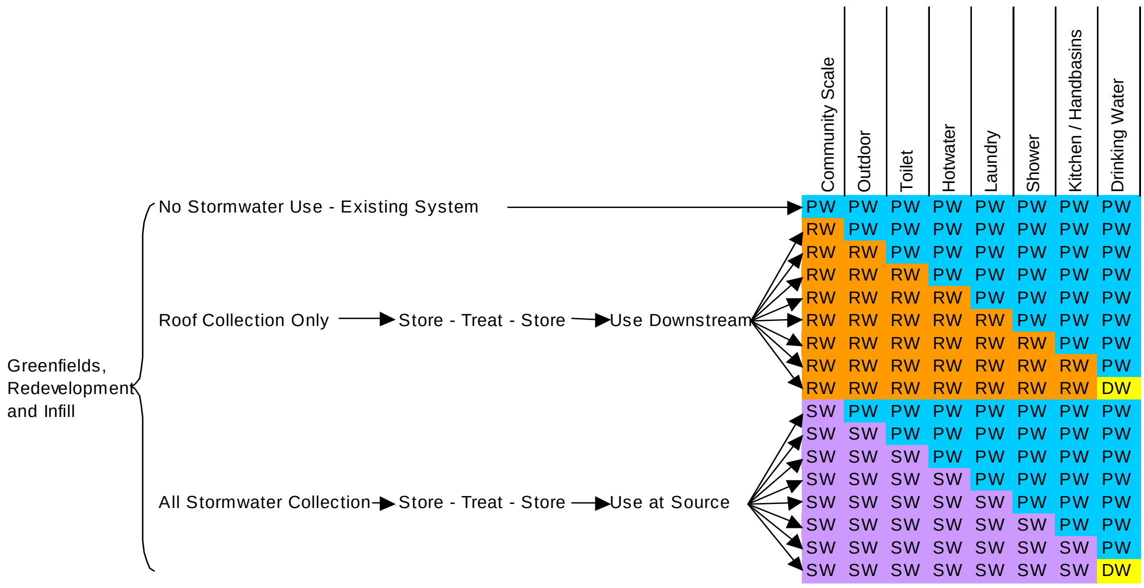


Figure 3.1 Sample of Stormwater Use Scheme Options Matrix

The first column in Figure 3.1 shows the area where the water is collected. In this example, water is collected from a greenfield, redevelopment or infill area. The next column shows either roofwater collection, stormwater collection or no stormwater use. Roofwater is water runoff collected only from the roof area. Stormwater is all water runoff collected in an urban area and may include or exclude roofwater and overflow. The third column is a compilation of the storage and treatment options. The fourth column shows the collected water either being used at the same area as the collection area, or otherwise used in a downstream area.

The final section of Figure 3.1 shows the type of water that is used for particular end uses. PW with blue shading stands for potable water. RW with orange shading stands for roofwater. SW with purple shading stands for stormwater and DW with yellow shading stands for drinking water. In the case of this diagram, PW represents the current system of distributing potable water through a central pipe system, while DW represents potable quality water distributed in bottles through the use of trucks.

The stormwater use scheme options matrix provides a useful guideline for the issues and options that need to be examined. This assists in refining the issues that are relevant in the decision making framework. It also provides a boundary so that irrelevant issues and options are not examined or time is not wasted researching ideas that cannot be implemented.

3.3.2 SCREENING OF STORMWATER USE SCHEME OPTIONS

The entire stormwater use scheme options matrix, provided in Figures A.1 to A.3, shows more than 150 options. To produce a realistic number of scheme options to be analysed, initial screening that could be applied, regardless of the study site, was conducted. Initial screening of the stormwater use scheme options was based on using existing broad scale social, economic and environmental considerations. Screening to eliminate stormwater use scheme options that were infeasible or clearly inferior was based upon current views and knowledge. However, future strains on resources and attitudinal changes in society and governmental views would mean that some inferior options would become feasible in the future.

The first option that was determined to be infeasible or inferior at this point in time was the delivery of potable water to the household by truck or bottled water. As potable water would be delivered by truck or bottled water, the pipe distribution systems would supply lower quality water to be used for all purposes other than drinking. This option was deemed inferior at this point in time due to prohibitively high costs relating to truck delivery of potable water as well as social concerns to ensure adequate access to drinking water for lower income households.

The second option that was included in the decision making framework but may be deemed infeasible or inferior was using stormwater as a potable water source. This option was included to ensure these ideas were kept at the forefront of government and community discussions. However, in areas with governing regulations which prohibit the use of stormwater for potable end uses, this option would be screened out as infeasible.

In the future, utilising stormwater as a potable water source may become more feasible with the introduction of Australian guidelines for stormwater "reuse". CRC for Water Quality and Treatment (2003) stated that these guidelines will be developed after the completion of guidelines assessing reuse of large-scale and on-site sewage effluent and greywater for non-potable uses. A draft of the sewage effluent and greywater guidelines was expected late 2004. All of these guidelines will be based on a risk based assessment for water utilisation and different end uses.

Initially, end uses were based on the areas where the water would be used, such as shower, kitchen, hand basins and laundry. After examination of regulations and water quality requirements, it became apparent that end uses based on the final water quality requirements (non-potable and potable) were more appropriate. Outdoor non-potable and indoor-non-potable were kept as two different end uses due to the need for separate pipework.

As well as different end uses, the potential collection areas were examined. This resulted in the option that utilised rainwater separately from stormwater in an existing urban area being excluded. While this option has been implemented in greenfield development sites, rainwater tanks in an existing urban area should be examined at a lot scale rather than a cluster scale development. This is beyond the scope of this current study and may be included in the possible future extension of the decision making framework.

The stormwater use scheme options that were deemed feasible, based on the initial screening tools described above, are shown in Figure 3.2. Initial screening reduced the total number of options by about two-thirds. While this was a large reduction, there were still almost fifty feasible options. As this was still too many options to analyse in detail, additional screening tools, as described in the Section 4.3, are included within the decision making framework. Initial screening is relevant for all study sites, while additional screening tools are specific for the different study sites and is designed so that the decision maker can further screen out infeasible options.

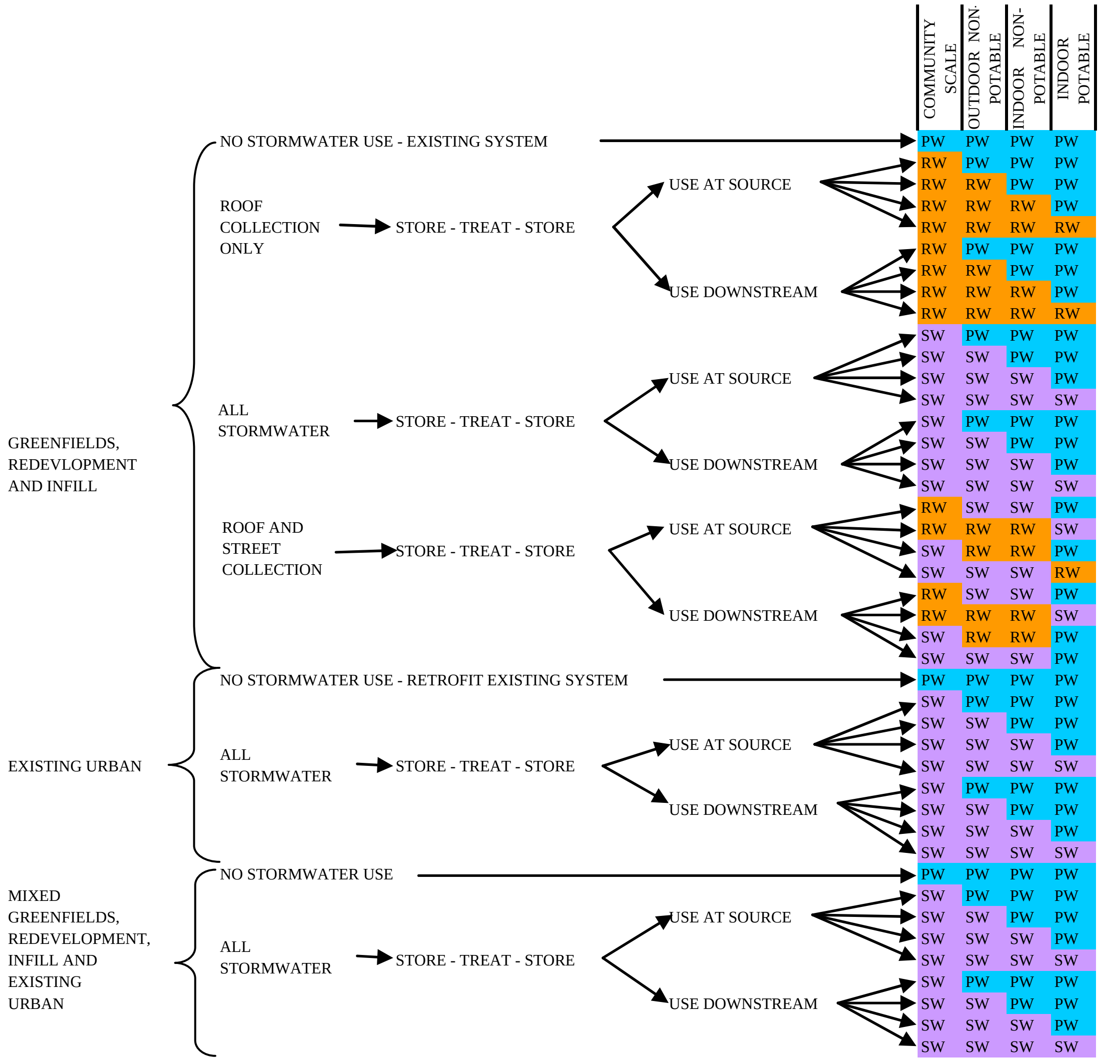


Figure 3.2 Matrix of Broadly Screened Stormwater Use Scheme Options

3.4 COMPONENTS OF A STORMWATER USE SCHEME

Before examining the decision making framework, the stormwater use scheme options need to be understood. These options are based on technical components and associated issues. As previously stated in Section 2.3.3, the technical components and associated issues of a stormwater use scheme are the areas where stormwater can be collected and utilised, collection methods, treatment options, storage options and distribution options. These issues are briefly presented in Sections 3.4.1 to 3.4.4 and described in detail in Section 4.4.

The relationships between the technical components and issues in relation to a cluster scale development is quite complex. There are a number of interactions and flow of water between the different components. A simplistic diagram representing the dominant relationships is demonstrated below in Figure 3.3. While these components are represented as isolated components, they may in fact be integrated and one component can have more than one function. An example is storage systems that also provide treatment. The technical components and issues are initially examined individually so that the function and issues of that component can be fully understood before being combined to form an integrated decision making framework.

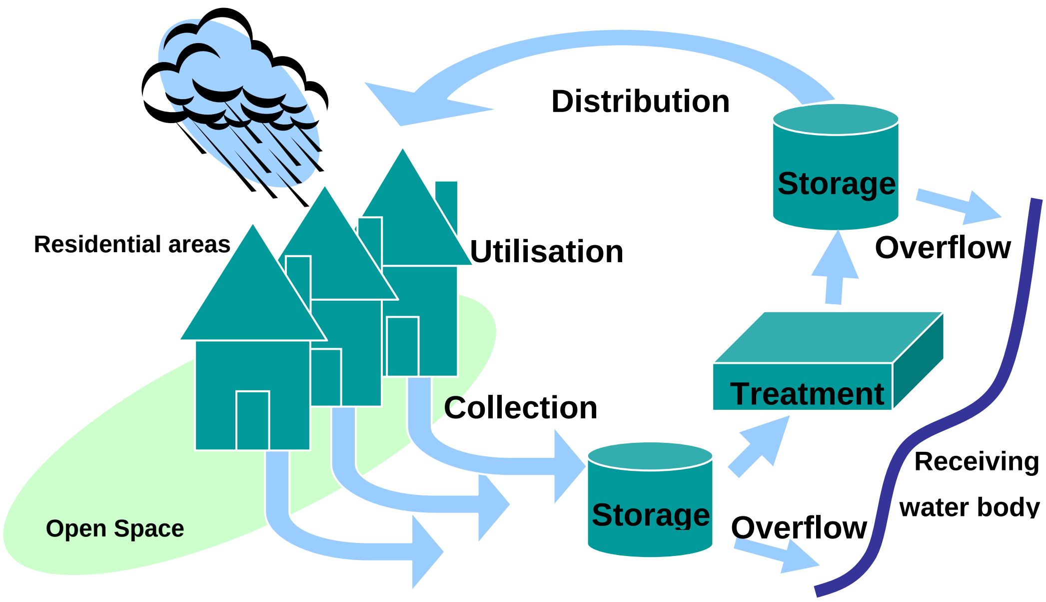


Figure 3.3 Basic Components of a Stormwater Use Scheme

3.4.1 Collection and End Use

The area where stormwater can be collected and utilised needs to be examined first. The site where the water can be utilised may be the same site where the water is collected from or this end use area may be a different site altogether. The collection and end use component has a number of elements to it. The first element is the general study site conditions. This includes ground conditions, size of the catchment and end use area, and zonal type.

Ground conditions need to be determined so that construction requirements and constraints can be identified. Knowledge of ground conditions also assists in determining the quantity of stormwater runoff. The size of the catchment and end use areas is required to identify stormwater runoff volumes and end use demands.

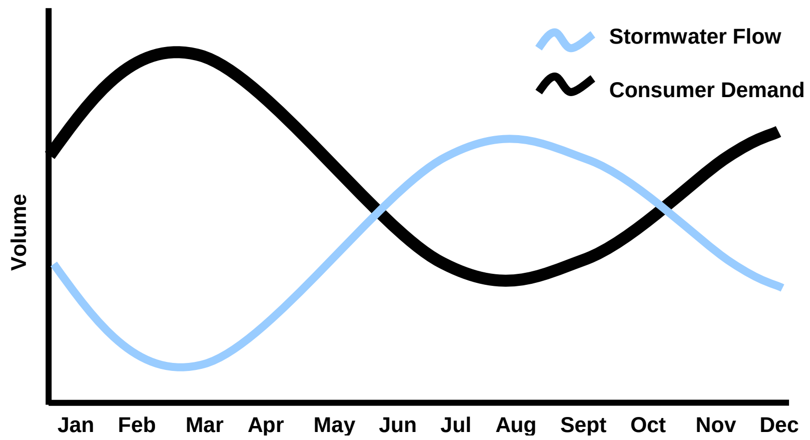
Identification of the zonal type is necessary so that the major issue of construction or modification of existing infrastructure within a stormwater use scheme can be determined. Zonal types are based on the infrastructure existing within the study site. Three zonal types are designated as follows:

- Greenfield, redevelopment or large infill areas;
- Existing urban areas; and
- Combination of greenfield, redevelopment, infill and existing urban areas

Greenfield, redevelopment and large infill areas do not have any existing infrastructure within the development site. This means there is more scope for designing the most suitable stormwater use system. While redevelopment and infill areas can have existing infrastructure external to the development area, the layout of the infrastructure within the site, including connections from the houses to the stormwater pipe system, would generally be constructed as part of the development. Since existing urban areas already have existing infrastructure, there are limitations of how a stormwater use scheme can be implemented within the existing constraints. The final zonal type was a combination of the above two zonal types.

In addition to general study site conditions, quantity and quality issues are examined as part of collection and end use. These include the quantity and quality of stormwater that can be collected, as well as the required end use demand and quality. The quantity of water that can be collected depends on climate, amount of rainfall that becomes runoff and the quantity of runoff captured and stored. Water quantity varies both temporally and spatially, and is one of the major issues or constraints for planning a stormwater use scheme.

End use demand also varies temporally and spatially. One of the biggest challenges with managing stormwater as an alternative supply source is that the temporal variation of end use demand is often not well matched with collection quantities and timing. As an example, the Government of South Australia (2004) presented a stylised graph demonstrating the variation between stormwater flow and consumer demand, as shown in Figure 3.4. This figure shows the highest water demand in summer when there is the least runoff and the lowest water demand in winter when there is the highest runoff. This variation between stormwater flow and consumer demand is highly influenced by irrigation demand. This means areas with smaller gardens or reduced irrigation demand may not have as large a variation between demand and stormwater flow.



Source: Government of South Australia (2004)

Figure 3.4 Stylised Seasonal Variation in Stormwater Flow and Consumer Demand for Water in Adelaide, South Australia

To determine end use demand, different types of end uses are identified. For this study, possible end uses are specified as follows:

- Residential outdoor non-potable;
- Residential indoor non-potable;
- Residential indoor potable; and
- Community scale irrigation.

As discussed in Section 1.2, industrial end uses are not specifically examined within this study. Instead, industrial uses are only included on the periphery. This means industrial uses can be included as part of the community scale irrigation end use, as this end use includes any end use external to residential use. Specific requirements and issues for industrials uses and demand are not discussed within this thesis.

Different end uses have specific quality requirements. Water which may be used for drinking or has the potential for human consumption has very high quality and risk minimisation requirements, such as those detailed in Australian Drinking Water Guidelines (NHMRC and ARMCANZ, 1996). An example of state regulations which include high quality and risk minimisation requirements is the *Safe Drinking Water Act 2003 (VIC)*. Water quality requirements are lower for areas where there is minimal risk of human consumption. However, water quality requirements for these areas still require reasonably high qualities and risk minimisation requirements due to the potential risk of accidental human consumption.

The quality of stormwater collected and the required end use quality are examined in parallel, as are the quantity of collected water and the potential end use demand. The link between the collected and required qualities is important since these issues are required for determining treatment requirements. The quantity of collection water and the potential end use demand are examined in parallel so that these quantities can be compared. This comparison usually results in a compromise required between the available stormwater runoff, stormwater yield, water demand and reliability of supply. The quantity of water that can be captured and converted to water yield is dependent on storage size, inflow pattern and end use pattern.

Collection options to transport the water from the collection area to the storage or treatment area are examined. These options include pipes, surface or overland flows, channel flows, infiltration trenches and permeable pavements. Some of these methods, such as pipes for small to medium flows and surface flows for large flows may be used in combination. Permeable pavements may act as a treatment system, as well as a method to collect the stormwater.

3.4.2 STORAGE

Feasible storage options and possible storage volumes are linked directly to site conditions and water demand. Required storage volume is also influenced by previous stormwater management practices. That is, sufficient additional space for flood control measures may need to be included as part of planning storage requirements for the stormwater use scheme.

For convenience of planning and comparing different storage options, the possible options are divided into five broad categories. These are as follows:

- Aquifer storage and recovery;
- In-ground open storage;
- Above-ground closed storage;
- Underground storage; and
- Existing water bodies.

Storage availability for aquifer storage and recovery is dependent on the naturally occurring spaces and capacities within the underground aquifer systems. An introduction to aquifer storage and recovery, as well as the limitations and benefits of this type of storage system was provided in Section 2.3.3.3. In summary, additional treatment requirements or pumping requirements can limit the feasibility of aquifer storage and recovery. However, aquifer storage and recovery has been found to be the most appropriate or cheapest to implement option in some cases where large storage volumes are required, especially when compared to constructing a new storage system.

In-ground open storage includes ponds, dams, constructed lakes and open water bodies such as lakes, rivers, streams and creeks. The base of the storage system can be below the surrounding natural surface level, and the pond surface above, at or below this level. Topography and land form influences where the storage system can be located and can constrain the possible storage volume. Public safety and issues of mosquitos or excessive bird droppings may be of concern with in-ground open storage options.

Above-ground closed storage options are similar to in-ground open storage except the system is covered and the base of the storage system consists of a foundation placed at ground level. This means the stored water is all higher than the surrounding area and aesthetics may be more of an issue than with other storage systems. Above-ground storage options include constructed or prefabricated tanks.

Tanks can be used for underground storage systems except that these systems are placed in excavations below ground level. As well as tanks transported to site and placed underground, concrete waterproof storage systems can be constructed in-situ.

Underground storage systems have added expenses due to the extra excavation requirements and may not be appropriate in hard ground or rocky areas. Existing water bodies are any water bodies that already exist and may encompass any of the above storage types.

3.4.3 TREATMENT

Treatment is a key component to relating the quality of the water collected to the required end use quality. Treatment methods to treat stormwater and broader water sources are examined. A required removal rate of pollutants can be determined by comparing contaminant levels in the collected water with the required water quality. Many water treatment technologies have published expected removal rates for the different types of pollutants. The behaviour of treatment systems means that the range of expected removal rates is sometimes quite broad, leading to some uncertainty in the effectiveness.

Treatment options are generally classified into primary, secondary and tertiary (or advanced) treatment. Primary treatment targets larger gross pollutants such as litter, leaves and branches. Secondary treatment targets solids that are held in suspension. Suspended solids results in turbid water and may have metals or other contaminants attached. Tertiary treatment targets dissolved solids such as nutrients and may be geared towards pollutant removal prior to discharge. Dissolved solids are not easily removed by settling.

Since the different treatment stages target different contaminants, a variety of treatment technologies are used in combination to produce acceptable water quality. This combination of treatment technologies is usually referred to as a treatment train. For example, litter normally needs to be removed with a gross pollutant treatment system prior to using a wetland to remove dissolved solids. This ensures litter does not interfere with the treatment processes in the wetland and reduce treatment train effectiveness.

Collection, distribution and storage methods are very closely linked to treatment and can be included as steps in the treatment train. These methods can act as a form of treatment. This means treatment is one of the key factors in examining integration of the technical components. These combinations of systems need to be investigated closely to ensure the most effective system is implemented.

3.4.4 DISTRIBUTION

In order to transport the water from the storage or treatment system to the end use area, distribution options are examined. The methods that can be implemented for distribution are very similar or the same as collection options. Distribution methods are pipes, infiltration or exfiltration trenches and permeable pavements.

3.5 SUMMARY

This chapter provided an overview of the issues that need to be examined to develop the decision making framework. The framework was designed to determine feasible stormwater use scheme options and propose the most appropriate stormwater use scheme for the study site being examined. Prior to determining feasible stormwater use schemes, theoretically feasible stormwater use scheme options were generated. The number of stormwater use scheme options was reduced based on current knowledge and constraints. The basic components that were used in the decision making framework was then provided. The decision making framework is described in detail in Chapter 4.

CHAPTER 4

DECISION MAKING FRAMEWORK

4.1 INTRODUCTION

Stormwater use is a relatively new concept which was developed using traditional stormwater management practices as well as water resourcing and holistic water management ideas. An overview of the links between past, current and future stormwater management practices was set out in Chapter 2. This provided an understanding of stormwater use and what was required to design a system to utilise stormwater. While systems have been designed and constructed to utilise stormwater, it was identified in Sections 1.2 and 2.3.6 that the planning and design processes have not been based on an integrated approach. The components that were required to address the issues relevant to stormwater use have not been examined in a holistic manner. The basic components of a stormwater use scheme were provided in Chapter 3. Chapter 4 extends the ideas presented in Chapter 3 and provides a detailed description of the decision making framework.

The decision making framework was developed in this study and described in this thesis to assist decision makers to use a holistic approach for determining the most appropriate stormwater use scheme option, taking into account local conditions, attitudes and constraints. The decision makers for these schemes were thought likely to be council employees, land developers and engineers.

Engineers working in consultancy companies have tended to have a vast amount of information relating to costs, decision processes and technological knowledge compared to information in the public domain. This information has generally not been released outside of these organisations due to commercial in-confidence. This has resulted in different companies utilising different resources and having different knowledge levels.

More important however, there has been no consistency in the decision making process and decisions have been made without sound scientific knowledge.

This decision making framework brings together the scientific and practical knowledge that is currently available, while being flexible enough to include future scientific and practical knowledge, as it becomes available. While there are a number of sources that provide guidelines and relevant information on particular stormwater use elements, this framework extends the previous work by integrating the existing information into a holistic decision making framework.

Due to the time constraints of this project, the focus of the decision making process was on the technical issues and financial costs. Since environmental and social issues are crucial to ensuring a balanced view is taken in the decision making process, these issues are included in the process through links and additional information sources. The issues additional to technical issues are provided to link the decision making framework to the larger management tool of integrated water management. This study should therefore be extended as new ideas and information become available.

This decision making framework was developed as an integrated planning tool to be used in the initial stages of developing water sourcing ideas. The framework to determine the most appropriate stormwater use scheme can be used as part of water management projects which examine all possible water sources. This planning tool is designed to take into account particulars of the area being studied. The final outcome is to identify the most appropriate or optimum stormwater use scheme option.

4.2 OUTLINE OF DECISION MAKING FRAMEWORK

The decision making framework aims to assist decision makers to determine the most appropriate stormwater use scheme option, taking local conditions and constraints into account. The framework was developed considering the major components and associated issues of a stormwater use scheme, namely collection, storage, treatment, end use and distribution. The basic outline of this framework is shown in Figure 4.1.

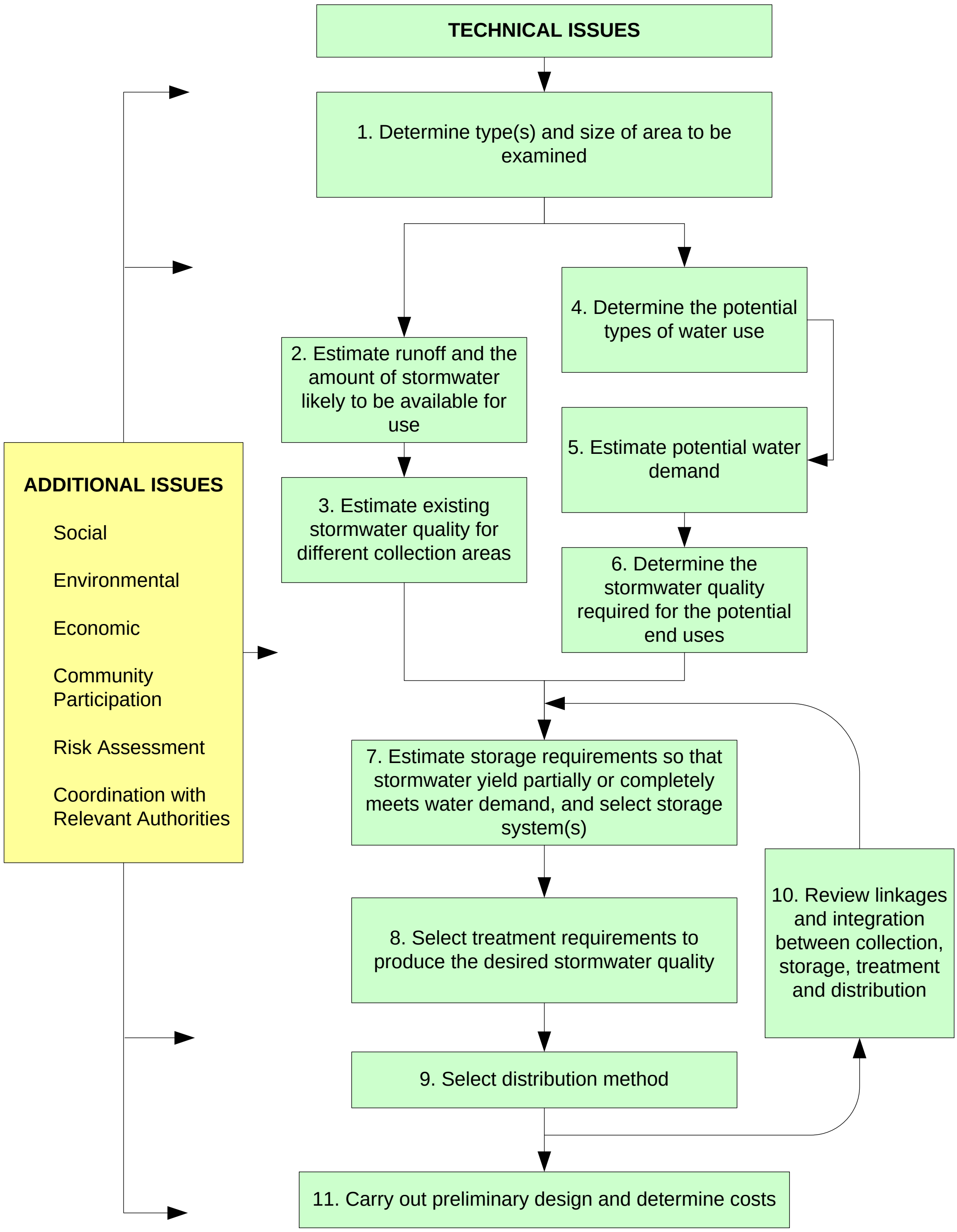


Figure 4.1 Outline of Decision Making Framework Including Technical and Additional Issues

The framework can be divided into different sections based on the components and associated issues that are linked together. Steps 1 to 6 in the framework (Figure 4.1) relate to collection issues and are based around matching stormwater runoff to demand and matching stormwater quality to required quality. The collection system options, size of the collection area, as well as the types of area such as greenfield and existing urban areas, are determined initially. The quantity and quality of stormwater runoff that can potentially be collected is then determined in conjunction with end use demands and required end use qualities.

Step 7 is related to storage issues, Step 8 is related to treatment issues and Step 9 is related to distribution issues. Step 10 is the most important step within the framework. This step is the key to integrating all of the above components and technical issues to form a holistic decision making tool. This integration is the basis of the project and aims to overcome the major research gap identified (Section 1.2). That is, the research to date has failed to develop a holistic approach to stormwater use schemes.

The final step (Step 11) of the decision making framework (as shown in Figure 4.1) is to develop designs and costs for planning purposes. This step is used as the basis for comparing the feasible technical components and associated issues. The technical issues are proposed as a part of a larger framework that takes into account additional issues such as environmental, social, economic issues. While designs and costs for planning purposes are shown at the end of the framework, some approximate costs for determining whether technical component options are feasible may be determined during the earlier stages of the framework.

4.3 SCREENING

In order to identify the most appropriate stormwater use scheme option for a particular study site, the possible options need to be identified. Section 3.3.1 described the method and components used to generate stormwater use scheme options that could theoretically be implemented. This method was based on a simplistic tree diagram utilising all of the component options to determine a vast range of stormwater use scheme options.

To reduce the number of scheme options to be analysed, Section 3.3.2 described screening based on environmental, social and economic issues that were used to reduce the number of feasible options. This screening was implemented as appropriate for all study sites. Additional screening tools are required to further reduce the number of stormwater use scheme options to be analysed in detail. Additional screening based on technical and non-technical issues are carried out on a case by case basis. Sections 4.3.1 to 4.3.6 provide a summary of the technical criteria that causes stormwater use scheme options to be deemed infeasible or inferior. These criteria are integrated throughout the steps of the decision making framework.

4.3.1 Regulatory Prohibitions on the Use of Stormwater for End Uses

The first criterion to consider is whether there are regulatory prohibitions on the use of stormwater for certain end uses. In particular, regulations may prohibit stormwater being used for potable end uses. The type of end uses covered under potable end uses and the areas where there is significant consumption of water in the household needs to be verified. Potable end uses generally include water supplying kitchen taps and hand basins. However, all indoor cold water taps and taps supplying water to showers and washing machines may also be categorised as potable end uses.

4.3.2 Insufficient Quantity of Water

Another possible criterion that limits the number of feasible stormwater use scheme options is an insufficient quantity of stormwater to meet the proposed end uses. This is particularly important if stormwater is the sole source of water, rather than being supplemented from existing water supplies. Insufficient quantities of water can be due to not enough rainfall in the area, insufficient runoff or an inadequate capture system. Factors such as infiltration capacity and evaporation influence the amount of rainfall that becomes runoff. Inadequate capture systems can be due to small inlets, losses from infiltration trenches or open systems resulting in excessive evaporation or seepage. Losses in the capture systems can also be due to storage sizes being too small or incompatible demand patterns resulting in large quantities of runoff becoming overflow.

There are a number of solutions to overcome the problem of insufficient quantity of water to meet end use demand. These solutions are based on either collecting more stormwater or otherwise reducing demand. Improved collection systems to minimise evaporation or exfiltration can result in larger volumes of water being collected. Alternatively, the catchment area can be extended to capture more runoff.

If insufficient quantities of stormwater are available, end use demand needs to be reduced. End use demand can be reduced by not supplying all end uses. Alternatively, reliability of stormwater supply can be reduced so that end use demand is only partially met. This requires stormwater to be supplemented with the existing water supply system or other water sources.

4.3.3 End Use Demand Not Matching Stormwater Runoff

The temporal and spatial pattern of the end use demand influences the likely success or otherwise of a stormwater use scheme. Temporal variability means there are different demands throughout the day, as well as throughout the year. Irrigation demand often has large temporal variability. In areas with large variability between summer and winter rainfall patterns, more irrigation is required in summer when there is less rainfall and vice versa in winter. This is not the case for every location, as some areas have relatively constant rainfall throughout the year, and therefore irrigation demand is fairly constant.

Spatial variability of demand can also be constant or variable. Spatial variability in terms of household water use is dependent on householder behaviour, and is very unpredictable on an individual basis. However, water use and demand can be more easily generalised on larger scales. To reduce end use demand, householder behaviour can be influenced and changed through education and regulations. Education can change behaviour of using showers or washing machines. Regulations can change behaviour either through water restrictions or enforcing the use of water efficient appliances and equipment. Strategies to change end use patterns through regulations and education can be included in the development of a stormwater use scheme and would minimise over design of the scheme.

4.3.4 Stormwater Options Not Appropriate for Study Site

There are some cases where there is no demand for certain end uses, for example community scale irrigation areas. Alternatively, an area consisting of only flats may have no gardens and therefore no irrigation demand. In each of these cases the end use which has no demand is not included in any of the calculations and decision making processes.

4.3.5 INSUFFICIENT SPACE OR FUNDS FOR TREATMENT

Under this criterion, the amount of treatment required is considered. The amount of treatment influences the quality of water produced, which governs the end uses that can be matched. If there is only space or funds for minimal treatment, end uses which require low-quality water can only be examined. If space is the only limiting factor, small sized treatment systems can be considered and are discussed in Section 4.4.3.1. This is a particular issue in existing urban areas where space is a limiting factor for implementation of stormwater use schemes.

4.3.6 INSUFFICIENT SPACE FOR STORAGE

Space can be a limiting factor in terms of available storage size. Where there is insufficient space to construct a storage system, either all end uses can not be met, or end use demand patterns need to be selected that more closely follow stormwater yield. Otherwise, the percentage of the end use that can be met must be reduced. This means the reliability of stormwater supply decreases.

4.4 TECHNICAL ISSUES OF DECISION MAKING FRAMEWORK

The screening described above is integrated into the technical issues of each step of the decision making framework (Figure 4.1). The decision making framework is divided into technical issues and additional issues. The focus of this study was on the technical issues. However, resources and information related to the additional issues are also briefly provided in Section 4.5. The technical issue which were briefly introduced in Section 3.4 are described in detail in Sections 4.4.1 to 4.4.3.

4.4.1 COLLECTION AND END USE

Steps 1 to 6 of the decision making framework, as shown in Figure 4.1, are related to the components and associated issues of collection and end use. Issues include quality, quantity, general study site conditions and collection options. Issues of quality and quantity are for both collected water and end use demand.

4.4.1.1 GENERAL STUDY SITE CONDITIONS

Step 1 in the decision making framework is to determine the type(s) and size of the area to be examined. This step relates to determining general study site conditions. The general study site conditions provide an understanding of the area that is being examined. This step compiles all of the information relating to the area size, ground conditions and zonal type.

In order to determine general study site conditions, the location of the study site needs to be identified. It is assumed for this project that the site is known. A specific neighbourhood may have been chosen, or a total catchment area may be examined. There may be some simplistic ideas behind why a certain site was selected, such as requirements to reduce stormwater runoff from an area or a desire to reduce potable water supply use in a certain area. However, there are also a number of complex issues that are beyond the scope of this research project. These include governance boundaries crossing a catchment area, political issues influencing what type of site would be selected, public pressure, reasoning behind targeting specific householders, as well as geographical limitations constraining the type of area that can be selected. These larger scale issues of site selection either need to be resolved prior to the planning stage or would be resolved in conjunction with utilising the decision making framework in the planning stage.

Identifying the study site consists of determining both the stormwater collection area as well as the proposed end use area. These areas can be the same area, have common overlapping areas or be two completely separate areas. If the areas are separate, the different areas may be closely located or some distance apart. These factors impact on eventual cost and ease of implementation of the scheme.

The general aim when trying to identify end use and collection areas is to examine the water demands that exist within the study site, and the areas which have the largest capture potential. If the focus of the project is to capture as much stormwater as possible, then large catchment areas should be examined. These should be matched to areas which either have fairly constant large water demands or end use patterns similar to the rainfall and potential runoff patterns.

If the focus of the project is to meet specific end use demands, then the end use areas are already known. A catchment area should be chosen as close to the end use area as possible to minimise distribution costs while obtaining sufficient stormwater runoff and yield.

Once the study site is identified, the size of the collection and end use area(s) needs to be determined. This is done by first obtaining plans or aerial maps of the area(s) showing the layouts of housing, road and grassed areas. The size of the area is then measured and scaled off from these plans based on the map or plan scale.

The zonal types of the catchment and end use areas are then determined. This is necessary because of the different infrastructure requirements and issues that are appropriate for the different zonal types. This project identified three different zonal types, as follows:

- Greenfield, redevelopment and/or infill area;
- Existing urban area; or
- Combination of greenfield, redevelopment, infill and existing urban area.

The above zonal types are distinguished by the stage of the housing development and state of the existing infrastructure. The importance of the zonal type, in terms of the decision making framework, is that limitations and restrictions are placed on the study site. This is of particular importance in terms of where drainage infrastructure can be constructed for a stormwater use scheme.

Greenfield, redevelopment and infill zonal types either do not have any existing residential development or otherwise the housing development was removed and would be reconstructed. A greenfield area is a new housing development area which was previously not zoned as a residential area. Zoning would be specific to individual planning schemes. Examples of non-residential zonings are Business, Industrial, Public Use, Public Park and Recreation, Special Use or Mixed Use Zones (obtained from the Victorian Planning Schemes website http://www.dse.vic.gov.au/planningschemes). An infill area is similar to a greenfield area, except that the infill area is surrounded by existing urban areas. A redevelopment area includes areas where the previous residential area has been demolished and a new housing development was planned.

The importance of the greenfield, redevelopment and infill zonal type in terms of the decision making framework is the location of existing infrastructure such as roads and utilities. In these zones, appropriate infrastructure is either not yet constructed within the development site, or any pre-existing infrastructure needs to be demolished and rebuilt to fit the new development layout. Greenfield sites may also not have any infrastructure surrounding the area. The cost of the new development can include construction of large infrastructure systems to connect to the existing systems, either nearby or far away. The distance between the new development site and the existing infrastructure may provide additional motivation for implementing new development ideas. Alternative water supply sources managed closer to the development site may minimise infrastructure requirements. Redevelopment or infill areas may have existing infrastructure on or near the boundary of the development site. This may limit the new development layout possibilities for the infrastructure, but generally the layout within the development is more flexible than within an existing urban area.

An existing urban area is any area with housing developments, fields, parklands and general developments already constructed. An existing urban area is also any area that does not fit within the previous zonal types. The infrastructure is already in place within an existing urban area. However, some older existing urban areas may have minimal or no drainage infrastructure.

The combination of greenfield, redevelopment, infill and existing urban areas is as the name suggests, a combination of the above two zonal types. The challenge with this zonal type is that some areas, such as the existing urban areas, have greater limitations and restrictions on how a stormwater use scheme can be implemented.

The type of feasible end use layout options for an area of existing urban or combined zonal types is limited due to initial screening that was conducted. Initial screening tools described in Section 3.3.2 stated that the options which separate roofwater and stormwater (including roofwater overflow) would not be examined within the existing urban or combined zonal type. The reason behind this was that it was assumed that the cost involved in converting all of the downpipes and housing drainage systems within an existing urban area would be too difficult and expensive to justify having separate collection systems.

If the decision maker (council employee, land developer or engineer) would like to examine separate collection systems as part of their study and the study area is a combined zonal type, the different zonal types need to be separated. The study could then examine separate roofwater and stormwater collection in any greenfield, redevelopment or infill areas. Any existing urban area in the study would not include examination of separate roofwater and stormwater use scheme options.

Once the zonal type of the study site is identified, the total collection and end use area(s) is divided into different sub-areas, namely residential, open space, industrial and commercial areas. The impervious and pervious areas within the total collection area are also identified and measured. Impervious areas are considered as roofs and pavements within residential, industrial and commercial areas. Pervious areas are any grass or vegetated areas. The division of areas and area measurements are used to identify different runoff conditions and demand patterns. These values are also inputted into modelling tools such as UVQ (Mitchell et al., 2003) and Aquacycle (Mitchell et al., 2001) to determine stormwater yield and demand. The use of this sub-area data in modelling tools is explained further in Section 4.4.2.2.

Residential areas are further divided into areas of similar characteristics. If these areas are only used for stormwater collection, then the similar characteristics are dependent on runoff characteristics. This includes areas with similar impervious and pervious area sizes including roof, pavement and garden areas. If these areas are also end use areas, then the characteristics include similar water demand patterns. If there is a wide variety in the block sizes, the residential area is grouped into separate sub-areas of similar block sizes. Within each residential sub-area, the average block size is estimated. Average block information is inputted into Table 4.1. If block sizes and characteristics are fairly similar, the entire residential area is represented by a single typical residential block.

Table 4.1 Collection Area Residential Block Data

	Total number of blocks	Average block size (m^2)	Average roof area (m^2)	Average pavement area (m^2)	Average garden area (m^2)	Average impervious area (m^2)	Average pervious area (m^2)
Typical residential block 1	E_1	F_1	G_1	H_1	I_1	$G_1 + H_1$	I_1
Typical residential block 2	E_2	F_2	G_2	H_2	I_2	$G_2 + H_2$	I_2
TOTAL COLLECTION AREA	ΣE_i					$\boldsymbol{\Sigma(G_i + H_i)}$	ΣI_i

The results from determining collection sub-area sizes and measurements are inputted into Table 4.2. This table shows total area for each collection sub-area type, as well as pervious and impervious areas. Sub-area data is used to determine the total impervious and total pervious area for the study site. All pervious and impervious areas within the study site should be included. This includes road areas and grassed and path areas beside the road. Any impervious areas within the open space area are also determined.

Table 4.2 Collection Area Overview Data

	Total area (ha)	Roof area (ha)	Road and pavement area (ha)	Grassed / vegetated area (ha)	Total impervious area (ha)	Total pervious area (ha)
Residential	(A)	(B)	(C)	(D)	(B + C)	(D)
Open space / community scale irrigation						
Industrial						
Commercial						
TOTAL COLLECTION AREA						

Both Tables 4.1 and 4.2 are linked together through the residential area, or the second row in Table 4.2. Equations 4.1 to 4.4 show the relationships between the total residential area and the average residential block. These equations can be used either as a check to verify the measurements off the maps or plans are correct, or to calculate total areas. Since open space / community scale irrigation, industrial and commercial areas tend to be more homogonous, these areas have not been subdivided further as for the residential area.

