IMPROVING THE WATER SUPPLY NETWORK BY MIXING RECYCLED WATER AND STORMWATER IN THE THIRD PIPE: A RISK MANAGEMENT FRAMEWORK

By

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ABSTRACT

Fresh water is a finite natural resource. Prolonged drought, record low inflows, population increase and climate change have increased the pressure on water authorities and conventional water supply systems. Additional measures such as demand management and the use of alternative water resources (e.g. recycled water and stormwater) have been considered by water authorities to ease pressure on the conventional water supply systems. Projects utilising both recycled water and treated stormwater in an integrated system have the potential to increase the security of supply and to improve water efficiency by using water supplies and water storages more effectively. The City West Water, the local water authority supplying water to the West of Melbourne (in Australia) had proposed to use combination of recycled water and treated stormwater through a novel approach of injecting treated stormwater into the 'third' pipe, which carries recycled water. In this new approach, mixing of the two types of water takes place inside the third pipe, in contrast to the current approach of using combined recycled water and stormwater treated and mixed at the source and delivered through the third pipe. This study investigated the issues and challenges that could be faced with this novel approach.

First step of this study was to develop a guideline to specify limits of water quality parameters which pose problems in the use of both recycled water and stormwater, as there is no such guideline in Australia to the author's knowledge. Relevant existing guidelines used in Australia and New Zealand, for water recycling were used to develop the proposed guideline. The water quality parameters included in the guideline were selected by reviewing the available literature to understand what water quality parameters caused issues in the use of both types of water separately and in combination. As the second step of the study, a risk management framework was developed to ensure the water quality as specified by the proposed guideline is supplied to the intended users. As the third step of the study, the developed risk management framework was applied to the Black Forest Road South Study Area in Melbourne. This study area has been selected by City West Water to supply third pipe water to new developments with the novel approach of injecting treated stormwater into the third pipe, which carries recycled water.

The proposed guideline for water quality and the risk management framework proposed in this study can be implemented in any project using combination of recycled water and

stormwater within Australia or overseas with required modifications to suit to local conditions.

This study paves a way forward in the Integrated Urban Water Management to utilise urban water systems to minimise their impact on the natural environment and to maximise their contribution to social and economic viability.

DECLARATION

I, Marina Primali Perera, declare that the Master's thesis entitles 'Combined use of Recycled Water and Treated Stormwater via Third Pipe' is no more than 60, 000 words in length including quotes and exclusive of tables figures, bibliography, 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.

[redacted] .... [redacted] ....

Marina Primali Perera Date

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1 INTRODUCTION

1.1 BACKGROUND

Water is of fundamental importance for human life, socio-economic development, as well as for healthy biosphere and ecosystems. Fresh water is a finite natural resource. Prolonged drought, record low inflows, population increase and climate change have increased the pressure on the water agencies. Additional measures such as water demand management and the use of alternative water resources (e.g. recycled water and stormwater) have been considered by water agencies to address to relieve the above pressures. Urban water management is now on the verge of a revolution in response to rapidly increasing water demands and to make urban water systems more resilient to climate change (Bahri, 2012). Integrated Urban Water Management (IUWM) is an approach which is used by urban water utilities to plan and manage urban water systems (i.e. water supply, wastewater and stormwater systems) to minimise their impact on the natural environment, to maximise their contribution to social and economic viability, and to engender overall community improvement (Maheepala et al., 2010). Integrated management of potable water and alternative water resources enhances the operational flexibility compared to the individual management of separate water systems. In order to understand the performance of integrated management of urban water resources, understanding of the issues and challenges of recycled water and stormwater projects separately is important.

Recycled water is now considered an important component of integrated water resource management, making possible to close or accelerate the urban water cycle and to preserve natural water resources and biodiversity (Lazarova et al., 2013). Successful recycled water projects exist all over the world. The common challenges inherent in recycled water projects are related to odour, colour, salinity and health issues. Stormwater is the runoff generated from storm events, and increases the generated volume as the impervious area are added because of the urban development. Proper management of stormwater in the new developments has the potential to address many of the issues affecting the health of waterways and water supply challenges facing the modern urban development. The new developments result in increased demands for water supply. They also have the potential to increase the volume of stormwater that can contribute to flooding. Stormwater harvesting and reuse is one of the viable options, that can be used to address both these issues. Harvested stormwater has commonly been used for irrigating public parks and golf courses, and other non-potable uses all over the world. The presence of microorganisms, nutrients, sediment, and heavy metals in urban stormwater generated from different surfaces have prompted the necessity to understand the associated public health risks prior to its usage.

Projects using both recycled water and treated stormwater in one integrated system have the potential for increasing the security of supply and improving water efficiency by using water supplies and water storages more effectively. With this approach, better use can be made of network infrastructure, optimisation of water resources, ensuring water quality and the public acceptance. Various types of pollutants present in these alternative water supply brings new challenges to water management. Identifying risks and preventive measures for risk control in alternative water supply system is essential to protect public and environmental health.

The study described in this thesis investigated the viability of combined use of recycled water and treated stormwater where treated stormwater is injected into the third pipe, which carries recycled water. This novel approach to inject treated stormwater into the recycled water pipe (third pipe) will have the benefits as outlined below over the conventional mixing methods within an enclosure such as in a mixing tank.

- The proposed injection system introduces different small scale treatment at the stormwater harvesting sites along the third pipe at strategic locations which will potentially have cost savings.
- More stormwater use reduces costlier treatments of recycled water.
- The addition of water sources to the pipe network as they become available and demand increases (as new developments are built along the pipeline path) will be a flexible feature unique to the proposed system.

The focus of study was on the quality of the combined water. However, there is no guideline available to control or manage the water quality of the combined use of treated stormwater and recycled water. This study developed a guideline for the combined use of treated stormwater and recycled water which is an important addition to the Integrated Urban Water Management.

This study was also aimed at developing a risk management framework to control risks due to quality of combined system of recycled water and treated stormwater in the third pipe. The Australian Guideline for Water Recycling – Phase 1 (NRMMC- EPHC-NHMRC, 2006) provides a nationally consistent approach to the management of health and environmental risks from water recycling. A central feature of risk management framework of this guidelines is that it is a generic framework and can be applied to any system of recycled water from treated sewage, greywater and stormwater. The same framework was applied to this project with the appropriate changes and modifications to the combined use with special attention to the mixing strategy which is treated stormwater injection into the third pipe. The framework developed for the combined use was applied to the Black Forest Road South area in West Werribee and Expanded Urban Growth Boundary project (WWEUGB) in Victoria.