$(A) = \Sigma\ (E_i \times F_i)$ + non-household road, pavement and grassed areas 4.1

$(B) = \Sigma (E_i \times G_i)$ 4.2

$(C) = \Sigma (E_i \times H_i)$ + non-household road and pavement areas 4.3

$(D) = \Sigma (E_i \times I_i)$ + non-household grassed areas 4.4

For each of Equations 4.1 to 4.4, non-household values would include road, pavement and grassed areas that are external to the residential block but are included in the residential catchment area. This includes residential roads, parks, verges and footpaths.

The focus on the above calculations is on the catchment area. The catchment area can be the same area as the end use area or can be a different area. Similar calculations are conducted for the end use area(s). The information compiled for end use area is more extensive than for the catchment area, as demand patterns are required. At this stage, the amount of grassed, open space and garden areas that are irrigated is determined. Basic estimation of the percentage of grassed areas that are irrigated, as well as estimated internal household demand can be inputted into modelling tools to determine water demand. Estimation or identification of housing occupancies and housing plot sizes are also used to estimate water demand for residential areas. Table 4.3 and Table 4.4 show the information required for the end use area. Equations 4.1 and 4.4 can also be used for Tables 4.3 and 4.4. Data sources for obtaining information to complete Tables 4.1 to 4.4 are provided in Appendix B.

Table 4.3 End Use Area Residential Block Data

	Total number of blocks	Average block size	Average pervious area	% Pervious area irrigated	Average housing occupancy
	(No.)	(m^2)	(m^2)	(%)	(People/house)
Typical residential block 1	E_1	F_1	I_1		
Typical residential block 2	E_2	F_2	I_2		
TOTAL END USE AREA	ΣE_i				

Table 4.4 End Use Area Overview Data

	Total area	Total pervious area	Pervious area irrigated	% Pervious area irrigated
	(ha)	(ha)	(ha)	(%)
Residential	(A)	(D)		
Open space / community scale irrigation				
Industrial				
Commercial				
TOTAL END USE AREA				

After area and zonal type calculations, the ground conditions need to be determined. This could be based on the Unified Soil Classification System (USCS) (ASTM, D2487-00) or the Australian Soil Classification system (ASC) (Isbell, 2002). The USCS divides the material into gravels, soils, sands, clays, organic soils and different combinations of the above. The ASC classifies the material under a hierarchical scheme. This means the soil can be classified to the detail required. The soil is classified in increasing detail under headings of order, suborder, great group, subgroup and family.

Ground conditions are very important in terms of construction requirements and feasibility of locating collection, storage, treatment and distribution options within the study site. Some soil types are more suitable to certain types of technical component options. For example, sandy soils are very well suited to infiltration trenches as the water can easily permeate through the soils. Infiltration trenches that have a clay layer at the base of the infiltration trench would ensure no exfiltration of the stormwater in stormwater use schemes. Ground conditions also influence the amount of rainfall that becomes runoff and may be required when estimating coefficient of runoff.

4.4.1.2 STORMWATER RUNOFF

Stormwater runoff is the amount of rainfall converted to surface flows and is one of the key parameters used to determine stormwater yield. Stormwater yield represents the quantity of water that is actually available for usage in a stormwater use scheme. Stormwater runoff becomes stormwater yield through a system's capture and storage potential, as well as a number of other factors. Yield is discussed in further detail in Section 4.4.2.2.

Due to the complexity of determining stormwater yield, the initial stages of the decision making framework focus on estimating monthly and yearly runoff, based on monthly and yearly rainfall data. This methodology was chosen because monthly and yearly rainfall and evaporation data is readily available from sources such as the Bureau of Meteorology website (www.bom.gov.au).

There are a number of methods that are available to determine runoff. The 'rational method' estimates the peak flow of a design storm based on average rainfall intensity for a design storm, runoff coefficient and area of catchment (Institution of Engineers

Australia, 1987). The Simple Method calculates yearly runoff based on annual rainfall volume and coefficient of runoff (Schueler, 1987), but mainly concentrates on calculating pollutant loads. The method chosen for this study is similar to both of these methods and uses monthly or yearly rainfall data, runoff coefficient and the size of the pervious or impervious areas. Equations 4.5 and 4.6 show the methods used to calculate impervious and pervious monthly runoff respectively. Monthly runoff volumes are inputted to Table 4.5 for use in the decision making framework.

$$\text{Impervious Runoff Volume (kL/month)} = \text{Rainfall (mm/month)} \times \text{Impervious Area (ha)} \times \text{Impervious Coefficient of Runoff} \times 10 \text{ (conversion factor)} \quad (4.5)$$

$$\text{Pervious Runoff Volume (kL/month)} = \text{Rainfall (mm/month)} \times \text{Pervious Area (ha)} \times \text{Pervious Coefficient of Runoff} \times 10 \text{ (conversion factor)} \quad (4.6)$$

Table 4.5 Calculation of Monthly and Yearly Runoff Volume in Decision Making Framework

Month	Rainfall depth (mm)	Impervious runoff volume (kL/month)	Pervious runoff volume (kL/month)	Total runoff volume (kL/month)
July				
August				
September				
October				
November				
December				
January				
February				
March				
April				
May				
June				
TOTAL YEARLY RUNOFF (kL/year)				

The second column in Table 4.5 contains the monthly rainfall data collected from the Bureau of Meteorology website (http://www.bom.gov.au/). The table months start at July and end in June to take into account the large irrigation requirements over the summer months, for later stages of calculations. The third and fourth columns are calculated using Equations 4.5 and 4.6 respectively. The fifth column is a summation of the pervious and impervious monthly runoff volumes. Different coefficients of runoff for impervious and pervious areas are used in Equations 4.5 and 4.6 respectively.

As a safety factor for runoff calculations, the pervious coefficient of runoff is recommended to be chosen as zero. A pervious coefficient of zero corresponds to only impervious runoff being included in the calculations and runoff from pervious areas disregarded. This safety factor means that the amount of stormwater is underestimated, which is a reasonable representation of the amount of stormwater runoff that would become stormwater yield.

The above calculations are very simplistic. The coefficient of runoff is a rough estimate of the amount of rainfall that becomes runoff. The coefficient of runoff does not take into account ground saturation prior to the storm event, frequency of storm events or evaporation for various storm events. These additional factors influence the amount of rainfall that becomes runoff. For example, if there are very infrequent rainfall events prior to a large amount of rain falling, the ground would be very dry and a large proportion of the rainfall could infiltrate into the ground. However, dry ground conditions could also result in larger amounts of rainfall becoming runoff if the pervious areas acted as impervious areas.

4.4.1.3 END USE DEMAND

The quantity of end use demand that can be met is directly related to stormwater yield. End use demand and stormwater yield need to be matched as closely as possible so that the maximum amount of runoff can be collected and/or the maximum demand can be met. The governing factor depends on whether there is a greater quantity of stormwater collected or end use demanded, as well as the patterns of supply and demand. The general study site condition information that was determined in Section 4.4.1.1 is used in conjunction with additional data to determine end use demand for the different potential end uses.

This research project focused on the use of stormwater in urban areas. Industrial areas have larger water demands than residential urban areas. For example, around a quarter of the urban water demand in Melbourne is utilised by the commercial and industrial sectors (Water Resources Strategy Committee for the Melbourne Area, 2001). However, the examination of industrial and commercial use of stormwater is more appropriate at an individual scale. As this project focused on cluster scale stormwater use, specific requirements for lot scale stormwater use in industrial areas have not been examined. Community scale irrigation end use has been included in the decision making framework and would accommodate any industrial uses that may be included in a cluster scale stormwater use scheme.

There are a number of end uses within a household, as shown in Figure 4.2. Residential end uses are divided in the decision making framework into outdoor non-potable, indoor non-potable and indoor potable, based on water quality and infrastructure requirements. Non-potable water quality requirements are the same or lower quality than potable water quality requirements. Indoor use requires additional indoor plumbing and infrastructure compared to outdoor use.

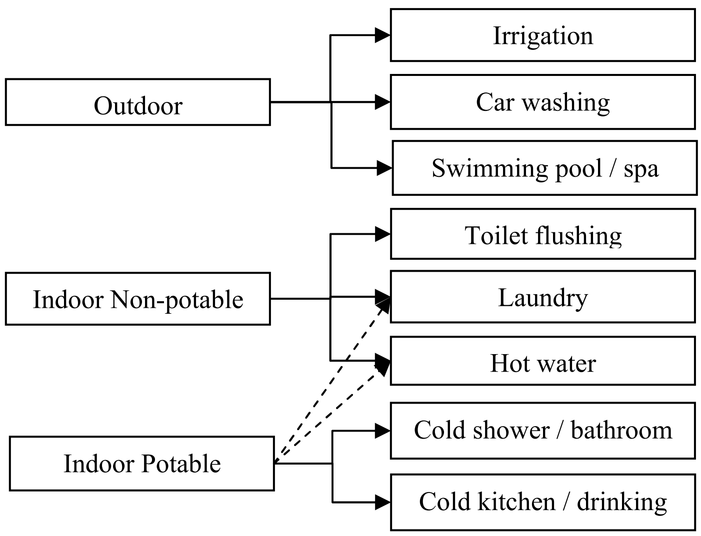


Figure 4.2 Household End Uses

The separation of end uses into indoor and outdoor use is self explanatory. Outdoor uses are all uses which occur outside of the household, such as garden irrigation and car washing. However, the separation between indoor non-potable and indoor potable end use is more complex due to differences between regulations and health authority requirements. The dotted lines in Figure 4.2 between laundry, hot water and indoor potable water use represent the uncertainty of these end uses being divided into either indoor potable or indoor non-potable end use.

It is reasonably standard practice to assume that water for toilet flushing does not require potable water quality (Hatt et al., 2004). Water piped to kitchen taps, as well as cold water taps in the bathroom and shower requires potable standard water. Water from hot water taps which enters the kitchen and bathroom is also assumed to require potable quality water (Coombes et al., 2003). However, the Figtree Place development in Newcastle found that a combination of rain water tanks and processes within the hot water system provided adequate treatment to improve rainwater to potable standard water (Coombes et al., 1999). This means non-potable quality water could be piped into the hot water system, although these results had not been replicated at a different study site. There does not seem to be a standard view of the required water quality for laundry end use. Local councils or government authorities could impose regulations so that water piped to laundry taps and hot water systems require potable quality water.

The above division of end uses and required water qualities are based on current practices and projects which have implemented stormwater use or wastewater reuse. The actual requirements for each study site needs to be determined individually. Due to the fact that guidelines for stormwater reuse are not being developed until at least 2005 (Section 3.3.2), a risk assessment as well as negotiation with local health authorities needs to be conducted during the decision making process. This process determines which end uses are acceptable for stormwater utilisation. Options to be examined include treating stormwater to potable water quality standard and using it for potable end uses, or treating stormwater to non-potable water quality which is acceptable within the household.

Once the division of the different end uses is determined, the demand for each end use needs to be estimated. Household water use and average values are available from water authorities and local governments. The yearly residential water use of major capital cities of Australia from 1995/96 to 2000/01 is shown in Table 4.6.

While average total household water use is relatively easy to obtain, it is more difficult to obtain the split between indoor and outdoor use or to obtain water use based on household sizes. However, average percentages of water use for different end uses are available. A number of studies published average domestic water consumption as shown in Table 4.7. This information is very dependent on local conditions, and indoor use varies widely between households and states. Therefore caution needs to be used if this generalised style of information is the basis for any end use demand calculations.

Table 4.6 Residential Yearly Water Use for Australian States

	Volume of water consumed kL/property/year					
City	1995/96	1996/97	1997/98	1998/99	1999/00	2000/01
Adelaide	280	319	345	309	301	271
Brisbane	408	396	337	278	225	273
Canberra	427	435	473	432	530	314
Darwin	213	241	245	230	238	531
Hobart	696	772	802	447	465	509
Melbourne	238	248	252	261	263	238
Perth	221	240	256	242	244	334
Sydney	311	326	348	298	320	255
POPULATION WEIGHTED AVERAGE	249	268	275	253	255	266

Source: Water Services Association of Australia Inc. (2001).

Table 4.7 Domestic Water Consumption

	Average consumption per average household (kL/year)	
	Melbourne[1]	Perth[2]
Toilet	46	41
Bathroom	62	62
Laundry	36	51
Kitchen	12	30
Miscellaneous		7
Average indoor consumption	*156*	*191*
Average outdoor consumption	*84*	*258*
Average total consumption	**240**	**449**

Source: [1] Water Resources Strategy Committee for the Melbourne Area (2001)

[2] Loh and Coghlan (2003)

Note: Outdoor consumption is subject to climatic conditions and varies nationally

Rather than estimating residential end use demands based on average Australian data, monitoring programs can be set up to directly measure end use demands of the study area. Monitoring programs are very expensive to conduct and are therefore rarely conducted for specific stormwater use study areas. However, research studying trends in household sizes and end use demand and patterns is being conducted (for example S. Gato [candidate for PhD on Forecasting Residential Demand in Melbourne, RMIT] 2003, pers. comm., 7 August). These studies are being conducted in research institutions or directly through water authorities and may provide more realistic end use demand estimations. Until this data is available, existing end use data needs to be used.

An example of state based end use demand information available is Cordell et al. (2002). Cordell et al. (2002) examined water use and demand for the Melbourne region using data provided by the three Melbourne urban retail water authorities: Yarra Valley Water, City West Water and South East Water. This report contained average annual indoor and outdoor residential use for different suburbs of Melbourne as well as seasonal water use for houses or flats. This data is a useful starting point for estimating monthly water demand or can be used for calibration of water demand values in modelling tools.

When information obtained from various sources provides only average annual indoor and outdoor demand, this data needs to be converted to monthly demand. Monthly demand can be variable, particularly when irrigation requirements are examined. Based on generalised water use demand studies, indoor water demand is assumed to be constant throughout the year. Therefore the difference between monthly indoor end use demands is dependent only on the number of days in each month. Equation 4.7 describes how monthly indoor demand is converted from average annual indoor demand.

$$\text{Monthly Indoor Demand} = \text{Yearly Indoor Demand} \times \frac{\text{no. of days in the month}}{365} \quad \text{............4.7}$$

The aim of estimating monthly demand is to compare these values to stormwater runoff to determine whether end use demand can be fully or partially met (Section 4.4.1.4). This comparison is based on meeting outdoor demand first. Indoor demand then needs to be further divided into different end uses if this demand can only be partially met after satisfying the outdoor demand. As described previously, indoor demand is assumed to be constant throughout the year and divided into potable and non-potable end uses. Published values of distribution of household water use, such as those shown in Table 4.8, can be used as the basis for estimating different indoor end use demands where no direct measurement are available.

Table 4.8 Distribution of Household Water Use

	Australian average		Melbourne		Yarra Valley (subset of Melbourne)	
	Total use[1]	Indoor use[4]	Total use[2]	Indoor use[4]	Total use[3]	Indoor use[4]
Outdoor or garden	34%	0	35%	0	31%	0
Toilet	20%	30%	19%	29%	14%	20%
Shower or bathroom	26%	39%	26%	40%	34%	49%
Washing machine or laundry	15%	23%	15%	23%	14%	20%
Others or kitchen	5%	8%	5%	8%	7%	10%
TOTAL	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Sources: [1] Water Services Association of Australia (2001).

[2] Water Resources Strategy Committee for the Melbourne Area (2001)

[3] Roberts (2003)

[4] Calculated using total use values (in the column to the left) excluding outdoor or garden use

Table 4.8 contains only a small sample of the variety of sources available regarding the distribution of indoor household water use. Data directly measured from the study site or a similar study site would be the most preferable data to be used. Information from local water authorities is also acceptable. Discretion must be used by the decision maker utilising this decision making framework about which indoor household water use distribution are the most appropriate for their study area.

Monthly outdoor household demand is more complex to determine than monthly indoor demand. Residential outdoor demand includes car washing, topping up of swimming pools and irrigation. Due to the dominating factor of irrigation requirements, the temporal distribution of outdoor demand is based only on irrigation requirements. Patterns of garden watering are difficult to predict as human behaviour is extremely variable between households, neighbourhoods and cities. However, the variability of irrigation demand can be approximated more closely when examining larger groups of people because variability in individual behaviour is smoothed out.

Irrigation demand is higher during hotter seasons in locations with less frequent rainfall (for example Figure 3.4). The basis for minimal irrigation requirements is to ensure plants do not die. While human behaviour is very complex when estimating watering requirements, vegetation watering requirements can be linked to evaporation. Equation 4.8 shows the relationship between irrigation requirements, evaporation and rainfall.

Irrigation = $\alpha \times$ evaporation - rainfall..4.8

Alpha (α) is a variable which can be adjusted to obtain the most acceptable distribution of monthly irrigation demand throughout the year. Trial and error is used to determine an appropriate value. The case study demonstrates this methodology in Section 5.3.3. The benefit of using Equation 4.8 is that local conditions are taken into account to determine irrigation requirements.

Another method to estimate monthly irrigation demand from yearly demand when measured data is not available is to base the monthly demand on available percentage distributions. While the total quantity of outdoor use varies across different climate conditions, the distribution can be considered to follow a similar pattern. The use of this method for determining outdoor use distribution can be verified by use of Equation 4.8. If there is a large discrepancy between the two methods, Equation 4.8 should be used as the basis for monthly distribution of outdoor end use demand as this equation takes into account local conditions.

Water Corporation in Perth, Western Australia conducted an in-depth study into residential water use including indoor and outdoor use (Loh and Coghlan, 2003). The temporal distribution of outdoor demand determined from this study is shown below in Table 4.9. The methodology used to determine the temporal pattern based on the data provided in Loh and Coghlan (2003) is shown in Appendix C.

Table 4.9 Monthly Distribution of Outdoor Water Demand Based on Perth Data

	Monthly temporal distribution of outdoor demand
January	17%
February	17%
March	13%
April	9%
May	3%
June	1%
July	1%
August	1%
September	1%
October	6%
November	13%
December	17%
TOTAL	**100%**

Source: Loh and Coghlan (2003)

4.4.1.4 COMPARISON OF STORMWATER RUNOFF AND END USE DEMAND

Monthly stormwater runoff is compared to estimated monthly end use demand to determine deficiencies in the amount of stormwater available. Stormwater runoff and end use demand quantities are compared prior to examining the role of storage in terms of stormwater runoff, yield and water demand. This comparison is used as a screening tool so that end use options are not examined further where there is insufficient stormwater to meet end use demand. Examining the temporal pattern of this comparison gives an indication of whether it is more appropriate to meet outdoor end use demand and possibly have an excess of potential yield in the winter months, or whether both indoor and outdoor demand can be met. The procedure to screen out infeasible options is based on the issues discussed in Section 4.3.2.

As an example, Figure 4.3 shows sample values of potential stormwater runoff with indoor, outdoor and total demand. This figure shows that stormwater runoff can either meet all indoor demand or partially meet both outdoor and indoor demand. Therefore some end uses need to be screened out as infeasible. It is preferable to discard potable indoor end use, as the treatment requirements are more significant. The type of end uses included in indoor end use demand need to be decided upon (Section 4.4.1.3). As potable indoor end use is screened out as infeasible, only two end use demands are examined. Outdoor end use and indoor non potable use would be the two feasible options examined in the decision making framework to determine the most appropriate stormwater use scheme.

Figure 4.4 shows a different stormwater runoff and demand pattern. In this case, runoff closely follows outdoor demand. Therefore, outdoor use would be examined in the decision making framework. All indoor use would be screened out as infeasible.

The comparison of stormwater runoff and demand patterns provide a quick method to determine whether there is sufficient runoff to meet demand. A detailed demonstration of this comparison tool used to screen out infeasible end use options is described in Section 5.3.4, through the use of the case study.

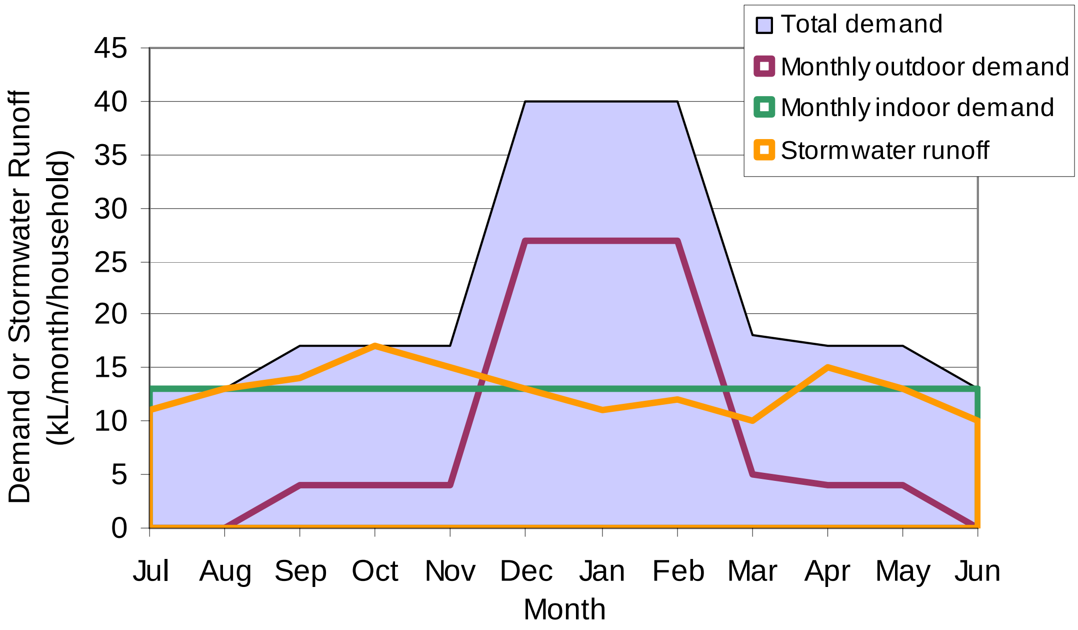


Figure 4.3 Example Graph Showing Non-matching Outdoor Demand and Stormwater Runoff Patterns

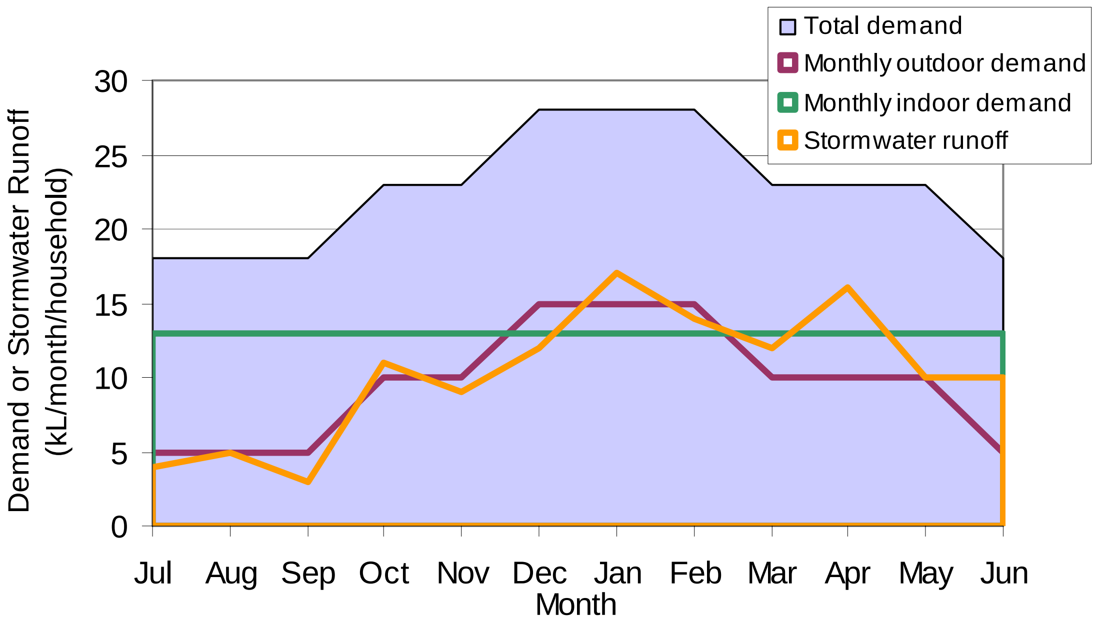


Figure 4.4 Example Graph Showing Matching Outdoor Demand and Stormwater Runoff Patterns

4.4.1.5 DETERMINATION OF FEASIBLE COLLECTION OPTIONS

Once stormwater runoff and end use demand have been compared, options for collecting stormwater need to be examined. Collection may either be from the location where rain fell and became stormwater runoff, or may be from a single collection point. Collection systems catch and transport the stormwater to either the storage or treatment area.

Secondary functions of collection systems, such as providing treatment as well as transport of collected water, are important in terms of identifying linkages between different stormwater technical components. The integration between the different functions of collection systems is very important in order to develop a more integrated final system. These issues are discussed further in Section 4.4.5.

In order to develop an integrated stormwater use scheme option, collection options and associated issues need to be understood. Figure 4.5 shows the methodology for determining the feasible collection options for a stormwater use scheme. This methodology identifies the feasible collection options, and then compares the different options to determine the most suitable option for the particular study site.

There are two different aspects of stormwater collection. Firstly, the method by which stormwater runoff can be collected is either gravity or pump assisted flow. Secondly, there are a number of options used to collect the stormwater. Collection options include:

- overland flow systems;
- infiltration trenches;
- permeable pavements; and
- pipe collection.

Overland flows, pipes and channels are the traditional method for collecting stormwater. Permeable pavements and infiltration trenches are newer technologies and are readily identified in a Water Sensitive Urban Design (WSUD) stormwater management system. The newer technologies also have the potential for dual purposes, such as providing treatment.

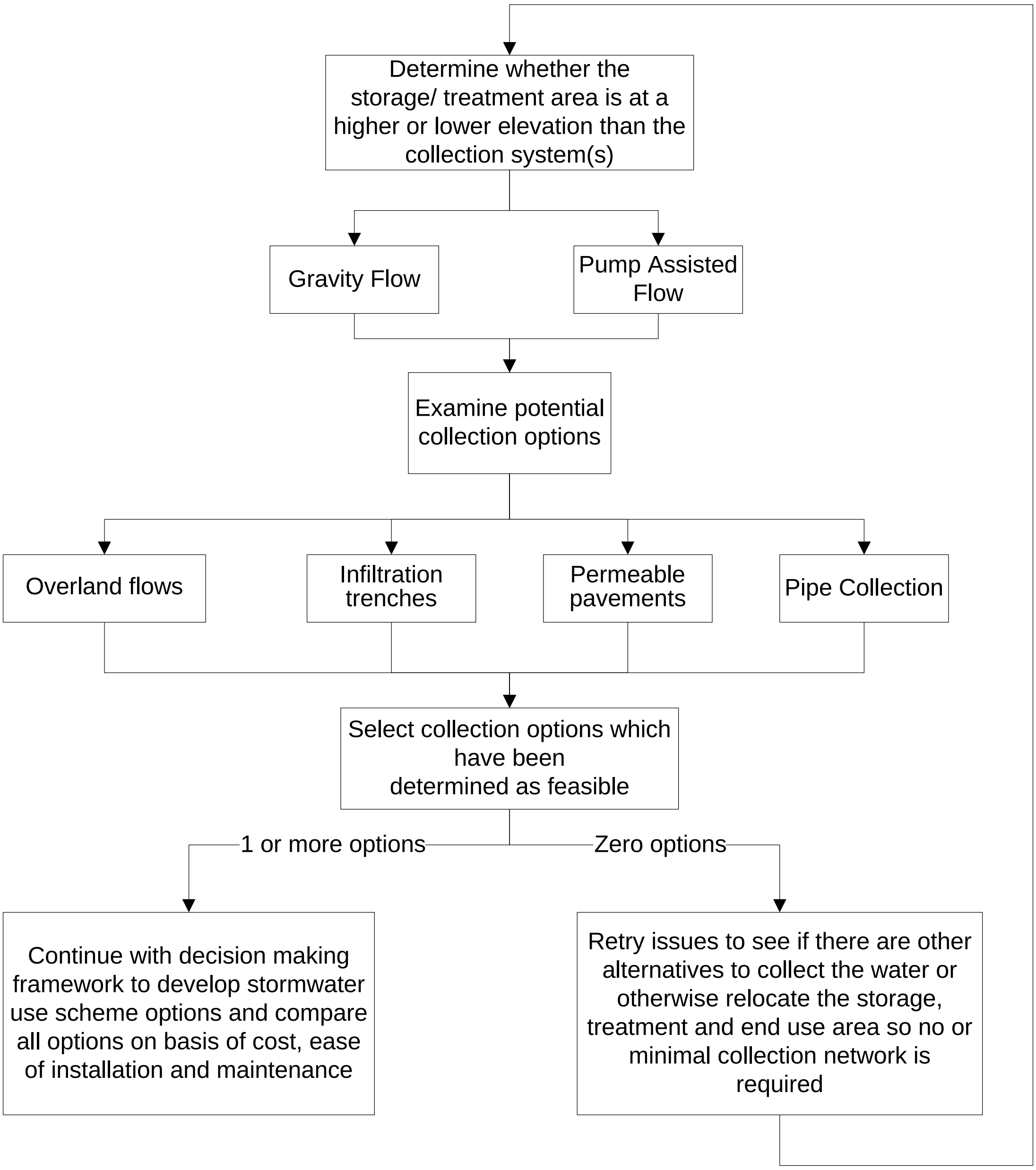


Figure 4.5 Methodology for Determining Feasible Collection Options

Determining feasible collection methods and options in the decision making framework is based on a number of basic variables. These variables are ground conditions, topography, safety issues, space restrictions and constraints such as conflicts with other services, building foundations or underground cables.

Ground conditions influence the type of collection system that can be constructed. Hard rocky ground conditions restrict the ability to construct underground systems, or at least increase construction costs. Generally, in hard rocky ground, collection systems which required deep excavations are excluded from being feasible as the construction costs are too high. The collection methods and options are described below, as well as information about the variables which influences the feasibility of each method / option.

(a) Gravity or Pump Assisted Flow

Gravity flow can only be used when there is sufficient height difference or head to allow the water to flow without assistance from the collection area to the lower elevation outlet point. Most traditional stormwater collection systems use only gravity flow, and the pipe collection system is designed to ensure there is sufficient head difference from the higher to lower elevation pipes, taking into account energy drops through structures such as stormwater pits and junctions. Stormwater use schemes should use similar principles to traditional stormwater management practices and utilise gravity flow for collection where possible. Pumps are required if the storage or treatment area can only be located at a higher elevation location or for extraction of stormwater from a central collection point.

(b) Overland Flows

Overland flows are traditionally used for large storm events, in conjunction with a pipe collection system. Pipes are traditionally designed to carry runoff from small to medium rainfall events, which are generally frequent events. The design frequency would depend on the local stormwater management design guidelines and is usually once in every five, ten or twenty years. Road layouts including slopes and kerb heights are designed to handle larger rainfall events as overland flows. These flows are quickly disposed or transported to an area that can either accept all of the flows, like a river or pond, or to a detention or retention basin. Detention and retention basins slowly release large flows downstream to reduce the possibility of flooding. Constructed concrete or natural channels can also be used to direct overland flows.

Factors which cause overland flows to be infeasible are safety issues and uncontrolled flows causing flooding. Overland flows need to be properly designed, managed and contained within specified areas. Otherwise the stormwater management system, including utilisation of stormwater, can not be effective and well managed. Managing the safety aspects of flooding is particularly important if all other collection options are determined as infeasible, as there is no alternative system to collect or contain the stormwater.

Overland flows in a stormwater use scheme need to have an efficient collection point. Otherwise, sufficient stormwater can not be collected and stormwater runoff or yield may not meet end use demand. Utilising overland flows is the only collection option that is not restricted by hard rocky ground conditions.

(c) Infiltration Trenches

Infiltration trenches are becoming more prevalent in WSUD stormwater management systems. Infiltration trenches have a number of benefits including providing filtration and treatment of the runoff through the infiltration system. By directing stormwater flows to enclosed underground areas, additional contamination or litter accumulation is minimised as these surface pollutants are not collected in the stormwater flow.

Infiltration trenches require sufficient reserve areas for the stormwater to infiltrate into the collection system. Infiltration trenches are most suited to permeable soil conditions, such as coarse ground soils, sands and gravels. Permeable materials can be transported to the study site and placed in excavations for the infiltration trench if the existing soil conditions are not suitable. To capture the maximum amount of stormwater runoff, exfiltration from the infiltration trench needs to be minimised. An impermeable lining can be placed at the bottom of the trench or the trench can be placed on an impermeable surface such as clay. Unsuitable ground conditions include hard rock, unless the decision maker decides to include additional costs to account for construction in the hard rocky ground.

Location of the infiltration trenches needs to be considered in terms of constraints within the area. This includes conflicts with services such as underground phone cables, electricity cables, gas pipes or water pipes. Other constraints may be insufficient open ground to locate the trenches. If there is insufficient space for the infiltration trench, then this collection option would be deemed as infeasible.

(d) Permeable Pavements

Permeable pavements allow infiltration of stormwater through the pavement either through gaps in the interlocking pavers or the pervious materials of the pavers. Permeable pavements are generally utilised to reduce stormwater flows and runoff, but new developments have been made so that storage and distribution systems can be integrated into the permeable pavement systems for stormwater utilisation.

Permeable pavements have the added benefit of treating the stormwater as it is infiltrated. Particles are trapped on the pavement surface and within the system. This means that maintenance and cleaning of the systems is very important to ensure no clogging occurs.

Permeable pavements have similar restrictions to infiltration trenches, particularly in terms of providing sufficient space and conflicts with services. However, as permeable pavements can be either grassed blocks or bricks or pavers, there are more options for locating permeable pavements including carparks and open fields. Ground conditions must be suitable for construction of permeable pavements.

(e) Pipe Collection System

Pipe collection is the traditional method for collecting stormwater. For this reason, there is a vast amount of information and tools to assist in stormwater pipe design and decision making. Pipe sizing and location are the most important issues in terms of designing a stormwater pipe system. The correct location needs to be selected so that there is no interference with other services or structures, as well as utilising gravity flow. Sufficient pipe slopes are required so that sediment does not settle in the bottom of the pipe. Additionally, the slope cannot be too steep so that high water velocities cause scouring of the pipes from the particles in the water.

Sizing of stormwater pipes is based on the flow needed to be collected. Local council or government regulations usually state the design storm event frequency that needs to be considered in designing the pipe system. This is usually a storm event that occurs an average one in every five, ten or twenty years.

Pipe collection of stormwater is generally feasible in all cases. Conflicts with underground cables can generally be avoided through changing horizontal alignment of the pipe system or changing the depth of the pipes. While hard rocky ground increases construction costs, stormwater pipes have been installed in these cases.

4.4.1.6 COMPARISON OF FEASIBLE COLLECTION OPTIONS

The number of collection options which are deemed feasible is either zero or one or more. Figure 4.5 shows that zero feasible collection options results in either re-examining the potential collection options or redesigning the possible layout of the storage, treatment and end use area so that minimal or no collection infrastructure is required. No collection infrastructure can be designed through all runoff being used directly where it falls. Otherwise infrastructure can be minimised through only overland flows or minimal distances between collection, storage, treatment and end use areas.

One or more feasible collection option(s) results in continuing the decision making framework to the next stages. This consists of examining further technical issues and developing feasible stormwater use scheme options. These options are compared based on financial costs and technical issues such as ease of installation and maintenance, as described in Section 4.4.6. The effects of environmental, social and economic issues are examined in more detail in Section 4.5.

4.4.1.7 STORMWATER QUALITY

In conjunction with examining collection options and comparing feasible systems, the quality of the stormwater to be collected needs to be determined. The general consensus from stormwater quality monitoring is that stormwater quality is highly variable (Duncan, 2003). Stormwater quality is dependent upon a number of issues, including catchment conditions, timing between rainfall events and the amount of pollutants dislodged from the ground and entering the stormwater runoff.

The variability of stormwater pollutant concentrations depending on local conditions reinforces the idea that local data is the most appropriate data for estimating stormwater quality. Direct monitoring of stormwater quality has been carried out infrequently due to high costs. If stormwater quality data is not available for the study site, areas of similar characteristics including ground conditions and rainfall patterns or areas near to the study site should be considered in obtaining the required data. When this data is not readily available, national and international data sets can be used as a basis for estimating stormwater quality. As this data is very general and accuracy may be uncertain, additional safety factors need to be included in the design to treat the stormwater to a higher quality. This ensures the stormwater is treated to sufficient standard if stormwater quality is lower than estimated.

Duncan (1999) conducted a review of the literature examining stormwater quality and provided a statistical overview of stormwater quality based on different land uses and collection areas. Duncan (2003) refined and updated this work. Pollutant loads and concentrations can be approximately estimated from either of these sources, which includes stormwater quality for different catchment areas and types of runoff.

Mudgway et al. (1997) presented tables demonstrating log mean and standard deviation pollutant values for stormwater. These tables are partly reproduced in Table 4.10. Table 4.10 examines both Australian and world data and includes data on water quality from roads, high density urban areas and roof runoff. The range of the contaminant levels in Table 4.10 were determined based on one log standard deviation of the mean provided in Mudgway et al. (1997). Caution must be used if these values are the basis for estimating stormwater quality as some parameters had significant difference between the populations. Other variables where a single value is given in Table 4.10 had only a single population value in Mudgway et al. (1997).

Computer modelling tools can also be used to estimate stormwater quality. MUSIC (Model for Urban Stormwater Improvement Conceptualisation) was developed as a tool to assist designing stormwater treatment measures (Wong et al., 2002). MUSIC can be used to simulate stormwater quality from urban catchments, as well as water quality after the stormwater passed through a number of treatment measures. This modelling tool simulates suspended solids, total nitrogen and total phosphorous concentrations over time, based on a variety of rainfall events.

MUSIC was developed as a stormwater management tool with a focus on conceptual design of stormwater treatment, rather than a tool for conceptual design of stormwater utilisation schemes. As such, additional quality requirements such as BOD, coliforms, viruses, pathogens and metals, are not included in the modelling tool. This tool would be most effective for conceptual design and sizing of required treatment measures and currently has only limited application to the stormwater use decision making framework. Use of MUSIC in the decision making framework may become more appropriate as issues relating to guidelines and treatment requirements are clarified, as described in Section 4.4.3.

Table 4.10 Urban Stormwater Contaminant Concentrations from Mudgway et al. (1997)

Pollutant	**All data**	**All roads**	**All high density urban**	**All roofs**
(mg/L)	**Australian data set**			
Suspended solids	42 - 479		35 - 389	
Total nitrogen	1.29 - 5.37		1.41 - 6.17	
Total phosphorus	0.08 - 0.72		0.09 - 0.78	
Lead	0.01 - 0.74	0.11	0.14 - 0.55	0.001 - 0.12
Zinc	0.23 - 1.70	0.48	0.28 - 1.51	0.19 - 2.88
Cadmium	0.0026 - 0.0182	0.0027	0.0027 - 0.0195	
Chromium	0.010 - 0.115		0.010 - 0.126	
Copper	0.02 - 0.18	0.08	0.02 - 0.20	
Nickel	0.01 - 0.04		0.01 - 0.04	
Biological oxygen demand	7.9 - 28.8		7.8 - 28.2	
	World data set			
Suspended solids	45 - 490	60 - 724	54 - 468	15 - 85
Total nitrogen	1.12 - 5.62	1.07 - 8.91	1.35 - 4.90	4.07 - 7.76
Total phosphorus	0.13 - 0.83	0.11 - 0.81	0.17 - 0.83	0.07 - 0.25
Lead	0.03 - 0.50	0.07 - 0.76	0.04 - 0.51	0.01 - 0.09
Zinc	0.08 - 0.78	0.14 - 0.87	0.08 - 0.58	0.05 - 3.47
Cadmium	0.0007 - 0.0115	0.0010 - 0.0085	0.0010 - 0.0132	0.0002 - 0.0013
Chromium	0.005 - 0.083	0.007 - 0.022	0.005 - 0.102	
Copper	0.02 - 0.17	0.03 - 0.40	0.02 - 0.14	0.01 - 0.09
Nickel	0.02 - 0.07	0.03 - 0.06	0.02 - 0.07	
Biological oxygen demand	5.6 - 25.7	8.7 - 31.6	6.9 - 26.3	4.0 - 4.0

Source: Mudgway et al. (1997)

4.4.1.8 END USE REQUIRED QUALITY

Water quality requirements for various stormwater end uses are one of the major challenges within this study. This is due to the fact that guidelines are focused on wastewater recycling. Implementation of stormwater utilisation schemes has generally preceded research.

There are a number of guidelines that are available for reference when developing stormwater use scheme options. Potable water quality requirements are quite specific in the requirements that need to be met and advice on monitoring and assessment of the water supply performance. Australian Drinking Water Guidelines (NHMRC and ARMCANZ, 1996) provide guidelines to the quality of drinking water including guideline values required for all potable water supply. These guidelines have been undergoing a rolling review to provide a preventative risk management approach to supply of potable water. A draft version of the updated Australian Drinking Water Guidelines (NHMRC and NRMMC, 2002) was released for consultation which closed in January 2003. These guidelines are relevant irrespective of the water source and focus on all potable end uses. This means these guidelines can be used as the basis for any stormwater use scheme options involving potable water use.

The challenge with other stormwater use scheme options is that there are no specific guidelines relating to stormwater as the water source or providing guidelines on quality requirements for different end uses. A number of other guidelines have been used in the past to provide guidance on the quality requirements for stormwater use schemes. Hatt et al. (2004) provide a good overview of the guidelines that have been used in stormwater use schemes in Australia. Such stormwater use schemes have generally utilised Guidelines for Sewerage Systems: Use of Reclaimed Water (ARMCANZ et al., 2000), or state based guidelines. The state based guidelines may be very similar as state based guidelines are often based on ARMCANZ et al. (2000).

The state and national guidelines generally focus on the following quality parameters:

- Coliforms, specified as faecal coliforms, thermotolerant coliforms and *E-coli* organisms;
- Viruses;
- Parasites;
- Turbidity;
- pH;
- Colour;
- Chlorine (Cl_2) residual;
- Biological Oxygen Demand (BOD);
- Non-filtrable residue (NFR); and
- Suspended Solids(SS).

As can be seen from the above list, several of these parameters focus on biological quality of water sources. This is due to biological contaminants being the main concern in wastewater. While these contaminants are also of concern in stormwater, water quality monitoring of stormwater regularly measures suspended solids, nitrogen and phosphorous, as seen in Table 4.10. Biological contaminants are not as regularly monitored in stormwater quality monitoring programs, as the previous focus of stormwater management means these contaminants have previously not been seen as critical.

In addition to providing guideline values for a number of required contaminant levels, the wastewater guidelines that have been used as a reference for stormwater use scheme options also provide recommended treatment levels. An example of this is EPA Victoria (2002). Table 4.11 was extracted from EPA Victoria (2002) and shows required quality parameter values, treatment processes required to achieve them and the acceptable uses for the different classes of water.