1.2 AIMS OF THE STUDY

The aims of the proposed study were:

1. To develop a guideline to manage water quality of combined use of recycled water and treated stormwater.
2. To set up a risk management framework to identify and control risks of combined water systems where treated stormwater is injected into the pipe carrying recycled water.
3. Demonstration of the proposed risk management framework through a case study applied to the Black Forest Road South area in West Werribee and Expanded Urban Growth Boundary Project (WWEUGB), which will be called as “study area” throughout the thesis.

1.3 METHODOLOGY IN BRIEF

(1) Development of a guideline for the combined water quality based on “fit for purpose” approach;

There are separate guidelines available for recycled water and stormwater to maintain quality. However, there is no guideline available for combined water use in Australia to the author’s knowledge. The first step of the methodology was to develop a guideline based on “fit for purpose”. That is combined water must be treated to a level that is suitable for its end use applications (i.e. treated for fit for the purpose). Combined water is planned to use for residential, municipal and commercial properties for irrigation, water features, utility washing, car washing, toilet flushing and clothes washing (City West Water, 2012).

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After reviewing the Australian Drinking Water Guideline (ADWG, 2013), the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC-ARMCANZ, 2000) and the Guidance for the Use of Recycled Water by Industry (ISI and CSIRO, undated), the common issues and challenges of the use of recycled water and stormwater and the water quality parameters accountable for these water quality issues were identified. These issues are basically related to identified parameters concentrations beyond a threshold limit and salinity, odour, colour, corrosion, health issues, deposits, scaling of pipes and fouling are some of the challenges identified based on the literature review (ADWG (2013), ANZECC-ARMCANZ (2000), ISI and CSIRO (undated).

After identifying the relevant water quality parameters, the next step was to propose the limits (or thresholds) for these parameters to mitigate the effects of the identified issues. The following guidelines were used to set these limits.

- EPA guidelines (EPA Victoria, 2003, EPA Victoria, 2005)
- Australian guidelines for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006) and Phase 2 (NRMMC-EPHC-NHMRC, 2009)
- Australian and New Zealand Guidelines for fresh and Marine Water Quality (ANZECC-ARMCANZ, 2000)

The most critical value (or lowest concentration specified among the guidelines) was selected as the threshold in the proposed guideline for each water quality parameter from the above guidelines. When selecting threshold values applicable to irrigation, short term trigger values were considered in the proposed guideline, as most irrigation equipment is likely to have less than 20 years design life (NRMMC-EPHC-NHMRC, 2009).

(2) Development of a risk management framework to identify and control risks of combined water systems where stormwater is injected into the third pipe carrying recycled water

The Australian Guidelines for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006) provides a generic risk management framework that can be applied to any recycled water system (i.e. recycled water produced by treated sewage, greywater or stormwater). The Phase 2 (NRMMC- EPHC- NHMRC, 2009) of the above guidelines which is for stormwater harvesting and reuse adopts the same risk management framework with relevant modifications. Therefore, this same risk management framework was applied to the proposed study of combined use of recycled water and treated stormwater. This framework has 12 elements. Commitment to responsible use and management of recycled water quality corresponds to Element 1. The systems analysis and management are covered under the planning stage of a project and is the core section of the framework. This section is the most relevant to this study as this is in planning stage and detailed study is done for the section of systems analysis and management. It has five elements (Elements 2 to 6), as listed below and explained in detail in the next chapters. These elements were adopted for this study. Elements 7 to 10 correspond to supporting requirements that demonstrate the commitment for the implementation. Elements 11 and 12 provide a basis for evaluation and continuous improvement under review part of the project after implementation.

- Element 2: Assessment of the combined use of recycled water and treated stormwater system
    - Identify intended use of third pipe water system
    - Assessment of water quality data
    - Hazard identification and risk assessment
- Element 3: Preventive measures for the combined use of recycled water and treated stormwater system
    - Preventive measures and multiple barriers
    - Identify critical control points to eliminate the risks of potential water quality deficiencies
- Element 4: Operational procedures and process control

  - Operational procedures to control risks involved in the operation of treatment plants and pumping stations
  - Operational monitoring to eliminate risks from the source to user
  - Corrective actions where operational parameters are not met
  - Equipment maintenance to eliminate the mechanical risks
  - Ensure that only approved materials and chemicals are used to eliminate the risks of inferior water quality
- Element 5: Verification of the combined use of recycled water and treated stormwater quality and environmental performance
- Element 6: Incident and emergency management
  - Ensure the emergency situations shall not lead to risks of water quality deficiencies
  - Ensure the risks of mechanical equipment failures are properly identified
  - Ensure alternative power supply facilities are provided

(3) Application of risk management framework to study area

The risk management framework proposed in the above section was applied to the study area of Black Forest Road South area (PSP 42.2). Combined water is planned to be used in the study area under the patronage of City West Water (CWW). The study area has an area of 500 ha, and is bounded by Black Forest road, McGrath road and Bulban road. It is envisaged that on completion, the PSP 42.2 will allow the development of approximately 5,000 new homes over the next 30 years. The anticipated future water demand is 800 ML/year. The CWW is planning to supply approximately 250 ML/year of combined recycled water and treated stormwater via third pipe to the developments. It is estimated that the Black Forest Road South Development Services Scheme and the broader Lollypop Creek catchment generate substantial amounts of stormwater that could be harvested for the use of this study area.

The framework Elements 2 to 6 (as briefly explained above) was applied to the study area to manage risks for the end use applications, as the project is in the planning stage. It is necessary to consider combined water project from source to the end user when applying the risk management framework. Combined water system consists of three subsystems as listed below.

1) Recycled water subsystem (from source to the first stormwater injection point)
2) Stormwater subsystem (from source to the stormwater injection point)
3) Combined water subsystem (from first stormwater injection point to the end use application)

The risk management framework has to be applied to the above mentioned three subsystems to complete the risk assessment of combined water project in the study area.

1.4 SIGNIFICANCE OF THE RESEARCH

This study introduces a novel concept of injecting treated stormwater into the third pipe carrying recycled water where the mixing of recycled water and treated stormwater takes place inside the third pipe. The other main feature of this system is that treated stormwater is added to the system whenever there are more demands along the pipe line, such as the water demand for residential developments and irrigation. This method of supplying combined water is a step forward in the popular concept of Integrated Urban Water Management.

The development of the water quality guideline for the combined use of recycled water and treated stormwater was one of the key steps of this study, as there is no such guideline developed so far in Australia to the author's knowledge. The basis for the selection of the water quality parameters in this guideline was identifying the parameters causing issues in the use of non-potable water related to salinity, odour, colour, corrosion and health. The acceptable limits of these parameters was set out by a "fit for purpose" approach. Existing guidelines currently in use were used to arrive at the limits of the parameters of the proposed guideline.

The introduction of the risk management framework for controlling risks of the combined use of recycled water and treated stormwater in the third pipe was the other important aspect of this study. For the development of this framework, the guidelines available for water recycling (NRMMC-EPHC-NHMRC, 2006) and stormwater harvesting and reuse (NRMMC-EPHC-NHMRC, 2009) were used. These guidelines had introduced risk management frameworks for recycled water and stormwater applications respectively, and these frameworks are similar. The same risk management framework was applied to this study with the appropriate changes and modifications to the combined use of recycled water and stormwater with special attention given to the mixing strategy. Thus, the developed framework will be a major contribution to scientific knowledge which will provide guidance in the design and development of combined water projects, where treated stormwater is injected into the recycled water pipe.

The final stage of the study was the application of the framework to the Black Forest Road South area in West Werribee and Expanded Urban Growth Boundary project (WWEUGB) in Victoria. Successful documentation of the risk management framework to the study area will be an encouragement to any water authority to adopt this innovative system for new developments.

The implementation of the combined water project, where stormwater is injected into the third pipe would expect significant savings of potable water per year and increase the amount of stormwater use while reducing the pollutant loads reaching the waterways.

1.5 OUTLINE OF THE THESIS

Chapter 1 provides the introduction of the study which includes the aims of the study and the brief methodology adopted to achieve the desired aims of the study. This chapter also describes the significance of this research.

Chapter 2 provides a review of the use of third pipe water in Australia and worldwide. This includes review of recycled water projects, stormwater projects and combined water projects.

Chapter 3 describes water quality issues and challenges in mixing recycled water with stormwater. It includes development of a guideline for the use of combined water (recycled water and treated stormwater) based on the issues and challenges of water quality.

Chapter 4 describes the risk management framework for combined use of recycled water and stormwater as used in this study. It consists of the methods to identify and control risks in combined water systems, based on the existing risk management systems for recycled water and stormwater in Australia.

Chapter 5 provides a description of the application of the risk management framework to the study area.

Chapter 6 summarises the study and includes the conclusion and the recommendations of the study.

2 COMBINED WATER IN A THIRD PIPE – ISSUES AND CHALLANGES

2.1 INTRODUCTION

Water reuse has a long history worldwide. Use of wastewater for agricultural irrigation extend back approximately 3000 years to the Greek Minoan Civilization (Asano et al., 2007). With the developments of sewerage systems in the nineteenth century, recycled water has been used mainly for crop production. The development of the activated sludge process around 1913 was a significant step toward advancement of wastewater treatment (Asano et al., 2007). Further technological advances in physical, chemical and biological processing of wastewater during the first half of the twentieth century extends the application of recycled water. Disinfection using chlorine began in the early 20th century and led to a dramatic drop in waterborne diseases. The Irvine Ranch Water District (IRWD) was the first water district in California to receive an unrestricted use permit from the state for its recycled water; such a permit means that water can be used for any purpose except for drinking (http://www.irwd.com/services/recycled-water). The use of the colour purple for pipes carrying recycled water was pioneered by the Irvine Ranch Water District in Irvine, California. The colour of recycled water pipes, known worldwide as Irvine Purple, originated at IRWD.

Recycled water application of irrigation from early stage has been evolved in many areas todate. Following are some end use applications of recycled water in current practice.

- Irrigation of lawns and gardens
- Landscape irrigation for golf courses, parks, cemeteries and freeways
- Toilet flushing, cooling tower makeup water and boiler feed water
- Groundwater recharge
- Advanced wastewater reclamation systems to augment potable water supplies

This chapter is structured to present the recycled water and stormwater projects separately to identify the issues and challenges first, which is important to understand the performance of integrated management of urban water resources. Then it is further extended to present the issues and challenges of projects using these two types of water combined (or mixed), which are not very common. This was done with the emphasis on assisting in the development of the risk management framework, described in the latter part of the thesis.

2.2 RECYCLED WATER PROJECTS

2.2.1 Overseas recycled water projects

The majority of recycled water projects worldwide are implemented for agricultural irrigation. Israel re-uses 75-80% of their total wastewater. It is estimated that recycled water will cover 50% of Israel's agricultural water needs by 2020 (Futran, 2013). In California, the Groundwater Replenishing System (GWRS) in Orange County is the world leader in groundwater recharge using recycled water for indirect potable reuse (Lazarova et al., 2013). Changi Water Reclamation Plant (CWRP), located at the eastern end of Singapore, is one of the largest and most advanced reclamation facilities in the world. In Japan, investigation of large-area reuse of wastewater started in 1964, and treated wastewater is reused for toilet flushing, recreational impoundment, industrial usage, agriculture and snow melting (Crook and Association, 2004). The major recycled water application in South Africa are aquifer storage and recharge, cooling in power stations and industrial application in paper industry.

Following are some recycled water projects overseas found in the literature (Crook and Association, 2004,Asano et al., 2007, Lazarova et al., 2013, Goren et al., 2014). For each project, a brief description, benefits and issues are discussed below.

1. Monterey County Water Recycling project, California, USA (Crook and Association, 2004, Lazarova et al., 2013)
   - Project description

     Wastewater plant was completed in 1997 and began delivering 76,000 m^3/d of reclaimed water for food crop irrigation in 1998. The treatment processes include coagulation, flocculation, sedimentation, filtration and chlorination. It is a centralised control system and distribution network consists of 74 km pipe line and 3 booster pump stations.
   - Benefits

     Water reuse is considered as the major factor for success of agricultural industry.

- Issues

  Sodium absorption ratio (SAR) and exchangeable sodium percentage are significantly higher in fields irrigated with recycled water, but are within the acceptable range. Efforts are underway to reduce salt concentration in wastewater through source control.

2. Dan Region Sewage Reclamation and Recharge project, Israel (Goren et al., 2014, Asano et al., 2007)

   - Project description

     Wastewater reclamation plant was completed in 1989 and began delivering 310,000 m^3/d of reclaimed water for food crop irrigation. The treatment processes include facultative oxidation ponds with reticulation, polishing ponds, ammonia stripping & re-carbonation and Soil Aquifer Treatment (SAT) using four recharge basins. SAT consists of controlled passage of effluent through the unsaturated soil and the aquifer. Distribution system consists of 100 recovery wells, 87 km pipes and local storage reservoirs. Main application is agricultural irrigation.

   - Benefits

     The largest reuse project in Israel with national importance with economic benefits

   - Issues

     Biofouling of the effluent pipeline and lack of capacity of the SAT system

3. Makuhari New Central Water Recycling Project, Tokyo, Japan (Lazarova et al., 2013)

   - Project description

     Wastewater treatment began in 1989. The treatment processes include activated sludge process, chemical coagulation, filtration, ozonation and chlorination. Tertiary treated recycled water is used for toilet flushing and agricultural irrigation. Supply capacity is 4120 m^3/d.