Table 4.11 Classes of Reclaimed Water and Corresponding Standards for Biological Treatment and Pathogen Reduction from EPA Victoria (2002)

Class	Water quality objectives - medians unless specified	Treatment processes	Range of uses– uses include all lower class uses
A	Indicative objectives < 10 E.coli org/100 mL Turbidity < 2 NTU < 10 / 5 mg/L BOD / SS pH 6 – 9 1 mg/L Cl2 residual (or equivalent disinfection)	Tertiary and pathogen reduction with sufficient log reductions to achieve: <10 E.coli per 100 mL; <1 helminth per litre; < 1 protozoa per 50 litres; & < 1 virus per 50 litres	Urban (non-potable): with uncontrolled public access Agricultural: eg human food crops consumed raw Industrial: open systems with worker exposure potential
B	<100 E.coli org/100 mL pH 6 – 9 < 20 / 30 mg/L BOD / SS	Secondary and pathogen (including helminth reduction for cattle grazing) reduction	Agricultural: eg dairy cattle grazing Industrial: eg washdown water
C	<1000 E.coli org/100 mL pH 6 – 9 < 20 / 30 mg/L BOD / SS	Secondary and pathogen reduction (including helminth reduction for cattle grazing use schemes)	Urban (non-potable) with controlled public access Agricultural: eg human food crops cooked/processed, grazing/fodder for livestock Industrial: systems with no potential worker exposure
D	<10000 E.coli org/100 mL pH 6 – 9 < 20 / 30 mg/L BOD / SS	Secondary	Agricultural: non-food crops including instant turf, woodlots, flowers

Source: EPA Victoria (2002)

The residential end uses that are acceptable for different classes of reclaimed water shown in Table 4.11 are very broad and are not as thoroughly defined as for agricultural uses. The definition of restricted public access has also not been clarified. It is not certain whether restricted public access includes a public irrigation area that is only irrigated at times of the day when the public is not likely to access the area, such as in the middle of the night. These or similar issues need to be clarified directly with the relevant authority such as EPA Victoria when designing a stormwater use scheme.

Guidelines on the Quality of Stormwater and Treated Wastewater for Injection into Aquifers for Storage and Reuse (Dillon and Pavelic, 1996) take into account processes that occur within the aquifer system. This results in lower water quality requirements for the injected water, as shown in Table 4.12.

Table 4.12 Guidance for Stormwater and Treated Wastewater Injectant Quality Requirements from Dillon and Pavelic (1996)

Contaminant	**Maximum concentration**		**Conditions or situations where maximum level should be reduced**
	Potable reuse	**Non-potable reuse**	
Suspended solids (mg/L)	30	30	Values have found to be acceptable in a variably cemented limestone aquifer. Where bore redevelopment is required more frequently than daily lower concentration required. Finer grained aquifers with no macroporosity.
Total dissolved solids (mg/L)	500	1000	Does not exceed the TDS of ambient groundwater. Where wastewater is more saline, it may need to be blended with surface water.
Faecal contaminants (cfu per 100mL)	10,000 (50 days residence)	10,000 (10 days residence)	Allow for 1 log removal per 10 days.
Nitrogen (mg/L)	10	<10	Ammonia concentration less than 0.5mg/L. For irrigation reuse, nitrate concentration in irrigation leachate is environmentally sustainable. Groundwater containing injectant discharges into surface waters or estuaries, receiving water concentration should remain below 0.1mg/L.

Source: Dillon and Pavelic (1996)

The current wastewater guidelines are based on specifying quality parameter levels. However, these guidelines are generally being updated using a preventative risk management based approach, similar to NHMRC and NRMMC (2002) as was the drinking water guidelines. The guidelines on greywater reuse and recycling are currently being developed based on a risk management approach by working groups overseen by the Environment Protection and Heritage Council and the National

Resource Management Ministerial Council Joint Steering Committee (CRC for Water Quality and Treatment, 2003). The first draft was expected to be completed late 2004. Work on the stormwater reuse and recycling guidelines will commence early 2005 and a draft is expected at the end of 2005, again based on a risk management approach.

Quality requirements for utilising stormwater as an alternative supply source are relatively ambiguous. The legal implications can be prohibitive if not managed and identified properly. Legal risks are discussed in Section 4.5.3.

4.4.2 STORAGE

Storage components and associate issues are shown as Step 7 in the decision making framework (Figure 4.1). This step is stated as "estimate storage requirements so that stormwater yield partially or completely meets water demand, and select storage system(s)." Figure 4.6 shows the methodology to determine feasible storage options for the stormwater use scheme in the decision making framework.

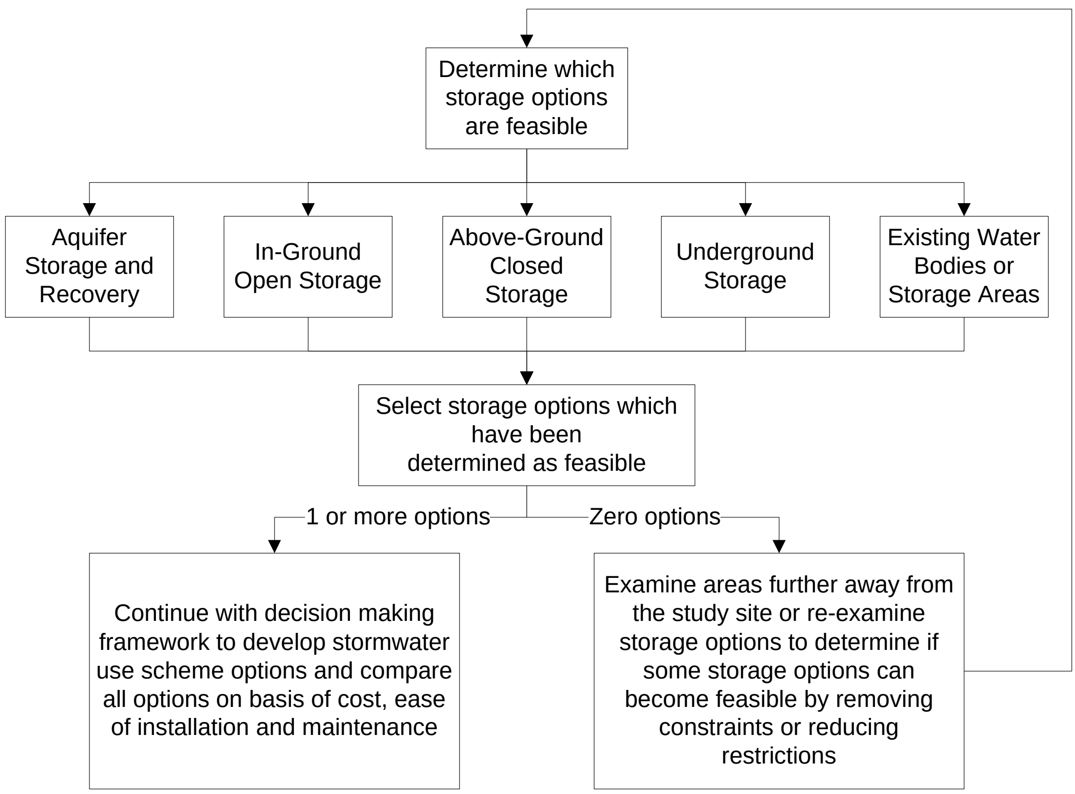


Figure 4.6 Methodology for Determining Feasible Storage Options

The flowchart shown in Figure 4.6 focuses on the issues directly relating to storage. However, the decision of which storage system is the most appropriate for the study site is directly related to issues of integration and how storage interacts with the other major issues related to treatment, distribution, collection and general study site conditions. Section 4.4.6 describes the methods used to compare the feasible storage options and determine the most appropriate storage option, with a focus on integration issues.

4.4.2.1 DETERMINATION OF FEASIBLE STORAGE OPTIONS

Five major storage options within a stormwater use scheme are examined in the decision making framework. A detailed analysis of the storage options is provided below, to complement the overview of the storage options provided in Section 3.4.2. These options are as follows:

- Aquifer Storage and Recovery;
- In-Ground Open Storage;
- Above-Ground Closed Storage;
- Underground Storage; and
- Existing Water Bodies or Storage Areas.

(a) Aquifer Storage and Recovery

Aquifer Storage and Recovery (ASR) is the injection of water (wastewater or stormwater) into naturally occurring underground caverns or storage systems for recovery and utilisation at a later stage. There are many issues that need to be examined to determine whether aquifer storage and recovery is feasible within the study area. The important issues are the availability of aquifers at an acceptable distance to the study site, groundwater quality within the aquifers and the suitability of injecting and retrieving stormwater from the aquifer. Dillon and Pavelic (1996) state that high land values, intensive development, inadequate topographic relief, high evaporation rates or toxic algae compromising the quality of stored water may limit the feasibility of using above-ground storages and reservoirs. In these cases, ASR may be the only suitable alternative.

Dillon and Pavelic (1996) provide a good background about the issues that need to be examined when implementing ASR. This includes stormwater quality, pre-treatment of source waters and clogging of injection wells. Treatment is usually required prior to injection and can also be required after recovery of the waters. The characteristics which are important in determining the suitability of aquifer storage and recovery are mentioned:

> *"Water quality has a direct bearing on the operational success of ASR (clogging), as well as impacts on groundwater quality" (Dillon and Pavelic, 1996, pp. 2-3)*

> *"Hydrogeological characteristics such as aquifer transmissivity play a vital role in determining suitability of ASR sites. Aquifers with high transmissivity are preferred as they can accept high rates of recharge, and so store large volumes of water. Formations targeted for recharge are usually sedimentary (carbonate, gravel and sand), with various degrees of consolidation, but may also include fractured rock." (Dillon and Pavelic, 1996, p. 3)*

The issues that are used to determine if ASR is feasible are based on technical feasibility, financial feasibility and environmental, economic and social feasibility. Financial feasibility is included as Step 11 in the decision making framework (Figure 4.1) and is described in Section 4.4.6. Environmental, economic and social feasibility is included as an additional issue and is described in Section 4.5.1.

The factors which deem ASR to be feasible / infeasible include the availability of an aquifer, transmissivity and groundwater quality. These factors are used to determine firstly whether a suitable aquifer is available and secondly if an ASR scheme is feasible. Feasibility depends upon the amount of water that can be injected and recovered and the suitability of the groundwater for the proposed end uses. To reduce transportation costs, the aquifer should not be far from the study site. The depth to the aquifer can also influence whether it is feasible to inject stormwater into the aquifer. Very deep aquifers require deep injection wells.

The amount of storage available influence the end use demands that can be met. Small storage sizes are suitable if either the end use demand is small or if end use patterns closely follow injection patterns. This means minimal storage is required as the water would be used shortly after it is injected. Storage size is not used as a screening tool to deem storage systems infeasible since storage size requirements are influenced by end use demand and patterns. Instead, storage volume requirements are analysed further in Section 4.4.2.2.

Beneficial use maps can be used to determine whether available aquifers are suitable for aquifer storage and recovery within a study site. These maps may use a beneficial use / segment matrix to represent the suitability of using groundwater for different uses. Victorian examples of beneficial use maps are provided in Appendix B.

If resources are available it may be useful to conduct geotechnical investigations to determine aquifer yield, the quality of the groundwater and potential treatment requirements. For planning and scoping studies, the beneficial use map series are acceptable for determining whether ASR is feasible for the study site. In particular, a relatively small study site may not justify the additional costs involved in pre-treatment, injection, recovery and post-treatment. Larger stormwater use schemes with high land values and limited space may be justified in using ASR.

(b) In-Ground Open Storage

In-ground open storage includes ponds, dams, constructed lakes and open water bodies such as lakes, rivers, streams and creeks. Open storage systems have a number of advantages including the ease of construction when placed at a suitable location, and aesthetic values. Determining a suitable location for an open storage system to minimise costs, and ensure long-term workability of the system is a key to implementing a successful stormwater use scheme. The issues which directly determine whether in-ground open storage is feasible are space availability, topographic conditions, constraints that restrict the ability to construct a storage system in the area, and soil and ground conditions.

There is a vast amount of literature and information available related to dam construction, including small dam construction (for example Nelson, 1985; United

States Bureau of Reclamation, 1965). This information can be utilised as the basis for in-ground open storage, as the ideas and requirements are very similar. Soil and ground conditions affect the type of storage system that can be constructed. In terms of in-ground open storage, ground conditions affect the amount of seepage, the volume of water that can be stored based on ground condition strength, and whether excavated material can be used to build dam walls or if imported material is required. Some useful information demonstrating how soil conditions affect dam construction is provided:

> *"In general, rock foundations are capable of carrying the weight of a dam but there are always a few dangers to be watched for: seepage can occur along the join between then rock foundation and the earth dam; weathering of rock commonly leads to the production of clays with consequent weakening; and permeable zones can be created by joints, faults and bedding planes when these are open." (Nelson, 1985, p. 31)*
>
> *"Inorganic clays … usually have sufficient strength to support earth dams up to 8 metres high." (Nelson, 1985, p. 32)*
>
> *"Gravel and sand … create problems mainly because of high seepage losses. Construction is usually practicable but only at a very high cost. It is better to avoid such sites and find an alternative location." (Nelson, 1985, p. 32)*

Topography and land form are very important in terms of site selection. Utilising the existing land form so that minimal excavation is required, as shown in Figure 4.7, is the most effective way to construct a storage system such as a dam. Land form also influences storage capacity that can be constructed. Inadequate topographic relief, or very flat areas, may result in excessive excavation costs to produce an acceptable storage volume. Utilising the local land form may mean that only downstream dam walls need to be constructed. The dam wall height and therefore storage capacity is limited by engineering principles of safety and slope stability. Space constraints also affected the feasibility of constructing in-ground open storage within the study site. This includes insufficient space, insufficient clearance above the ground and conflicts with services or access to underground utilities.

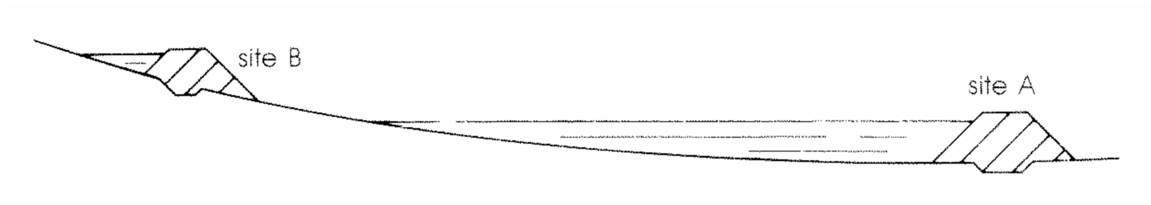


Figure 4.7 Effect of Topography on Storage Capacity (Nelson, 1985)

(c) Above-Ground Closed Storage

Above-ground closed storage options are tanks or containers of different shapes, materials and sizes. Tanks could either be pre-formed or constructed on-site. Pre-formed tanks are made from various materials with the most easily available being corrugated stainless steel or polyethylene. Due to increased consumer interest and demand in water tanks, there are a large variety of pre-formed water tanks. These tanks come in a variety of sizes, ranging from very small 200 litre household rainwater tanks to large 50 to 500 kilolitre tanks. Tanks also come in a large range of colours and different shapes. While most tanks are cylindrical, some tanks have been designed to be slimmer to fit along fences or walls, although these tanks usually have small volumes. Constructed tanks are usually made of concrete and require water proofing such as PVC or polyethylene lining or bituminous paint. Concrete can be precast and transported to site or may be constructed and poured on-site.

A concrete foundation is usually required to ensure stability of the tank and support the heavy weight of the tank. Some tanks have stands so that they are not placed directly on the ground, but larger tanks are usually placed directly on the concrete foundation. Soil and ground conditions need to have sufficient strength to support the weight of the tank. While a concrete foundation is usually constructed below the tank, the ground needs to be of sufficient strength to support the foundation. This can be overcome by replacing soil which is too soft with imported material compacted on-site. Otherwise, compaction of soft soils can increase the soil strength sufficiently.

The issues that need to be examined to determine the feasibility of above-ground closed storage are similar to in-ground open storage issues. These include space availability, topographic conditions and soil and ground conditions. As with in-ground open storage, above-ground closed storage requires relatively large land take. In areas with limited space availability or high land costs, above-ground closed storage may be deemed infeasible.

Topographic conditions influence the placement of a water tank. While it is preferable to locate in-ground open water storages in valleys to reduce excavation requirements, it is preferable to locate tanks on flat ground. Valleys and steep areas require excavation, material compaction and placement, as shown in Figure 4.8.

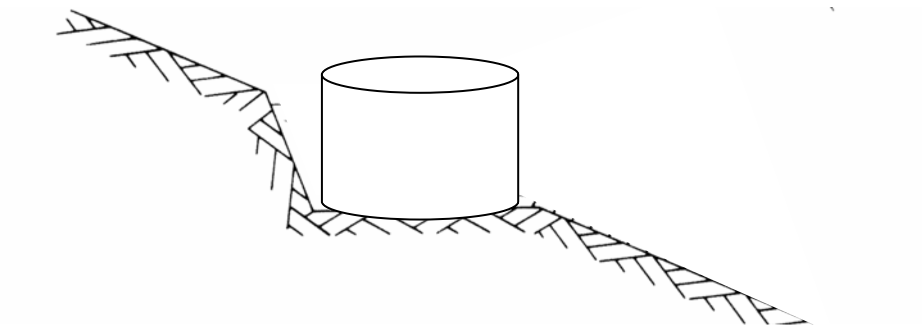


Figure 4.8 Effect of Topography on Excavation and Infill Requirements (adapted from Nelson, 1985)

(d) Underground Storage

Tanks and containers can also be used for underground storage systems. Underground storage systems require excavation and covering so that the top of the storage system is below the natural surface level. Tanks can be transported to site and placed underground, or concrete waterproof storage systems can be constructed in-situ.

Other types of underground storage systems include drainage cells or interlocking devices placed underneath permeable pavements. Devices such as the Atlantis Corporation reuse tanks include matrix systems beneath the infiltration device that can store water (Environment Australia, 2002c).

The issues that are examined to determine the feasibility of underground storage are soil and ground conditions and space availability. While underground storage systems do not require as much land take as above-ground closed or in-ground open storage systems, underground storage systems need to be placed in areas which provide access to the tank for maintenance requirements. However, underground tanks can be constructed below other structures such as car parking areas. They can also be placed beneath open space areas such as playing fields or golf courses. The open space area is therefore able to be maintained for its original purpose so that land take is not required, other than during construction.

Soil and ground conditions influence the feasibility of underground storage. While it is possible to excavate in all ground conditions, the expense involved excavating in hard rocky ground may deem underground storage as infeasible. However, the costs of excavating in these conditions may be justified if other options had high costs due to high land values or limited space. As with in-ground and above-ground storage, the soil needs to have enough strength to support the underground storage system.

(e) Existing Water Bodies or Storage Areas

Existing water bodies or storage areas are storage systems of any type, as described in Sections (b) to (d) above, that already exist and may or may not be in use. Existing water bodies include lakes, rivers, streams and creeks. After determining whether there are any existing water bodies or storage areas, the amount of additional storage available needs to be determined. If additional storage capacity is required, it is necessary to investigate whether storage capacity could be expanded. The landform and local conditions need to be examined to determine whether local conditions are conducive to expanding storage capacity. Storage capacity in a pond or lake in a valley area can be increased by building up the downstream bank of the water body. An example of this is shown in Figure 4.9.

Flood requirements also need to be examined when determining additional available storage space. The traditional stormwater management system, as described in Section 2.2, is concerned with flood reduction and removal of stormwater from urban areas as quickly as possible. This means that a number of ponds, rivers and water courses have additional capacity within the system to capture and retain flood waters. These flood retention and safety capabilities need to be either maintained or incorporated into any stormwater use scheme.

Another important issue in terms of existing water bodies is the environmental impact for storing additional water within the water body. Fauna and flora may have adapted to the existing flow conditions. If the water levels are maintained at a higher level to capture additional stormwater runoff, some flora and fauna species may be disrupted and not capable of surviving the new conditions.

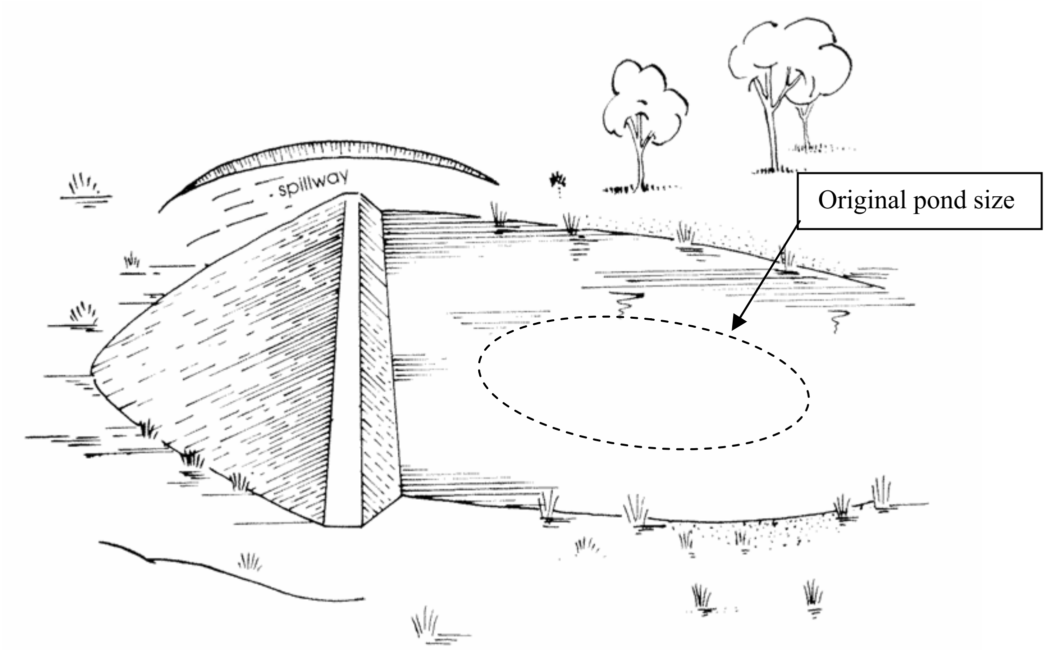


Figure 4.9 Embankment Construction to Increase Natural Pond Storage Capacity (adapted from Nelson, 1985)

4.4.2.2 ESTIMATION OF STORAGE REQUIREMENTS

Once feasible storage options are identified, the required storage capacity needs to be estimated. Storage capacity requirements can be estimated based on stormwater runoff, stormwater yield, end use and losses in the system. The purpose of determining storage capacity requirements is to determine whether stormwater yield can partially or fully meet end use demand.

Stormwater yield is the amount of stormwater that can be collected and utilised to meet the proposed end uses. While a large proportion of stormwater can be collected, the amount that becomes yield is dependent on the amount of stormwater that can be stored and the quantity that becomes overflow or disappears through evaporation or infiltration. To store sufficient water either large storage sizes are required so that all of the collected stormwater can be stored until required for use, or the stormwater collection pattern has to closely follow end use demand pattern. If the stormwater collection pattern and the end use demand pattern closely match, minimal storage is required.

Stormwater yield is dependent upon a number of different variables. These variables included rainfall pattern, amount of rainfall converted to runoff (utilising permeability and climate conditions such as evaporation and infiltration), available storage volume, storage infiltration, storage evaporation, storage leakage, end use pattern (volume, temporal and spatial variability) and stormwater flow (volume, temporal and spatial variability). These variables can be inputted into computer models such as Aquacycle (Mitchell et al., 2001) and UVQ (Mitchell et al., 2003) to determine stormwater yield and reliability of stormwater supply. The Aquacycle and UVQ computer models are based on the general water balance equation, as provided in Equation 4.9. UVQ is an enhancement of Aquacycle to include contaminant balances of different water streams.

$$\text{Precipitation} + \text{Imported water} = \text{Evaporation} + \text{Stormwater Use} + \text{Wastewater Use} + \text{Change in Storage} + \text{Losses} \quad \text{......4.9}$$

A trial and error methodology is required to estimate storage capacity requirements considering reliability of stormwater supply. Reliability of supply determines how often end use demand is met either through sufficient volume of supply or the number of events or days where end use demand is met. A higher reliability of supply results in larger storage capacity requirements. Larger storage capacity requirements result in larger construction and maintenance costs. The decision maker needs to determine the minimum reliability of supply that is required and the reliability that would be preferred. A compromise may then be needed between required reliability, preferred reliability and total storage capacity that can be constructed. Alternatively, a number of storage capacity options can be examined to determine the effect of decreasing storage capacity on reliability of stormwater supply. Feasibility of storage options depends on whether the decision maker wishes the largest amount of storage available to be the highest priority or whether additional storage availability above minimum requirements is not important.

The parameters required to be input into Aquacycle or UVQ have already been determined through the initial stages of the decision making framework (Section 4.4.1). Input values such as areas of different neighbourhoods divided into road and open space areas and daily rainfall and evaporation are used in the model to estimate stormwater runoff. End use input data affects the change in storage, as water is removed from the storage system to meet the end use demand. Estimated storage capacity volumes then produce stormwater reliability of supply information. Certain values may be changed to produce different stormwater use scheme options such as supplying different end uses or different stormwater storage capacities.

Calibration values are required to verify that the values the model produced are realistic. Yearly, monthly or daily imported water, wastewater and stormwater data are compared to the modelled data selected from a representative or reference year to validate the yearly water balance model. Where reference data is not available, yearly imported water and stormwater values calculated in Section 4.4.1.2 can be used as the basis for calibration.

UVQ and Aquacycle were specifically developed to examine stormwater and wastewater use at a neighbourhood scale. Other models are available which examine stormwater use at a household level which can be expanded to the catchment scale. Further information on these models can be found in McAlister et al. (2003).

An important issue to consider when determining storage is the back-up system. As stormwater flow is usually highly variable, there may be times when there is no stormwater flow but still water use demand. In these cases, a back-up system is required. A study of implemented stormwater use schemes found that using mains water connected to the storage system is one of the main back-up systems to supplement stormwater (Hatt et al., 2004). When connecting mains water supply to the storage system as a back-up supply, backflow prevention is required to ensure no contamination of the mains water system.

4.4.3 TREATMENT

Treatment was a very difficult technical issue to come to terms with in this project for a number of reasons. There are no guidelines that specifically deal with stormwater use and different end uses, although they are under preparation (Sections 2.3.5 and 3.3.2). These guidelines under preparation will be based on a risk management approach (CRC for Water Quality and Treatment, 2003).

There are also challenges in terms of treatment efficiencies and matching treatment systems to the appropriate required end use quality. In particular, while there are a number of case studies developed to utilise stormwater, these case studies tend to utilise traditional stormwater treatment measures without certainty that the required end use quality would be produced. Thus monitoring and evaluation of these projects is extremely important.

To adapt to these challenges, several different approaches are proposed in this study for determining treatment requirements. These approaches determine treatment requirements based on:

- removal rates;
- end use requirements;
- or case studies.

4.4.3.1 Treatment Options Available

There are a vast amount of treatment technologies available. While only some of these technologies have been used for stormwater utilisation projects, there is the potential for any type of water treatment system to be utilised for this purpose. Treatment technologies have various capacities and target removal of different types of pollutants. Generally, treatment options are classified into primary, secondary and tertiary treatment. The order in which the treatment is required, as well as the size of pollutants that are targeted influence whether a treatment technology is primary, secondary or tertiary treatment.

There are a number of documents providing guidance on the type of treatment that could be used to improve stormwater quality. For example, the Victorian Stormwater Committee (1999) provide an outline of the type of treatment technologies that are available. These guidelines include stormwater management technologies that come under primary, secondary and tertiary treatment, as well as expected pollutant removal rates. Other guidelines (for example ACT Government, 1997; NSW Recycled Water Coordination Committee, 1993; Queensland Government Environmental Protection Authority, 2003) were similar in treatment technologies. The state based wastewater reuse and recycling guidelines need to be adapted to stormwater, since there are no specific guidelines for stormwater. An overview of how these treatment technologies can be related to stormwater use schemes is provided below.

Primary treatment removes larger pollutants such as leaves, litter and branches. These larger contaminants need to be removed first so that they do not interfere with other processes. Larger size pollutants such as rubbish and litter are the most noticeable and unsightly of pollutants. Public perception of any stormwater use scheme would decrease rapidly if larger contaminants are visible within the stormwater use stream. Primary treatment includes screens, trash racks and gross pollutant traps.

Secondary treatment technologies remove sediments but can also be effective at removing larger pollutants or dissolved or attached pollutants. Sediments and suspended solids are also unsightly in a stormwater use scheme. Secondary treatment technologies include permeable pavements, infiltration trenches, grass swales, detention basins and sand filters. A number of these secondary treatment technologies can also be used as collection systems.

Tertiary treatment is very important in a stormwater use scheme, more so than in a stormwater management and disposal system. Tertiary treatment removes dissolved particles and provides disinfection. Dissolved pollutants include bacterial contaminants as well as metals. Disinfection removes or decreases the bacterial contaminant levels so they are not a health concern. For effective disinfection, suspended solids must first be largely removed so that these solids do not interfere with the disinfection process. For this reason, the treatment train and order of unit processes is very important so that suspended solids are removed during primary or secondary treatment stages. Disinfection options include ozone, chlorine or ultraviolet (UV) irradiation. Tertiary treatment systems for stormwater management are generally focused on wetlands. Wetlands require large space and land take to perform effectively.

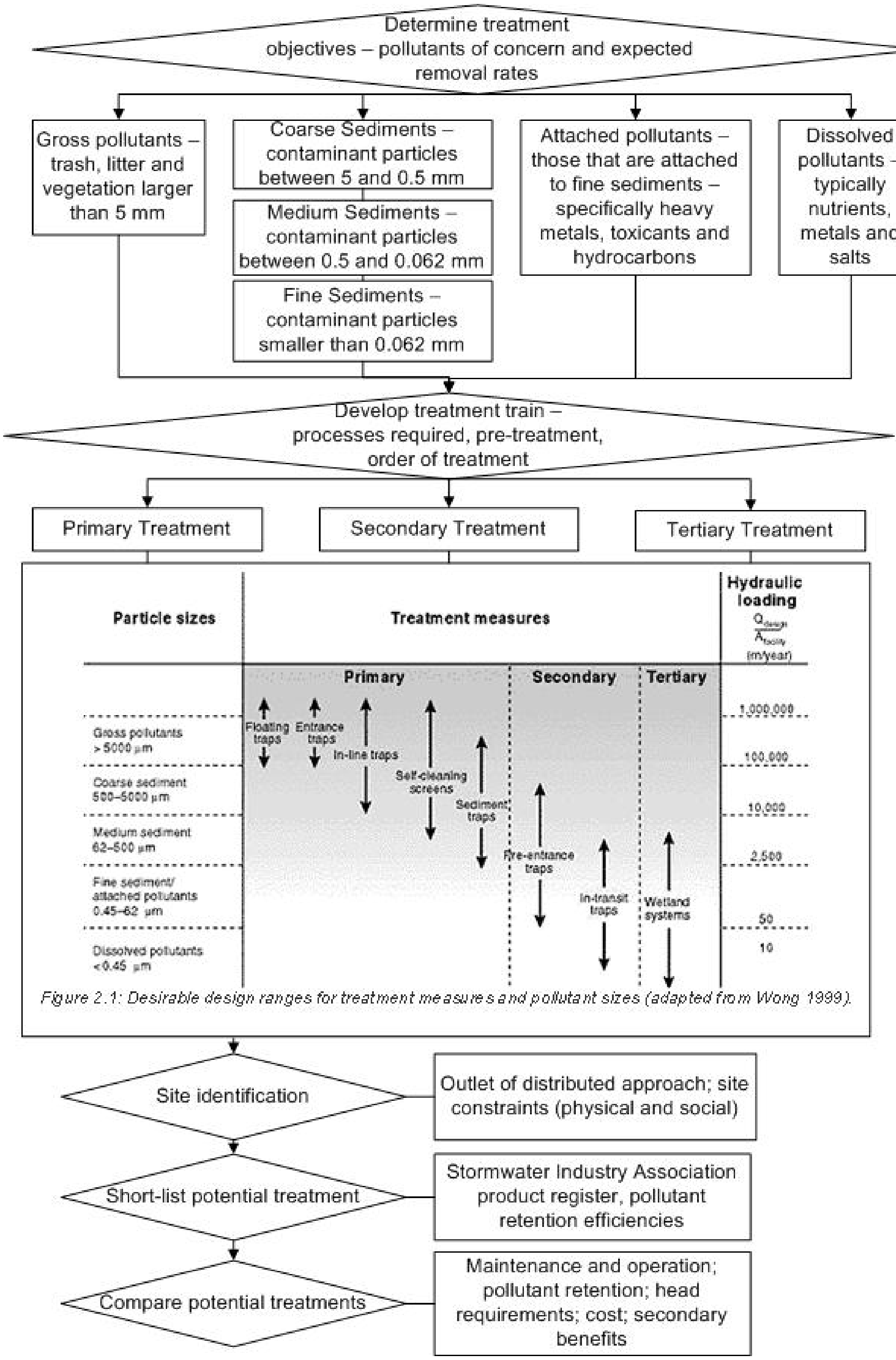
Limited space for storage and treatment means that different methods for treatment may need to be examined. Small scale on-site effluent treatment systems can be examined to provide sufficient treatment with minimal land take. These types of systems would normally be used for wastewater treatment, and are based on biological treatment. There has been minimal implementation of small scale treatment systems for stormwater use schemes. Any system designed for treatment in a stormwater use scheme would require physical and/or chemical treatment systems rather than biological treatment systems due to the variability in flow and lower levels of biological contaminants in stormwater than in wastewater. While there are a number of commercially available small scale on-site water treatment plants, it is very difficult to obtain information about these treatment systems due to commercial in-confidence.

4.4.3.2 TREATMENT REQUIREMENTS BASED ON REMOVAL RATE

After examination of available treatment options, the methods to determine treatment requirements are investigated. A potentially simplistic method to determine treatment requirements is to compare the incoming stormwater quality to the required end use quality of specific contaminants. As incoming and outgoing quality levels are known, removal rates can be determined. Published removal rates for treatment technologies can be examined to determine treatment requirements. This methodology is used for determining treatment requirements based on improving stormwater quality prior to disposal to water bodies including rivers and the ocean. As such, there are a number of guidelines available utilising these ideas. For example Melbourne Water Corporation (2002a) and the Victorian Stormwater Committee (1999).

Melbourne Water Corporation produced a website to collate information related to Water Sensitive Urban Design (WSUD) and stormwater. This website included a summary of the principles and steps included in the Victorian Stormwater Committee (1999) guidelines. The Melbourne Water Corporation WSUD website describes the steps involved in selecting a treatment measure (www.wsud.melbournewater.com.au). Figure 4.10 is a representation of the method described on the Melbourne Water Corporation website.

Figure 4.10 provides the key issues that need to be identified when selecting a treatment system. The most important issues are the pollutants of concern and the expected removal rates, as well as the processes required. Treatment processes include the order of treatment and any pre-treatment required. This methodology is very effective when examining stormwater treatment for disposal of the stormwater to water bodies after treatment. However, there are difficulties in adapting this methodology to stormwater use scheme treatment requirements.



Source: Melbourne Water Corporation (2002b)

Figure 4.10 Treatment Requirements Based on Melbourne Water Corporation Treatment Train

Figure 4.10 was refined and adapted to explicitly demonstrate how treatment train and removal efficiency information can be used for the stormwater use scheme decision making framework. This adaptation is shown as Figure 4.11 and includes references of where the data can be determined or estimated as well as the key issues to determine the treatment requirements and feasibility.

The flowcharts shown in Figure 4.10 and Figure 4.11 assume that removal rates for different types of pollutants are already determined or available. This is the case for pollutants such as gross solids, suspended solids, attached pollutants and dissolved solids that are used as the basis for designing treatment systems for discharge of stormwater to water bodies. However, the majority of recycled water guidelines are based on biological contaminants such as E-coli, viruses and BOD. Removal rates have not been determined for these contaminants.

The general method that has been used in implemented stormwater use schemes has been to manage the system as a stormwater management system, as though the water was to be discharged into a natural water body. The treatment train methodology (Figure 4.11) has generally been followed, with the addition of adding a disinfection system at the end of the treatment system to account for the water being utilised in the urban area with public access. The validity of using this methodology has not yet been tested and monitoring data and reporting is not easily available. The concern with this decision making system is that practice has preceded solid research and knowledge. While at present these issues may be of concern, once research and monitoring of implemented schemes have been more thoroughly published, these concerns may be found to not be justified.

Due to the challenges discussed above, this methodology was not used in this study. Section 4.4.3.4 describes the methodology used in this case study. However, with the development of new approaches to quality guidelines and development of more information relating to treatment technologies and additional pollutant rate removals, this methodology could be useful in the future. A risk management based approach for stormwater use guidelines, as well as monitoring and verification of implemented project performance, would mean that treatment technologies could be chosen based on the design removal rates and management of the associated risks.

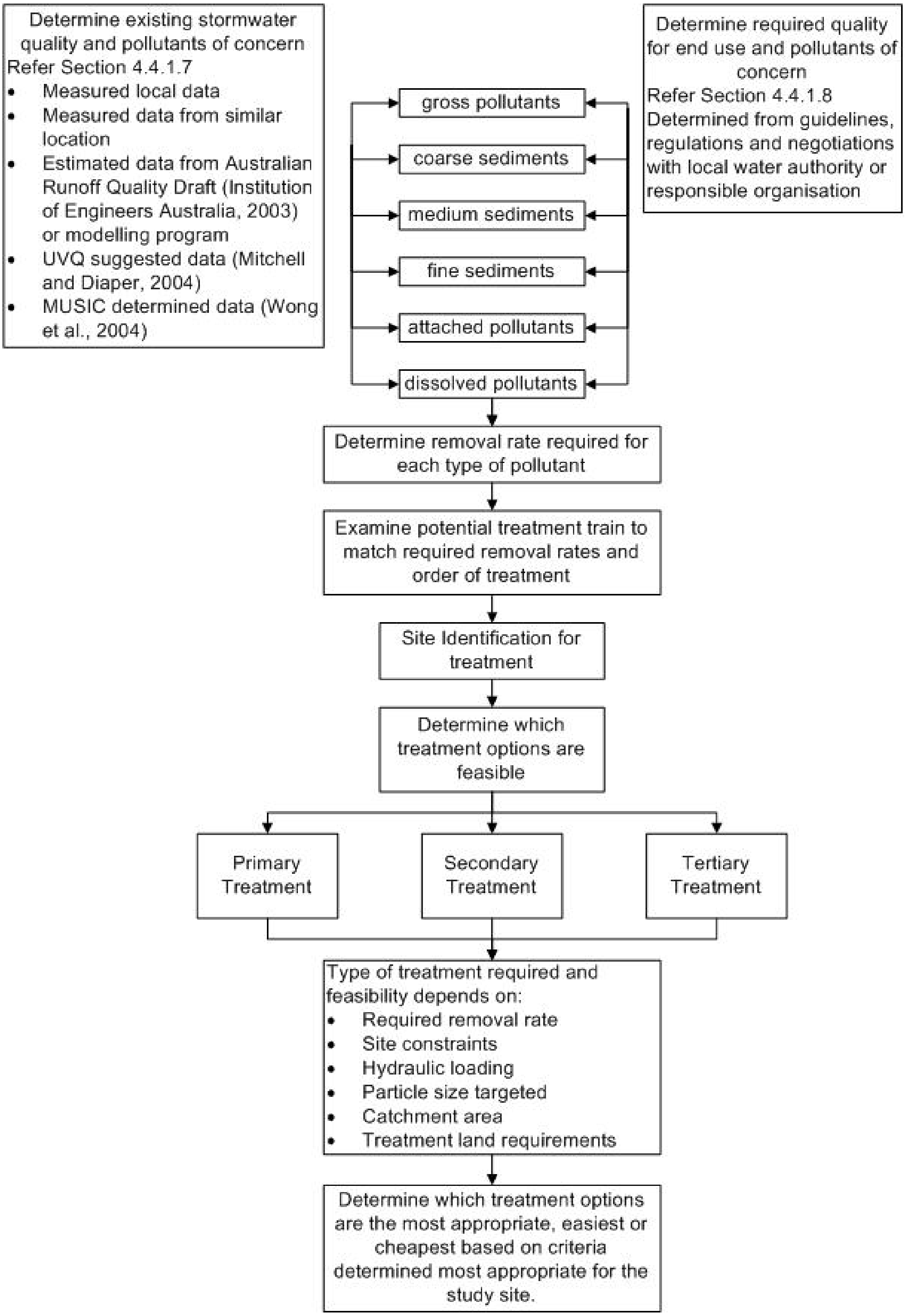


Figure 4.11 Treatment Flowchart Based on Treatment Removal Rates

4.4.3.3 TREATMENT REQUIREMENTS BASED ON END USE REQUIREMENTS

A different approach to determining treatment requirements is to first determine end use requirements. This method is very similar to a typical water treatment system. The treatment system is chosen based on the requirements to meet the end use water quality. Figure 4.12 demonstrates this methodology.

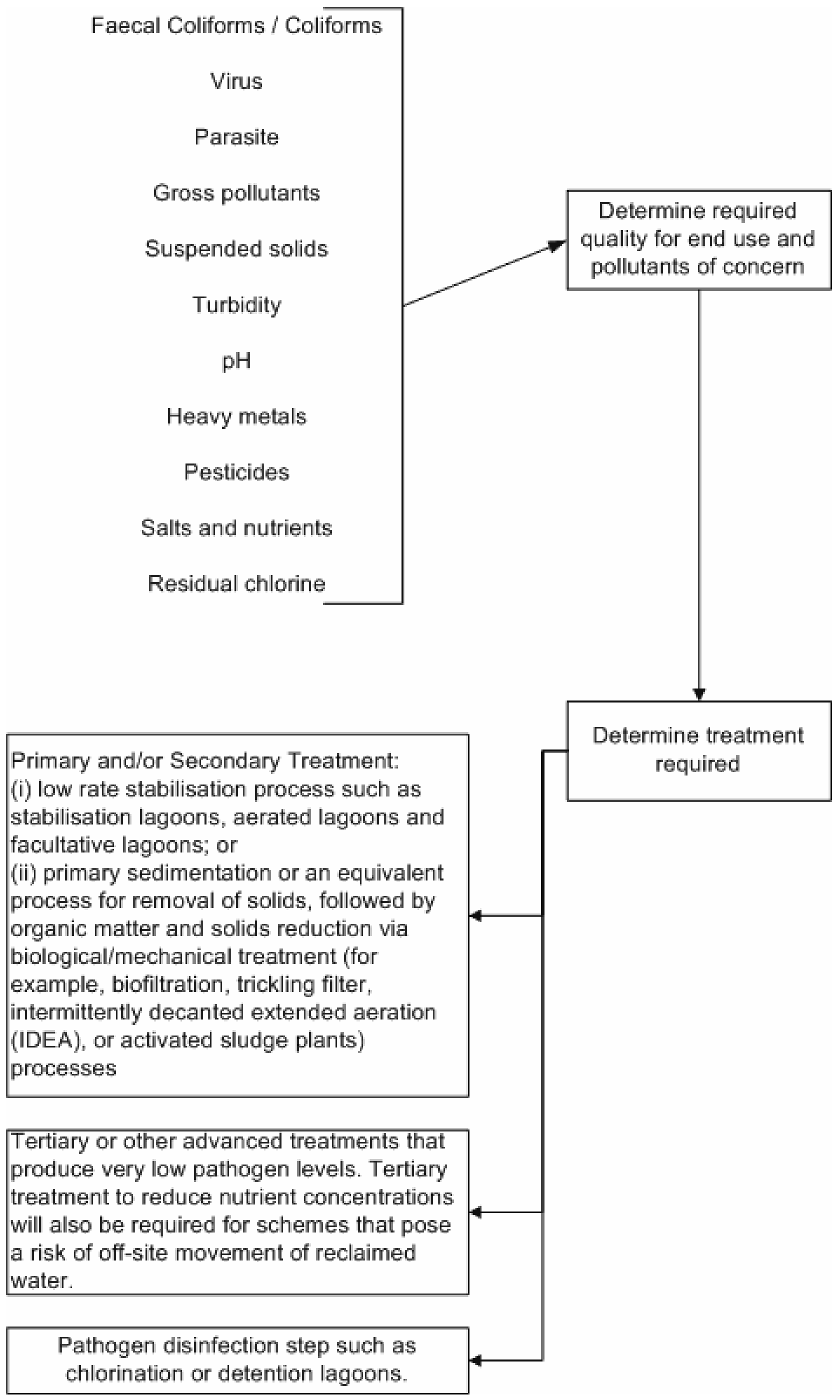


Figure 4.12 Treatment Flowchart Based on End Use Requirements (adapted from EPA Victoria, 2002)

This treatment flowchart based on end use requirements is very similar in outcome to the treatment flowchart based on removal rates (Section 4.4.3.2). That is, the treatment processes required are secondary treatment such as sedimentation, tertiary or advanced treatment and then pathogen removal. Similarly, the required removal efficiencies for treatment systems may be uncertain in terms of stormwater. In particular, biological treatment measures may not work effectively if incoming organic contaminant levels are not as high or are more variable than wastewater. Alternatively, pollutants of concern in stormwater such as nutrients and metals may not be targeted in the treatment process.