   - Benefits

     Increase water security in high population density area

- Issues

  Higher energy consumption in treatment process

4. Orange County Water District – Water Factory 21, California, USA (Asano et al., 2007, Crook and Association, 2004)
   - Project description

     The first permit for the project was issued in 1971 under the condition of blending with deep well water prior to injection into the aquifer. Secondary effluent is treated through lime classification, re-carbonation, mixed media filtration, reverse osmosis, UV radiation and blended with deep well water. Tertiary treated recycled water is used for urban and agricultural irrigation, power plant cooling and wetlands creation and enhancement.
   - Benefits

     Eliminated discharge of wastewater to the surface waters
   - Issues

     N-nitrosodimethylamine (NDMA) and 1, 4-dioxane, which are classified as human carcinogens, were found in reclaimed water and exceeded the prescribed levels of States guideline. Treatment train was later modified to include advanced oxidation process (AOP) to avoid this problem.

5. NEWater, Singapore (Lazarova et al., 2013)
   - Project description

     The pillar of Singapore's water sustainability is NEWater. High-grade reclaimed water produced from treated used water that is further purified using advanced membrane technologies and ultra-violet disinfection, making it ultra-clean and safe to drink. The first NEWater plants were opened in 2003. In 2010, Singapore's largest NEWater plant was completed. Singapore's four NEWater plants can meet up to 30% of the nation's water needs. NEWater is primarily produce water for non-potable industrial uses. This water is supplied to commercial premises for air-conditioner cooling, petrochemical and refinery industries for process cooling, boilers and general washing purposes. It is delivered via a separate distribution network to industrial and commercial customers. The demand for NEWater has grown from 18,200 m^3/d in 2003 to 273,000 m^3/d 2014.

- Benefits

  Water security of the country is increased.

- Issues

  Comprehensive water quality monitoring and winning the public acceptance were some challenges of the project. Higher energy consumption is an issue and continuous research is being carried out to find cost effective solutions.

2.2.2 Australian recycled water projects

Recycled water has been used in Australia for a long time. Land application of effluent, initially serving as the treatment process, commenced in Australia at Islington, South Australia in 1881. The Islington Farm was replaced with the Bolivar Wastewater Treatment Plant in 1969. A much larger land-based plant was developed at Melbourne's Werribee sewage farm from 1892, operating with grass filtration system (Radcliffe, 2004). With the publication of the Ecologically Sustainable Development Report in 1991, the Australian states began establishing environment protection agencies and authorities. However, until 2003, the National Water Reform Framework had excluded recycled water from its considerations (Campbell, 2003). Victoria's Guidelines for the Use of Reclaimed Water were also updated and reissued in 2003 (EPA Victoria 2003).

The common challenges inherent to recycled water projects are odour, colour and health issues.

Following are some recycled water projects in Australia found in the literature (Asano et al., 2007, Apostolidis et al., 2011, Tedra Australia Pty Ltd, 2011, Lazarova et al., 2013,). For each project, a brief description, benefits and issues are discussed below.

1. Virginia Pipeline Scheme in Adelaide, Australia (Asano et al., 2007,Lazarova et al., 2013)

   - Project description

     The Virginia Pipeline Scheme was completed in 1999 and was the first large-scale agriculturally based water recycling scheme in Australia. The

Virginia Pipeline has more than 100 km of pipes bringing treated wastewater from the Bolivar wastewater treatment plant and provides an alternative source of water to local irrigators. The Bolivar Waste Water Treatment plant (WWTP) treatment process includes primary treatment (screening and primary sedimentation tank), secondary treatment (aeration tanks or lagoons and clarification units) and tertiary treatment (disinfection). To further improve the quality of recycled water, the Dissolved Air Flotation and Filtration (DAFF) plant has been constructed at Bolivar. The DAFF Plant treatment process (dissolved air flotation, micro filtration and disinfection) was selected as the most economical solution to reduce the salt level of treated waste water. The WWTP Class "A" recycled water, classified as the highest grade in South Australia is then distributed through the Virginia Pipeline Scheme to the Adelaide Plains. Recycled water is used for unrestricted irrigation of vegetable and salad crops.

- Benefits

  Water reuse is considered as the major factor for success of agricultural industry ($200 million/Year). The Virginia Pipeline Scheme has decreased the volume of nutrient rich treated effluent entering St Vincent Gulf (approximately 75% decrease in the Nitrogen and 40% decrease in phosphorus loading from 1996 to 2003) (Kelly et al., 2003)

- Issues

  When nitrogen and phosphorus concentration in recycled water exceed the natural requirement, plant growth is affected. This could be managed with appropriate irrigation management practice.

2. Western Corridor Recycled Water Scheme in Queensland, Australia (Apostolidis et al., 2011,Lazarova et al., 2013)

   - Project description

     The Western Corridor Recycled Water Scheme is the largest water recycling scheme in Australia by 2009 and has treatment capacity to provide 236,000 m^3/day. Main application is supply recycled water to power stations, reducing demand on traditional water sources. The project uses secondary wastewater from Brisbane and Ipswich, to produce purified recycled water. It consists of three advanced water treatment plants – located at Bundamba, Luggage Point and Gibson Island, and the treatment processes include microfiltration, reverse osmosis and advanced oxidation by UV radiation. Recycled water quality meets the Australian Drinking Water Guidelines (Lazarova et al., 2013). Industrial applications and power station use are major applications of the scheme. Purified recycled water is blended with water in Wivenhoe dam and used as indirect potable use, when storage is below 40% (Apostolidis et al., 2011).

- Benefits

  Reduce nutrient loads into Brisbane and Bremer Rivers and Moreton Bay as a result of further treatment of treated wastewater in Advanced Water Treatment Plant (AWTP).

- Issues

  When flood water is filled in water supply storages, recycling scheme cannot operate at full capacity.

3. Altona Recycled water project in Melbourne, Australia (Tedra Australia Pty Ltd, 2011)

   - Project description

     The Altona recycled water project has a wastewater Treatment Plant (AWTP) and Recycled Water Plant (ARWP). The treatment processes of AWTP include Aeration reactors, an aerobic digester, tertiary filters and UV disinfection units. The ARWP utilises ultrafiltration and reverse osmosis, to remove excess salt from the treated wastewater. The project supplies up to 2.5 million m^3/year of recycled water to an industry, golf courses and public open spaces in the Altona area. The recycled water used for golf courses and public open spaces is demineralised using a single-pass, reverse-osmosis system, while industrial-grade recycled water is treated using a two-pass, reverse-osmosis system.

   - Benefits

     The project has the effect of reducing prices to customers as potable water is replaced by recycled water.

- Issues

  Quality of the secondary treated water coming into the ARWP varied significantly for short periods, and occasionally the recycled water leaving the plant did not meet the agreed water quality standards. Operational design of the plant has been changed to address the problem.

4. Kooragang Recycled Water Scheme (KRWS) in New South Wales, Australia

   - Project description

     The Kooragang Recycled Water Scheme (KRWS) is the largest recycled water project in the region and has the capacity to produce 3.3 million m^3/year of recycled water. Treated wastewater by Hunter Water Corporation (HWC) is diverted to KRWS, which uses membrane filtration and reverse osmosis to produce high-quality recycled water. Recycled water produced in KRWS is then transported to industrial customers on Kooragang Island via an 8 km pipeline.

   - Benefits

     Save up to 3.3 million m^3 of drinking water each year

   - Issues

     Chlorine Contact time (Ct) in the chlorine contact tank had fallen below the critical limit. Error was identified and has been rectified and the faulty valve has been replaced.

5. Rouse Hill Recycled Water Project in New South Wales, Australia (Asano et al., 2007 Apostolidis et al., 2011,Lazarova et al., 2013)

   - Project description

     The Rouse Hill recycled water project is Australia’s first dual water supply scheme. It started in 1995 and supplies recycled water via third pipe system for toilet flushing, watering gardens, washing cars and other outdoor purposes. Treatment processes include primary sedimentation, activated sludge operated for nitrogen and phosphorus removal, coagulation, flocculation, clarification, filtration, chlorine disinfection and pH control.

- Benefits

  Reduction of drinking water demand by about 40%

- Issues

  A cross connection was discovered in 2004 and affected 82 homes. Unauthorised plumbing work in household was the reason and it was rectified.

2.3 STORMWATER PROJECTS

The potential presence of a range of contaminants in urban stormwater due to the stochastic variations in rainfall and catchment hydrology, as well as source contributions from different activities have prompted the necessity to understand the associated public health risks prior to utilising urban stormwater for higher value end uses (Chong et al., 2013). Previously, a number of studies have found diverse contaminants present in stormwater, which include suspended solids, nutrients, heavy metals, polycyclic aromatic hydrocarbons, pesticides, herbicides, faecal indicator bacteria (FIB), pathogens, and others (Eriksson et al., 2007, Duncan, 1999, Aryal et al., 2010, Vezzaro and Mikkelsen, 2012). Traditional stormwater treatment methods such as sand filters and bioretention require ongoing maintenance to ensure the performance while grass swale and wetland require a large land footprint for adequate levels of treatment. High rate treatment systems include fibre filters, deep bed filters and biofilters which can achieve a relatively high pollutant removal at a high rate (Aryal et al., 2010).

2.3.1 Overseas stormwater projects

Stormwater harvesting and reuse is considered as a good option for sustainable water management all over the world. Singapore has been harvesting urban stormwater runoff to supplement its water supply for more than 20 years (Lim et al., 2011). Stormwater harvesting has been used in Germany since 1980, as a cost effective solution to overcome problems in combined sewer system (Nolde, 2007). In USA, stormwater harvesting is encouraged to avoid pollution of natural waterways, while Tokyo in Japan, it was a solution to cater higher demand of water.

Below are some of the successful overseas stormwater harvesting projects found in the literature (Crook and Association, 2004, Nolde, 2007, Lim et al., 2011, Pitt et al., 2012, PUB (Singapores National Water Agency), 2013). For each project, a brief description, benefits and issues are discussed below.

1. Stormwater harvesting projects, Singapore (Lim et al., 2011, PUB(Singapores National Water Agency), 2013)
    - Project description

      Singapore use most of the land area as stormwater catchments to harvest stormwater. To harvest stormwater from urban catchments, effective pollutant source management is needed to ensure that water quality of the runoff is acceptable with minimal health risk. Stormwater is collected through a comprehensive network of drains, canals, rivers, stormwater collection ponds and reservoirs before it is treated for drinking water supply. The treatment processes include primary treatment (coagulation and sedimentation), filtration (sand filter or membrane filtration) and disinfection (chlorine and/or ozone).
    - Benefits

      Improved water security of the country and answer to the flooding problem
    - Issues

      Bad odour or taste exists in the treated stormwater and could be eliminated with activated carbon

2. Berlin–Lankwitz stormwater project, Germany (Pitt et al., 2012)
    - Project description

      The Berlin–Lankwitz stormwater project supplies treated stormwater to 80 apartments and 6 small business places (200 persons) with high-quality water for toilet flushing and garden watering and has been in operation since 2000. The scheme includes sedimentation grit chamber, initial collection stormwater reservoir, biological treatment, UV disinfection and treated water storage.
    - Benefits

      First flush diversion avoids highly polluted first flush entering the stormwater treatment system. Also it provides protection of receiving waters and increase water security in the area.

- Issues

  After a long drought period in summer, relatively high BOD concentration (up to 45 mg/L) were reported.

3. Santa Monica Urban Runoff Recycling Facility project (SMURRF) in California, USA (Crook and Association, 2004)

   - Project description

     An average of 1800 m^3/d of urban runoff generated in parts of the cities of Santa Monica and Los Angeles is treated by conventional and advanced treatment systems at the SMURRF. Dry weather runoff from the stormwater drain system (after screening) is conveyed to the treatment facility using pumps. Then it is stored in a raw water storage after going through rotating drum and grit chamber. The treatment system of raw stormwater includes dissolved air flotation, microfiltration and UV disinfection. Once treated, the water is stored in a clean water storage and safe for all landscape irrigation and dual-plumbed systems. In clean water storage, if the TDS is in between 1000 mg/L to 1500 mg/L, the treated water is blended with potable water to reduce TDS level up to 1000 mg/L, before it leaves from the storage.

   - Benefits

     It eliminates pollution of Santa Monica bay caused by urban runoff during dry season (dry weather flow). Also it provides cost effective treatment and producing high quality water for reuse.

   - Issues

     When UV is used as the only disinfection method, there is no disinfectant residual in the distribution system. Then it is possible for bacteria growth inside the distribution system, because of the presence of nutrients and non-uniform usage. Bacteria growth inside the pipe causes colour and odour problems. To address the issue of bacteria growth, chlorination is added for the purpose of maintaining chlorine residual in the distribution system.