The other aspect of using this methodology to determine treatment requirements is that the system may be over designed. While organic contamination of stormwater can be equal or greater than wastewater during some rainfall events, other events have much lower levels. Over design is not a problem in terms of risk and safety, but could increase costs. This may result in the stormwater use scheme being unacceptable in some cases. As with the methodology based on removal rates (Section 4.4.3.2), this methodology is not appropriate at this point in time since monitoring data and reporting is not easily available and has not been used in this study. This methodology may be more useful as guidelines based on risk assessment are introduced and the effectiveness of treatment technologies specifically designed for stormwater utilisation schemes are more thoroughly understood and researched.

4.4.3.4 TREATMENT REQUIREMENTS BASED ON CASE STUDIES

The methodology proposed based on case studies is the most appropriate methodology at the current point in time due to the available resources and information. This methodology examines previous case studies and the quality of water produced. This information is used as the basis for deciding upon treatment measures for new case studies. In line with this, an assessment of the reliability and potential risk of this system also needs to be conducted. Since this methodology may change as new guidelines become available, the proposed decision making system in this study may be updated as monitoring data and research into the associated effectiveness of these systems is increased.

The typical treatment system that has been used for stormwater utilisation schemes has been a wetland system followed by some form of disinfection. These systems have often implemented irrigation as the end use. Hatt et al. (2004) collated an inventory of stormwater treatment and re-use systems in Australia. This report examined the system components and design, as well as costs, benefits and performance issues. As with the research project described in this thesis, Hatt et al. (2004) focused only on general stormwater runoff and did not examine systems which utilised only roof runoff. They identified that treatment technologies based on Water Sensitive Urban Design (WSUD) practices were designed or implemented in the same manner whether the stormwater was being treated prior to disposal or treated for utilisation. This approach was identified as not necessarily appropriate since WSUD based guidelines are generally focused on ecosystem protection. Ecosystem protection does not require as stringent guidelines as stormwater use. Hatt et al. (2004) identified the stormwater use case studies shown in Table 4.13 as having monitoring programs that verified the treatment systems produced water quality to meet the specified guidelines.

Table 4.13 Stormwater Utilisation Case Studies with Acceptable Performance

Project	Treatment system	End use(s)	Water sources	Compliance with guideline
Figtree Place, NSW, Australia	Detention basin, ASR	Irrigation, bus department washing	Runoff from paved areas, lawns and gardens	NHMRC and ARMCANZ (1996)
Bowies Flat Wetland Qld, Australia	Wetland	Irrigation	Conventional stormwater collection	Not described
Homebush Bay, NSW, Australia	Gross Pollutant Traps, wetlands, microfiltration, reverse osmosis, chlorine disinfection, dechlorination	Irrigation, toilet flushing, fire fighting, environmental flows	High and low traffic areas, some roof runoff	NSW Recycled Water Coordination Committee (1993)
Parafield Stormwater Harvesting Facility SA, Australia	Wetlands, ASR	Irrigation, wool cleansing	Local catchment stormwater	Local EPA requirements
Parfitt Square SA, Australia	Sediment trap, gravel reed bed, grassed swale, ASR	Irrigation	Carpark, upstream sub-catchment stormwater	Not described
Santa Monica Urban Runoff Recycling Facility, USA	Screening, dissolved air floatation, microfiltration an UV disinfection	Irrigation, toilet flushing	Low flow dry weather runoff from city stormwater drains	Regulated by California Department of Health Services

Source: Hatt et al. (2004)

In terms of feasible systems, Figtree Place has shown that rainwater tank storages and hot water systems can provide sufficient treatment when collecting roof water only. This one case study has shown that the hot water has met or exceeded the drinking water guidelines (Coombes et al., 1999). Other developments are in the process of replicating these systems (McLean, 2003).

The Urban Stormwater: Best Practice Environmental Management Guidelines (Victorian Stormwater Committee, 1999) are also based on ecosystem protection. These guidelines use pollutant removal rates as the target to be achieved when determining treatment technologies. The application of this methodology to stormwater use schemes could mean that suspended solid levels are removed by the required percentage rate, but the suspended solid level in the treated water are not of an acceptable level for irrigation or toilet flushing.

As a final caution to implementing this methodology based on case studies for determining treatment requirements, the following should be noted:

> *"Existing practice is far ahead of research, which may pose a danger to the future adoption of such measures. Just one high profile case of public health or environmental failure of a re-use project (conducted without sound scientific backing) could undermine public confidence in re-use nationally, costing our society time and money in the much needed adoption of future water re-use technologies" (Hatt et al., 2004, pp. 41-42)*

4.4.4 DISTRIBUTION

Distribution is the final technical component to be examined. Options to collect and distribute water are very similar, as both involve transporting water from one site to another. The decision making framework for distribution options is very similar to collection options, and therefore the reader is directed to Section 0 for details of the key issues and discussion points. Only the differences between these systems are discussed here.

Figure 4.13 shows the decision making flow chart for distribution options and issues. This flowchart is very similar to the collection options flowchart, although there are a number of differences. Overland flows are not used for distribution purposes. The only case where overland flows are used for distribution is where runoff is allowed to flow directly over and infiltrate into an area requiring irrigation. However, this would usually occur directly at the collection area and would not undergo storage and treatment prior to distribution. Therefore this system is not technically a cluster scale stormwater use scheme, and distribution is not required. Distribution is also different to collection in that the additional option of either single or dual pipe distribution can be examined. The other main difference was that pump assisted flow is more likely to be utilised, especially if pressurised water is required at the final end use location.

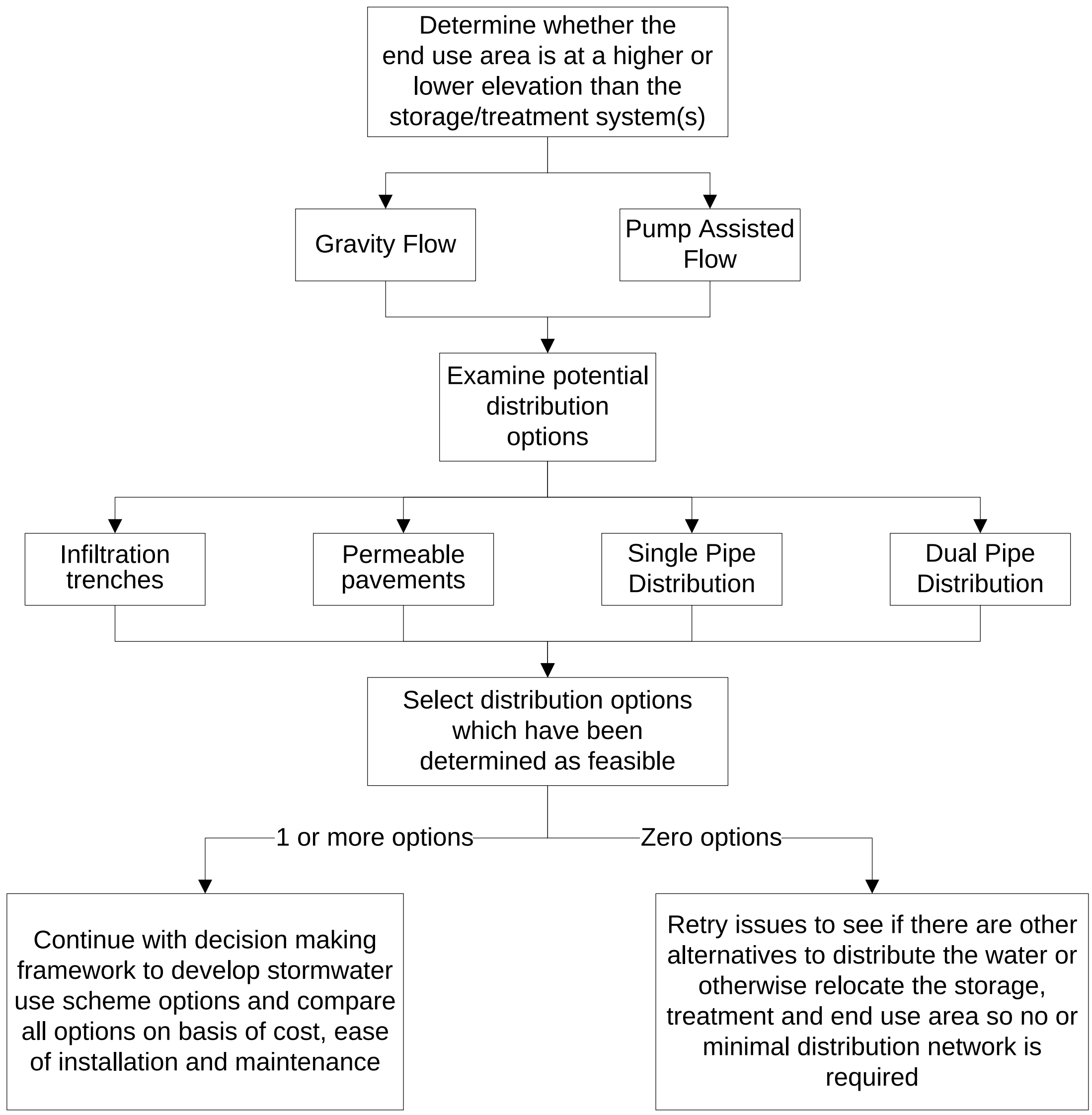


Figure 4.13 Methodology for Determining Feasible Distribution Options

(a) Gravity or Pump Assisted Distribution

Gravity flow can be used to direct flows from the storage and treatment area to the end use area through gravity. This means sufficient height difference between these two areas is required, with the end use area located at a lower elevation than the collection or storage / treatment area. The height difference needs to be sufficient to ensure all of the water reaches the end use location. Sufficient velocities in the pipe when flowing need to be maintained to ensure small particles and sediments do not collect in the bottom of the distribution system. This is less of a concern in distribution than with collection, as the treatment system should remove all sediments and particles that would settle at the bottom of the distribution system.

Where gravity flow cannot be used, such as where pressurised flow is required, pumps must be used to transport the water from the storage and treatment area to the end use area. Pump requirements depend upon distance travelled as well as pressure requirements.

(b) Single Pipe Distribution

Single pipe distribution is the traditional water supply distribution method. For this project, single pipe distribution is classified as one pipe used to distribute water to the household. This system is sometimes called a double pipe system, as one pipe is used to distribute water to the household and the other pipe is used to transport liquid waste from the household. However, as this project is focused only on the distribution aspect of water supply, single pipe distribution is the most appropriate nomenclature.

The only case where there is a single pipe distribution system in a stormwater use scheme is when stormwater is being provided to all end uses. This is the case either where stormwater is treated to a potable water quality or if piped water distribution is only for non-potable uses. In the first case, stormwater is either the only source of water to the household or is mixed with the potable water supply. The second case has drinking water delivered to the household in bottles. Stormwater is distributed through a single pipe to meet all other household needs. The latter case was deemed infeasible at the current point in time (Section 3.3.2).

This means that single pipe distribution can only be used where there are no regulations or laws which prohibit stormwater to be used for potable water and it was safe to do so. Single pipe distribution is also deemed infeasible where stormwater runoff and end use demand calculations determine that there is insufficient water to meet all household end use demands (Section 4.3.2).

Constraints which restrict the ability to construct underground pipes must be identified. This includes underground cables or pipes. The ground conditions and how this affects the ability to construct underground pipes also needs to be identified. Hard rocky ground may be expensive to excavate, although pressurised pipes can be laid shallower to follow topography and therefore should not be as much of a problem compared to a gravity system. Different locations for placement of the pipes or including additional costs to accommodate excavation costs can be included when deep excavations are required in hard rocky ground.

(c) Dual Pipe Distribution

Dual (rather than single) pipe distribution is the most likely form of distribution for a stormwater use scheme. This is because it is generally difficult to meet all end use demands with Australian rainfall patterns and space, quality and cost considerations.

Dual pipe distribution has two different forms, depending on the type of end uses that are being supplied. Where only household irrigation or outdoor non-potable uses are being supplied, the stormwater pipe system needs to be connected only to the outside of the household. This means no change to internal house infrastructure is required in an existing urban area. Where one or more indoor uses are to be supplied, the pipe distribution system needs to go to the household structure and be connected to the internal plumbing system. This results in dual plumbing systems within the house.

4.4.5 INTEGRATION OF TECHNICAL COMPONENTS

The aim of this project is to produce a more holistic method to examine stormwater use schemes. The linkages and optimisation of stormwater use scheme options is the key component to developing an integrated decision making framework. Optimisation of the stormwater use scheme provides the benefit of minimising system requirements.

4.4.5.1 OPTIMISATION BASED ON QUANTITY ISSUES

Matching stormwater and end use quantity and quality are key issues in designing an effective stormwater use scheme. Quantity and quality of stormwater and end use varies both spatially and temporally. To ensure stormwater and end use are closely matched, the temporal and spatial patterns need to be examined. Temporal patterns of stormwater runoff or yield can be matched to end use demand patterns by identifying catchment or end use areas that have similar patterns. Areas in rain shadows may have limited rainfall and runoff, and may therefore be avoided as a catchment area. The catchment area can be based on a highly urbanised area with increased runoff compared to highly vegetated areas. This increases stormwater runoff and potentially stormwater yield. Caution is required as runoff quality may decrease with the increased runoff in highly urbanised areas.

The collection area can be increased or decreased to optimise the quantity of water to be collected and distribution requirements. In cases when the maximum amount of runoff is being captured, end uses can be changed to more closely match stormwater runoff and yield patterns. For example, end uses with a constant demand throughout the year can be matched to catchment areas with uniform rainfall and runoff patterns.

4.4.5.2 OPTIMISATION BASED ON QUALITY ISSUES

As with matching quantity patterns, patterns of water quality and required end use can be matched. Fit-for-purpose is a key linking issue. The type of water collected as well as the catchment area that is selected can provide different water qualities. Matching water quality to end use quality requirements can result in minimal or no treatment being required. Areas which produce high quality water may be able to be used directly for certain end uses. Alternatively, excluding certain catchment areas that produce runoff of lower quality can increase runoff quality. A simple method would be to collect roofwater separately from street and stormwater runoff. Also, runoff from a highly industrial area may be collected separately and used for industrial purposes which did not require high quality water.

Treatment requirements can also be optimised by matching treatment to end use quality requirements. The treatment system needs to be carefully designed, with a full knowledge of incoming stormwater quality so that the treatment systems produce the required end use quality. Improved water quality may be optimised by choosing collection, storage or distribution systems that provide treatment so that only minimal additional treatment is required. A well designed system results in a treatment system that is neither excessively nor inadequately designed. However, a safety factor may need to be included in the treatment system for unforseen circumstances and risk management requirements.

4.4.5.3 OPTIMISATION BASED ON DUAL FUNCTIONS OF TECHNICAL COMPONENTS

Optimisation of a stormwater use scheme can easily be achieved through utilising technical component options that have more than one function, such as storage and treatment, as mentioned in Section 4.4.5.2. Storage systems such as tanks or ponds which have some detention time can provide a degree of treatment through settling of larger particles. Storage systems can also be designed so that flow patterns encourage heavier materials to settle out at the inlet or a certain part of the storage system. Collection and distribution systems such as permeable pavements and infiltration trenches can also act as a form of primary treatment by filtering out larger to medium sized particles.

Treatment systems, such as wetlands, can be designed to provide a degree of storage capacity. Similarly, permeable pavements used for collection can provide treatment as well as storage beneath the pavement system. Aquifer storage and recovery can also be used for both storage and treatment.

In a similar manner, distribution systems can contain an amount of storage or vice versa. For example, rivers or creeks can store as well as transport water. Storage can be provided in larger ponds and deeper creek areas along the river or creek pathway, with flows providing distribution through the system.

4.4.5.4 OPTIMISATION SPECIFIC TO DIFFERENT TECHNICAL COMPONENTS

Available space for storage may be a limiting factor when designing a stormwater use scheme. Stormwater collected from fields or roads can be stored directly below the collection area through technologies such as infiltration, permeable pavement and underground storage systems to minimise space requirements.

Methods for optimisation can also be identified in the linkages between storage type and end uses. One option for developing a stormwater use scheme is to supply stormwater through a low pressurised pipe system to on-site tanks rather than providing pressurised mains. The additional storage requirements at each household needs to be compared to the option of no individual storage systems. This type of system may be harder to justify when more than one on-site tank is required for each household for different end uses.

The potential benefit of cluster scale stormwater use schemes is that distribution requirements are minimised compared to large city based water distribution systems. To ensure this is effective, the distance between storage, treatment, collection and end uses need to be optimised. Collection of all types of water at a single point can be designed to minimise distribution requirements. Alternatively, the number of pipes to meet the end uses can be minimised through providing only one type of water or examining only certain end uses.

In terms of optimising the distribution system, the collection area may be able to be linked with distribution by utilising slopes and land form of the collection area to minimise pump requirements. The demand area can also be relocated to a lower elevation area so that gravity flows rather than excessive pumping systems can be implemented.

4.4.6 FINANCIAL COSTS

For each technical component, there may be one or more feasible option. The feasible collection, storage, treatment or distribution options are combined to produce several stormwater use scheme options. The stormwater use scheme options are compared based on financial costs. While environmental and social issues are extremely important in examining the feasibility of stormwater use schemes, these issues are quite complex. The approach towards environmental and social aspects and issues of stormwater use are discussed further in Section 4.5.1.

Financial issues to be examined are divided into a number of topics as follows:

- Pumping and transport;
- Excavation and compaction;

- Materials, construction and installation;
- Land take and opportunity costs; and
- Maintenance.

Within each topic, there are a number of issues and costs that need to be determined. Appendix B provides a description of items which are costed for each stormwater use scheme option under the financial issues listed above. A description of the situations which require certain items to be costed, as well as the technical components and associated issues is also provided in Appendix B.

Engineering and construction costing guides are available to estimate costs. Rawlinsons Group (2003) and Cordell Building Publications (2003) are the most recognised costing guides in Australia. Costs for traditional stormwater management systems such as land shaping for overland flows and pipe trenching and construction are readily available in these guides, but those relating to newer technologies are not as easily available. These costs need to be sought directly from manufacturers or construction companies. All of the costs are put together in a simplistic Bill of Quantity (BOQ) style table so that different stormwater use scheme options with different collection, storage, treatment and distribution components can be compared. As all technical components are linked, the options within the Bill of Quantity are integrated so that the influence of different technical components can be examined. This is particularly important when one component has a number of functions. The financial costs and benefits are demonstrated in the case study in Section 5.8.

To obtain a balanced view of financial costs, a life cycle cost assessment should be conducted. Life cycle costs take account of capital costs, operation and maintenance costs over the life of the component and recovery costs at the end of the product life cycle. The life cycle cost assessment proposed in this study is based on product life cycles. Cradle to grave total life cycle costs are not proposed to be examined. While cradle to grave analysis provides an understanding of environmental and economic issues of the different components, this type of analysis is extremely time consuming with minimal information available to reference.

Taylor (2003) identifies a lack of understanding and documentation of life cycle costs for structural stormwater quality management measures. He summarises the requirements under the Australian Standard for Life Cycle Costing and presents an example of a simple life cycle cost model. Taylor (2003) is very useful as a basis of life cycle costs assessment.

The methodology for implementing life cycle costing is expanded through a literature review conducted by Taylor (2004) into the life cycle costs of stormwater best management practice elements. A collation of relevant costing information and identified cost and size relationships for different stormwater best management practices is produced from this literature review. Taylor (2004) states that these relationships will be verified and updated for inclusion as a new module to the MUSIC modelling program. Until this time, the cost and relationships presented by Taylor (2004) can be used for life cycle costing of certain stormwater treatment and management systems.

Another good source of costing information is Victorian Stormwater Committee (1999). While these cost examples are around 5 years old, commercial in-confidence issues have meant that compiled information of overall costs are not easily available. These values may be more appropriate for stormwater management systems rather than stormwater utilisation schemes and are suited to the treatment requirement methodology based on removal rate (Section 4.4.3.2).

4.5 ADDITIONAL DECISION MAKING FRAMEWORK ISSUES

4.5.1 SOCIAL, ENVIRONMENTAL AND ECONOMIC COSTS AND BENEFITS

Social, environmental and economic costs and benefits are extremely important in any stormwater use scheme. These issues can be the motivating factor behind implementation, as well as influence the acceptance and necessity of these schemes. The challenge with social, environmental and economic issues is that these issues tend to be intangible. It is quite difficult to place an understood and agreed value on these issues. On the other hand, technical issues can be associated with an agreed monetary value.

The ease of implementing a financial cost and benefit system without considering social, environmental and sustainability issues does not necessarily equate to an acceptable methodology being developed. Acceptable methods to include environmental, social and economic issues in the assessment framework for stormwater use schemes, as well as other alternative sources and water management systems, is vital to ensure long-term sustainability of our natural resources. These methods must be researched and developed through industry and community participation. Research is currently being undertaken in a number of areas to develop methods to assess sustainability of water systems (Maheepala et al., 2003; McLean, 2003). As this research becomes available, these methods need to be implemented as part of the technical decision making framework, so that the current basis of system financial costing does not perpetuate the idea that stormwater use schemes are too expensive and can never be implemented.

Aesthetics and noise can be identified as important social issues relevant to the stormwater use scheme. Construction noise needs to be managed and pump noise may need to be controlled. Aesthetic problems for above-ground closed storage may be reduced by selecting tank colours that blend in with the surrounding environment. Aesthetic impacts are minimal for underground storage as the storage system is not visible. There can be positive aesthetic benefits from the in-ground open storage system as this may be an attractive addition to the area and may increase land and property prices (Section 2.3.4). However high land values may add to the challenge of using empty space for storage systems as these spaces may have more perceived monetary value to be sold for development.

The priority for many stormwater use schemes is either to minimise downstream impacts by improving stormwater quality and decreasing stormwater runoff or reduce potable water use through utilisation of alternative water sources. Water quality improvements provide environmental benefits to the ecosystem. Utilisation of urban stormwater may revert stormwater flows to pre-development conditions, therefore being of benefit to the local environment. Changes in flow conditions need to be identified to determine the environmental impact.

The amount of land take required to store water is an important issue. Any plans for utilising parklands or community spaces as storage areas needs to look at the impacts on the local community and the challenges in terms of zoning requirements of the council or government.

Issues that are particular to open storage areas are rate of evaporation, animal contamination and possibility of toxic algae blooms and risks related to safety issues. Risks and safety issues are discussed further in Section 4.5.3. Areas with high evaporation rates are more suited to closed, underground or aquifer storage to minimise impact of evaporation.

4.5.2 COMMUNITY PARTICIPATION AND ISSUES

Community participation from the initial planning stage of a stormwater use scheme is vital to ensure an appropriate system is implemented, utilised and managed. Recycled water schemes are often reliant on costs being recouped through the users. If a stormwater use scheme is implemented in an area where it is not wanted by the community or for end uses that the community does not approve of, the scheme would have great difficulties in being implemented and maintained successfully.

Active participation of the community in the decision making process should minimise any long-term negative effects and risks of the stormwater use scheme being applied in the wrong manner. Local residents are usually aware of their local conditions and the systems that would work in their area. Through education and participation, an effective and positive stormwater use scheme can be implemented and maintained. Public participation can influence water demand, end uses utilised, maintenance requirements, aesthetic values and management issues. Understanding of the system and general satisfaction or feeling of ownership of the implemented system is likely to be improved through community participation.

While the ideas and issues involved in community participation are not specifically examined as part of this study, it is important that these issues are included in the decision making framework.

4.5.3 RISK ASSESSMENT

Risk assessment is very important for determining the feasibility of a stormwater use scheme. This is especially the case with the update of ARMCANZ et al. (2000) being based on risk management principles (CRC for Water Quality and Treatment, 2003). Hazard Analysis and Critical Control Point (HACCP) is a risk analysis tool that was originally developed for the food industry and is based on the engineering system Failure, Mode and Effect Analysis (FMEA). These tools identify problems or hazards in different stages of operation and have been adapted to the water management industry.

HACCP uses a preventative approach so that potential hazards are identified and can be effectively monitored and risks minimised. These principles clarify the method to identify hazards in the process system, prioritise hazards, manage critical hazards and monitor the implementation of the risk management system including documentation. These principles are just as valid for a stormwater use scheme as in the food industry. The hazards may be similar in terms of risk of contamination and health concerns. The processes that need to be examined are the collection, storage, treatment and distribution systems.

NHMRC and NRMMC (2002) adapted the HACCP principles to determine risk management requirements for the supply of drinking water. The links between the draft Australian Drinking Water Guidelines (NHMRC and NRMMC, 2002) and HACCP is provided below in Table 4.14.

Table 4.14 Comparison of HACCP and the Proposed Drinking Water Guidelines Framework

HACCP	Framework for management of drinking water quality
1. Hazard identification and preventive measures	Water supply system analysis, hazard identification and risk assessment(element 2) Preventive measures and multiple barriers (element 3)
2. Critical control points	Critical control points (element 3)
3. Critical limits	Operational monitoring (element 4)
4. Monitoring system for each critical control point	Operational monitoring (element 4)
5. Corrective actions	Corrective action (elements 4 and 5)
6. Verification / validation	Equipment capability and maintenance (element 4) Drinking water quality monitoring, consumer satisfaction (element 5) Validation of processes, design of equipment (element 9) Audit of drinking water quality management (element 11)
7. Documentation and record keeping	Management of documentation and records (element 10)

Source: NHMRC and NRMMC (2002)

An example of another risk management tool that has been used for stormwater management is described in Victorian Stormwater Committee (1999). This risk management system requires input through a stakeholder workshop to identify and rank the risks of the stormwater management system. The processes to most effectively manage these risks are then determined and included in the stormwater management plan.

Risks specific to stormwater use schemes are similar to those related to other recycled water schemes. One of the main risks relates to health concerns based on possible contamination of supplied water or human consumption, particularly if the stormwater is not treated to drinking water guidelines. Risk management principles may identify access to stormwater treated to non-potable standards as being a priority. The risk of contamination may be minimised through limiting access to the area where the stormwater would be applied. This could be either through closing of irrigation areas to the public or irrigating during night times when there is less risk of the water coming into human contact.

Supplied stormwater that is not being used for the intended use may also be identified as a risk. There is a chance that people may consume water from any number of sources within or external to the house. For example, water supplied to the shower may not be required to meet drinking water guidelines although some people may unintentionally or deliberately drink some of the shower water through washing their teeth in the shower.

The risk of the treatment system failing may also be examined. Overflows or bypasses of the treatment system can result in untreated water being supplied to the end uses. There is also the risk of contamination of the potable water supply with stormwater provided for non-potable uses. Backflow prevention and ensuring there are no cross connections between the potable water and stormwater use distribution system reduces these risks.

Safety risks include general water body safety issues with access to children and the risk of drowning. Safety fences or signage can be constructed to ensure children do not have access to the open water body. This results in a compromise between aesthetic values of the water body and safety concerns. Better slopes may also be utilised to minimise the possibility of people slipping or falling into the storage system.

Open storage areas may become areas of fauna habitats. While this can add to the aesthetic value, measures to reduce the impact of animal droppings contaminating the storage area and decreasing water quality may need to be examined. Quality concerns also need to be managed with the possibility of toxic algae impacting on the stored water. This is of particular concern when the water body is relatively still. Still water can also result in mosquito breeding and health concerns. Quality and health issues may be improved through ensuring regular draw down and replenishment of the water supply.

Flood protection issues may lead to another form of risk. Where a system is meant to be used for both stormwater utilisation and flood protection, the risk of the system failure and flood occurrence needs to be considered. Back-up or alternative systems may need to be considered.

Legal risks also need to be identified. Moore (2003) examines the potential legal risks for use of reclaimed water, based on the regulatory framework in Victoria. There are a number of areas of potential legal liability which are classified as "*common law liability in tort, liability under contract and liability under specific legislation*" (Moore, 2003, p. 70). The key issue that is identified is that in order to reduce potential legal liability, guideline requirements should be complied with. Where the water is not treated to potable standards, the water should be treated to standards suiting the proposed end use. Additionally, practices should be put in place to minimise the risk of the water being used in situations where it is not intended.

4.5.4 Coordination with Relevant Authorities

Coordination with relevant authorities is extremely important for successful development and implementation of a stormwater use scheme. This is particularly true at this point in time as there are no guidelines specific to stormwater utilisation. Coordination with authorities should identify any issues during early stages of the planning process and should minimise the legal and other risks associated with schemes. Relevant authorities include councils, local and state governments and environmental protection authorities.

4.6 SUMMARY

The decision making framework developed in this study is a useful tool to assist decision makers in the planning and implementation of stormwater use scheme options. The steps of the decision making framework are based around technical components and associated issues. This framework involves collating general site information, identifying feasible technical options, comparing feasible technical options and optimising the linkages between all of the technical components. The associated issues of each technical component influence the feasibility of the technical components as well as providing a sound basis for optimising a holistic stormwater use scheme.

Integration of all of the technical components is essential to ensure an optimum system is implemented. In particular, technical components and associated issues cannot be examined in isolation as each component and issue influences the other components and issues. This was particularly seen when technical components have more than one function.

As well as the technical issues examined in the decision making framework, additional issues such as social, environmental, economic and risk issues were discussed. These issues are important so that the concepts behind implementing a stormwater use scheme take into account the larger picture of examining all water resources and sustainable practices. While assessment of these additional issues is still at the early stages with no recognised system available, the decision maker must be aware of these issues.

The decision making framework is meant to be a practical tool that can be implemented by the decision maker to plan systems for any study site. In order to provide an understanding of the processes required to implement the developed decision making framework, a case study was conducted. Chapter 5 demonstrates the application of the decision making framework to a study site and identifies the practicalities with using this framework.

CHAPTER 5

DEMONSTRATION OF THE DECISION MAKING FRAMEWORK

5.1 INTRODUCTION

The decision making framework developed in Chapter 4 is proposed as a practical tool to determine the most appropriate stormwater use scheme that can be implemented for a study area being examined. A case study was chosen to demonstrate the practicality of using this tool and is described in this chapter. The case study is located in an existing urban area in the west of Melbourne, Australia.

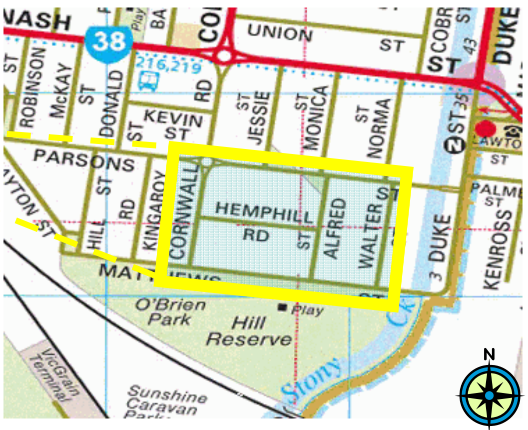
An existing urban area was chosen as the case study due to the potential for the greater impact in terms of minimising potable water use for non-potable end uses. While greenfield areas are a lot more flexible in terms of implementing stormwater use schemes, the population and the number of developments being constructed is relatively small compared to the number of existing households. The majority of the urban population lives in existing urban areas and these are the areas where the greatest impact, in terms of total urban water resource management, can be achieved.

The existing urban area chosen for the case study is located in the suburb of Sunshine in the City of Brimbank. A description of the case study site is provided in Section 5.2. Sections 5.3 to 5.8 describe the application of the decision making framework to the case study, concentrating on collection, end use, storage, treatment, distribution and financial cost aspects of the framework. Additional issues (in addition to technical issues) were also briefly examined, but detailed analysis of these additional issues was beyond the scope of this project. These issues included social, environmental and economic costs and benefits, community participation, risk assessment and coordination with relevant authorities and are discussed in Sections 5.9 and 5.10.

5.2 CASE STUDY SITE

The case study area is located in the suburb of Sunshine, in the south-east of the City of Brimbank. The City of Brimbank is located to the west of Melbourne's Central Business District, as shown below in Figure 5.1. The study site is the area enclosed by Parsons Street, Cornwall Road, Matthews Street and Walter Street. Stony Creek is an urban waterway which is located to the south-east of the study site. Stony Creek consists of underground pipes flowing from north to south until the corner of Duke Street and to the south-east of the study site, where it becomes an open waterway. A detailed aerial photo with contours showing the study area is provided in Appendix D. This detailed aerial photo was used as the basis to determine information for the general study site conditions (Section 5.3.1).

Source: www.brimbank.vic.gov.au



Source: www.street-directory.com.au

Figure 5.1 Location of Case Study Site

The City of Brimbank had a population in 2001 of nearly 163,000 with a population density of approximately 13.3 people per hectare on average (i.d., 2003a). While the City of Brimbank includes greenfield, infill, redevelopment and existing urban areas, the case study site was chosen because it was located in an existing urban area, as stated earlier.

The infrastructure and housing development in the case study area was fairly well established. However, there was minimal urban stormwater drainage infrastructure. During periods of large rainfall, flooding had occurred on some of the properties in the area. Discussions with Brimbank City Council officers revealed that the City Council was planning to improve infrastructure in the area. As a part of this infrastructure improvement, the opportunity of including stormwater use in the stormwater management system was examined in this study. This meant that a stormwater use scheme could be directly compared to the option of improving stormwater management without stormwater utilisation.

The potential benefit of including stormwater use in the case study area was that general infrastructure costs may be off set by being able to use stormwater to replace mains water. Reduction in mains water use could result in a reduction in household water costs. However, the price of the utilised stormwater would determine the savings to the household. The utilised stormwater price would be dependent on the charging mechanism used to meet construction and maintenance costs of the stormwater supply system. These benefits were also examined as part of the decision making framework.

5.3 COLLECTION AND END USE

Collection and end use information was gathered through the first six steps of the decision making framework. These steps are reproduced below in Figure 5.2 and consisted of examining stormwater quality and quantity, as well as end use required quantity and quality.

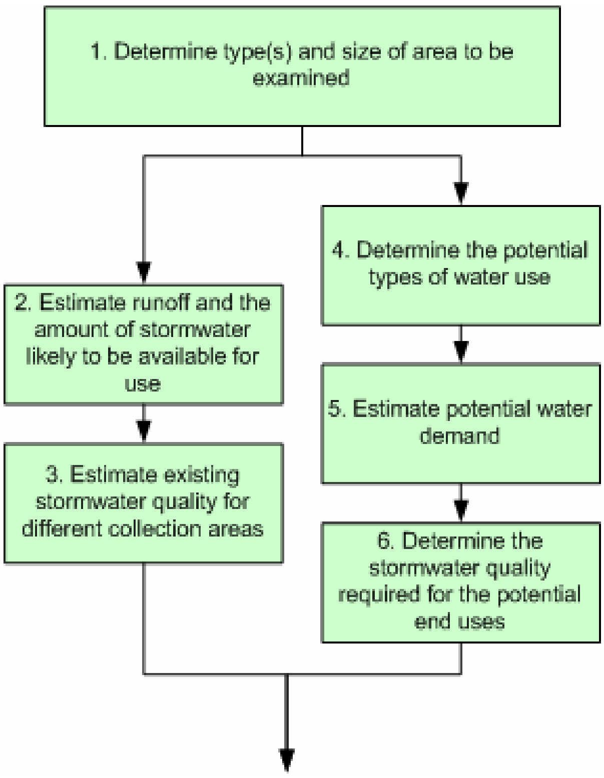


Figure 5.2 Decision Making Framework Steps Related to Collection and End Use

5.3.1 GENERAL STUDY SITE CONDITIONS

Information about the general study site conditions provide an understanding of the area being examined and determine any limitations and constraints relevant for that area. General study site conditions include ground conditions, zonal type and size of the catchment and end use area.

The focus of this case study was to manage stormwater, concentrating on the utilisation of stormwater. Therefore, the priority for this case study was to utilise the maximum amount of stormwater while also minimising flood risks.

The collection area examined was the entire case study residential area. The potential end use areas examined were the collection area and the Tom O'Brien Reserve (Figure 5.1). The Tom O'Brien Reserve is located to the south of the case study collection area. All types of end use were initially examined until screening in the decision making framework determined that certain end uses were not feasible.

After the collection and end use areas were identified, the zonal types of these areas were determined. Since the case study is an existing urban area, the zonal type was therefore an existing urban area. There are no commercial or industrial areas within the study site. The study site is a residential area with a small amount of open space on the road verge and stormwater drainage clearance areas. One block was not developed, but was included as part of the residential area on the assumption that this block would be developed at some point in time. The other open space area was the Tom O'Brien Reserve.

The size of these areas was then measured. An aerial photograph of the area was obtained from the Brimbank City Council, as shown in Appendix D. This aerial photograph was used to determine average housing sizes and the amount of impermeable surfaces. The aerial photograph was overlayed with the block boundary layout, existing drainage infrastructure and contour levels. Figure 5.3 shows the street layout and contours of the case study area.

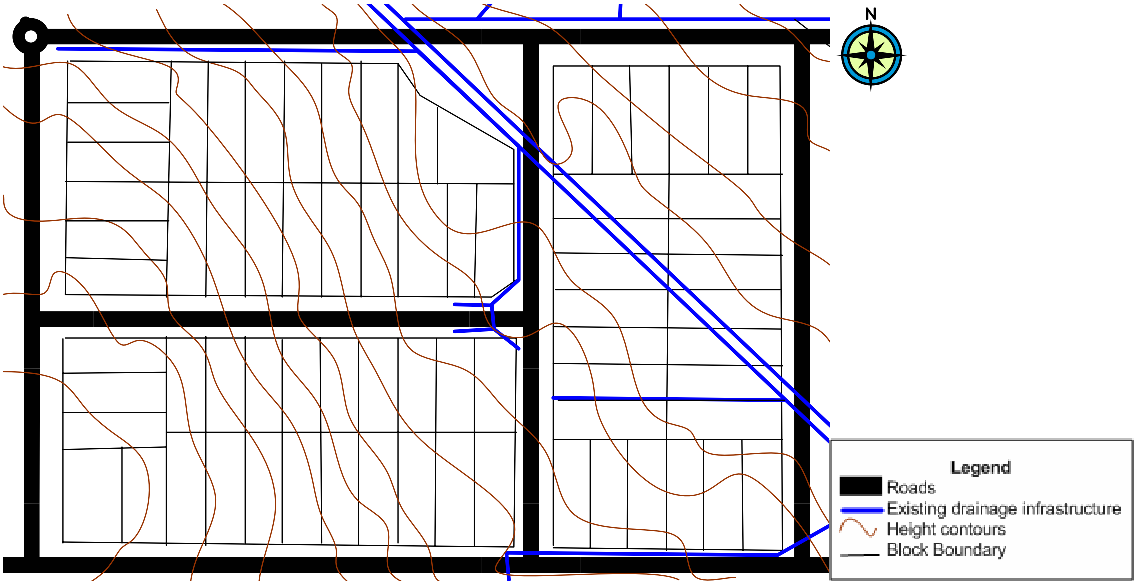


Figure 5.3 Street Layout and Contours of Case Study Area

The housing blocks in the residential area of the case study were very similar in characteristics, such as land block size, garden size and roof area. As such, the residential area was examined as one area. Within a larger study site, the residential area may be separated into different residential areas.

Area characteristics for the case study were determined. In this case study, the end use and collection areas were the same. The collection area residential block and overview data information is shown in Tables 5.1 and 5.2 respectively. Calculations used to determine the input values for these tables are given in Appendix E1. All of the information for these tables was determined through the aerial photograph provided by Brimbank City Council.

The residential block and overview data characteristics for the end use area are shown in Tables 5.3 and 5.4 respectively. Since the end use area was the same area as the collection area, end use data was directly taken from Tables 5.1 and 5.2. Additional information that was required for estimating end use demand patterns were the average housing occupancy and the percentage pervious area irrigated.

The link in the Brimbank City Council website (i.d., 2003b) stated that the forecast average household occupancy for the suburb of Sunshine was 2.62 in 2001. The forecast data for the average household occupancy was estimated at five yearly intervals, from 2.62 in 2001 to decrease to 2.57 in 2006, and then to 2.59 for both 2011 and 2016. A value of 2.6 persons per household was inputted into Table 5.3 and used for modelling purposes so that the system was designed to accommodate current and future water use.

Table 5.1 Collection Area Residential Block Data for Case Study

	Total number of blocks	Average block size	Average roof area	Average pavement area	Average garden area	Average impervious area	Average pervious area
	(No.)	(m^2)	(m^2)	(m^2)	(m^2)	(m^2)	(m^2)
Typical residential block	72	600	300	75	225	375	225

Table 5.2 Collection Area Overview Data for Case Study

	Total area	Roof area	Road and pavement area	Grassed / vegetated area	Total impervious area	Total pervious area
	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)
Residential	6.12	2.16	1.32	2.64	3.48	2.64
Open space / community scale irrigation	8.40	0	0	8.40	0	8.40
Industrial	0	0	0	0	0	0
Commercial	0	0	0	0	0	0
TOTAL COLLECTION AREA	14.52	2.16	1.32	11.04	3.48	11.04

Table 5.3 End Use Area Residential Block Data for Case Study

	Total number of blocks	Average block size	Average Pervious area	Pervious area irrigated	% Pervious area irrigated	Average housing occupancy
	(No.)	(m^2)	(m^2)	(m^2)	(%)	(Persons/house)
Typical residential block	72	600	225	225	100	2.6

Table 5.4 End Use Area Overview Data for Case Study

	Total area	Total pervious area	Pervious area irrigated	% Pervious area irrigated
	(ha)	(ha)	(ha)	(%)
Residential	6.12	2.64	1.62	61
Open space / community scale irrigation	8.40	8.40	8.40	100
Industrial	0	0	0	0
Commercial	0	0	0	0
TOTAL END USE AREA	14.52	11.04	10.02	91

The percentage pervious area irrigated was estimated from the aerial map as the amount of residential and community scale irrigation areas that were to be irrigated. It was assumed that the road verge and grassed areas were not irrigated (1.02 ha), while the residential gardens (1.62 ha) and The Tom O'Brien Reserve (8.4 ha) were fully irrigated. This was equivalent to 91% of the total area being irrigated.