4. Renaissance Project, West Farm Beach in Florida, USA (Pitt et al., 2012)
    - Project description
      The Renaissance project has been operated since 2002. Stormwater runoff from the Pineapple Park neighbourhood and parts of the convention centre is collected through the canal and is directed to a 20,000 m^2 settling basin. Alum and polymers are also added for the control of heavy metals, nutrients, oils and grease. Treated stormwater is then pumped in to the 20,000 m^2 wetland, where it is further cleaned through interaction with wetland plants. Then part of the treated stormwater is discharged to the Lake Worth Lagoon (approximately 1.35 million m^3 per year), while the other part is pumped in to the West Palm Beach Water Treatment Plant for further treatment. More than 1.15 million m^3 per year of treated stormwater is added to the City's water supplies.
    - Benefits
      Reducing stormwater runoff to the Lake Worth Lagoon (reducing adverse impacts), increasing flood protection levels in the low-lying Pineapple Park neighbourhood and providing the required surface water management needs (water quality and quantity) for the City Place and Palm Beach County Convention Centre re-development projects are the benefits of the Renaissance Stormwater Harvesting Project.
    - Issues
      Elevated levels of lead are reported. Lead is primarily from materials and components associated with service lines and home plumbing. Customer education or awareness is done to avoid the use of plumbing materials with lead.

2.3.2 Australian stormwater projects

In urban areas in Australia, stormwater is considered as a nuisance in earlier days. Water Sensitive Urban Design (WSUD) offers an alternative to the traditional conveyance approach (BPEMG, 2006). Through WSUD, stormwater is also added to the urban water cycle and incorporated into the urban design and minimised environmental degradation and improve aesthetics. The technology and design of WSUD elements in Australia has been evolved since 2000 with many projects demonstrating innovation (Wong, 2006).

Below are some of the successful stormwater harvesting projects in Australia found in the literature (Blaess et al., 2006, Kus and Kandasamy, 2009, Asoka Jayaratne, 2011, Corbett, 2012, Leonard et al., 2014). For each project, a brief description, benefits and issues are discussed below.

1. Kalkallo Stormwater Harvesting Project in Melbourne, Australia (Asoka Jayaratne, 2011, Corbett, 2012)
    - Project description

      The Kalkallo Stormwater Harvesting project won the 'Master-planning and design' category of the Victorian Stormwater Industry Association 2009 Stormwater Excellence Awards. The catchment area of this project is 160 hectares of industrial land at Merrifield. Stormwater is collected via traditional stormwater drains and directed to a series of treatment ponds and wetlands which remove pollutants. Partially treated stormwater enters a large wetland for further pollutant removal. The wetland overflows into a 65000 m^3 capacity open storage basin. Stormwater is then pumped from the storage basin into a treatment plant. The treatment processes include inclined-plate clarifier (Lamella Plate Separator), Coagulation/Ultra-filtration, Reverse Osmosis and Advanced Oxidation and Chlorination. The treatment plant produces a higher than drinking water quality end product. The project delivers around 365 million litres of treated stormwater annually. Initially it is supplied as third pipe water for non-potable water applications and eventually, it is hoped it can supplement the potable water supply with rigorous monitoring.
    - Benefits

      Stormwater pollutants discharging into Kalkallo Creek, will be reduced with an estimated average annual reduction of 1.46 tonnes of Nitrogen.
    - Issues

      The Kalkallo Stormwater Harvesting Project has open storages and Blue-green algae (BGA) problems are anticipated, which cause operational challenges.

2. Troups Creek stormwater recycling project in Narre Warren North, Melbourne, Australia (McCarthy D, Undated,)
    - Project description

      The Troups Creek stormwater recycling project was developed in Narre Warren North (40km South East direction from Melbourne). Treated stormwater supply via third pipe was commenced in 2012 to 58 urban allotments in Avenview Estate. Treated stormwater is used for flushing toilets, watering plants and vegetables in the garden and the lawn, washing cars, cleaning the outside of home and outdoor furniture and fighting fires. Stormwater is being extracted from the downstream end of the Troups Creek Wetland. Then partially treated stormwater from the wetland is passed through a comprehensive treatment train including gross screening, chlorination, coagulation, sand filtration, activated carbon filters, membrane filtration, ultraviolet radiation, chlorination and further membrane filtration.
    - Benefits

      Stormwater harvesting reduces demand on potable water for suitable uses, such as irrigation and toilet flushing. Stormwater harvesting can also reduce urban flooding, improve the quality of run-off and reduce the volume of run-off flowing into creeks and waterways.
    - Issues

      Increases in turbidity between the wetland's outlet structure and the feedwater inlet to the treatment system was observed and simple monitoring was proposed to detect such increases.

3. Kogarah Town Square – Sydney in NSW, Australia (Kus and Kandasamy, 2009)
    - Project description

      Kogarah is a city, located 15 kilometres south of Sydney. This Town Square development involves the construction of 220 residential apartments, 225 parking spaces, commercial retail space and a public library. The development is situated on the ridge between the densely urbanised catchments of the Cooks River and the Georges River which flow into Botany Bay. Both the rivers and the bay are degraded. The collected stormwater (with the exception of first-flush runoff) is filtered via a gross pollutant trap and stored in underground storage tanks. Then stormwater is treated through physical and biological treatment such as sand filters and biologically engineered 'ecosoil'. The treated stormwater is used for toilet flushing, car washing, water features in the Town Square and landscape irrigation. In periods of high stormwater flow, surge tanks will regulate the water flow prior to discharge into the stormwater system. First-flush runoff is separately treated by Low Flow Filtration System (LFFS). It involves a specifically designed stormwater pit that captures and filters the highly polluted first-flush stormwater runoff from the kerb and channel of urban road. Then the first-flush stormwater runoff is directed to filter media, which consists of 200 mm thick sand, followed by 100 mm layer of coarse aggregate. Filtered water then passes through perforated pipeline into the adjacent garden bed.

- <u>Benefits</u>

  This project has reduced demand for drinking water in the city centre by 42% and saves over two million litres of drinking water a year. The LFFS is easily fitted with existing kerb and channel system of urban road and cost effective.

- <u>Issues</u>

  Replacement of filter media of the LFFS is needed quarterly, because of oily crust form layer due to first flush.

4. Lochiel Park residential development, South Australia, Australia (Blaess et al., 2006, Leonard et al., 2014)

   - <u>Project description</u>

     The Lochiel Park is a 109 dwellings residential development, in approximately eight kilometres north-east of the Adelaide CBD, South Australia. The project was completed in 2009 and includes nine-year monitoring program until 2018. This residential development was established with the aim of becoming a model green village. This system uses captured stormwater from a 190-hectare adjacent urban catchment which is cleaned through a wetland system and aquifer storage recovery scheme after passing through a gross pollutant trap prior to reuse in houses. The treated stormwater is supplied via a third pipe for toilet flushing, washing machines use and irrigation. Runoff from the Lochiel Park development is treated by bioretention systems and swales at the street level prior to discharge to the River Torrens.

- Benefits

  Potable water use in Lochiel Park household is reduced by 78% from the South Australia average usage.

- Issues

  The Gross Pollutant Trap (GPT), which filters stormwater, is not functioning well and cost to maintain the GPT has been higher than the cost anticipated.

2.4 COMBINED WATER (RECYCLED & STORMWATER) PROJECTS

Projects using both recycled water and treated stormwater in one integrated system have the potential for increasing the security of supply and improving water efficiency by using water supplies and water storages more effectively.

2.4.1 Overseas combined water projects

Below are some combined water projects overseas found in the literature (Puerta and Suarez, 2002, Vymazal, 2005, Lim et al., 2011, Tredoux et al., 2011, Avila et al., 2013, PUB (Singapores National Water Agency), 2013). For each selected project, a brief description, benefits and issues are discussed below.

1. Combined water use in Singapore (Lim et al., 2011, PUB (Singapores National Water Agency), 2013)

   - Project description

     NEWater produces highly treated recycled water that has been recognised as safe and sustainable source of water exceeding the drinking water standards of the World Health Organisation (WHO). Approximately 11,000 m^3 of water produced by NEWater per day (2.5% of the Singapore’s daily water requirement) is added to a stormwater reservoir. Then combined water (NEWater and raw stormwater) is further treated through Singapore's normal drinking water treatment system. Figure 2.1

shows the schematic illustration of the Singapore's water treatment process.

- Benefits

  Potable water demand was reduced by 30% and is expected to reduce 55% by 2060. Also it ensures long term sustainability of Singapore's water resources.

- Issues

  Higher energy consumption was an issue and continuous research work is being conducted to investigate low energy consumption for water treatment methods

2. Atlantis MAR (Management of Aquifer Recharge) in Cape Town, South Africa (Tredoux et al., 2011)

   - Project description

     The Atlantis Water Resource Management Scheme has initiated the application of artificial groundwater recharge as a water management tool for bulk water supply in Southern Africa. Various combinations of urban stormwater and treated wastewater from sources in the town have been infiltrated into the aquifer over the years to maximise the amount of available groundwater. Domestic and industrial wastewater is treated separately and only the domestic wastewater is reused. Similarly, the peak flow and base flow in the stormwater system are channelled to different recharge basins to maintain good quality water in selected areas of the aquifer. Figure 2-2 is the schematic illustration of the treatment process of Atlantis MAR (Management of Aquifer Recharge) in Cape Town.

   - Benefits

     Recharge system has been in operation for more than 20 years and ensure the sustainability of the Atlantis water supply being in Arid Region. Also evaporation is minimised.

   - Issues

     Managing the salinity level of water is one of the toughest challenges in this system. Also clogging of boreholes, slow recharge rate and high cost of extraction are some other issues.

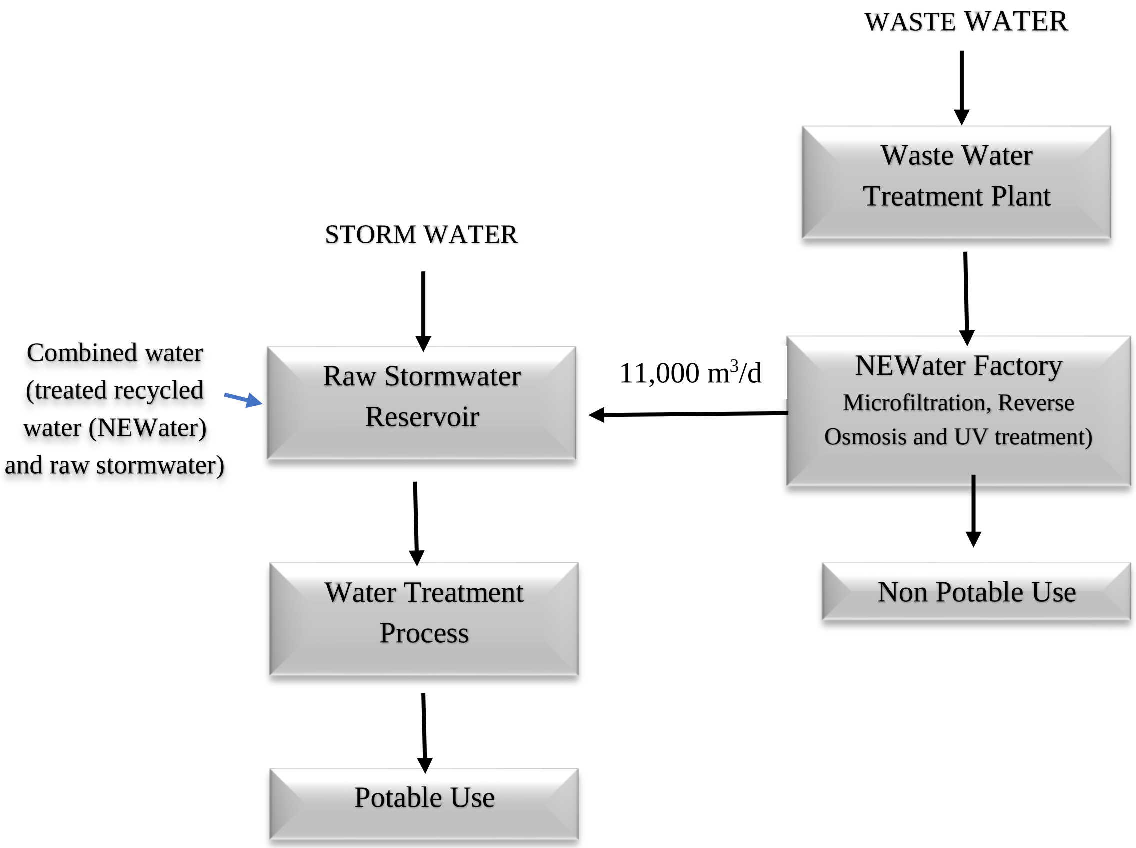


Figure 2-1: Singapore's water treatment process

(**Source**: http://www.pub.gov.sg/water/Pages/default.aspx)