In addition to area characteristics for the collection and end use area of the case study, ground conditions were identified. The ground conditions in the Sunshine area consisted of newer volcanics, namely extrusive tholeiitic to alkaline basalts, minor scoria and ash (Natural Resources and Environment, 1997). This quaternary basalt was classified as clay in terms of construction and excavation requirements (Walsh et al., 1976).

5.3.2 STORMWATER RUNOFF

To determine stormwater runoff, monthly and yearly rainfall and evaporation data were required. This data was downloaded from the Bureau of Meteorology website (www.bom.gov.au). The closest rainfall stations to the suburb of Sunshine, which were available on the website, are Maribyrnong, Laverton, Essendon and Melbourne Airport. Laverton and Melbourne Airport rain stations had evaporation as well.

The Maribyrnong rain station data was used to obtain monthly and yearly rainfall. The Melbourne Airport climate station data was used to obtain monthly and yearly evaporation. The rainfall and evaporation data is shown in the second and third columns respectively of Table 5.5. Note the base data from the Bureau of Meteorology was given from January to December while the data in Table 5.5 was adjusted to July to June.

Sample calculations determining monthly impervious and pervious runoff volumes are shown in Appendix E2. The impervious coefficient of runoff was selected as 0.9 in these calculations, as it is commonly used to compute the coefficient of runoff for impervious areas in urbanise catchments for use in the Statistical Rational Formula (Institution of Engineers Australia, 1987). The pervious coefficient of runoff was selected as 0.0. This value was selected based on the reasons described previously in Section 4.4.1.2. That is, ignoring pervious stormwater runoff provides an underestimation of the stormwater runoff, as a method to take into account losses of potential stormwater collection.

Table 5.5 Monthly and Yearly Runoff Volume for Case Study

Month	Rainfall depth (mm)	Evaporation (mm)	Impervious runoff volume (kL/month)	Pervious runoff volume (kL/month)	Total runoff volume (kL/month)
July	40.0	52.7	1,253	0	1,253
August	45.8	65.1	1,434	0	1,434
September	51.9	114.0	1,626	0	1,626
October	57.3	136.4	1,795	0	1,795
November	53.3	156.0	1,669	0	1,669
December	48.2	232.5	1,510	0	1,510
January	40.3	226.3	1,262	0	1,262
February	40.8	224.0	1,278	0	1,278
March	40.7	170.5	1,275	0	1,275
April	46.3	99.0	1,450	0	1,450
May	49.4	80.6	1,547	0	1,547
June	39.0	51.0	1,221	0	1,221
TOTAL YEARLY	**553.0**	**1608.1**	**17,320**	**0**	**17,320**

Runoff for the Tom O'Brien Reserve was not determined. This was because the Tom O'Brien Reserve was completely pervious and the runoff calculations were based on a pervious coefficient of runoff of 0.0.

5.3.3 END USE DEMAND

End use demand was estimated in order to identify which end uses could be met with the potential stormwater available represented by stormwater runoff. The end uses that were examined in the case study were indoor and outdoor residential use for the houses within the catchment area as well as irrigation use for the Tom O'Brien Reserve.

Cordell et al. (2002) determined yearly total household demand, as well as indoor and outdoor demand. The annual average water use for Sunshine was reported as 193, 46 and 239 kL/year/household for indoor, outdoor and total water use per dwelling respectively. This data was based on the average household water use for the years 1999/00 and 2000/01. Calculations to determine indoor demand (both monthly and yearly) are shown in Appendix E3. The yearly outdoor demand and daily indoor demand for different end uses are also shown in Appendix E3.

The outdoor monthly demand was more complex to estimate. Two methods, as described in Section 4.4.1.3, were used to estimate the monthly outdoor demand. The first method was based on evaporation and rainfall, as described by Equation 4.8.

Monthly evaporation and rainfall were previously obtained (Section 5.3.2). The monthly evaporation was based on the Melbourne Airport rainfall station data, while the monthly rainfall was based on the Maribyrnong rainfall station data. The alpha value in Equation 4.8 was determined using an iterative process in Excel, and determined as 42%. This alpha value was used to calculate monthly outdoor demand for the case study. The calculations to determine the alpha value and the outdoor demand using the evaporation / rainfall equation are shown in Appendix E4.

The alternative method for determining monthly household outdoor demand was based on measured monthly outdoor demand distributions. These distributions have been measured for certain areas around Australia and may not have the same climate conditions as the study area. The monthly temporal distribution of outdoor demand for Perth was the only available outdoor demand available and was used for this case study. The monthly distribution of outdoor demand determined using the evaporation / rainfall equation, and from Perth data is shown in Table 5.6.

Table 5.6 Percentage Monthly Temporal Distribution of Household Outdoor Usage for Study Area

	Monthly distribution determined using evaporation / rainfall equation (Appendix E4) %	Monthly distribution from Perth data[1] %	Monthly distribution adapted from evaporation / rainfall equation and Perth data %
July	0	1	1
August	0	1	1
September	0	1	1
October	0	6	1
November	6	13	7
December	25	17	26
January	27	17	26
February	26	17	26
March	15	13	8
April	0	9	1
May	0	3	1
June	0	1	1
TOTAL	**100**	**100**	**100**

Source: [1] Loh and Coghlan (2003)

The Perth temporal distribution showed high constant demand for the summer months which decreased over the winter months. The Perth summer monthly demand of 17% (December, January and February) was quite low compared to the summer demand range (25% to 27%) determined using the evaporation / rainfall equation. Since the demand determined using the evaporation / rainfall equation takes into account local conditions, this high summer demand was likely to be more appropriate. However, the evaporation / rainfall equation did not take into account human behaviour. The Perth data was therefore increased to meet the evaporation / rainfall equation values over the summer months, while retaining some demand over the non-summer months. These values are also shown in Table 5.6, and used for this case study to determine the monthly demand based on the total yearly residential demand of 3,312 kL/year. The monthly indoor and outdoor demand for the study area is shown in Table 5.7.

Table 5.7 Monthly Residential Demand for Case Study Area

	Indoor demand kL/month	Outdoor demand adapted from evaporation / rainfall equation and Perth data kL/month
July	1,180	33
August	1,180	33
September	1,142	33
October	1,180	33
November	1,142	232
December	1,180	861
January	1,180	861
February	1,096	861
March	1,180	265
April	1,166	33
May	1,180	33
June	1,142	33
TOTAL	**13,896**	**3,312**

The irrigation demand for the Tom O'Brien Reserve was then determined based on the evaporation and rainfall equation (Equation 4.8). An iterative process to determine the alpha value could not be used for the Tom O'Brien Reserve because total yearly demand was not known. Therefore the same value of α as for the residential area (42%) was used. As with the residential area, negative irrigation was found for some months. These negative values, representing wet periods and resulting runoff, were filtered out and replaced with zero. Both the filtered and non-filtered monthly demand for the Tom O'Brien Reserve irrigation is shown in Table 5.8. The Perth temporal distribution was based on residential household demand and was therefore not used for determining irrigation requirements of the Tom O'Brien Reserve.

Table 5.8 Monthly Irrigation Demand for Tom O'Brien Reserve

	Non-filtered demand determined from evaporation / rainfall equation kL/month	Demand determined from evaporation / rainfall equation kL/month
July	-1,486	0
August	-1,532	0
September	-306	0
October	37	37
November	1,070	1,070
December	4,219	4,219
January	4,662	4,662
February	4,539	4,539
March	2,644	2,644
April	-369	0
May	-1,283	0
June	-1,462	0
TOTAL	10,734	**17,172**

5.3.4 COMPARISON OF STORMWATER RUNOFF AND END USE DEMAND

Stormwater runoff was then compared to end use demand to provide an approximate estimate of the end uses that can be met. The stormwater runoff and end use demand values that were calculated previously are shown in Table 5.9. The total residential demand and the Tom O'Brien Reserve irrigation demand were also plotted against stormwater runoff and are shown in Figure 5.4. Table 5.9 and Figure 5.4 show that only the residential demand or the Tom O'Brien Reserve irrigation demand could be met, but not both.

The Tom O'Brien Reserve irrigation demand had a very high demand in summer and minimal or no demand during winter. The temporal pattern of the residential demand followed the temporal demand of the stormwater runoff more closely than the Tom O'Brien Reserve demand. Since only residential or the Tom O'Brien Reserve demand can be met and the Tom O'Brien Reserve demand pattern does not match stormwater runoff, the irrigation demand was not examined as one of the end uses.

Table 5.9 Comparison of Stormwater Runoff and End Use Demand for Case Study

	Stormwater runoff	Residential demand adapted from evaporation / rainfall equation and Perth data			Tom O'Brien Reserve demand
Month	Total runoff volume kL/month	Outdoor demand kL/month	Indoor demand kL/month	Total monthly demand kL/month	Total monthly demand kL/month
July	1,253	33	1,180	1,213	0
August	1,434	33	1,180	1,213	0
September	1,626	33	1,142	1,175	0
October	1,795	33	1,180	1,213	37
November	1,669	232	1,142	1,374	1,070
December	1,510	861	1,180	2,041	4,219
January	1,262	861	1,180	2,041	4,662
February	1,278	861	1,096	1,927	4,539
March	1,275	265	1,180	1,445	2,644
April	1,450	33	1,166	1,175	0
May	1,547	33	1,180	1,213	0
June	1,221	33	1,142	1,175	0
Total Yearly	**17,320**	*3,312*	*13,896*	**17,208**	**17,172**

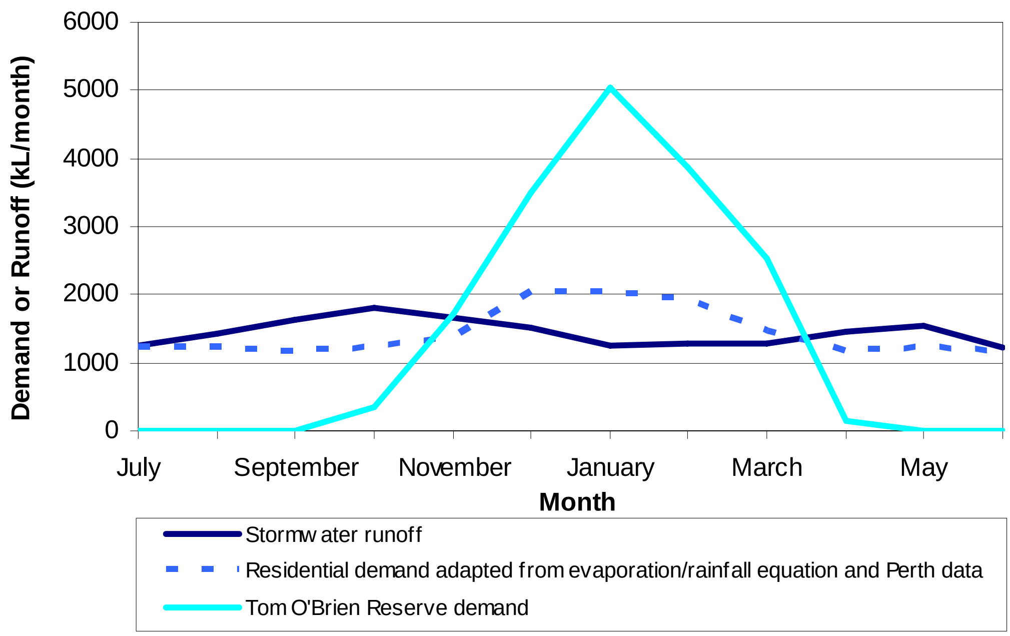


Figure 5.4 Total Demand for Residential Case Study Area and the Tom O'Brien Reserve Compared to Stormwater Runoff

The residential demand was then examined more closely in terms of stormwater runoff. Figure 5.5 shows stormwater runoff as well as indoor, outdoor and total residential demand. This figure showed that all winter demand could be met. Total summer demand could only be partially met. Part of the indoor or outdoor demand would not be met over the summer months, unless the storage size was sufficient to store excess winter flows.

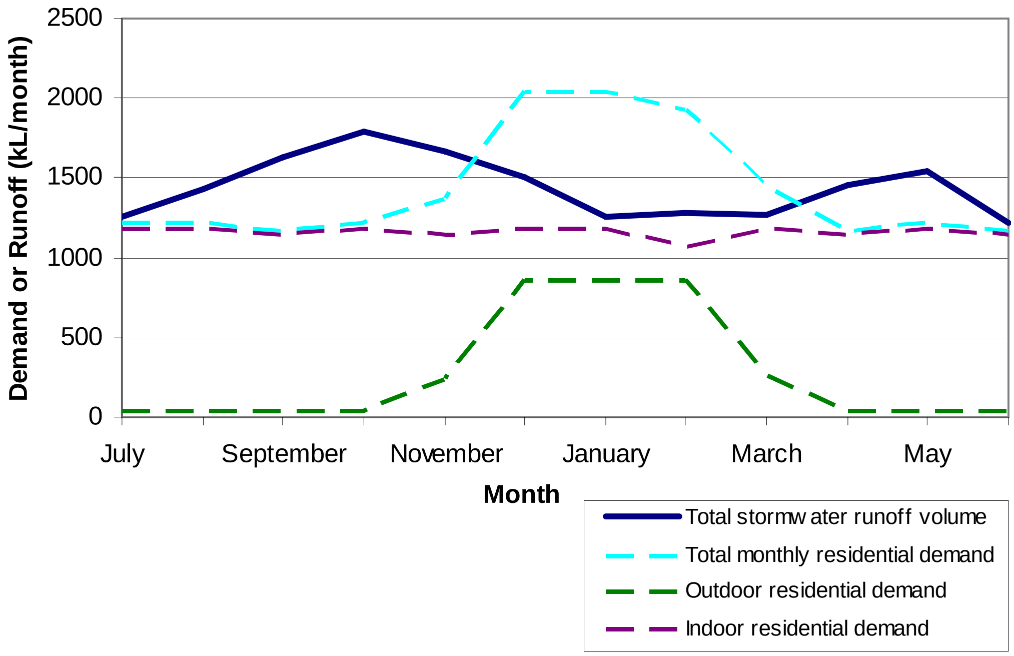


Figure 5.5 Indoor, Outdoor and Total Residential Demand Compared to Stormwater Runoff

The methodology to determine which, if any, end use demand could be screened out and not examined in further detail was based on examining the simplest end use demands in terms of infrastructure and treatment requirements first. Since the outdoor demand did not require any indoor plumbing, this demand was the simplest end use demand. The next simplest demand was indoor non-potable as quality and treatment requirements were less compared to indoor potable demand, which was examined last. As can be seen from Figure 5.5, all outdoor demand ignoring all other demands could be met.

Table 5.10 shows the monthly percentage of indoor demand that could be met if outdoor demand was already met. Indoor demand for the months of December, January, February and March could only be partially met. As the percentage that could be met was still reasonable, there was insufficient reason to disregard any end use. As such, all indoor and outdoor end use demands were examined in the decision making framework.

Table 5.10 Percentage of Indoor Demand Met Assuming All Outdoor Residential Demand is Met for Case Study Area

Date	% Indoor demand met
July	100
August	100
September	100
October	100
November	100
December	55
January	34
February	38
March	86
April	100
May	100
June	100

Four end use demand options were examined, as well as the base case where no stormwater use was implemented. Community scale irrigation, in this case the Tom O'Brien Reserve, was determined to not be examined and to be supplied by the existing water supply system. The end use demand options that were examined were as follows:

- Outdoor demand supplied by stormwater with all other demands supplied by the existing water supply system;
- Indoor non-potable residential demand supplied by stormwater with all other demands supplied by the existing water supply system.
- Outdoor demand and indoor non-potable residential demand supplied by stormwater with all other demands supplied by the existing water supply system;
- All residential demand (outdoor, indoor non-potable and indoor potable) supplied by stormwater with community scale irrigation (the Tom O'Brien Reserve demand) supplied by the existing water supply system.

5.3.5 COLLECTION OPTIONS

The decision making framework consisted of determining whether gravity assisted or pump flows would be used to collect the stormwater. The case study area was all sloping towards a central collection point in the south-east. Therefore gravity assisted flow was examined for stormwater collection.

The collection options that were assessed to determine which were feasible were overland flows, infiltration trenches, permeable pavements and a pipe collection system. The current stormwater collection system was overland flows which were collected in few stormwater pipes. It was determined that as a minimum, this system should be upgraded to cope with additional flows to minimise flooding which has occurred in the area. As such, overland flows without the use of pipes were deemed infeasible.

Permeable pavements would require replacement of large areas of pavement or grassed areas to provide sufficient area for collection of the stormwater. Since the case study is an existing urban area where pavements were already in place and replacement of these systems would be extremely costly, permeable pavements were not examined further.

Infiltration trenches were similar to permeable pavements except that they could be laid in trenches which do not take up much space. There was no reason to deem infiltration trenches infeasible, and therefore infiltration trenches were examined further as a possible stormwater collection option.

Gravity flow for collection of the stormwater was determined to have two feasible collection options that were examined in more detail. These were pipe collection system and infiltration trenches. These two options were compared against each other, as shown in Section 5.7.

5.3.6 STORMWATER QUALITY

There was no stormwater quality monitoring data for the case study area. This meant that average stormwater quality data was required to provide an estimation of the water quality being examined. However, an indication of the pollutants of concern was available from the “Stormwater Management Plan for Brimbank City Council” (AWT Victoria and TBA Planners, 1999). Litter was of concern for the entire municipality with the pollutants of concern identified as dissolved pollutants, particulate pollutants and gross pollutants.

As an indication of the stormwater quality, the mean values of some pollutants for an urban area was taken from Duncan (2003). This information is shown in Table 5.11.

Table 5.11 Indication Mean Values of Stormwater Quality for an Urban Area from Duncan (2003)

Parameter	Units	Urban roads (mean values)	Residential (mean values)
Suspended Solids (SS)	mg/L	250	120
Total Phosphorous	mg/L	0.25	0.4
Total Nitrogen	mg/L		2.6
Chemical Oxygen Demand (COD)	mg/L	65	75
Biological Oxygen Demand (BOD)	mg/L	15	12
Oil & Grease	mg/L		81
Total Organic Carbon (TOC)	mg/L		15
pH		6	6.85
Turbidity	NTU	6	70
Total Lead	mg/L	0.22	0.14
Total Zinc	mg/L	0.45	0.15
Total Copper	mg/L	0.09	0.035
Total Cadmium	mg/L	0.0022	0.0024
Total Chromium	mg/L		0.011
Total Nickel	mg/L		0.025
Total Iron	mg/L		1.6
Total Manganese	mg/L		0.15
Total Coliforms	CFU/100mL		170000
Faecal Coliforms	CFU/100mL		21000
Faecal Streptococci	CFU/100mL		50000

5.3.7 END USE REQUIRED QUALITY

There were no specific guidelines for utilisation of stormwater in Victoria. The Guidelines for Environmental Management: Use of Reclaimed Water (EPA Victoria, 2002) was used in the case study as the basis for determining the required quality for the non-potable (outdoor and indoor) residential end use demand options. As the case study was in an urban area and required uncontrolled access, Class A water was determined as the quality guideline to be reached. The main contaminants of concern were E.coli, BOD and suspended solids for Class A water. These guidelines stated that a minimum standard of secondary treatment to produce median concentrations of BOD of 20 mg/L and SS of 30 mg/L would be required. Primary sedimentation or an equivalent process for removal of solids as well as turbidity reduction and disinfection would also be required.

For the end use demand option supplying stormwater to all end uses, Australian Drinking Water Guidelines (NHMRC and NRMMC, 2002) was used as the basis for determining water quality requirements. Microbial, physical and chemical quality requirements were examined as per the guidelines. The risk management framework basis of NHMRC and NRMMC (2002) would need to be examined as part of the additional decision making framework issues (Section 5.10).

5.4 STORAGE

5.4.1 STORAGE OPTIONS

The following storage options were examined to determine which storage options were feasible to be examined in further detail:

- Aquifer Storage and Recovery (ASR);
- In-ground open storage;
- Above-ground closed storage;
- Underground storage; and
- Existing water bodies or storage areas.

5.4.1.1 AQUIFER STORAGE AND RECOVERY

The beneficial use maps for South West Victoria (DCNR, 1995a,b) were used to determine the feasibility of Aquifer Storage and Recovery (ASR) for the study site. Figures 5.7 to 5.10 have been extracted from the South Western Victoria area maps (provided in Appendix F) and show the area being examined and the appropriate beneficial use. Figure 5.6 shows the legend used for above figures.

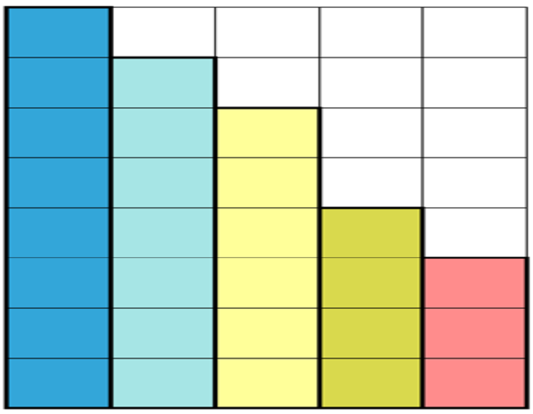


Figure 5.6 Legend Used for Figures 5.7 to 5.10 (DCNR, 1995a,b)

Water table aquifers are aquifers that are closest to ground level and at the height of the water table. As such, groundwater in the water table aquifers discharges to rivers, streams and wetlands (DCNR, 1995a). Individual aquifers at depth lower than the water table were combined into Lower, Middle or Upper Tertiary aquifer systems for ease of representation on the beneficial use maps (DCNR, 1995b). These terms corresponded to the age and depth of the aquifer, with aquifer in the Lower Tertiary aquifer system generally located at the lowest depths.

Figure 5.7 shows the beneficial uses for the Lower Tertiary system aquifers around the Melbourne region. The star shows the location of the case study site. The beneficial use and aquifer salinity ranges matrix (Figure 5.6) shows that the aquifers in this area could be used for potable mineral water, irrigation, stock water, industry, ecosystem protection, and buildings and structures beneficial uses.

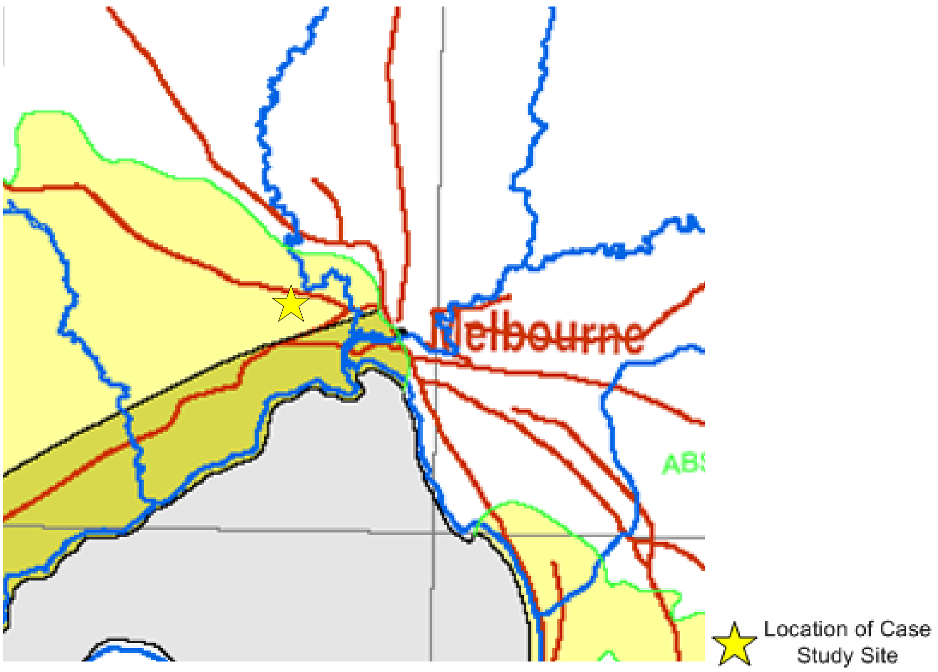


Figure 5.7 Lower Tertiary Aquifer System (DCNR, 1995b)

Beneficial uses for the Middle Tertiary aquifer system is shown in Figure 5.8. A lack of data meant that the beneficial uses of the Middle Tertiary system aquifers for the case study site was not known.

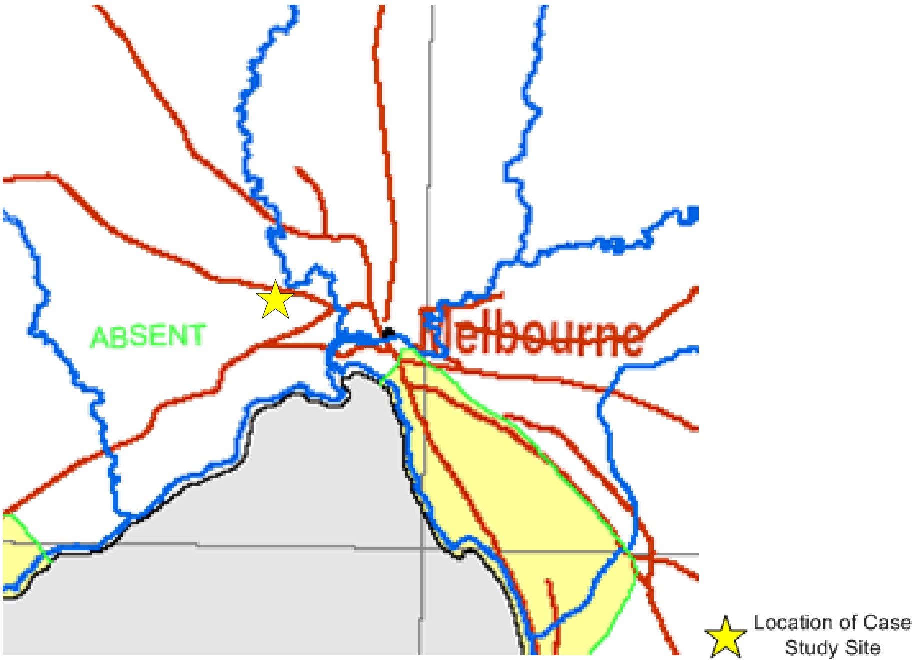


Figure 5.8 Middle Tertiary Aquifer System (DCNR, 1995b)

The possible beneficial uses for Upper Tertiary system aquifers (Figure 5.9) and water table aquifers (Figure 5.10) were the same. The possible beneficial uses for the case study site for these aquifers were stock water, industry, ecosystem protection and buildings and structures.

Figure 5.9 Upper Tertiary Aquifer System (DCNR, 1995b)

Figure 5.10 Water Table Aquifers (DCNR, 1995a)

Figures 5.6 to 5.10 showed that while there was acceptable quality groundwater available in the lower tertiary aquifer system, the aquifer systems which were closer to the ground were not acceptable for irrigation or potable mineral water. Therefore, Aquifer Storage and Recovery was not examined further as a storage option for this study site. While treatment could treat the groundwater of the Upper Tertiary and water table aquifer systems with water salinity of 3,501 to 13,000 mg/L to become acceptable for irrigation or potable uses, the small size of the study site would not justify the large treatment requirements to obtain suitable water quality. The requirement of pre-treatment of the stormwater prior to injection would also add to treatment requirements for the small study site to make this option infeasible.

5.4.1.2 In-Ground Open, Above-Ground Closed and Underground Storage

There were three possible sites for placing either in-ground open, above-ground closed or underground storage systems. These areas, as shown below in Figure 5.11, are as follows:

- Vacant block on Walter Street;
- Stormwater reserve on the corner of Alfred and Parsons Streets; and
- Tom O'Brien Reserve.

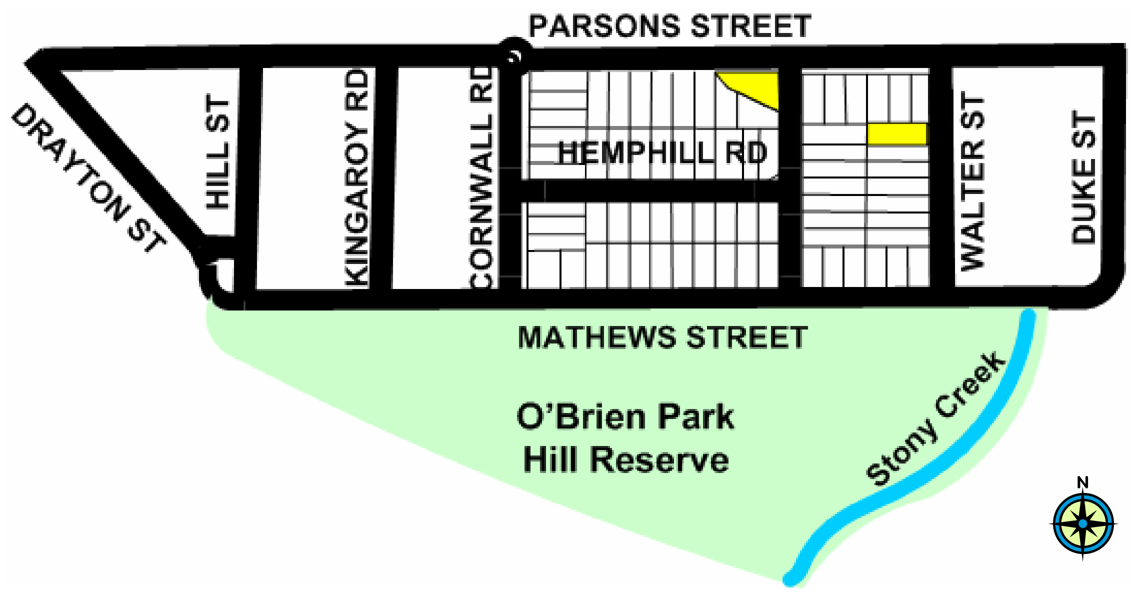


Figure 5.11 Location of Possible Storage Areas for Case Study

The vacant block was not suitable for placement of storage as this area was a residential block yet to be developed. This site was therefore not examined further for any storage option.

The stormwater reserve was limited in size and restrained by the surrounding blocks and roads. A clearance area of 10m wide along the alignment of the underground stormwater pipes in the reserve area was required to provide access for maintenance requirements. There was additional space of 312 m^2 outside the clearance area available for placement of storage systems. The close proximity of the stormwater pipes and limited space meant that only storage options with minimal construction and excavation requirements were feasible. Therefore, the stormwater reserve was not acceptable for in-ground open or underground storage. Above-ground closed storage was feasible and examined further within the stormwater reserve area.

The Tom O'Brien Reserve was identified as quite a large area which had a number of suitable sites to place a storage system. The Tom O'Brien Reserve was generally at a higher elevation than the study area, with the area along Stony Creek to the south-west of the study site at a lower elevation. This reserve was approximately 8.4 ha in size. Not all of this area was available for placing a storage system since part of the reserve included the Stony Creek embankment. There was also playground equipment located within the reserve. Approximately half of the reserve area was available for placement of a storage system. The Tom O'Brien Reserve was determined as a suitable location for placing in-ground open, above-ground closed or underground storage systems.

5.4.1.3 EXISTING WATER BODIES OR STORAGE AREAS

The only existing water body within close proximity to the case study site was Stony Creek. Stony Creek was located to the south-east of the study area. This creek received water from two large stormwater drains (1,800 mm diameter pipes). The general creek level and height of the creek banks above this level meant there was additional storage capacity within the alignment of the creek. However, the creek was along a floodplain and the additional capacity was required for flood management purposes to accommodate large storm event flows. Therefore no existing water bodies or storage areas were examined as a feasible storage option for this study area.

5.4.1.4 FEASIBLE STORAGE OPTIONS

It was determined that there were four feasible storage options that could be examined in further detail. These were in-ground open storage, above-ground closed storage or underground storage within the Tom O'Brien Reserve, or above-ground closed storage within the stormwater reserve.

5.4.2 STORAGE REQUIREMENTS

UVQ (Urban Volume and Quality) (Mitchell and Diaper, 2004) was used as the computer modelling tool to estimate storage requirements. The UVQ model input values and how the input values were obtained are shown in Appendix G.

The UVQ model of the study site was initially calibrated using the monthly and yearly stormwater runoff and end use demand values previously determined in Sections 5.3.2 and 5.3.3. The climate file chosen to run the model including the calibration was based on daily rainfall from the Sunshine rain gauge station and evaporation from the Melbourne Airport rain gauge station. All climate data were obtained from the Bureau of Meteorology.

The Sunshine rainfall station data was found to be incomplete. Therefore the years of incomplete data were not used and the model was run for each year from 1972 until

1990. The year of 1989-1990 was used as the reference year to calibrate the model parameters. This year was chosen as being representative for the study area, particularly as Melbourne Water (2002) considers this year an average rainfall year for the study area rainfall district.

Calibration was conducted through a trial and error process. The simulated flow volumes, using the reference year of 1989-1990, were compared to the observed flow volumes which were calculated previously (Tables 5.4, 5.9 and G.5). The calibration variables (Table G.4) were then adjusted until a good fit was found between the simulated and observed values. The determined calibration values were specific for the case study site. Calibration variables for stormwater flows include the capacity of water that could be stored in the soil structure, effective roof, paved and road areas and initial losses of the roof, paved and road areas. Calibration variables for water demand flows are the trigger to irrigate for garden and open space areas. *"The trigger to irrigate represents the level of soil wetness that the irrigator wants to maintain"* (Mitchell and Diaper, 2004, p. 45). Verification should be conducted with rainfall data and stormwater and water demand flows for a year that is not the modelled or calibration years. Verification of the model was not conducted for the study area as only average stormwater and water demand flows were available, rather than values for a specific year.

After calibration, the UVQ model was then used to determine the storage size requirements. UVQ is based on a daily time step. Annual reliability data was used to determine required storage capacity for the different feasible end use demand and storage options. This was used as the key indicator for determining storage capacity as it provides a simplistic method to assess the performance of the stormwater use scheme. The term "annual reliability" in this model is a measure of the demand volume that was supplied in the modelled year. The term "average annual reliability" in the UVQ model is the average value of the annual reliability measured for each year that was simulated.

An 80% average annual reliability was selected for this case study to maximise the amount of stormwater utilised for each option. This equated to maximising the reduction in mains water consumption within the constraints of each stormwater use scheme option. For the case study, when reliability of the stormwater supply was less than 100%, the existing water supply system was assumed to be connected to the stormwater use system as a backup supply to meet deficient end use demand.

UVQ was run a number of times to simulate the different feasible end use demand options (Section 5.3.4) and storage options (Section 5.4.1.4). The feasible end uses that were modelled for the case study were outdoor non-potable demand, outdoor non-potable and indoor non-potable demand, indoor non-potable demand only and all end uses demand including indoor potable. The four feasible storage options required only two types of storage systems to be modelled. These two systems were an open storage system which had an exposed surface and a closed storage system which had no exposed surface. The closed storage system represented both above-ground closed storage and underground storage. The exposed surface of the open storage system meant that additional storage capacity was required to account for evaporation of the stored water.

The feasible storage options at the different storage sites required the consideration of the largest storage size that could be fitted at each site. The largest storage size that could fit within the stormwater reserve site was approximately 500 kL. The Tom O’Brien Reserve storage site area was not as limited, and theoretically could fit an open storage system having land take of up to 8.4 ha. Realistically, the smallest amount of land take required was seen as the preferable option.

5.4.2.1 Simulation of Outdoor or Outdoor and Indoor Non-Potable Demand with Closed Storage

Outdoor (garden irrigation) was initially examined as the end use demand which was supplied by stormwater. A trial and error methodology was used to determine required storage capacity. Storage volumes were inputted and run in the UVQ model until an 80% annual average reliability was obtained. This resulted in 3,000 kL storage capacity for closed storage supplying residential outdoor demand being required at the Tom O’Brien Reserve.

The storage option located on the stormwater reserve was approached in a different manner. As the maximum storage capacity for this site was 500 kL, an 80% annual reliability could not be achieved. Therefore, the annual average reliability of 47% was noted for the storage capacity of 500 kL supplying outdoor demand at the stormwater reserve site and examined at a later stage (Section 5.8), taking into account that the intended reliability was not achieved.

Stormwater to supply outdoor (garden irrigation) and indoor non-potable (toilet flushing) demand was the next end use option examined. The trial and error methodology was used to determine that a 4,000 kL storage capacity system was required for the closed storage system supplying these demands. As with the simulation of outdoor demand, an 80% annual reliability could not be achieved for the 500 kL storage capacity system located on the stormwater reserve. Due to the different end use demand pattern, an annual average reliability of 50% could be achieved and was therefore noted for supplying outdoor and indoor non-potable demand with this storage capacity.

5.4.2.2 Simulation of Outdoor or Outdoor and Indoor Non-Potable Demand with Open Storage

The methodology to determine open storage capacity requirements was similar to determining closed storage capacity requirements, except there were two unknown variables of storage capacity and exposed surface. UVQ was therefore run a number of times to obtain average annual reliability for different storage capacities and exposed surfaces, initially examining only outdoor demand. These values are shown in Table 5.12. The average annual reliability was plotted against the storage capacity for different areas of exposed surface and is shown in Figure 5.12. The average annual reliability reached a plateau with storage capacity between around 7,000 to 13,000 kL for the different amounts of exposed surface area. Above this volume, the average annual reliability increased only slightly. At lower storage capacities, an increase in the amount of exposed surface decreased the average annual reliability.

Figure 5.12 was used to determine the exposed surface area that would be modelled for the open storage option supplying outdoor demand within the Tom O'Brien Reserve. As can be seen from Figure 5.12, to obtain 80% average annual reliability, a storage capacity between 3,500 kL to 6,000 kL for open storage was required. An exposed surface area of 2,000 m^2 was selected as this value minimised land take requirements while ensuring a reasonable depth of the storage system. UVQ was then run for open storage with an exposed surface area of 2,000 m^2 and through trial and error, the required storage capacity to achieve 80% average annual reliability was determined as 4,200 kL.

Table 5.12 Storage Capacity and Average Annual Reliability for Different Exposed Surface Areas

Storage capacity kL	Average annual reliability % (no exposed surface – closed storage)	Average annual reliability % (1000 m^2 exposed surface)	Average annual reliability % (2000 m^2 exposed surface)	Average annual reliability % (5000 m^2 exposed surface)
500	47	45	42	36
1000	60	57	54	47
2000	72	69	66	58
3000	80	76	73	65
4000	86	82	79	71
5000	91	87	84	76
6000	93	91	88	80
7000	93	93	91	84
8000	94	93	93	87
9000	94	94	93	89
10000	94	94	94	91
12000	94	94	94	93
14000	94	94	94	94
16000	94	94	94	94

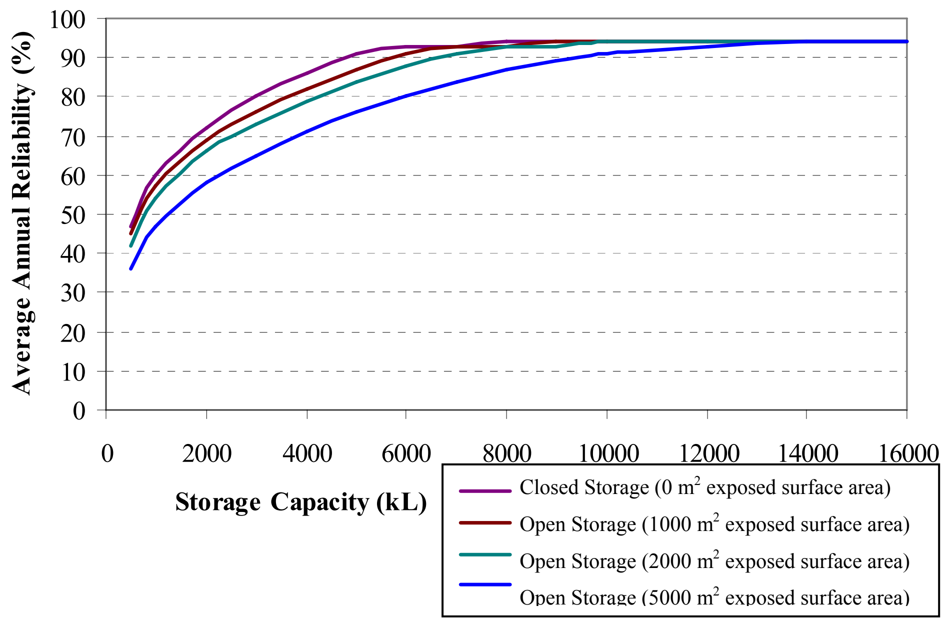


Figure 5.12 Storage Capacity versus Average Annual Reliability for Case Study which meets Outdoor Demand

An exposed surface area of 2,000 m^2 was also selected for the open storage option supplying both outdoor and indoor non-potable demand within the Tom O'Brien Reserve. Through trial and error, the required storage capacity was determined as 5,300 kL for this option.

5.4.2.3 SIMULATION OF INDOOR NON-POTABLE DEMAND WITH CLOSED STORAGE

Examination of indoor non-potable demand consisted of selecting toilet flushing as the only end use demand to be supplied with stormwater. Trial and error simulation of the case study area determined that 110 kL closed storage capacity was sufficient to obtain an 80% annual average reliability. This storage capacity would fit both within the Tom O'Brien Reserve and stormwater reserve storage areas. Since the storage capacity was so small and could easily be contained within a closed system, open storage was not examined for indoor non-potable demand.

The 110 kL required storage capacity was much smaller than for other end use demands since the quantity of water to be supplied was less and the constant demand meant the storage would be regularly utilised thereby requiring less storage capacity. The small storage size meant that there would be large amounts of stormwater spillage and less stormwater utilisation than for the other options.

5.4.2.4 SIMULATION OF ALL END USE DEMANDS WITH CLOSED STORAGE

The end use options for modelling stormwater utilisation at the cluster scale in UVQ only allowed garden irrigation or toilet flushing as possible options. The model could be adapted to simulate all end use options by modelling rainwater tanks at each individual lot which was supplied by stormwater. As this project was not examining rainwater tanks or lot scale technology, an alternative method was used to model stormwater supply to all end use demands. The method used for the case study was to input the total indoor end use water demand (203.4 L/capita/day – Appendix E3) into the toilet indoor water usage field (Appendix G). This method meant all end use demands were modelled as being supplied by stormwater.

Through trial and error, it was determined that the maximum average annual reliability that could be reached for stormwater supplying all end use demands was 78%. The minimum required storage to reach this reliability was 10,000 kL and beyond this capacity, the average annual reliability could not be improved. This storage capacity was selected as the required storage capacity for supplying all end use demands, even though the intended reliability was not quite achieved.

Open storage was not examined for supplying all end use demands as it was assumed it would be difficult to control quality issues with a large storage system, particularly for potable quality requirements. Additionally, the large storage capacity would be more suited to being placed underground to minimise land take.

5.4.2.5 Summary of Storage Capacity Requirements for Simulated Options

The selected storage systems and required storage capacities are summarised in Table 5.13. Table 5.13 also shows the minimum annual reliability for the different storage options. Since average annual reliability was a measure of the average reliability for each year that was modelled, the minimum annual reliability was the year that obtained the lowest reliability. The minimum annual reliability showed that there was less variation in the reliability for supply of indoor non-potable and potable use compared to outdoor demand requirements, as indoor demand were relatively constant. Table 5.13 also shows the average quantity of stormwater that was utilised for each storage option.

Table 5.13 Storage Options for Case Study

Storage Option	End use(s)	Storage capacity (kL)	Average annual reliability (%)	Minimum annual reliability (%)	Average use of stormwater (kL/year)
Above-ground or underground closed storage in Tom O'Brien Reserve	Outdoor	3,000	80	47	7,596
	Indoor non-potable	110	80	73	3,231
	Outdoor and indoor non-potable	4,000	80	55	10,850
	All end uses	10,000	78	49	18,500
Open storage in Tom O'Brien Reserve	Outdoor	4,200 (2,000 m^2 exposed surface area)	80	50	7,627
	Outdoor and indoor non-potable	5,300 (2,000 m^2 exposed surface area)	80	56	10,784
Closed storage in stormwater reserve	Outdoor	500	47	32	4,489
	Indoor non-potable	110	80	73	3,231
	Outdoor and indoor non-potable	500	50	38	6,742

5.5 TREATMENT

The methodology that was used to determine the treatment requirements for this case study was initially based on implemented case studies (Section 4.4.3.4), followed by examining small scale on-site effluent treatment systems (Section 4.4.3.1). For irrigation and non-potable residential uses, existing stormwater use schemes have implemented treatment systems which include initial screening, followed by a wetland or infiltration system and disinfection (Hatt et al., 2004). This system was therefore selected as the treatment system in the case study for outdoor and/or non-potable end uses and would be used to treat the stormwater to Environmental Protection Authority Victoria (EPA Victoria) Class A requirements (EPA Victoria, 2002). Since the decision making framework is for the planning stage of a project, detailed treatment designs were not required. In particular, the size of the wetland was not required as generalised cost comparison tools which are based on the collection area, rather than the size of the wetland could be used (Section 5.8).

Wetlands were the more commonly used treatment systems when larger space was available for placing a treatment system (Hatt et al., 2004). While a wetland could fit within the Tom O'Brien Reserve, this would leave minimal recreational space. Therefore, because of the space constraints of the case study, small scale on-site effluent treatment systems were also examined for the case study area. Small scale on-site effluent treatment systems were assumed to be able to be designed to treat the stormwater to potable water standards for the case study.

The capabilities of small scale on-site effluent treatment technologies were quite difficult to determine as there has been minimal or no work on these treatment systems for stormwater utilisation. A number of small scale wastewater treatment systems have been implemented (Radcliffe, 2004). However, these systems were based on biological treatment systems which require constant and high levels of biological contaminants for the treatment system to work effectively. Physical and chemical treatment processes in the small scale on-site effluent treatment system would be more appropriate to treat stormwater, as biological contaminant levels in stormwater are extremely variable.

Physical and chemical treatment processes in a small scale on-site effluent treatment system may include dissolved air floatation, or filtration systems such as microfiltration, ultrafiltration, nanofiltration and reverse osmosis. Chemical pre-treatment is often used to improve the performance of these systems (Aqueous Solutions, 2004). Caution would be required with chemical systems so that there were no harmful residuals left in the water stream after treatment, which cause environmental problems on the receiving waterways. These issues would need to be discussed in consultation with local environmental protection authorities.

Small scale on-site effluent treatment systems had the added difficulty of commercial in-confidence problems when trying to identify the systems which were appropriate for the case study. The difficulties of commercial in-confidence and sensitivity of data meant that no information could be obtained for this research project. One company could not provide costing or layout details due to commercial in-confidence. Another company stated that they had problems with obtaining EPA Victoria approvals due to chemical residues and therefore had no appropriate treatment systems. Additional work to examine small scale treatment systems would require work beyond the scope of this case study. The additional work includes discussions with relevant government authorities including the local environmental protection authority.

The lack of stormwater recycling guidelines and adapting existing recycling guidelines to a risk based approach have meant that industries have had difficulties in developing package or small scale on-site effluent treatment systems. As was found with many of the issues being examined in the project, the information is not easily and readily available for stormwater use implementation. To ensure this information becomes available in the public domain, research or government bodies need to produce summary data while protecting commercial in-confidence. A suggested format may be similar to the life cycle costing information presented in Taylor (2004), with the information expanded to include the technology components or complete systems of small scale on-site effluent treatment systems.

Due to the unavailability of information about small scale on-site effluent treatment systems, the end use demand option which included potable demand was not examined any further in the case study. Therefore three treatment options were examined for supplying outdoor and/or indoor non-potable end uses to Class A water standards (EPA Victoria, 2002). The first two treatment options were wetland systems with UV disinfection. Pre-treatment was either through the infiltration trench, which was used as the collection system, or through stormwater pit entry traps in the stormwater pipe collection system. The final treatment system that was examined was the use of infiltration trenches and UV disinfection, where a wetland would not fit within the available space. In this case, additional treatment may occur in the small 500 kL tank storage system.

5.6 DISTRIBUTION

The methodology to determine feasible distribution options was very similar to collection options. The main difference was that distribution requirements depended on the type of end use as well as the location of the storage and treatment system compared to the end use area. The elevation and location of the end use area in the case study meant that pump assisted flow was required to return the collected water to the end use area. Permeable pavement and infiltration or exfiltration trenches for distribution of the collected water would have only been feasible with gravity distribution and therefore was not considered any further for this case study.

Single or dual pipe distribution systems were examined for this case study. Single pipe distribution would only have been feasible where all end uses were supplied by stormwater, which was determined as not being feasible (Section 5.5). Dual pipe distribution for the case study would consist of constructing a new pipe system for supply of stormwater and maintaining the existing water supply system. Dual pipe distribution was the only feasible distribution option and was examined for the options which had outdoor end use and/or indoor non-potable end use. Detailed design of the distribution system was not conducted. However, proposed layouts of the distribution system to either the Tom O’Brien Reserve or the stormwater reserve were used as the basis for determining costs (Section 5.7 and 5.8). Pipe sizes were estimated from end use demands determined previously (Section 5.3.3).

5.7 INTEGRATION OF TECHNICAL COMPONENTS

There were a number of feasible options for each technical component. In order to determine the feasible stormwater use scheme options for the case study, the feasible technical components were integrated, as shown in Table 5.14. The combination of the feasible technical components resulted in nineteen feasible scheme options. These options are discussed further in Section 5.8.

Table 5.14 Case Study Technical Component Options

Collection type and option	**Storage option**	**End use(s)**	**Neighbourhood storage capacity (kL)**	**Treatment option**	**Distribution type and option**
Gravity flow with pipe or infiltration trench collection	Closed storage in Tom O'Brien Reserve	Outdoor	3,000	Wetlands or infiltration trench to Class A Standards	Pump distribution with dual pipes
		Indoor non-potable	110		
		Outdoor and indoor non-potable	4,000		
	Open storage in Tom O'Brien Reserve	Outdoor	4,200	Wetlands or infiltration trench to Class A Standards	Pump distribution with dual pipes
		Outdoor and indoor non-potable	5,300		
	Closed storage in the stormwater reserve	Outdoor	500	UV treatment with infiltration trench to Class A Standards	
		Indoor non-potable	110		
		Outdoor and indoor non-potable	500		

Figures 5.13 to 5.15 show examples of the layouts of the feasible stormwater use scheme options described in Table 5.14. Figure 5.13 shows infiltration trench collection with storage and treatment located in the stormwater reserve area. Figure 5.14 shows the layout of the stormwater use scheme options which had gravity collection with pipes, open or closed storage in the Tom O'Brien Reserve, a wetland treatment system, and pump distribution with dual pipes. Only the stormwater reticulation system is shown. The existing water supply system is not shown. Figure 5.15 is the same as Figure 5.14 except that infiltration trenches for collection are shown.

The integration of the technical components described in Table 5.14 and shown in Figures 5.13 to 5.15 was examined to identify optimisation of the stormwater use scheme. The focus was to identify areas where different technical components could be minimised through the integration of the technical component options. Infiltration trenches used to collect the stormwater reduced treatment requirements. This meant that the amount of pre-treatment was reduced compared to pipe collection for the case study.

In terms of storage and treatment, the capacity of wetlands could be increased to act as a storage system. This may require redesign of the wetland system to take into account the impact on treatment processes with the increased storage capacity. Closed storage also minimised treatment requirements as there were no additional contaminants entering the system. Finally, large storage systems with long retention times or series based storage systems could act as a sedimentation treatment system. This could therefore reduce treatment requirements.

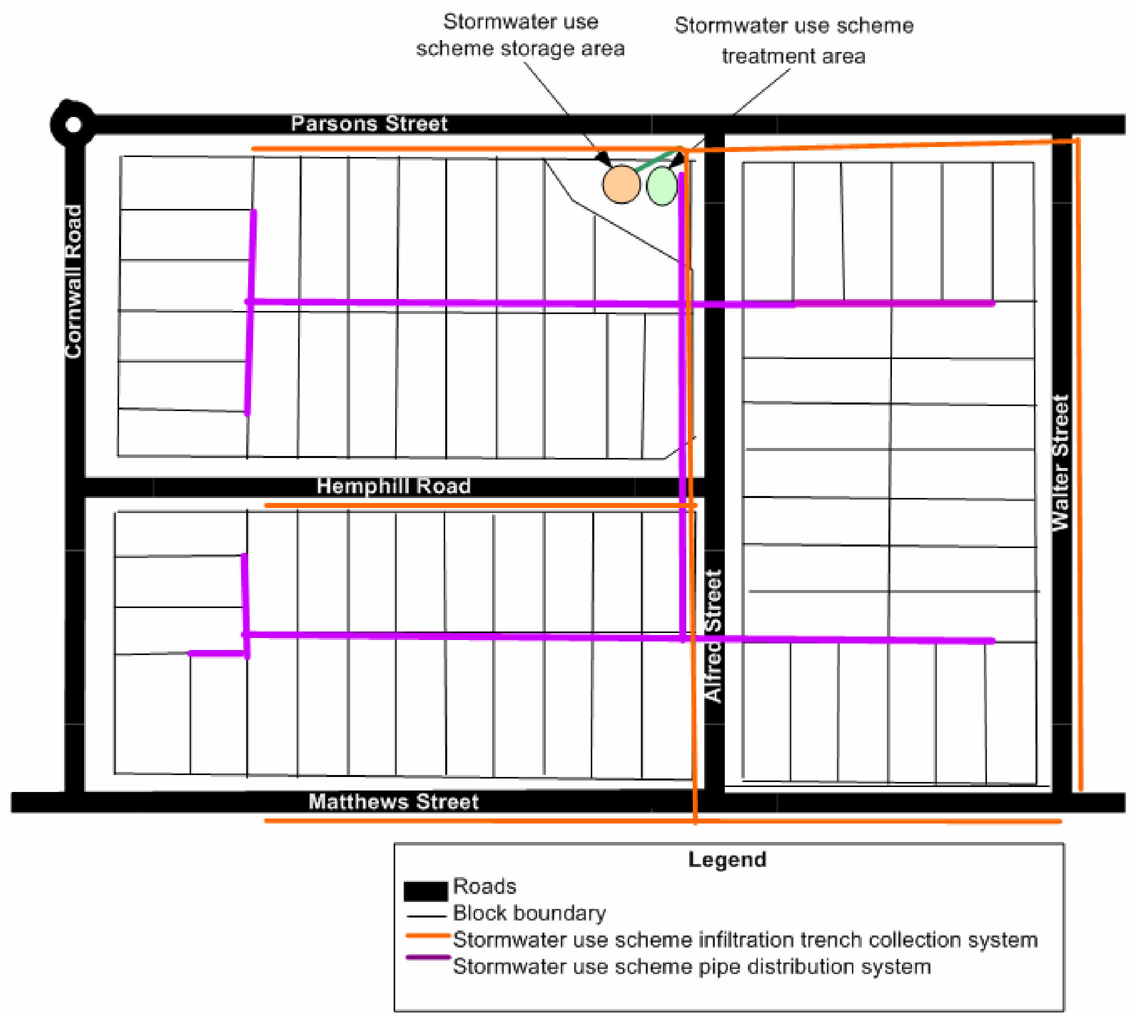


Figure 5.13 Stormwater Use Scheme Option Layout with Infiltration Trench Collection, Storage in Stormwater Reserve, Disinfection Treatment and Pipe Distribution

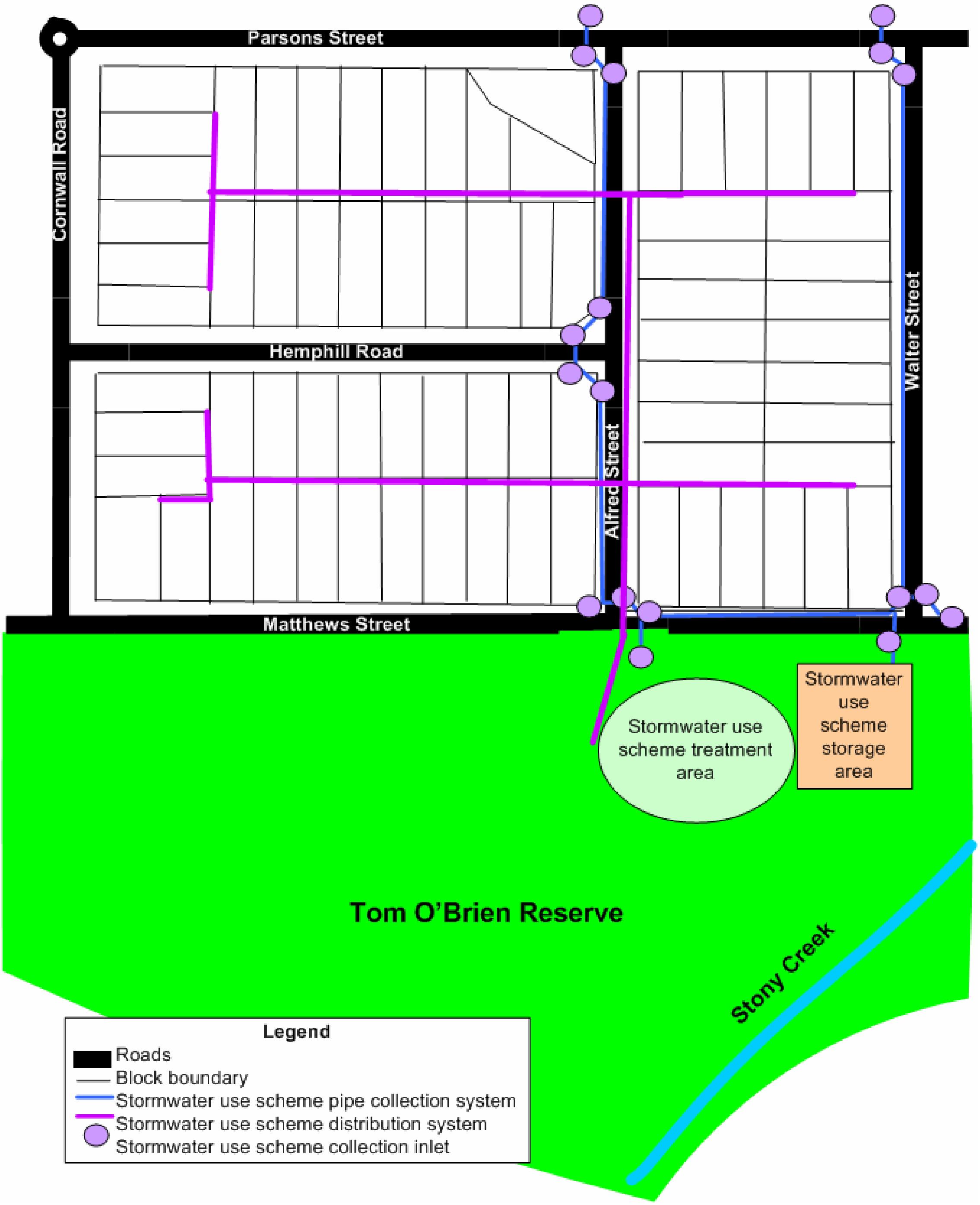


Figure 5.14 Stormwater Use Scheme Option Layout with Pipe Collection, Storage in Tom O'Brien Reserve, Wetland Treatment and Pipe Distribution

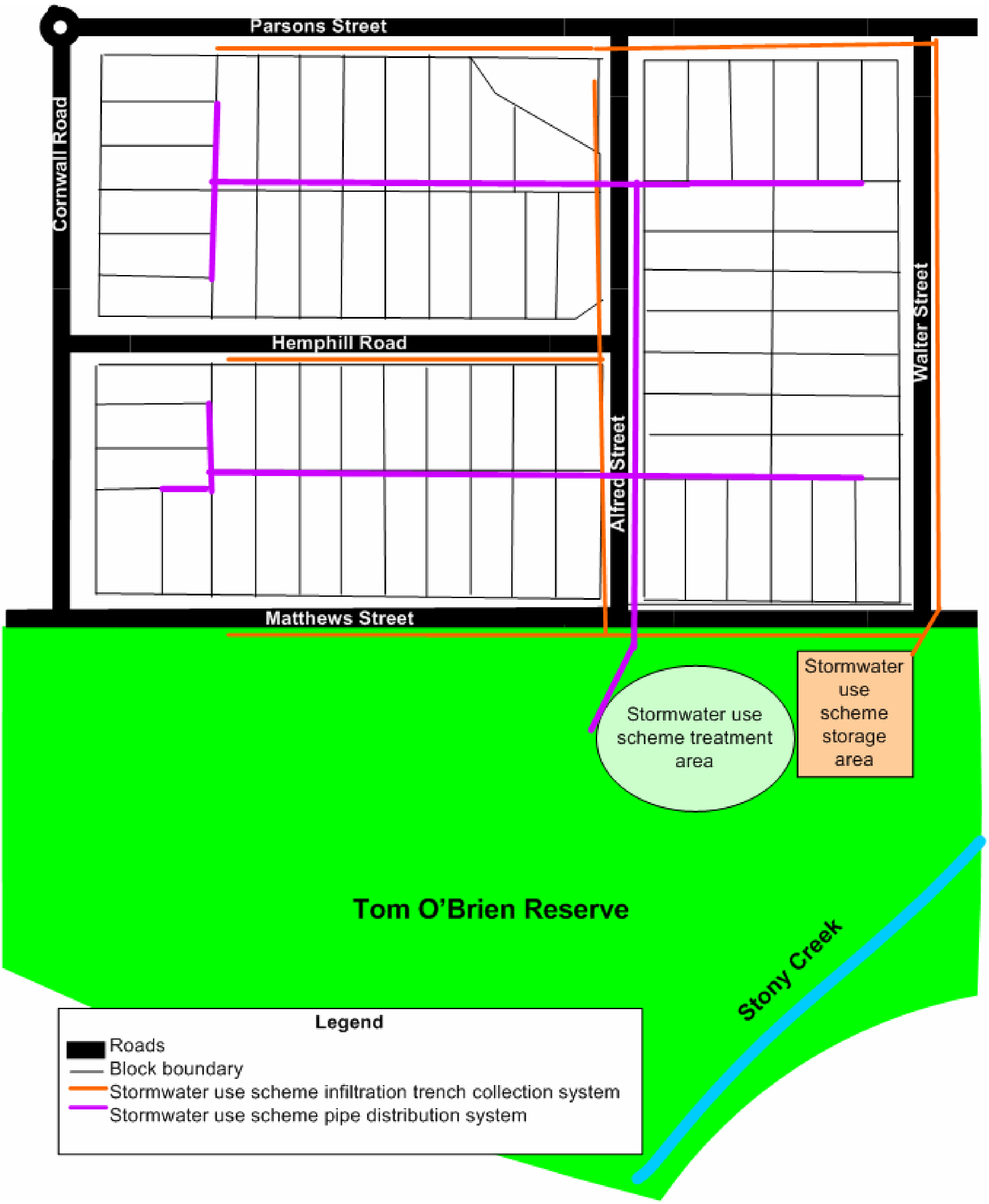


Figure 5.15 Stormwater Use Scheme Option Layout with Infiltration Trench Collection, Storage in Tom O'Brien Reserve, Wetland Treatment and Pipe Distribution

5.8 FINANCIAL COSTS

The financial costs included costing of the different technical components (Section 4.4.6). Appendix B contains an overview of the issues and components that would need to be costed for each stormwater use scheme option. The financial costs were based on the following five items:

- Pumping and transport
- Excavation and compaction
- Materials, construction and installation
- Land take and opportunity costs
- Maintenance

Not all components required the consideration of all above items for the case study. For example, the collection systems do not require costing of any pumping or transport items. Operation costs would also be required. In this case study, operation costs were minimal and therefore included as maintenance costs. A bill of quantities was set up in Excel to determine the costs for the nineteen stormwater use scheme option shown in Table 5.14.

A base case where there was no stormwater use was also costed. The base case consisted of costing construction of stormwater pipes and included an in-line pipe treatment system based on costs in Rawlinsons Group (2003). Detailed cost estimates are provided in Appendix H. Taylor (2004), Rawlinsons Group (2003), G. Chapman-Hill (2004, pers. comm., Pioneer Water Tank Quote, 23 August) and Southern Plumbing Plus (2005, pers. comm., Plumbing Supply Quote, 25 June) were used to estimate costs of the feasible technical components for the case study (Table H.1) with a summary of the component option costs provided in Table H.2. The technical component costs were then integrated to determine the stormwater use scheme option costs (Table H.3). A summary of the stormwater use scheme option costs are shown in Table 5.15.

Table 5.15 Summary of Cost Estimates for Case Study

Collection option	Storage option		**End use option**	Treatment option	Distribution option	Minimum annual reliability %	Average annual reliability %	Average use of stormwater kL/year	Stormwater use scheme option	**TOTAL $**
No Stormwater Use						0	0	0	Base Case	**$88,659**
Pipe	Tom O'Brien Reserve	Above-ground closed	**Outdoor**	Wetland	Dual	47	80	7,596	01	**$605,791**
Pipe	Tom O'Brien Reserve	Above-ground closed	**Indoor non-potable**	Wetland	Dual	73	80	3,231	02	**$270,474**
Pipe	Tom O'Brien Reserve	Above-ground closed	**Outdoor and indoor non-potable**	Wetland	Dual	55	80	10,850	03	**$779,268**
Pipe	Tom O'Brien Reserve	Underground	**Outdoor**	Wetland	Dual	47	80	7,596	04	**$682,560**
Pipe	Tom O'Brien Reserve	Underground	**Indoor non-potable**	Wetland	Dual	73	80	3,231	05	**$271,157**
Pipe	Tom O'Brien Reserve	Underground	**Outdoor and indoor non-potable**	Wetland	Dual	55	80	10,850	06	**$874,865**
Pipe	Tom O'Brien Reserve	In-ground open	**Outdoor**	Wetland	Dual	50	80	7,627	07	**$383,640**
Pipe	Tom O'Brien Reserve	In-ground open	**Outdoor and indoor non-potable**	Wetland	Dual	56	80	10,784	08	**$467,052**
Infiltration	Tom O'Brien Reserve	Above-ground closed	**Outdoor**	Wetland	Dual	47	80	7,596	09	**$639,291**
Infiltration	Tom O'Brien Reserve	Above-ground closed	**Indoor non-potable**	Wetland	Dual	73	80	3,231	10	**$303,975**
Infiltration	Tom O'Brien Reserve	Above-ground closed	**Outdoor and indoor non-potable**	Wetland	Dual	55	80	10,850	11	**$812,769**
Infiltration	Tom O'Brien Reserve	Underground	**Outdoor**	Wetland	Dual	47	80	7,596	12	**$716,061**
Infiltration	Tom O'Brien Reserve	Underground	**Indoor non-potable**	Wetland	Dual	73	80	3,231	13	**$304,658**
Infiltration	Tom O'Brien Reserve	Underground	**Outdoor and indoor non-potable**	Wetland	Dual	55	80	10,850	14	**$908,366**
Infiltration	Tom O'Brien Reserve	In-ground open	**Outdoor**	Wetland	Dual	50	80	7,627	15	**$417,141**
Infiltration	Tom O'Brien Reserve	In-ground open	**Outdoor and indoor non-potable**	Wetland	Dual	56	80	10,784	16	**$500,552**
Infiltration	Stormwater reserve	Above-ground closed	**Outdoor**	Infiltration trench and disinfection	Dual	32	47	4,489	17	**$214,081**
Infiltration	Stormwater reserve	Above-ground closed	**Indoor non-potable**	Infiltration trench and disinfection	Dual	73	80	3,231	18	**$209,401**
Infiltration	Stormwater reserve	Above-ground closed	**Outdoor and indoor non-potable**	Infiltration trench and disinfection	Dual	38	50	6,742	19	**$254,863**

Detailed designs of each stormwater use scheme option were not required for the decision making framework, as this framework is for the planning stage of design. Approximate guideline values were sufficient to compare the feasible scheme options. For example, the required wetland size did not need to be determined. The case study area (6.12 ha) was used as the basis to determine wetland construction costs based on the wetland cost per hectare of collection. Pipe or infiltration costs were estimated with the proposed pipe layouts (Figures 5.13 to 5.15) and stormwater pipe sizes estimated using the rational method (Institution of Engineers Australia, 1987).

The financial costs in Table 5.15 were then examined in terms of end use demands that were met, reliability of supply and financial viability. In order to include the benefits of reducing mains water consumption, the average annual reliability and average use of stormwater were used as criterion. With no other environmental or social information available, this would be equivalent to the amount of mains water reduced each year. As average annual reliability is 80% for almost all options, minimum annual reliability (the year that obtained the lowest volumetric reliability) was used to compare the reliability of supply. Figures 5.16 to 5.18 show the cost, minimum annual reliability and average use of stormwater respectively for each stormwater use scheme option. The stormwater use scheme option number is included beside each data point. The different end uses supplied are grouped together to identify costs, reliability and stormwater use for comparable options which supply similar end use demands.

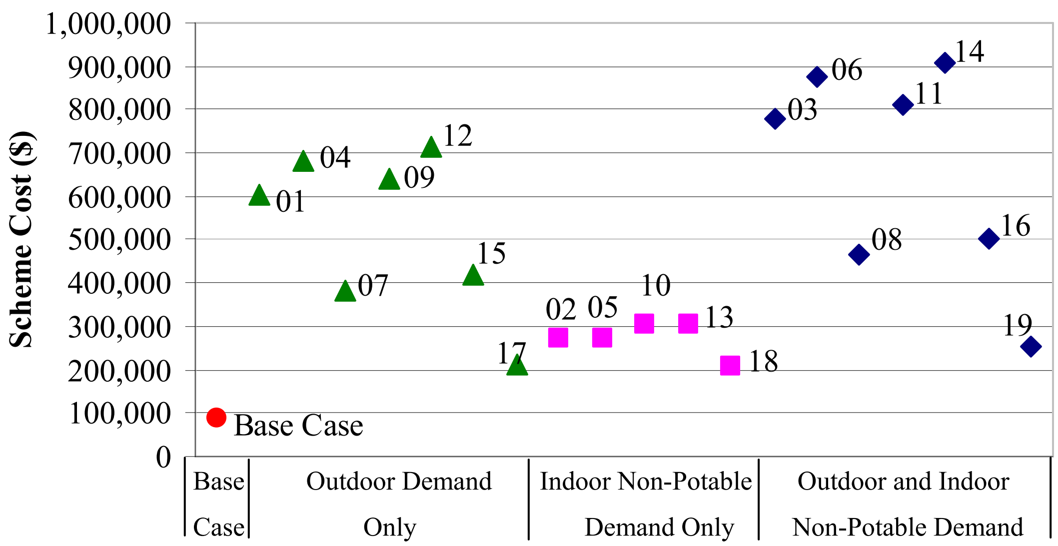


Figure 5.16 Costs versus End Use Demand for Stormwater Use Scheme Options

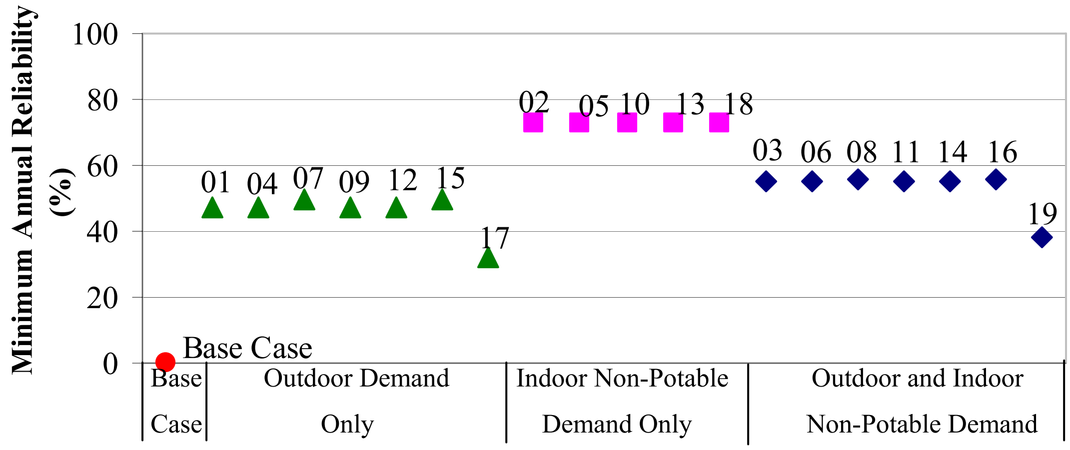


Figure 5.17 Minimum Annual Reliability versus End Use Demand for Stormwater Use Scheme Options

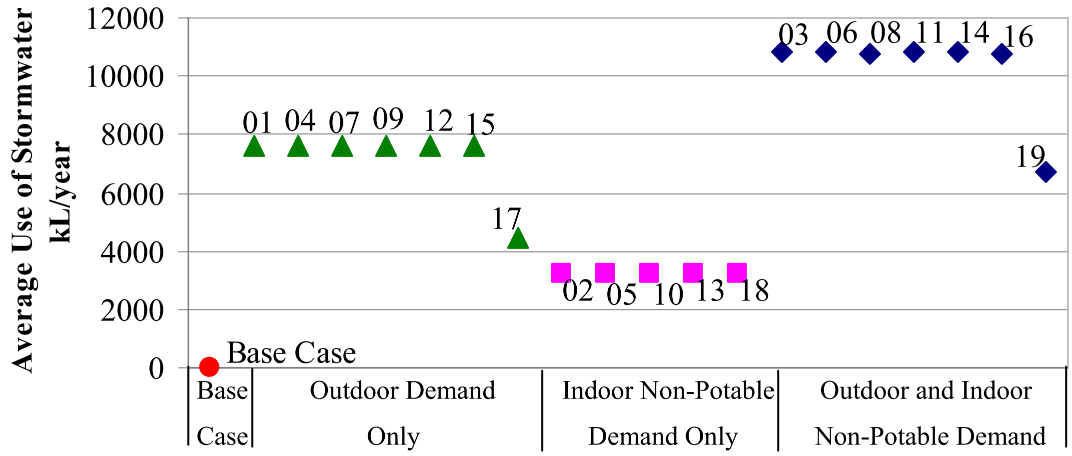


Figure 5.18 Average Use of Stormwater versus End Use Demand for Stormwater Use Scheme Options

Figure 5.16 shows that stormwater use scheme options 17 and 18 were the cheapest option in financial terms, excluding the base case. However, option 18 only supplied toilet flushing requirements and utilised the lowest amount of stormwater (Figure 5.18). All options which supplied indoor non-potable demand only (stormwater use scheme options number 02, 05, 10, 13 and 18) were inferior due to the small quantities of stormwater that were utilised.

Options 17 and 19 were the cheapest options that supplied outdoor demand only and outdoor and indoor non-potable demand respectively. However, options 17 and 19 had the lowest annual reliabilities (Figure 5.17) and did not achieve the intended average annual reliability of 80%, instead only achieving average annual reliabilities of 47% and 50% respectively (Table 5.15). These values reinforced the fact the less stormwater was utilised with these options. As additional economic and environmental benefits were not examined for this case study, stormwater use scheme options 17 and 19 were determined as inferior due to the reliability and quantity of stormwater used and would not be implemented.

Stormwater use scheme options 07 and 08 were the most cost effective options that respectively supplied outdoor demand only, and outdoor and indoor non-potable demand, while achieving the required average annual reliability. These scheme options also had the highest minimum reliability and average yearly volume of stormwater utilised for those end use demands. Scheme options 15 and 16 were also comparable. Therefore, stormwater use scheme options 07, 08, 15 and 16 were the superior options. Due to the difference in costs between stormwater use scheme options 07 and 08 not being very substantial, the additional benefit of supplying indoor non-potable demand as well as outdoor demand would mean scheme option 08 may be the preferred stormwater use scheme option. The superior options would need to be examined in terms of wider issues and benefits, to determine the most suitable option. Examination of these options in the broader context of environmental, social and economic terms is discussed further in Section 5.9.

The decision making framework was developed as a planning tool. Therefore, the superior options would be examined in further detail after implementation of the decision making framework. Funding of the case study would either have been a limited value or be adaptable to the costs that were estimated from the decision making framework. Financial viability may mean that non-inferior stormwater use scheme options could be examined further, as well as the superior scheme options, to ensure that options with high financial costs but higher environmental, social or economic benefits were not disregarded.

5.9 SOCIAL, ENVIRONMENTAL AND ECONOMIC COSTS AND BENEFITS

A detailed analysis of the social, environmental and economic costs and benefits for the case study was beyond the scope of this thesis. However, issues that were relevant for this project were examined briefly.

Social issues included access to the Tom O'Brien Reserve. This reserve was used for recreational needs. However, the recreational value would need to be examined. The close proximity to the train line may mean that recreational value would not be very high. This could minimise problems for locating water storage and treatment requirements within the reserve.

Access to open storage areas and wetlands would need to be examined to minimise safety concerns. Aesthetics of the stormwater use scheme would also be an important issue. Underground storage systems would have minimal aesthetic problems, as they could not be seen. Wetlands and open water bodies could add aesthetic value if managed properly.

Since the case study is in an existing urban area, disruption to the community during the construction phase was also identified as a potential social issue. Methods to minimise these disruptions as well as communicate the construction requirements, should reduce community concerns. This would need to be included in community consultation.

Environmental impacts on Stony Creek would need to be estimated. Removal of stormwater pollutants as well as treatment of stormwater overflow may result in an increase in health of the creek. Peak flows may be reduced and creek flows may begin to be returned to pre-development conditions.

While many of the above issues have been negative costs and concerns, the environmental, social and economic benefits need also to be identified. Potential benefits include minimisation of potable water requirements, reduction in potable water costs, reduction in flooding of properties and aesthetic improvement of the reserve through the addition of water bodies and wetlands. Construction of the stormwater use scheme in conjunction with required drainage infrastructure for the area may also improve attitudes towards the drainage improvements. Community scale issues beyond the case study area include minimising stormwater pollution on receiving water bodies and utilisation of stormwater as a resource.

5.10 COMMUNITY PARTICIPATION, RISK ASSESSMENT AND COORDINATION WITH RELEVANT AUTHORITIES

As with social, environmental and economic issues, detailed examination of community participation, risk assessment and coordination with relevant authorities were beyond the scope of this project. These issues were examined briefly, as described below.

Discussions with relevant water and health authorities would be required to determine which end uses would be appropriate for the stormwater use scheme. These discussions would also identify whether there are treatment systems that would not be appropriate for stormwater use schemes. Examples of issues that would make treatment systems inappropriate are chemical residuals causing environmental concerns or insufficient treatment capabilities to achieve the required end use quality.

Approval of the proposed stormwater use scheme would need to be sought. To ensure resources and money were not wasted, regular discussions should be held with the authorities throughout the planning and implementation stages. This would ensure that too much time would not be invested in stormwater use schemes that would not be approved. Only systems that were potentially feasible and could be approved would be examined in detail. Regular discussions with the relevant authorities would also ensure approval was more easily established as the designer and the authorities would both be aware of the requirements and potential solutions.

Approval of the stormwater use scheme would include approval of the treatment systems to meet required water standards, as well as a monitoring program. Treatment requirements may be optimised by identification of the actual stormwater quality for the area being examined. This would be through stormwater monitoring programs.

Risk assessment would need to be carried out as part of the additional issues of the decision making framework. Risk assessment would be very important in terms of examining stormwater use for potable end uses and risks associated with accidental drinking of non-potable water.

Detailed analysis of providing potable water from stormwater was not examined for this case study. In addition to discussions with relevant water and health authorities, a risk assessment and identification of stormwater quality and verification of associated treatment requirements to meet drinking water standards would be required, if potable end uses were to be supplied from stormwater.

Like most other engineering projects, the case study would not be able to proceed any further without community participation. Social acceptance of the project would direct whether the project would be successful. The effectiveness of the stormwater use scheme would be influenced by community participation and understanding of the project. Community participation would also need to communicate to the community the potential costs and benefits through discussions and education programs.

5.11 SUMMARY

The decision making framework was demonstrated through the use of a case study. This case study was in an existing urban area in the suburb of Sunshine, to the west of the Melbourne central business district, in Victoria, Australia. An existing urban area possesses the greatest potential impact on water sourcing and sustainability issues, and was selected because previous research was focused on greenfield sites. The general study site conditions provided an understanding of the opportunities and limitations within the study site. This included the limited space available in the existing urban area, and the potential collection and end use areas consisting of the residential area and the Tom O’Brien Reserve.

Area characteristics as well as ground conditions were determined for construction purposes. Stormwater quality was estimated from published data as no stormwater monitoring data was available for the area. The end use required quality was identified as Victorian EPA Class A quality.

Stormwater runoff and end use demand were determined and compared with each other and identified that only the residential demand could be met with potential stormwater runoff. Therefore only the residential was examined in further detail. Within residential demand, outdoor, indoor non-potable and indoor potable end use demands were examined in that order in further detail. While all residential demand could not be met, particularly over the summer months, there was insufficient reason to not examine all potential residential end uses in further detail.

The decision making framework assisted in determining feasible options for the different technical components of collection, end use, storage, treatment and distribution. The storage options that were examined in further detail were in-ground open storage, above-ground closed storage and underground storage within the Tom O'Brien Reserve, as well as above-ground closed storage on the stormwater reserve. The UVQ modelling tool was used to estimate the storage capacities that were required to produce an average annual reliability of 80%.

Treatment options that were identified were a wetland system in conjunction with pre-treatment and disinfection, as well as small scale on-site effluent treatment systems. However, commercial in-confidence issues and impacts of chemical residuals on receiving waterways meant that the small scale on-site effluent treatment systems could not be examined further. Feasible distribution options were identified as dual pipes for non-potable end uses and single pipe for all end uses. Since all end uses including indoor potable demand were not examined due to difficulties with package treatment systems, only the dual pipe distribution was examined in further detail.

The feasible technical components were then integrated to determine nineteen feasible stormwater use scheme options. This integration was the key to developing a holistic decision making framework. The integration of the technical components also identified opportunities to optimise the stormwater use scheme options through minimising treatment and land take opportunities.

Comparison of all the stormwater use scheme options based on financial costs determined that scheme option 08 was the most effective option in terms of reliability, quantity of stormwater used and end uses met. This option supplied outdoor and indoor non-potable demand with the use of an in-ground open storage system, wetland system with pre-treatment and disinfection, pipe collection and dual pipe distribution. However, stormwater use scheme options 07, 15 and 16 were also superior in terms of costs, reliability and use of stormwater compared to the other scheme options. These options would likely have had additional environmental, social and economic issues. However, issues additional to technical issues were only examined briefly, due to the limitations of the scope of this project. Community participation, risk assessment and coordination with relevant authorities were also examined briefly.

CHAPTER 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY AND CONCLUSIONS

This research project developed a decision making framework to assist decision makers to use an integrated approach for determining the most appropriate stormwater use scheme option, taking into account local conditions, attitudes and constraints. The decision makers for this project are council workers, land developers and engineers. In order to develop an integrated decision making framework, this project analysed the technical components of a stormwater use scheme, generated possible stormwater use scheme options, developed tools to screen out inferior or infeasible options and demonstrated the use of the decision making framework through a case study. Section 6.1 provides a summary of the work conducted and the conclusions arisen from this work.

6.1.1 LITERATURE REVIEW

Review of the literature examined past, current and future stormwater management practices including utilisation of stormwater. The first conclusion from the literature review was that the four main technical components of collection, storage, treatment and distribution needed to be examined in an integrated manner for implementation of a stormwater use scheme. There were a number of benefits or motivators of stormwater use including reduced potable water main demand and high public support for stormwater use. Conversely, there were a number of barriers to implementation of stormwater use schemes including biased costing comparisons, quality and health concerns and uncertainties in legal implications and responsibilities. The research gaps that were identified from the literature review and used as the basis for the development and demonstration of the decision making framework included limited research into stormwater use in existing urban areas, application of small scale on-site effluent treatment systems to stormwater use and the research to date failing to develop a holistic approach to stormwater use schemes.

6.1.2 OVERVIEW OF A STORMWATER USE SCHEME

The focus of the decision making framework was on the technical components of cluster scale stormwater use schemes in urban areas. Key ideas of the framework were presented as providing access to relevant information in an easy to access location and demonstrating the potential for stormwater use in an existing urban area. The decision making framework was developed based on scientific and practical knowledge that was available during the development of the framework, while being adaptive enough to include future scientific and practical knowledge, as it becomes available.

Possible stormwater use scheme options were generated using collection, storage, treatment, distribution and end use technical components and associated issues. Infeasible or inferior scheme options were initially screened out on the basis of current environmental, social and economic issues that were relevant for all study sites. This meant that some of the stormwater use schemes that were screened out as infeasible for this point in time may become feasible in the future. After initial screening, there were approximately 40 possible stormwater use scheme options. The schemes that were screened out as infeasible were as follows:

- Delivery of potable water to the household through trucks or bottle water;
- Using stormwater as a potable water source where regulatory prohibitions do not allow for stormwater to supply potable water demands;
- Collection and utilisation of roofwater and stormwater (plus any roof runoff overflow) in separate systems for existing urban areas; and
- End uses based on specific end uses such as shower or bathroom taps rather than water quality and infrastructure requirements.

A description of the technical components and associated issues relevant to stormwater use schemes was provided in Chapter 3. Three zonal types for the research project were designated as greenfield, redevelopment and large infill areas; existing urban areas; or a combination of zonal type areas. Collection options used pump assisted or gravity flow.

Collection options that were examined were surface or overland flows, infiltration trenches, permeable pavements and pipe collection. This research project specified possible end uses as residential outdoor, residential indoor non-potable, residential indoor potable and community scale irrigation. Possible storage options examined in this research project were aquifer storage and recovery, in-ground open storage, above-ground closed storage, underground storage and existing water bodies. Gravity or pump assisted flow distribution options examined were infiltration or exfiltration trenches, permeable pavements and single or dual pipes. The technical components (collection, storage, treatment and distribution) and associated issues were included as the main components of the decision making framework.

6.1.3 DECISION MAKING FRAMEWORK

The decision making framework was described in detail in Chapter 4. The framework was developed to examine the feasible technical components of a stormwater use scheme to determine the most appropriate or superior stormwater use scheme option. The decision making framework consists of eleven steps. Screening tools based on technical issues as well as environmental, social and economic issues are included in each step of the decision making framework. These additional screening tools are implemented on a case-by-case basis as screening is specific to each study site. Additional screening includes insufficient quantity of water or insufficient space for storage or treatment.

The steps of the decision making framework are based around compiling information and determining feasible options for the technical components and associated issues. Steps 1 to 6 in the decision making framework relate to collection and end use issues. General study site conditions, collection options and the quantity and quality of collected stormwater are determined. The type of end use and end use demand and required quality is also determined. The initial six steps of the decision making framework are based around matching stormwater runoff to demand and matching stormwater quality to required quality. The relationship between stormwater quality and required end use quality is related to treatment requirements.

The storage, treatment and distribution options, as described in Section 6.1.2, were examined in detail in Chapter 4. The feasibility of the storage, treatment and distribution options for the study site is determined in Steps 7 to 9 of the decision making framework. Storage requirements are also estimated in Step 7. Determination of treatment requirements is based on either contaminant removal rates, end use requirements or case studies. Determination of treatment requirements based on case studies is the recommended system for the decision making framework due to the information and resources available at the current point in time.

Step 10 of the decision making framework focuses on the integration of all of the technical components and associated issues. The technical components analysed in the previous steps is integrated to develop feasible stormwater use scheme options. Integration of the technical components also provides opportunities to optimise the stormwater use scheme options through examining quantity issues, quality issues and multiple functions of technical components.

The feasible stormwater use scheme options are compared in Step 11 of the decision making framework based on financial costs and associated issues such as reliability of supply, end use demands met and quantity of stormwater utilised. Issues additional to technical issues are also briefly examined. These issues include social, environmental and economic costs and benefits. Additionally, community participation, risk assessment and coordination with relevant authorities may influence the feasibility of implementing a stormwater use scheme and therefore are also briefly examined.

6.1.4 DEMONSTRATION OF THE DECISION MAKING FRAMEWORK

This decision making framework was demonstrated with the use of a case study located in the suburb of Sunshine, to the west of the Melbourne central business district, in Victoria, Australia. An existing urban area was chosen for the case study as existing urban areas have the potential to impact greatly on water use in urban areas.

The case study general study site conditions were examined. The existing urban area zonal type consisted of a residential and open space area (i.e. Tom O'Brien Reserve). It also had a stormwater reserve. The residential area was determined as the collection and end use area, with the open space area only examined as a potential end use area. The sizes and characteristics of a typical residential block and overview data of the collection and end use areas were determined.

Potential stormwater runoff from the collection area as well as end use demand was determined utilising methods described in the decision making framework. Stormwater runoff and end use demand was then compared. This comparison determined that a partial and limited amount of the community scale irrigation demand for the Tom O'Brien Reserve open space area could be met and was therefore not examined in further detail. Only residential demands supplied by stormwater with all other demands supplied by the existing water supply system were examined. The end use demand options that were investigated were outdoor demand only, indoor non-potable demand only, outdoor and indoor non-potable demand or all residential demand.

The quality of the stormwater collected was estimated from Duncan (2003). EPA Victoria (2002) was used as the basis for end use quality for non-potable demand. NHMRC and NRMMC (2002) was used to establish potable end use demand quality requirements. The collection options that were determined to be feasible were gravity flow using pipe collection or infiltration trenches.

Four feasible storage options were determined for the case study area as in-ground open storage, above-ground closed storage or underground storage within the Tom O'Brien Reserve, or above-ground closed storage within the stormwater reserve. Urban Volume and Quality – UVQ (Mitchell et al., 2003) to determine required storage capacity to provide a volumetric average annual reliability of 80%. Required storage capacity varied between 110 kL and 5,300 kL for the different storage and end use demand options. Due to space constraints, above-ground closed storage within the stormwater reserve could not meet the proposed average annual reliability. Since annual reliability was a measure of the average reliability for each year that was modelled, the year that obtained the lowest reliability (minimum annual reliability) and the average quantity of stormwater that was utilised was used as a measure of the performance of the stormwater use scheme options.

Treatment requirements were then examined. Due to the unavailability of information about small scale on-site effluent treatment systems, the end use demand option which included potable demand was not examined any further in the case study. The treatment system, with initial screening, followed by a wetland or infiltration system and disinfection, was examined as the treatment option for supplying outdoor and/or indoor non-potable end uses. Dual pipes with pump distribution were determined as the only feasible distribution option for the case study.

The integration of the feasible collection, storage, treatment and distribution components determined there were nineteen feasible stormwater use scheme options. Integration of the technical components identified that the stormwater use scheme could be optimised by minimising treatment requirements when infiltration trenches were used for collection, compared to pipe collection.

The feasible stormwater use scheme options, as well as the base case with no stormwater use, were compared on the basis of financial cost, reliability of supply and quantity of stormwater utilised. This comparison determined that the stormwater use scheme options supplying indoor non-potable demand only were inferior. Stormwater use scheme option 08 was the most superior option and supplied outdoor and indoor non-potable demand with the use of an in-ground open storage system, wetland system with pre-treatment and disinfection, pipe collection and dual pipe distribution. However, stormwater use scheme options 07, 15 and 16 were also superior in terms of costs, reliability and use of stormwater compared to the other scheme options. These options supplied outdoor only or outdoor and indoor non-potable demand with either a pipe or infiltration collection system.

Possible environmental, social and economic costs and benefits were briefly examined for the case study. Community participation, risk assessment and coordination with relevant authorities were also examined briefly. The case study demonstrated how the decision making framework could be utilised to examine opportunities with stormwater through planning stormwater use schemes to replace drainage systems when these systems need to be upgraded or replaced for maintenance reasons. The case study also demonstrated the ease of implementing the decision making framework and the benefit of examining stormwater use schemes in an integrated manner.

6.2 RECOMMENDATIONS

The decision making framework is a useful tool for planning and implementation of stormwater use schemes and is proposed to be used as part of the larger context of total water management including social, environmental and economic issues. This ensures the framework provides a holistic view of water resources and decision making. While this research project only examined stormwater use, the decision making framework can be adapted to examine all water sources and the most effective option for implementation.

Based on the findings of this research project, a number of recommendations for future work are proposed. The quality requirements and risk assessment process for identifying these requirements need to be clearly established. Most importantly, the completion of the stormwater reuse and recycling guidelines based on a risk management approach (CRC for Water Quality and Treatment, 2003) would need to be implemented as part of the required end use and treatment components of the decision making framework.

Recommendations for this research project include expanding this decision making framework to identify the optimum scales of stormwater use schemes. Optimisation would find a balance between maintenance and treatment requirements so that costs are not excessive for a study site while ensuring the scheme does not become too large to minimise benefits. An effective yet simple to use costing tool needs to be developed so that all environmental, social and economic costs are determined and actual benefits of stormwater use schemes can be determined. As the decision making framework may be developed in the future, industrial uses can be included within the methodology developed as part of this thesis.

Additional research that includes extended analysis on the potential feasibility of utilising aquifer storage and recovery (ASR) in areas beyond South Australia should also be conducted. This could include research into recommended depths to the aquifer before injection costs become too expensive and the treatment requirements compared to non-ASR systems.

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APPENDICES

APPENDIX A

POSSIBLE STORMWATER USE SCHEME OPTIONS

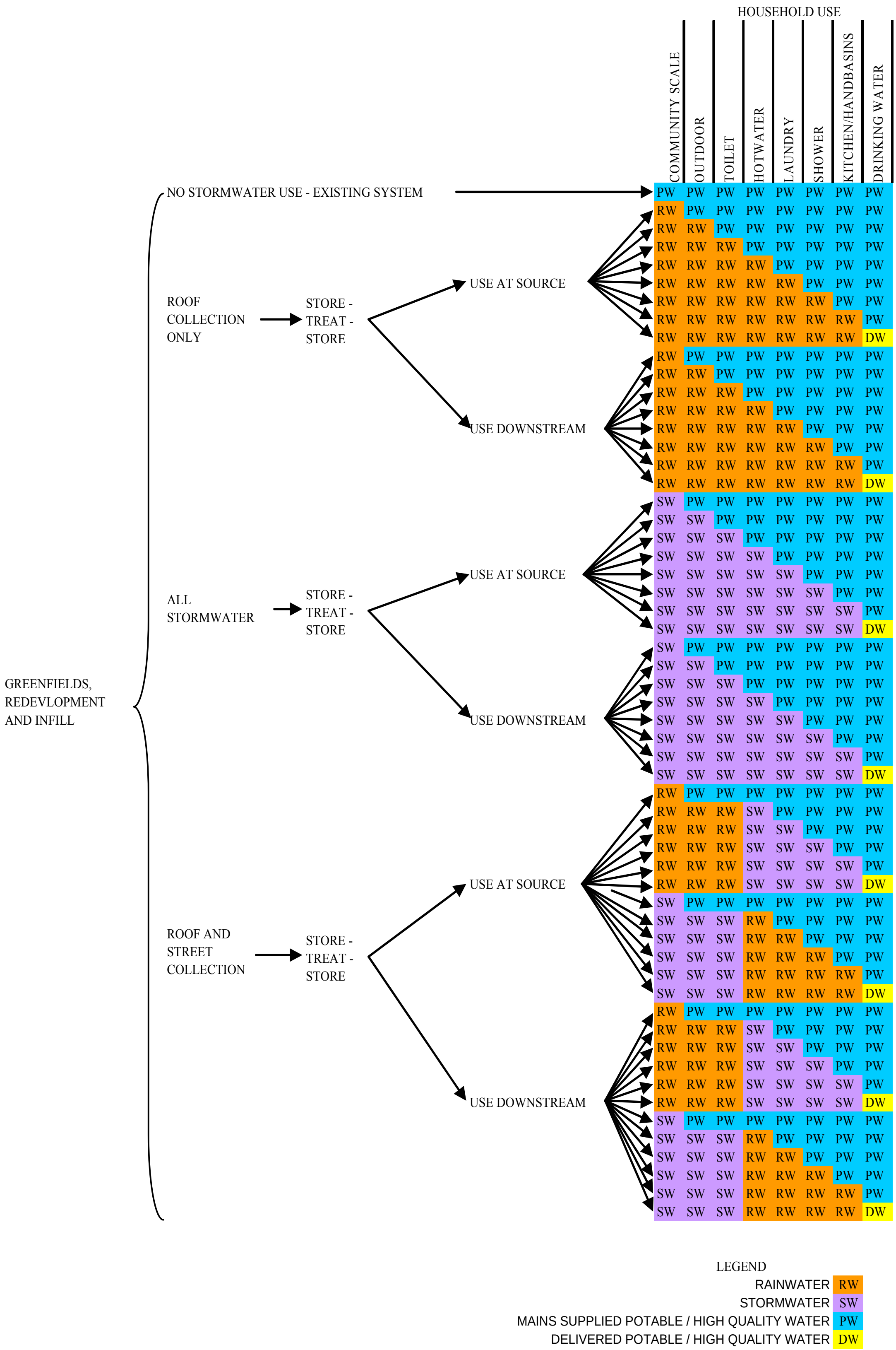
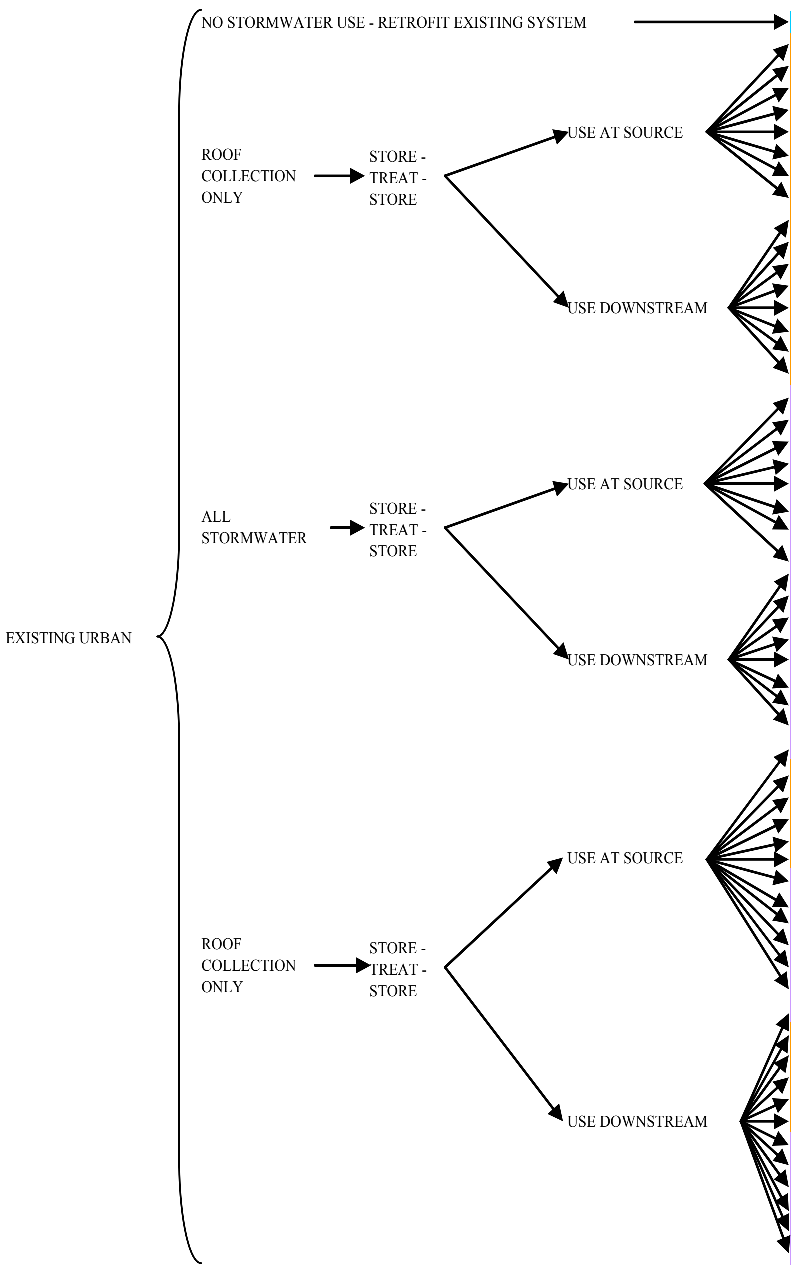


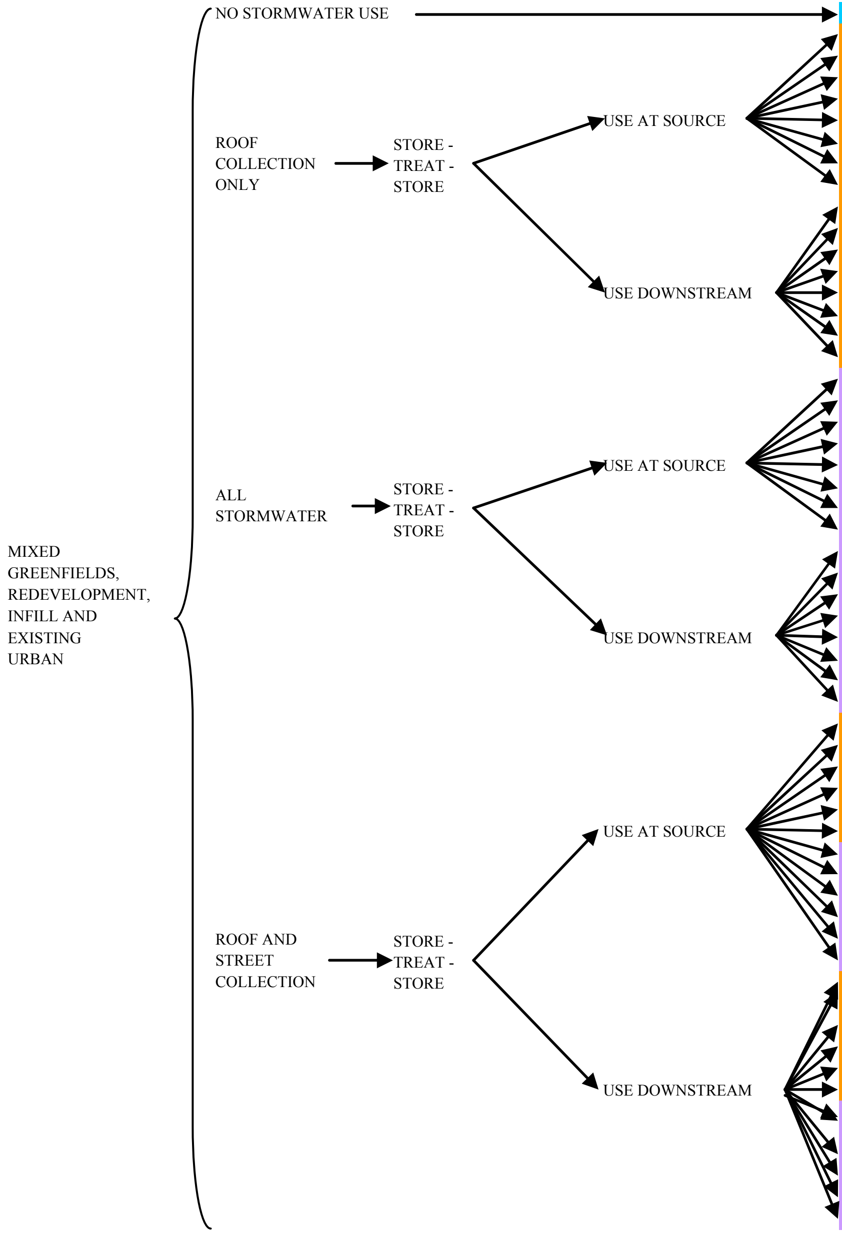
Figure A.1 Matrix of Possible Stormwater Use Scheme Options for Greenfield, Redevelopment and Infill Areas



COMMUNITY SCALE	HOUSEHOLD USE: OUTDOOR	TOILET	HOTWATER	LAUNDRY	SHOWER	KITCHEN/HANDBASINS	DRINKING WATER
PW	PW	PW	PW	PW	PW	PW	PW
RW	PW	PW	PW	PW	PW	PW	PW
RW	RW	PW	PW	PW	PW	PW	PW
RW	RW	RW	PW	PW	PW	PW	PW
RW	RW	RW	RW	PW	PW	PW	PW
RW	RW	RW	RW	RW	PW	PW	PW
RW	RW	RW	RW	RW	RW	PW	PW
RW	RW	RW	RW	RW	RW	RW	PW
RW	RW	RW	RW	RW	RW	RW	DW
RW	PW	PW	PW	PW	PW	PW	PW
RW	RW	PW	PW	PW	PW	PW	PW
RW	RW	RW	PW	PW	PW	PW	PW
RW	RW	RW	RW	PW	PW	PW	PW
RW	RW	RW	RW	RW	PW	PW	PW
RW	RW	RW	RW	RW	RW	PW	PW
RW	RW	RW	RW	RW	RW	RW	PW
RW	RW	RW	RW	RW	RW	RW	DW
SW	PW	PW	PW	PW	PW	PW	PW
SW	SW	PW	PW	PW	PW	PW	PW
SW	SW	SW	PW	PW	PW	PW	PW
SW	SW	SW	SW	PW	PW	PW	PW
SW	SW	SW	SW	SW	PW	PW	PW
SW	SW	SW	SW	SW	SW	PW	PW
SW	SW	SW	SW	SW	SW	SW	PW
SW	SW	SW	SW	SW	SW	SW	DW
SW	PW	PW	PW	PW	PW	PW	PW
SW	SW	PW	PW	PW	PW	PW	PW
SW	SW	SW	PW	PW	PW	PW	PW
SW	SW	SW	SW	PW	PW	PW	PW
SW	SW	SW	SW	SW	PW	PW	PW
SW	SW	SW	SW	SW	SW	PW	PW
SW	SW	SW	SW	SW	SW	SW	PW
SW	SW	SW	SW	SW	SW	SW	DW
SW	PW	PW	PW	PW	PW	PW	PW
RW	RW	RW	SW	PW	PW	PW	PW
RW	RW	RW	SW	SW	PW	PW	PW
RW	RW	RW	SW	SW	SW	PW	PW
RW	RW	RW	SW	SW	SW	SW	PW
RW	RW	RW	SW	SW	SW	SW	DW
SW	PW	PW	PW	PW	PW	PW	PW
SW	SW	SW	RW	PW	PW	PW	PW
SW	SW	SW	RW	RW	PW	PW	PW
SW	SW	SW	RW	RW	RW	PW	PW
SW	SW	SW	RW	RW	RW	RW	PW
SW	SW	SW	RW	RW	RW	RW	DW
SW	PW	PW	PW	PW	PW	PW	PW
RW	RW	RW	SW	PW	PW	PW	PW
RW	RW	RW	SW	SW	PW	PW	PW
RW	RW	RW	SW	SW	SW	PW	PW
RW	RW	RW	SW	SW	SW	SW	PW
RW	RW	RW	SW	SW	SW	SW	DW
SW	PW	PW	PW	PW	PW	PW	PW
SW	SW	SW	RW	PW	PW	PW	PW
SW	SW	SW	RW	RW	PW	PW	PW
SW	SW	SW	RW	RW	RW	PW	PW
SW	SW	SW	RW	RW	RW	RW	PW
SW	SW	SW	RW	RW	RW	RW	DW

LEGEND
RAINWATER RW
STORMWATER SW
MAINS SUPPLIED POTABLE / HIGH QUALITY WATER PW
DELIVERED POTABLE / HIGH QUALITY WATER DW

Figure A.2 Matrix of Possible Stormwater Use Scheme Options for Existing Urban Areas



HOUSEHOLD USE

COMMUNITY SCALE	OUTDOOR	TOILET	HOTWATER	LAUNDRY	SHOWER	KITCHEN/HANDBASINS	DRINKING WATER
PW	PW	PW	PW	PW	PW	PW	PW
RW	PW	PW	PW	PW	PW	PW	PW
RW	RW	PW	PW	PW	PW	PW	PW
RW	RW	RW	PW	PW	PW	PW	PW
RW	RW	RW	RW	PW	PW	PW	PW
RW	RW	RW	RW	RW	PW	PW	PW
RW	RW	RW	RW	RW	RW	PW	PW
RW	RW	RW	RW	RW	RW	RW	PW
RW	RW	RW	RW	RW	RW	RW	DW
RW	PW	PW	PW	PW	PW	PW	PW
RW	RW	PW	PW	PW	PW	PW	PW
RW	RW	RW	PW	PW	PW	PW	PW
RW	RW	RW	RW	PW	PW	PW	PW
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SW	SW	PW	PW	PW	PW	PW	PW
SW	SW	SW	PW	PW	PW	PW	PW
SW	SW	SW	SW	PW	PW	PW	PW
SW	SW	SW	SW	SW	PW	PW	PW
SW	SW	SW	SW	SW	SW	PW	PW
SW	SW	SW	SW	SW	SW	SW	PW
SW	SW	SW	SW	SW	SW	SW	DW
SW	PW	PW	PW	PW	PW	PW	PW
SW	SW	PW	PW	PW	PW	PW	PW
SW	SW	SW	PW	PW	PW	PW	PW
SW	SW	SW	SW	PW	PW	PW	PW
SW	SW	SW	SW	SW	PW	PW	PW
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SW	SW	SW	SW	SW	SW	SW	DW
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RW	RW	RW	SW	PW	PW	PW	PW
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SW	SW	SW	RW	PW	PW	PW	PW
SW	SW	SW	RW	RW	PW	PW	PW
SW	SW	SW	RW	RW	RW	PW	PW
SW	SW	SW	RW	RW	RW	RW	PW
SW	SW	SW	RW	RW	RW	RW	DW
RW	PW	PW	PW	PW	PW	PW	PW
RW	RW	RW	SW	PW	PW	PW	PW
RW	RW	RW	SW	SW	PW	PW	PW
RW	RW	RW	SW	SW	SW	PW	PW
RW	RW	RW	SW	SW	SW	SW	PW
RW	RW	RW	SW	SW	SW	SW	DW
SW	PW	PW	PW	PW	PW	PW	PW
SW	SW	SW	RW	PW	PW	PW	PW
SW	SW	SW	RW	RW	PW	PW	PW
SW	SW	SW	RW	RW	RW	PW	PW
SW	SW	SW	RW	RW	RW	RW	PW
SW	SW	SW	RW	RW	RW	RW	DW

LEGEND
RAINWATER RW
STORMWATER SW
MAINS SUPPLIED POTABLE / HIGH QUALITY WATER PW
DELIVERED POTABLE / HIGH QUALITY WATER DW

Figure A.3 Matrix of Possible Stormwater Use Scheme Options for Mixed Greenfield, Redevelopment Infill and Existing Urban Areas

APPENDIX B

DATA SOURCES AND REFERENCES FOR COLLECTING DATA INFORMATION

Appendix B contains information and links to data and resources to assist with implementation of the decision making framework. The focus of the information is in providing Victorian examples, as this was the focus of the project and case study. However, similar data and information would be available for other states and countries.

B.1 COLLECTION AND END USE DATA SOURCES

Information relating to sizes of different areas can be easily determined by scaling off maps and plans[1]. Aerial photos are relatively easy to obtain and can be used to estimate housing plot, pavement and garden sizes. The Australian Government organisation, Geoscience Australia (http://www.ga.gov.au/) has links to information about aerial and topographic maps. Geoscience Australia sells digital maps and data. They also have access to free downloads, such as topographic maps of certain scales. Auslig (http://www.ga.gov.au/nmd/products/purchasing/retailers.htm) and International Map Trade Association (http://www.maptrade.org/) also provide a list of map retailers in Australia. Councils, local government and planning agencies may have copies of maps and plans of their local area.

B.2 GROUND CONDITIONS DATA SOURCES

Geological information can be found from Geoscience Australia (http://www.ga.gov.au/).

B.3 END USE DEMANDS

Information which is used to estimate end use demands may not be very easy to obtain. Some data may be obtained from the Australian Bureau of Statistics (http://www.abs.gov.au). Alternatively, local councils and governments may collate

[1] Scaling off maps consists of measuring the areas either through planimeters or simple estimation using rulers. The scale of the map needs to be taken into account to determine the actual area. For example, an area measured as 10 cm^2 on a map of scale 1:2,000 is equivalent to 4,000 m^2 (10 x 2,000 x 2,000 = 40,000,000 cm^2 = 4,000 m^2). Electronic data usually requires specific graphic computer programs (for example AutoCAD) for viewing maps and plans. Graphic computer programs generally have tools to directly determine areas.

information regarding local conditions. For example, the City of Brimbank has a link that provides information about each suburb, including population density and average household size (http://www.id.com.au/Brimbank/commprofile/default.asp).

In Victoria, the Department of Sustainability and Environment has a website “know your area” providing information about residential areas in Melbourne as well as Australian capital cities (http://www.dse.vic.gov.au/research). This website provides data on the households and percentage of households that have 1, 2, 3, 4 or 5 or more people per household. This data can be used to estimate average household size, if not specifically provided. Household size is required to estimate indoor household water use, which in turn is used to determine end use demand for households (Sections 4.4.1.1 and 4.4.1.3).

B.4 AQUIFER STORAGE AND RECOVERY

Within Victoria, the former Victorian Department of Conservation and Natural Resources (now the Department of Sustainability and Environment) produced a series of groundwater beneficial use maps for the upper tertiary, middle tertiary, lower tertiary and water table aquifer systems (DCNR, 1995a,b). This map series collated various borehole, drilling and chemical information. The quality and yield information provided an indication of the potential or existing beneficial uses for which the groundwater could be used. A reliability diagram was also provided in these maps to indicate the amount of data that was used to produce different sections of the beneficial use maps. The maps for the South Western Victoria water table aquifers and the regional aquifer systems are provided in Appendix F as Figures F.1 and F.2. Additional maps for other areas of Victoria can be downloaded from the Victorian Groundwater website (http://www.nre.vic.gov.au/dnre/grndwtr/grndwtr.htm). The practicality of using beneficial use maps needs to be considered, because these maps may change with time, as shown below:

> *“It is difficult to assess potential use, as demand for water and the economics of groundwater extraction may change as surface water resources become fully utilised. Current water quality usage criteria may not apply in the future … In a number of circumstances however,*

aquifer yield, rather than water quality, may be the factor which limits future usage." (DCNR, 1995a,b)

B.5 OVERVIEW OF TECHNICAL COMPONENTS TO BE COSTED

An overview of the technical components that would need to be costed when comparing stormwater use scheme options is provided below.

(a) Pumping and transport

Determining costs for pumping and transport would only be required for pump collection and distribution options. Gravity flow would not have any associated costs under the pumping and transport topic, unless there were items for transport that were not included in the other costing topics. Pump requirements and costs would depend on the amount of flow required, pump size, power requirements and the head difference between the collection or distribution area and storage, treatment or end use area.

(b) Excavation and compaction

Pipes were generally located beneath the ground surface, so trenches would be excavated for placing the pipe system. Infiltration trenches would also require trench excavation. Permeable pavements may require some excavation to even the surface for placement of the pavement or for placing drainage cells beneath the pavement system. Overland flows could either be accommodated in existing road layouts or may require land reforming and excavation to form open channels.

Aquifer storage and recovery would generally require minimal material extraction to construct the injection and recovery wells. Minimal excavation may also be required for above-ground closed storage to produce a solid foundation. Above-ground open storage and underground storage would require excavation for construction of the storage system.

Compaction and filling would be required for covering stormwater pipe trenches. Imported permeable material may be required for infiltration trenches. Compaction of the bottom layer of the infiltration trench or open channels could be required to minimise exfiltration of the collected stormwater. Some compaction would also be required for above-ground closed and underground storage systems to provide a solid foundation for the storage tank.

Costs for excavation would depend on ground conditions, depth of excavation, excavation width, lineal length of trenches or channels and storage volume. Rocky ground would increase excavation costs. Filling costs would depend on the type of material required for filling and the quantity of fill material. Compaction costs would depend on machinery type, type of compaction and depth of material to be compacted. Site preparation may also need to be costed. Excavation prices would generally include plant and machinery hire.

(c) Materials, construction and installation

Stormwater pipe costs would depend on pipe size, length and material. Stormwater pipe sizes would be determined by pipe slopes and flows to be carried in the pipes. Local council or government regulations would generally dictate stormwater pipe design requirements. Installation costs would need to include any connections or disconnections to existing stormwater pipes.

Permeable pavement materials would include the pavement and drainage cells or structure required beneath the pavement. Costs would be dependent on the type of paver and area of the pavement to be constructed. Permeable pavements could also require perforated pipes if this system was used for collection and transport of the stormwater beneath the permeable pavement system.

Material costs for infiltration trenches would include fill material. Perforated pipes may be required for placement at the bottom of the trench to transport the collected stormwater. A lining or impermeable material may be required at the base of the infiltration trench to minimise exfiltration, as well as for channels used to collect overland flow. Overland flows which did not require additional construction, but instead took advantage of the existing road layout and urban flows, may not have any material costs.

The material required to be costed for above-ground closed storage was either the tank or the material to construct the tank such as concrete and reinforcement, as well as waterproofing or lining if required. Transportation, installation and foundation material must also be accounted for in addition to the purchase price of tanks. Connection from the collection system to the tank must also be costed. Fill material may be required as covering for underground storage, as well as for expanding storage capacity through increasing embankment areas for existing water bodies or storage areas.

Dual pipe systems would require different colour pipes for alternative water sources and potable water supply. Signage would also be required to identify pipes containing non-potable water. Where pumps were required, materials for pumping stations to contain the pumps could also be required. Stop valves and other material to ensure no cross contamination between the potable water and stormwater supply would also be required.

(d) Land take and opportunity costs

The value of the land to be occupied by the collection, storage, treatment or distribution system may be an additional issue to be costed, if the decision maker believed this was an important issue. Opportunity costs would tend to be more of an issue in a greenfield site where the land developer could lose money by not selling available land. In an existing urban area, all possible development areas would (generally) have already been developed. This would mean only parklands or grassed areas would be used as storage sites, and land opportunity costs may not be appropriate.

(e) Maintenance

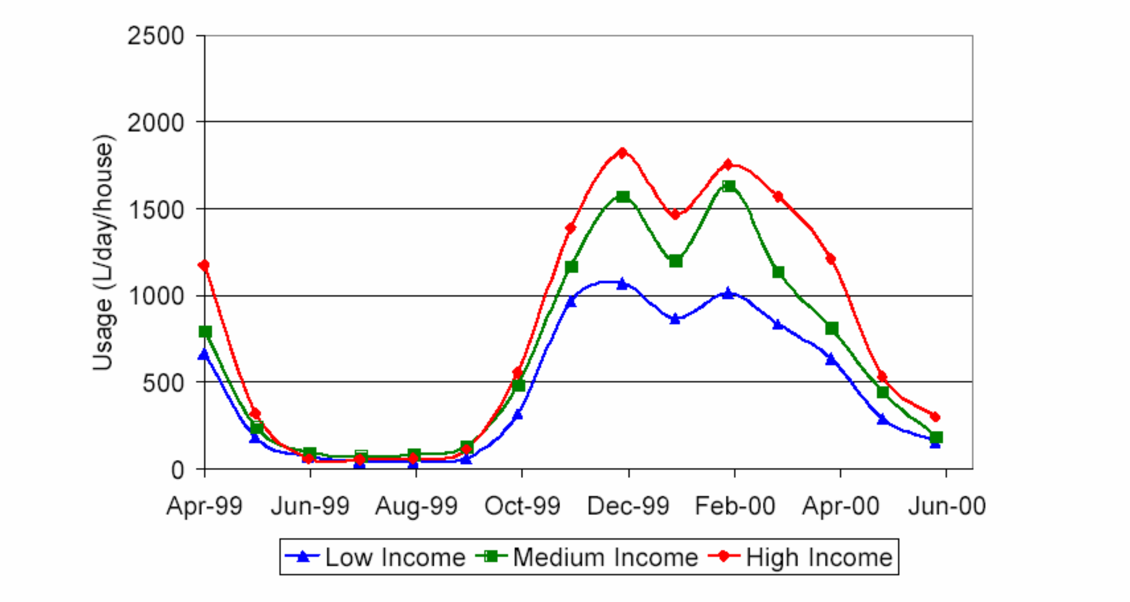
Maintenance requirements would include replacement of materials, for example replacement of parts of a collection system due to age or damage. Maintenance would also cover landscape requirements such as grass mowing and watering. Additional maintenance requirements would include cleaning of permeable pavements and infiltration trenches to stop clogging of the infiltration system. Stormwater pipes should be designed to provide sufficient velocity within the pipes so that there was minimal accumulation of solids in the pipes and cleaning would not be required.

The main issue of maintenance for storage systems was removal of settled material through dredging or material vacuuming. Underground storage would generally be more expensive to dredge due to the opening and excavation of the covering. Alternatively, a small manhole through which vacuum type equipment could remove the sediments could be included in the original design. If excavation was required, cleaning would therefore be less frequent, with additional space to contain the sediment being required. Disposal and transport of the dredged material would also need to be included in maintenance costs.

APPENDIX C

CALCULATION OF MONTHLY OUTDOOR WATER DEMAND BASED ON PERTH DATA

The basis of determining seasonal variation of outdoor household demand was the Domestic Water Use Study in Perth (Loh and Coghlan, 2003). Figure 4.1 of Loh and Coghlan (2003) showed the monthly ex-house usage in terms of low, medium and high income households. However, this figure had a misprint on the x-axis values, stating the February value as January. Therefore, the figure from Loh et al. (2003), which is the same figure without any misprints, was used for this project to estimate the monthly percentage distribution of residential outdoor use. This figure is shown below in Figure C.1



Source: (Loh et al., 2003)

Figure C.1 Estimates of Ex-House Water Demand from Perth for Single Residential Houses

The values for each month were estimated from the above figure and are shown in Table C.1 below. The January value in Figure C.1 is abnormally low compared to the surrounding months (December and February) which are almost the same. The data in Figure C.1 was only measured for one year and there was unusual seasonal rainfall that fell during the monitoring period. Therefore, the January value in Table C.1 was estimated in this study as the same value as December. The values for low, medium and high income households show the influence of income on ex-house water use. The percentage distribution for each month was calculated using the medium-income values. This was determined using the following Equation C.1.

$$\text{Monthly Percentage} = \frac{\text{Monthly Household Usage for Medium Income}}{\text{Total Household Usage for Medium Income}} \quad \text{......................C.1}$$

Table C.1 Single Residential Ex-house Usage and Monthly Distribution for Perth (read from Loh et al., 2003)

	Ex-house water demand			Monthly distribution for medium income
	Low income L/day/house	Med income L/day/house	High income L/day/house	%
Jan	1,800	1,550	1,050	17
Feb	1,800	1,550	1,050	17
Mar	1,550	1,200	800	13
Apr	700	800	1,200	9
May	350	300	250	3
Jun	100	100	100	1
Jul	100	100	100	1
Aug	100	100	100	1
Sep	150	100	100	1
Oct	550	500	350	6
Nov	1,400	1,200	1,000	13
Dec	1,800	1,550	1,050	17
TOTAL		9,050		100

Figures C.2 and C.3 are provided in this Appendix to compare Perth and Melbourne temperature, rainfall, and evaporation data. They demonstrate that the temperature and evaporation temporal patterns of Perth and Melbourne are very similar. While the temporal rainfall patterns for Perth and Melbourne are not closely matched, the temperature and evaporation would mean that the temporal distribution of irrigation requirements may be similar for these two areas. For this reason, utilisation of the Perth monthly percentage distribution of the residential outdoor demand is reasonable for case study areas in Melbourne.

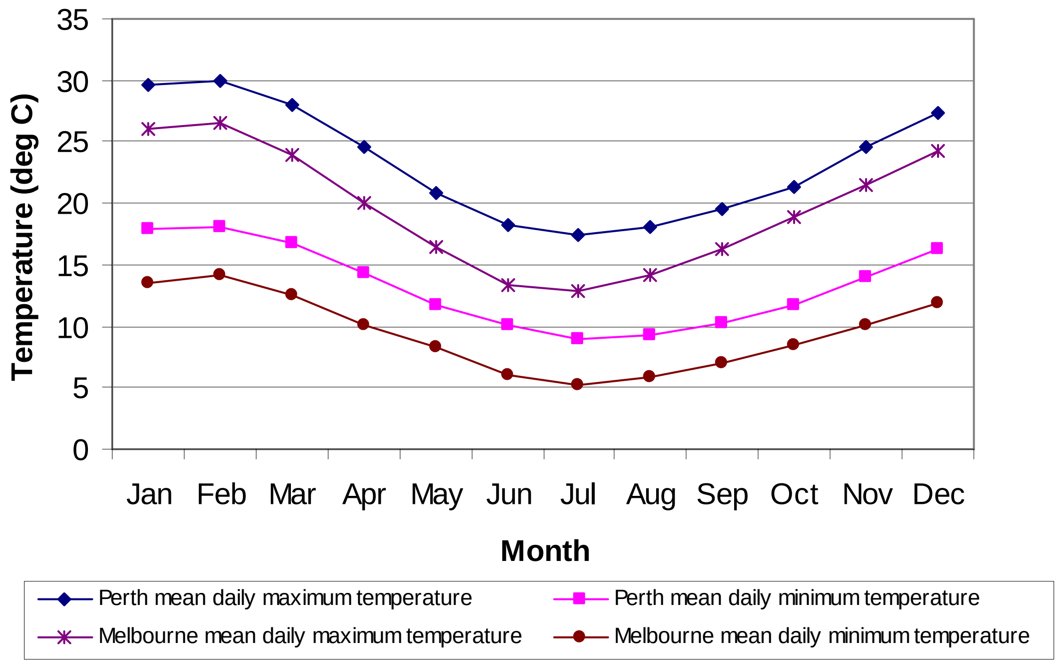


Figure C.2 Comparison of Perth and Melbourne Mean Monthly Temperatures

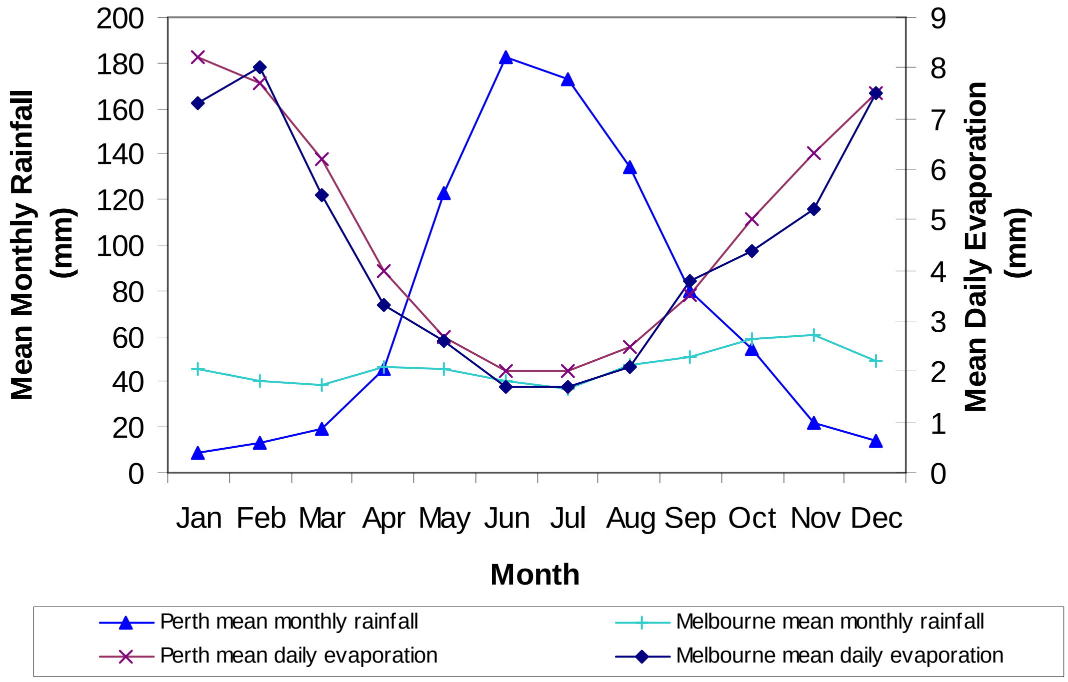


Figure C.3 Comparison of Perth and Melbourne Rainfall and Evaporation

APPENDIX D

AERIAL PHOTOGRAPH OF CASE STUDY AREA

Figure D.1 Aerial Photograph of Case Study Area

LEGEND			
stormwater pipe system	property boundary	contour	
D, B, M	Melbourne Water Corporation notation for stormwater system		

APPENDIX E

CASE STUDY CALCULATIONS

APPENDIX E1

Collection and End Use Calculations

Equations 4.1 to 4.4 were used to determine the total area values, as shown below. These equations use average block information with the results input into Table 5.2. In these equations:

- (A) = Residential total area
- (B) = Residential roof area
- (C) = Residential road and pavement area
- (D) = Residential grassed / vegetated areas
- (E_i) = Total number of blocks for typical residential block number n
- (F_i) = Average block size for typical residential block number n
- (G_i) = Average roof area for typical residential block number n
- (H_i) = Average pavement area for typical residential block number n
- (I_i) = Average garden area for typical residential block number n

(A) = Σ ($E_i \times F_i$) + non-household road, pavement and grassed areas 4.1

$$(\text{Residential Total Area}) = \frac{72 \times 600}{10{,}000} + 0.17 + 0.38 + 0.23 + 0.2 + 0.43 + 0.31 + 0.08$$

= 6.12 ha

(B) = Σ ($E_i \times G_i$) 4.2

$$(\text{Residential Roof Area}) = \frac{72 \times 300}{10{,}000}$$

= 2.16 ha

(C) = Σ ($E_i \times H_i$) + non-household road and pavement areas 4.3

$$(\text{Residential Road and Pavement Area}) = \frac{72 \times 75}{10{,}000} + 0.17 + 0.38 + 0.23$$

= 1.32 ha

(D) = Σ ($E_i \times I_i$) + non-household grassed areas 4.4

$$(\text{Residential Grassed / Vegetated Area}) = \frac{72 \times 225}{10{,}000} + 0.2 + 0.43 + 0.31 + 0.08$$

= 2.64 ha

APPENDIX E2

Sample Monthly Impervious and Pervious Runoff Volume Calculations

Equations 4.5 and 4.6 were used to determine impervious and pervious runoff volume respectively. An example of each calculation is shown below. The impervious area and pervious area values were taken directly from Table 5.2.

Impervious Runoff Volume (kL/month) = Rainfall (mm/month) × Impervious Area (ha) × Impervious Coefficient of Runoff ×10 (conversion factor) 4.5

July Impervious Runoff Volume = 40.0 × 3.48 × 0.9 × 10

= 1,253 kL / month

Pervious Runoff Volume (kL/month) = Rainfall (mm/month) × Pervious Area (ha) × Pervious Coefficient of Runoff ×10 (conversion factor) 4.6

July Pervious Runoff Volume = 40.0 × 11.04 × 0.0 × 10

= 0 kL / month

APPENDIX E3

Yearly, Monthly and Daily Indoor Demand and Yearly Outdoor Demand Calculations

The yearly end use demand for the study site was determined by multiplying the average value by the number of households, as follows.

Case study yearly indoor use = 193 × 72

= 13,896 kL/year/end use area

Case study yearly outdoor use = 46 × 72

= 3,312 kL/year/end use area

Case study total yearly use = 239 × 72

= 17,208 kL/year/end use area

Monthly indoor demand was estimated to compare to monthly stormwater runoff. Monthly outdoor demand calculations are shown in Appendix E4. An example of calculating indoor monthly end use demand using Equation 4.7 is shown below.

$$\text{Monthly Indoor Demand} = \text{Yearly Indoor Demand} \times \frac{\text{no. of days in the month}}{365} \quad ....4.7$$

July Indoor Demand = (13,896 × 31) ÷ 365

= 1,180 kL/month

Indoor demand could then be divided into different end use demands. Indoor water use volumes were determined from the yearly indoor demand and the percentage distribution of indoor use taken from Water Resources Strategy Committee for the Melbourne Area (2001), as shown in Table E3.1. Yearly indoor demand was determined as shown below. Occupancy and number of households was obtained from Table 5.3.

Population of case study site = average occupancy × number of households

= 2.6 × 72

= 187.2 persons

Indoor demand (per capita) = case study site yearly demand ÷ population

= 13,896 ÷ 187.2

= 74.2 kL/capita/year

= 203.4 L/capita/day

Water use values in Table E3.1 (i.e. column 3) were determined by multiplying the percentage distribution (e.g. 40%) by the daily indoor demand (203.4 L/capita/day).

Table E3.1 Indoor Water Use for Different Household End Uses

Indoor Water Use	Percentage Distribution[1] %	Water Use (Litre/capita/day)
Kitchen	8	15.6
Bathroom	40	81.3
Toilet	29	59.4
Laundry	23	46.9
TOTAL	**100**	**203.4**

Source: [1] Water Resources Strategy Committee for the Melbourne Area (2001)

APPENDIX E4

Alpha Value and Monthly Outdoor Demand Calculations

Yearly outdoor demand was calculated in Appendix E3. Monthly outdoor demand for the case study was calculated using either the evaporation / rainfall equation (Equation 4.8) or using Perth distribution data (Section 5.3.3 and Appendix C). The method using the evaporation / rainfall equation to calculate monthly outdoor demand for the case study is shown below.

Irrigation = $\alpha \times$ evaporation - rainfall...4.8

An Excel spreadsheet was set up to determine the alpha value iteratively. Equation 4.8 was initially used with annual data to provide an approximate (starting) value for α that is suitable for the case study area, as shown below.

Yearly Irrigation (kL/year) = (α × evaporation – rainfall) × irrigation area

$= (\alpha \times 1608.1 - 553.0) \times (225 \times 72 \times 100\%) \div 1{,}000$

$= 26051\ \alpha - 8959$

The irrigation area was determined with information taken from Table 5.3. Annual evaporation and rainfall data was taken from Table 5.5. Thus, yearly irrigation requirements for the households in the case study area could be estimated. However, the estimated yearly irrigation requirements were already determined as the total annual household outdoor use (Appendix E3). This was 3,312 kL/year for the case study area. Therefore the value of α was estimated as follows.

$$\alpha = \frac{3312 + 8959}{26051}$$

$$= 47\%$$

Monthly residential irrigation demand was then determined using the same method, as for yearly irrigation, but considering the initial value for α as 47%. However, the value of α of 47% found that a number of months returned negative irrigation demands, which are not feasible. These negative values were automatically transformed to zero through the use of a conditional 'if' function in the developed spreadsheet. The alpha value was changed iteratively until the yearly outdoor demand, (with negative values changed to zero), equalled 3,312 kL/year. A final value of 42% for α was found for the case study.

The yearly percentage distribution of the household irrigation was then determined based on this calculated α value. The monthly household irrigation demand, values for calculating demand and yearly percentage distribution are shown below in Table E4.1.

Table E4.1 Case Study Monthly Household Irrigation Demand

	Mean monthly rainfall	Monthly evaporation from mean daily	Irrigation	Demand	Demand	Yearly percentage distribution
	mm	mm	mm	kL/month	kL/month	%
July	40.0	52.7	-17.7	-286.6	0	0
August	45.8	65.1	-18.2	-295.5	0	0
September	51.9	114.0	-3.6	-58.9	0	0
October	57.3	136.4	0.4	7.2	7	0
November	53.3	156.0	12.7	206.4	206	6
December	48.2	232.5	50.2	813.7	814	25
January	40.3	226.3	55.5	899.2	899	27
February	40.8	224.0	54.0	875.3	875	26
March	40.7	170.5	31.5	510.0	510	15
April	46.3	99.0	-4.4	-71.1	0	0
May	49.4	80.6	-15.3	-247.5	0	0
June	39.0	51.0	-17.4	-282.0	0	0
TOTAL	**553.0**	**1608.1**	**127.8**	**2,070.2**	**3,312**	**100**

APPENDIX F

BENEFICIAL USE MAP SERIES MAPS FOR THE SOUTH WESTERN VICTORIA REGIONAL AQUIFER SYSTEMS AND WATER TABLE AQUIFERS

The beneficial use maps for the South Western Victoria regional aquifer systems and water table aquifers are provided in Figures F.1 and F.2. These figures were sourced from DCNR (1995a,b). Due to the size of Figures F.1 and F.2, some of the text and information cannot be clearly read. However, Figures F.1 and F.2, as well as beneficial use maps for North Western Victoria and Eastern Victoria, can be downloaded directly from the website (http://www.nre.vic.gov.au/dnre/grndwtr/grndwtr.htm).

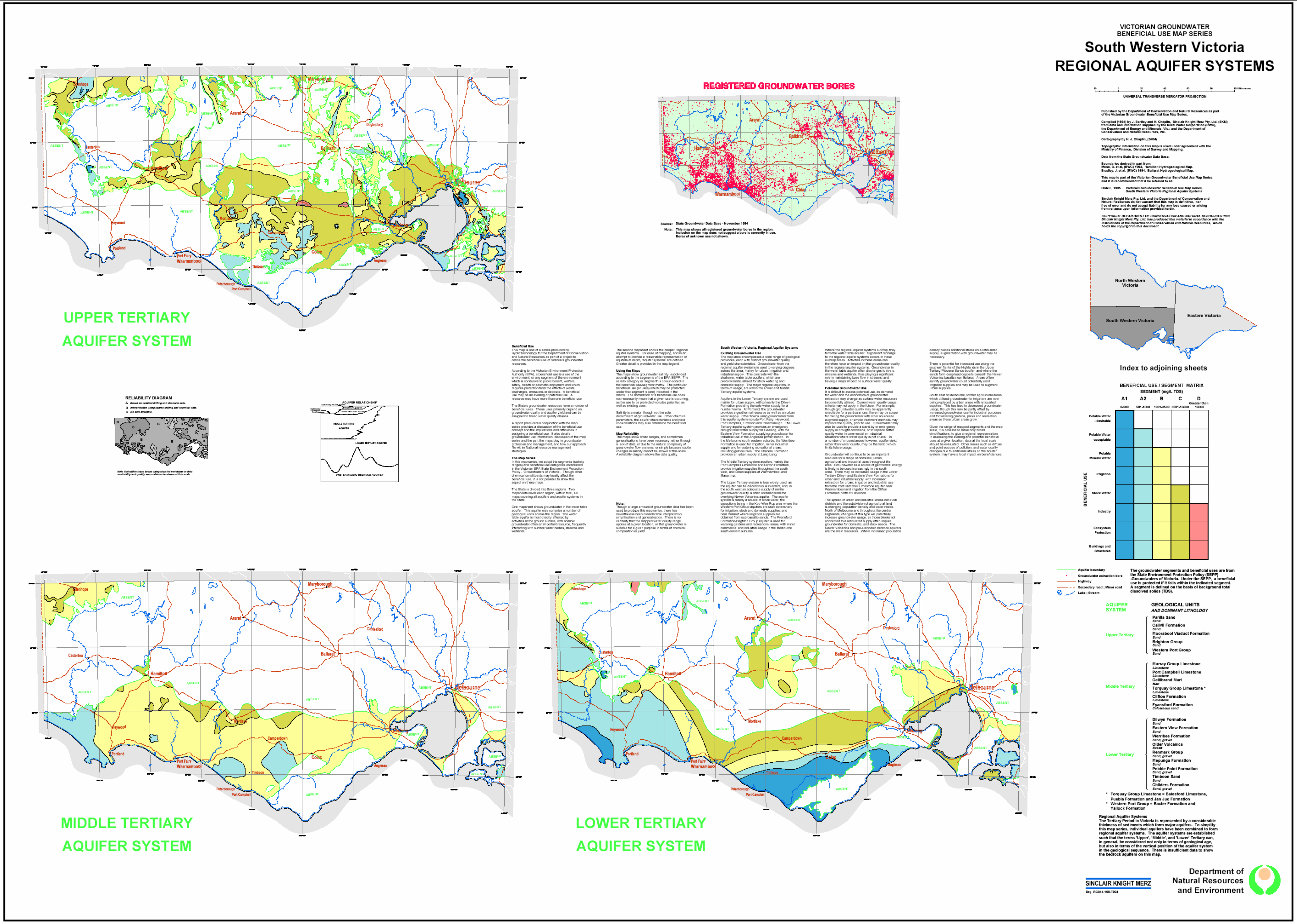


Figure F.1 Beneficial Use Map for the South Western Victoria Regional Aquifer Systems (sourced from DCNR, 1995b)

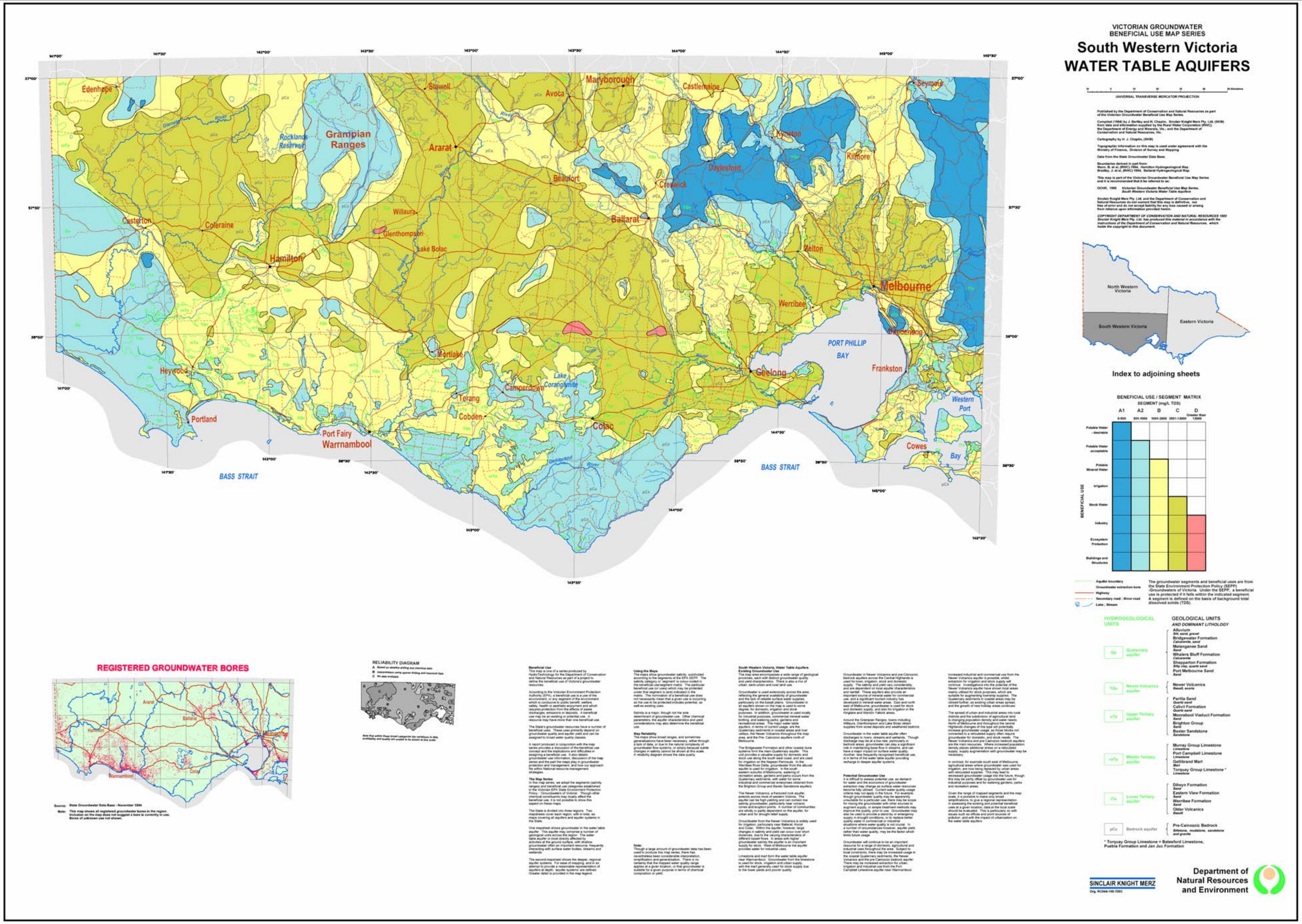


Figure F.2 Beneficial Use Map for the South Western Victoria Water Table Aquifers (sourced from DCNR, 1995a

APPENDIX G

UVQ INPUT VALUES

The UVQ model is separated into a number of input frames. These frames correspond to different issues. The main menu is divided into physical characteristics, water flow, calibration values, snow variables (not used in this case study), land block, neighbourhood and study area. Within each main menu item, there are either one or more input frames.

Physical characteristics are all area, water use and contaminant levels related to the study area. The number of input frames for physical characteristics depends on the number of neighbourhoods (areas of typical residential blocks) selected for the study area. Water flow relates to how the wastewater and stormwater flow between the different neighbourhoods within the study area. Calibration values show the simulated values of water and contaminant balances, with calibration values which can be changed to provide a better fit between the model and observed values. Land block, neighbourhood and study area main menu items relate to storage capacities and sizes, backup supply information and selection of end uses supplied by different water sources.

For this case study, two neighbourhoods were selected. Neighbourhood 1 was the residential area surrounded by Parsons Street, Cornwall Road, Matthews Street and Walter Street. Neighbourhood 2 was the Tom O'Brien Reserve. Tables G1.1 to G1.5 show the UVQ input values for the case study site. Each table corresponds to the different main menu items.

Table G.1 Project Information

Field	Data	Data Source / Comments
Project description	Parsons Street	
Study area (ha)	14.52	Measured from aerial photograph (Figure D.1)
Number of neighbourhoods	2	Selected from Figure D.1
Soil store types	Partial Area	
Contaminants for analysis in this study	Nitrogen, Phosphorous, Suspended Solids	
Optional user defined contaminants	none	

Table G.2 Physical Characteristics of Land Blocks and Neighbourhoods

Field	**Neighbourhood 1**	**Neighbourhood 2**	**Data Source / Comments**
Neighbourhood Frame			
Total Area (ha)	6.12	8.4	Table 5.2
Road Area (ha)	0.78	0	Figure D.1
Open Space Area (ha)	1.02	8.4	Table 5.2
Percentage of Open Space Irrigated (%)	0	100	Table 5.4
Imported supply leakage (%)	0	0	
Wastewater as Exfiltration (ratio)	0	0	
Land Block Frame			
Number of Land Blocks	72	0	Table 5.3
Block Area (m^2)	600	n/a	Table 5.3
Average Occupancy	2.6	n/a	Table 5.3
Garden Area (m^2)	225	n/a	Table 5.3
Roof Area (m^2)	300	n/a	Table 5.2
Paved Area (m^2)	75	n/a	Table 5.2
Percentage of Garden Irrigated (%)	100	n/a	Table 5.3
Proportion Roof Runoff to Spoondrain (ratio)	0	n/a	
Wastewater Outputs Frame			
Wastewater from Neighbourhood goes to:	0	0	Represents all wastewater and stormwater values flowing external to the study site rather than to the other neighbourhood
Stormwater from Neighbourhood goes to:	0	0	

Table G.2 Physical Characteristics of Land Blocks and Neighbourhoods continued…

Indoor Water Usage & Contaminants Frame			**Data Source / Comments**
Kitchen L/c/d	15.6		Table E3.1
Bathroom L/c/d	81.3		Table E3.1
Toilet L/c/d	59.4 (or 203.4 when all end use demands are modelled)		Table E3.1
Laundry L/c/d	46.9		Table E3.1
Bathroom Contaminant Loads (mg/c/d)	N:462, P:22, SS:8303		Contaminant values were taken from the real life example of Heathwood in Queensland provided by Mitchell and Diaper (2004).
Toilet Contaminant Loads (mg/c/d)	N:13704, P:1568, SS:36240		
Kitchen Contaminant Loads (mg/c/d)	N:238, P:42, SS:3990		
Laundry Contaminant Loads (mg/c/d)	N:327, P:152, SS:4858		
Other Contaminants Frame			**Data Source / Comments**
Road Runoff (mg/L)	N:1.6,P:0.21,SS:75		Contaminant values were taken from the real life example of Heathwood in Queensland provided by Mitchell and Diaper (2004).
Roof First Flush (mg/L)	N:3.2, P:0.42, SS:15075		
Fertilizer to POS (mg total)	N:0, P:0, SS:0		
Evaporation (mg/L)	N:0, P:0, SS:0		
Ground Water (mg/L)	N:0.11, P:0.007, SS:0.26		
Imported (mg/L)	N:0.11, P:0.007, SS:0.26		
Rainfall (mg/L)	N:1.33, P:0.087, SS:17		
Pavement Runoff (mg/L)	N:1.6, P:0.21, SS:75		
Roof Runoff (mg/L)	N:1.6, P:0.21, SS:75		

Table G.3 Water Flow

Stormwater and Wastewater Flow Paths of Neighbourhoods			
Field	**Neighbourhood 1**	**Neighbourhood 2**	**Data Source / Comments**
Stormwater from Neighbourhood goes to:	0	0	
Wastewater from Neighbourhood goes to:	0	0	

Table G.4 Calibration Variables

Calibration Variables ~first cut estimates pre-calibration			
Field	**Neighbourhood 1**	**Neighbourhood 2**	**Data Source / Comments**
Stormwater Frame			
Percentage Area of Soil Store 1	20	50	Determined by trial and error until the stormwater and imported water values obtained by the UVQ model approximately equalled the observed stormwater and imported water values
Capacity of Soil Store 1 (mm)	50	50	
Capacity of Soil Store 2 (mm)	100	100	
Roof Area Maximum Initial Loss	0.5	0.5	
Effective Roof Area (%)	100	100	
Paved Area Maximum Initial Loss (mm)	0.5	0.5	
Effective Paved Area (%)	100	100	
Road Area Maximum Initial Loss (mm)	0.5	0.5	
Effective Road Area (%)	100	100	
Base Flow Index (ratio)	0.3	0.45	
Base Flow Recession Constant (ratio)	0.00001	0.00001	
Irrigation Frame			
Garden Trigger to Irrigate (ratio)	0.5	0.5	
Open Space Trigger to Irrigate (ratio)	0.43	0.48	
Contaminant Soil Store Removal Frame			
Contaminants	N:40, P:70, SS:70	N:40, P:70, SS:70	estimated
Wastewater Frame			
Infiltration Index (ratio)	0.05	0.05	Data obtained from Mitchell and Diaper (2004) but irrelevant for case study site which did not examine wastewater impacts
Infiltration store recession constant (ratio)	0.1	0.1	
Percentage Surface Runoff as Inflow	3	3	
Dry Weather Overflow Rate (%)	0	0	
Wet Weather Overflow Trigger (kL)	9999999	9999999	

Table G.5 Observed Neighbourhood Flow Volumes and Quality for Calibration

Field	**Neighbourhood 1**	**Neighbourhood 2**	**Data Source / Comments**
Average Volumes Frame - Neighbourhood Tab			
Imported Water - Observed (kL/y or ML/y)	17236	17172	Table 5.9
Wastewater - Observed (kL/y or ML/y)	n/a		Wastewater not examined for case study site
Stormwater - Observed (kL/y or ML/y)	17320		Table 5.5
Quality Frame (contaminants) - Neighbourhood Tab			
Stormwater - Observed			Contaminants not examined for case study site
Wastewater - Observed			

APPENDIX H

DETAILED COST ESTIMATES FOR CASE STUDY

Table H.1 Detailed Costing of Technical Components for Case Study

References / Notes		Unit	Rate ($/unit)	Quantity	Cost ($)
Pipe / gravity flow collection					
	Excavation and compaction				
Rawlinsons Group (2003, p. 457)	Trench excavation by machine (x 300mm wide) 500mm total depth in clay	m	7.70	560	$4,312.00
	Materials, construction and installation				
	F.R.C non presure pipe (Class 2) with rubber ring joints:				
Rawlinsons Group (2003, p. 463)	225mm dia	m	61.60	130	$8,008.00
	375mm dia	m	105.60	220	$23,232.00
	450mm dia	m	127.60	210	$26,796.00
	300mm dia	m	85.25	0	$0.00
	600mm dia	m	196.90	0	$0.00
	Medium Duty mesh grated sump including excavation in typical material, sump size:				
Rawlinsons Group (2003, p. 466)	450 x 450 x 600mm deep	No.	378.40	18	$6,811.20
	600 x 600 x 600mm deep	No.			$0.00
	Land take and opportunity costs				
	n/a - this is all public land and paths, which will still be available for use				
	Maintenance				
				Sub-total	$69,159.20
Infiltration trenches gravity flow collection					
	Excavation and compaction				
	(included in construction and installation costs)				
	Materials, construction and installation				
Taylor (2004, p. 6) using Sydney data	Infiltration Trench	m	138	700	$96,600.00
	Maintenance				
Taylor (2004, p. 6)	Annual Maintenance	% of construction cost	10%	$96,600.00	$9,660.00
				Sub-total	$106,260.00
Above-ground closed storage - 110 kL					
	Excavation and compaction				
Rawlinsons Group (2003, p. 208)	Level ground under floor slabs, paving and the like, including compaction	m^2	2.31	60	$138.60
	Materials, construction and installation				
Rawlinsons Group (2003, p. 456)	127,000L ribbed colourbond sheet steel, polyethylene lined water tank, 8.7m dia	No	10,010.00	1	$10,010.00
Rawlinsons Group (2003, p. 227)	Reinforced concrete 25MPa slab and thickening on fill not exceeding 150mm thick	m^3	201.30	9	$1,811.70
	Land Take and Opportunity Costs				
	Land value	$\$/m^2$			
	Maintenance				
Taylor (2004, p. 9)	Annual Maintenance assumed to be 3% of storage construction cost	% of construction cost	3%	$11,960.30	$358.81
				Sub-total	$12,319.11

Table H.1 Detailed Costing of Technical Components for Case Study continued…

References / Notes		Unit	Rate ($/unit)	Quantity	Cost ($)
Above-ground closed storage - 500 kL					
	Excavation and compaction				
Rawlinsons Group (2003, p. 208)	Level ground under floor slabs, paving and the like, including compaction	m^2	2.31	177	$408.87
	Materials, construction and installation				
G. Chapman-Hill (2004, pers. comm., 23 August)	512,000L steel lined water tank, including delivery and installation, 11.36m dia	No	50,640.00	1	$50,640.00
Rawlinsons Group (2003, p. 227)	Reinforced concrete 25MPa foundation beams	m^3	187.00	27	$5,049.00
	Land Take and Opportunity Costs				
	Land value	$\$/m^2$			
	Maintenance				
Taylor (2004, p. 9)	Annual Maintenance assumed to be 3% of storage construction cost	% of construction cost	3%	$56,097.87	$1,682.94
				Sub-total	$57,780.81

References / Notes		Unit	Rate ($/unit)	Quantity	Cost ($)
Above-ground closed storage - 3000 kL					
	Excavation and compaction				
Rawlinsons Group (2003, p. 208)	Level ground under floor slabs, paving and the like, including compaction	m^2	2.31	1145	$2,644.95
	Materials, construction and installation				
G. Chapman-Hill (2004, pers. comm., 23 August)	1,028,000L steel lined water tank, including delivery and installation, 18.04m dia	No	117,000.00	3	$351,000.00
Rawlinsons Group (2003, p. 227)	Reinforced concrete 25MPa foundation beams	m^3	170.00	138	$23,460.00
	Land Take and Opportunity Costs				
	Land value	$\$/m^2$			
	Maintenance				
Taylor (2004, p.9)	Annual Maintenance assumed to be 3% of storage construction cost	% of construction cost	3%	$377,104.95	$11,313.15
				Sub-total	$388,418.10

References / Notes		Unit	Rate ($/unit)	Quantity	Cost ($)
Above-ground closed storage - 4000 kL					
	Excavation and compaction				
Rawlinsons Group (2003, p. 208)	Level ground under floor slabs, paving and the like, including compaction	m^2	2.31	1527	$3,527.37
	Materials, construction and installation				
G. Chapman-Hill (2004, pers. comm., 23 August)	1,028,000L steel lined water tank, including delivery and installation, 18.04m dia	No	117,000.00	4	$468,000.00
Rawlinsons Group (2003, p. 227)	Reinforced concrete 25MPa foundation beams	m^3	187.00	184	$34,408.00
	Land Take and Opportunity Costs				
	Land value	$\$/m^2$			
	Maintenance				
Taylor (2004, p. 9)	Annual Maintenance assumed to be 3% of storage construction cost	% of construction cost	3%	$505,935.37	$15,178.06
				Sub-total	$521,113.43

Table H.1 Detailed Costing of Technical Components for Case Study continued…

References / Notes		Unit	Rate ($/unit)	Quantity	Cost ($)
Underground storage - 110 kL					
	Excavation and compaction				
Rawlinsons Group (2003, p. 206)	Excavate for basement or similar, not exceeding 3.00m deep, in clay	m^3	20.63	120	$2,475.00
Rawlinsons Group (2003, p. 208)	Level ground under floor slabs, paving and the like, including compaction	m^2	2.31	60	$138.60
	Materials, construction and installation				
Rawlinsons Group (2003, p. 456)	127,000L ribbed colourbond sheet steel, polyethylene lined water tank, 8.7m dia	No	10,010.00	1	$10,010.00
	Land Take and Opportunity Costs				
	Land value	$/m^2			
	Maintenance				
Taylor (2004, p. 9)	Annual Maintenance assumed to be 3% of storage construction cost	% of construction cost	3%	$12,623.60	$378.71
				Sub-total	$13,002.31
Underground storage - 3000 kL					
	Excavation and compaction				
Rawlinsons Group (2003, p. 206)	Excavate for basement or similar, not exceeding 3.00m deep, in clay	m^3	20.63	3500	$72,187.50
Rawlinsons Group (2003, p. 208)	Level ground under floor slabs, paving and the like, including compaction	m^2	2.31	1145	$2,644.95
	Materials, construction and installation				
G. Chapman-Hill (2004, pers. comm., 23 August)	1,028,000L steel lined water tank, including delivery and installation, 18.04m dia	No	117,000.00	3	$351,000.00
Rawlinsons Group (2003, p. 227)	Reinforced concrete 25MPa foundation beams	m^3	187.00	138	$25,806.00
	Land Take and Opportunity Costs				
	Land value	$/m^2			
	Maintenance				
Taylor (2004, p. 9)	Annual Maintenance assumed to be 3% of storage construction cost	% of construction cost	3%	$451,638.45	$13,549.15
				Sub-total	$465,187.60
Underground storage - 4000 kL					
	Excavation and compaction				
Rawlinsons Group (2003, p. 206)	Excavate for basement or similar, not exceeding 3.00m deep, in clay	m^3	20.63	4500	$92,812.50
Rawlinsons Group (2003, p. 208)	Level ground under floor slabs, paving and the like, including compaction	m^2	2.31	1527	$3,527.37
	Materials, construction and installation				
G. Chapman-Hill (2004, pers. comm., 23 August)	1,028,000L steel lined water tank, including delivery and installation, 18.04m dia	No	117,000.00	4	$468,000.00
Rawlinsons Group (2003, p. 227)	Reinforced concrete 25MPa foundation beams	m^3	187.00	184	$34,408.00
	Land Take and Opportunity Costs				
	Land value	$/m^2			
	Maintenance				
Taylor (2004, p. 9)	Annual Maintenance assumed to be 3% of storage construction cost	% of construction cost	3%	$598,747.87	$17,962.44
				Sub-total	$616,710.31

Table H.1 Detailed Costing of Technical Components for Case Study continued…

References / Notes		Unit	Rate ($/unit)	Quantity	Cost ($)
In-ground open storage - 4,200 kL					
	Excavation and compaction				
Rawlinsons Group (2003, p. 206)	Excavate for basement or similar, not exceeding 3.00m deep, in clay	m^3	20.63	4200	$86,625.00
	Materials, construction and installation				
Rawlinsons Group (2003, p. 212)	Waterproofing three coats liquid application	m^2	37.40	2000	$74,800.00
	Land Take and Opportunity Costs				
	Land value	$\$/m^2$			
	Maintenance				
Taylor (2004, p. 9)	Annual Maintenance assumed to be 3% of storage construction cost	% of construction cost	3%	$161,425.00	$4,842.75
				Sub-total	$166,267.75
In-ground open storage - 5,300 kL					
	Excavation and compaction				
Rawlinsons Group (2003, p. 206)	Excavate for basement or similar, not exceeding 3.00m deep, in clay	m^3	20.63	5300	$109,312.50
	Materials, construction and installation				
Rawlinsons Group (2003, p. 212)	Waterproofing three coats liquid application	m^2	37.40	2500	$93,500.00
	Land Take and Opportunity Costs				
	Land value	$\$/m^2$			
	Maintenance				
Taylor (2004, p. 9)	Annual Maintenance assumed to be 3% of storage construction cost	% of construction cost	3%	$202,812.50	$6,084.38
				Sub-total	$208,896.88
Treatment - In-line pipe treatment system					
Rawlinsons Group (2003, p.469)	"Humeguard" inline system; 600 dia pipe, 1.10 cum/s max hyd. cap.	No.	1	$19,500	$19,500.00
				Sub-total	$19,500.00
Treatment - Wetlands with pre-treatment					
	Excavation and compaction				
	included in material and cosntruction costs				$0.00
	Materials, construction and installation				
Taylor (2004, p. 5)	based on greenfield wetlands	/ha treated area	12,000.00	6.12	$73,440.00
	Disinfection system	Item	1,000.00	1	$1,000.00
Taylor (2004, p. 3)	Side entry pit traps	No.	200.00	18	$3,600.00
	Land Take and Opportunity Costs				
	Land value	$\$/m^2$			
	Maintenance				
Taylor (2004, p. 5)	Annual Maintenance	Item	10000	1	$10,000.00
				Sub-total	$88,040.00

Table H.1 Detailed Costing of Technical Components for Case Study continued…

References / Notes		Unit	Rate ($/unit)	Quantity	Cost ($)
Treatment - Wetlands with no pre-treatment (combined with infiltration trenches)					
	Excavation and compaction				
	included in material and cosntruction costs				$0.00
	Materials, construction and installation				
Taylor (2004, p. 5)	based on greenfield wetlands	/ha treated area	12,000.00	6.12	$73,440.00
	Disinfection system	Item	1,000.00	1	$1,000.00
	Land Take and Opportunity Costs				
	Land value	$/m^2			
	Maintenance				
Taylor (2004, p. 5)	Annual Maintenance	Item	10000	1	$10,000.00
				Sub-total	$84,440.00
Dual pipe pump distribution from Tom O'Brien Reserve					
	Pumping and Transport				
Rawlinsons Group (2003, p. 560)	Compact (close coupled) ISO pump set Up to 10 L/s @ 9m head (1.5kW)	No	3,597.00	1	
	Excavation and compaction				
Rawlinsons Group (2003, p. 457)	Trench excavation by machine (x 100 to 150mm wide) 1000mm total depth in clay	m	7.26	1000	$7,260.00
	Materials, construction and installation				
	PVC pipe to A.S./N.Z.S. 1477-1996 with solvent joints, laid in trench				
Rawlinsons Group (2003, p. 453)	80mm dia	m	26.40		$0.00
	100mm dia	m	34.93	1000	$34,925.00
Rawlinsons Group (2003, p. 454)	80mm Tee	No	37.68		$0.00
	100mm Tee	No	30.25	4	$121.00
Rawlinsons Group (2003, p. 454)	80 mm Elbow	No	28.05		$0.00
	100 mm Elbow	No	26.18	3	$78.54
	Land Take and Opportunity Costs				
	n/a - this is all public land and paths, which will still be available for use				
	Maintenance				
	Annual Maintenance				
				Sub-total	$42,384.54
Dual pipe pump distribution from from the corner of Parsons Street and Alfred Street					
	Pumping and Transport				
Rawlinsons Group (2003, p. 560)	Compact (close coupled) ISO pump set Up to 10 L/s @ 9m head (1.5kW)	No	3,597.00	1	$3,597.00
	Excavation and compaction				
Rawlinsons Group (2003, p. 457)	Trench excavation by machine (x 100 to 150mm wide) 1000mm total depth in clay	m	7.26	650	$4,719.00
	Materials, construction and installation				
	PVC pipe to A.S./N.Z.S. 1477-1996 with solvent joints, laid in trench				
Rawlinsons Group (2003, p. 453)	80mm dia	m	26.40		$0.00
	100mm dia	m	34.93	650	$22,701.25
Rawlinsons Group (2003, p. 454)	80mm Tee	No	37.68		$0.00
	100mm Tee	No	30.25	6	$181.50
Rawlinsons Group (2003, p. 454)	80 mm Elbow	No	28.05		$0.00
	100 mm Elbow	No	26.18	2	$52.36
	Land Take and Opportunity Costs				
	n/a - this is all public land and paths, which will still be available for use				
	Maintenance				
	Annual Maintenance				
				Sub-total	$31,251.11

Table H.1 Detailed Costing of Technical Components for Case Study continued…

References / Notes		Unit	Rate ($/unit)	Quantity	Cost ($)
Retrofitting houses for indoor water use					
	Excavation and compaction				
Rawlinsons Group (2003, p. 457)	Trench excavation by machine (x 100 to 150mm wide) 1000mm total depth in clay	m	7.26	2160	$15,681.60
	Materials, construction and installation				
	Rehau pipe straight 5 metre length				
Southern Plumbing Plus (2005)	16mm dia	m	11.01	576	$6,341.76
	20mm	m	15.80		$0.00
	16mm Tee	No	3.87	72	$278.64
	20mm Tee	No	4.72		$0.00
	16mm Elbow	No	2.67	72	$192.24
	20mm Elbow	No	3.67		$0.00
Rawlinsons Group (2003, p. 660)	Cistern Inlet Valve	No	17.00	144	$2,448.00
	Labour and Installation	Hrs	55.00	288	$15,840.00
	Land Take and Opportunity Costs				
	n/a - this is all public land and paths, which will still be available for use				
	Maintenance				
	Annual Maintenance				
				Sub-total	$40,782.24
Extra costs for Mains Water Backup supply					
	Pumping and Transport				
Rawlinsons Group (2003, p. 560)	Single phase electric motor and pump includingatuomatic float switch control 3.2 L/s @ 12m head (750kW)	No	1,903.00	1	$1,903.00
	Control panel for 3 phase operation including duty alternator, alarm level, pump failure alarm	No	4,147.00	1	$4,147.00
	Materials, construction and installation				
	PVC pipe to A.S./N.Z.S. 1477-1996 with solvent joints, laid in trench				
	100mm dia	m	34.93	10	$349.25
Rawlinsons Group (2003, p. 453-454)	100mm Tee	No	30.25	1	$30.25
	100 mm Elbow	No	26.18	1	$26.18
Southern Plumbing Plus (2005)	Backflow prevention valve	No	1	20	$20.00
	Maintenance				
	Annual Maintenance assumed to be 3% of pump cost	% of construction cost	3%	$6,475.68	$11,313.15
				Sub-total	$17,788.83

Table H.2 Summary of Technical Component Option Costs

Technical Component	Option	Cost
Collection		
	Pipes	$69,159.20
	Infiltration Trench	$106,260.00
Storage		
	110 kL above-ground closed	$12,319.11
	500 kL above-ground closed	$57,780.81
	3,000 kL above-ground closed	$388,418.10
	4,000 kL above-ground closed	$521,113.43
	110 kL underground closed	$13,002.31
	3,000 kL underground closed	$465,187.60
	4,000 kL underground closed	$616,710.31
	4,200 kL in-ground open	$166,267.75
	5,300 kL in-ground open	$208,896.88
	Extra costs for Mains Water Backup supply	$17,788.83
Treatment		
	In-line pipe treatment system (for base case)	$19,500
	Wetlands with pre-treatment	$88,040.00
	Wetlands with no pre-treatment	$84,440.00
Distribution		
	Dual pipe distribution from Tom O'Brien Reserve	$42,384.54
	Dual pipe distribution from the corner of Parsons and Alfred Street	$31,251.11
	Retrofitting houses for indoor water use	$40,782.24

Table H.3 Costing of Case Study Stormwater Use Scheme Options

Stormwater use scheme option	Collection option	Storage option (including mains water backup)	Treatment option	Distribution option	**TOTAL**
Base Case (No stormwater use)	Pipes $69,159	none $0	In-line pipe treatment system $19,500	none $0	**$88,659**
01 (Tom O'Brien Reserve)	Pipes $69,159	3,000 kL above ground closed $406,207	Wetlands with pretreatment $88,040	Dual Pipes outdoor use $42,385	**$605,791**
02 (Tom O'Brien Reserve)	Pipes $69,159	110 kL above ground closed $30,108	Wetlands with pretreatment $88,040	Dual Pipes indoor use $83,167	**$270,474**
03 (Tom O'Brien Reserve)	Pipes $69,159	4,000 kL above ground closed $538,902	Wetlands with pretreatment $88,040	Dual Pipes outdoor and indoor use $83,167	**$779,268**
04 (Tom O'Brien Reserve)	Pipes $69,159	3,000 kL underground closed $482,976	Wetlands with pretreatment $88,040	Dual Pipes outdoor use $42,385	**$682,560**
05 (Tom O'Brien Reserve)	Pipes $69,159	110 kL underground closed $30,791	Wetlands with pretreatment $88,040	Dual Pipes indoor use $83,167	**$271,157**
06 (Tom O'Brien Reserve)	Pipes $69,159	4,000 kL underground closed $634,499	Wetlands with pretreatment $88,040	Dual Pipes outdoor and indoor use $83,167	**$874,865**
07 (Tom O'Brien Reserve)	Pipes $69,159	4,200 kL open storage $184,057	Wetlands with pretreatment $88,040	Dual Pipes outdoor use $42,385	**$383,640**
08 (Tom O'Brien Reserve)	Pipes $69,159	5,300 kL open storage $226,686	Wetlands with pretreatment $88,040	Dual Pipes outdoor and indoor use $83,167	**$467,052**
09 (Tom O'Brien Reserve)	Infiltration $106,260	3,000 kL above ground closed $406,207	Wetlands with no pretreatment $84,440	Dual Pipes outdoor use $42,385	**$639,291**
10 (Tom O'Brien Reserve)	Infiltration $106,260	110 kL above ground closed $30,108	Wetlands with no pretreatment $84,440	Dual Pipes indoor use $83,167	**$303,975**

Table H.3 Costing of Case Study Stormwater Use Scheme Options continued…

Stormwater use scheme option	Collection option	Storage option (including mains water backup)	Treatment option	Distribution option	**TOTAL**
11 (Tom O'Brien Reserve)	Infiltration $106,260	4,000 kL above ground closed $538,902	Wetlands with no pretreatment $84,440	Dual Pipes outdoor and indoor use $83,167	**$812,769**
12 (Tom O'Brien Reserve)	Infiltration $106,260	3,000 kL underground closed $482,976	Wetlands with no pretreatment $84,440	Dual Pipes outdoor use $42,385	**$716,061**
13 (Tom O'Brien Reserve)	Infiltration $106,260	110 kL underground closed $30,791	Wetlands with no pretreatment $84,440	Dual Pipes indoor use $83,167	**$304,658**
14 (Tom O'Brien Reserve)	Infiltration $106,260	4,000 kL underground closed $634,499	Wetlands with no pretreatment $84,440	Dual Pipes outdoor and indoor use $83,167	**$908,366**
15 (Tom O'Brien Reserve)	Infiltration $106,260	4,200 kL open storage $184,057	Wetlands with no pretreatment $84,440	Dual Pipes outdoor use $42,385	**$417,141**
16 (Tom O'Brien Reserve)	Infiltration $106,260	5,300 kL open storage $226,686	Wetlands with no pretreatment $84,440	Dual Pipes outdoor and indoor use $83,167	**$500,552**
17 (Stormwater reserve)	Infiltration $106,260	500 kL above ground closed $75,570	UV Treatment $1,000	Dual Pipes outdoor use $31,251	**$214,081**
18 (Stormwater reserve)	Infiltration $106,260	110 kL above ground closed $30,108	UV Treatment $1,000	Dual Pipes indoor use $72,033	**$209,401**
19 (Stormwater reserve)	Infiltration $106,260	500 kL above ground closed $75,570	UV Treatment $1,000	Dual Pipes outdoor and indoor use $72,033	**$254,863**