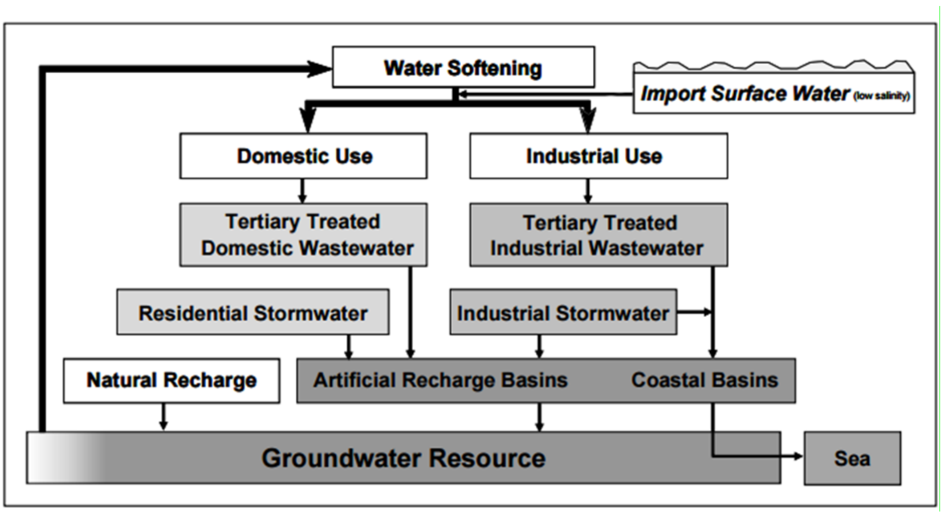


Figure 2-2: Atlantis MAR (Management of Aquifer Recharge) in Cape Town's treatment process.

(**Source**: http://researchspace.csir.co.za)

2.4.2 Australian combined water projects

Below are some combined water projects in Australia found in the literature (Anda et al., 2006, Chapman, 2006, Goddard, 2006, Hurlimann, 2008, Farrelly and Davis, 2009 Phuntsho et al., 2011). For each selected project, a brief description, benefits and issues are discussed below.

1. Sydney Olympic Park combined water project (Chapman, 2006 Phuntsho et al., 2011)
    - <u>Project description</u>

      The Sydney Olympic Park comprises 430 hectares of diverse parklands. There are 175 hectares of wetlands and 20 hectares of woodlands. The Sydney Olympic Park has a locally integrated approach to water conservation based on stormwater reuse, wastewater reprocessing and water demand reduction. Treatment is done after mixing of two types of water which is a notable feature in this project. The brickpit reservoir (where the mixing takes place) has a capacity of approximately 300 ML and is designed to hold both stormwater and treated sewage. Water from the brickpit reservoir goes through a water reclamation plant consisting of a MF/RO (microfiltration and reverse osmosis) system. The plant can treat up to 7 ML of water per day. A third pipe is used to deliver the treated water from the reclamation plant after treatment. The quality of water meets the specified standard for the project and it can be used for identified end use applications such as laundering clothes, washing pets, pool filter backwashing, irrigation of vegetable gardens and parks, ornamental fountains, firefighting, washing cars and toilet flushing. Billing rate of the third pipe water was $1.73 per kilolitre for the period from 1 July 2013 to 30 June 2014. That is approximately 20% less than the drinking water cost charged by Sydney Water for the same period. This scheme saves about 850 ML of drinking water per year. Figure 2.3 shows the schematic diagram of the Sydney Olympic Park combined water treatment process.

- <u>Benefits</u>

  Potable water demand is reduced by 50% and 800,000 m^3/year sewage are treated and reused. Also 700,000 m^3/year stormwater is harvested.

- <u>Issues</u>

  Metallic corrosion is observed in cooling systems.

  Biological growth is observed in the cooling systems, as warm and moist environment promotes biological growth.

  Risk of Legionella bacteria propagating in the cooling towers caused by iron salt in recycled water

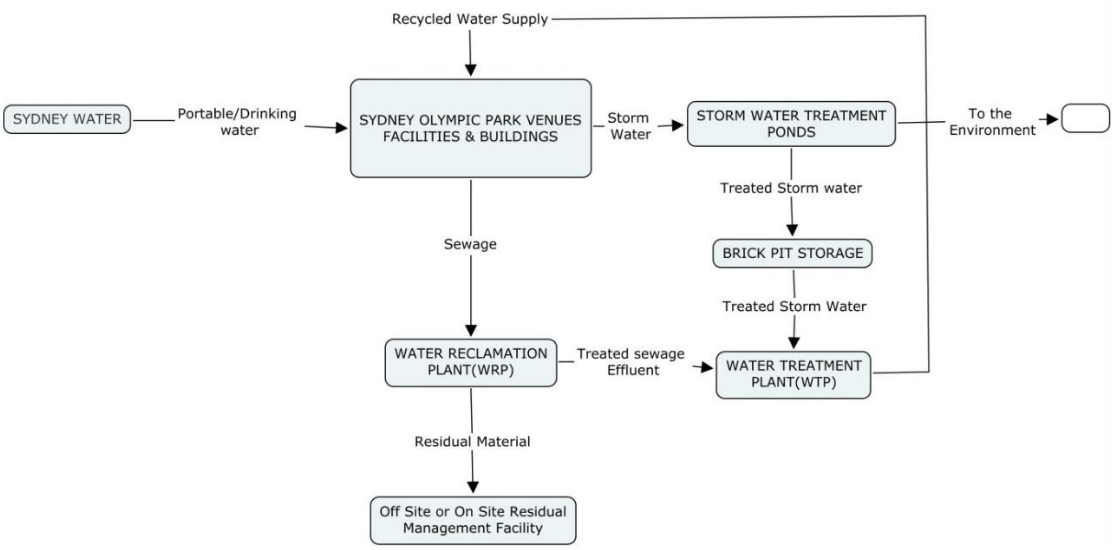


Figure 2-3: Schematic Diagram of Sydney Olympic Park recycle process

2. Mawson Lakes Development Project (Anda et al., 2006, Hurlimann, 2008)

   - <u>Project description</u>

The Mawson Lakes Development Project is located 12 km North of Adelaide. This is one of the initial developments in Australia, dual plumbed, to provide combined water other than the potable water. Combined water is only permitted for defined non potable applications namely toilet flushing, garden watering, car washing and irrigation of public open spaces, In the Mawson Lakes project, water supplied via the third pipe is a mix of treated wastewater from South Australian Water Bolivar Sewage Treatment Works and cleansed stormwater from the Parafield Airport catchment, adjacent to Mawson Lakes. A notable feature of this scheme is that treatment is done before mixing. Wastewater undergoes treatment of dissolved air flotation, filtration and chlorination. Stormwater is cleansed biologically in reed beds. Both treated stormwater and recycled water are pumped to a large tank, combined water is then pumped primarily for community facilities, such as parks and ovals. The potable demand had reduced from 210 kL/year in 2005 to 170 kL/year in 2011, and average residential potable demand had reduced from 140 kL/year to 125 kL/year per connection. The approximate mixing ratio of recycled water to stormwater used in the project is 75:25. The charge for combined water by SA Water is reduced to $2.18/kL from $2.59/kL from July, 2013 to encourage more people to use it. That compares with an average of $3.45/kL for mains water. Figure 2.4 shows the schematic diagram of the Mawson Lakes residential development combined water process.

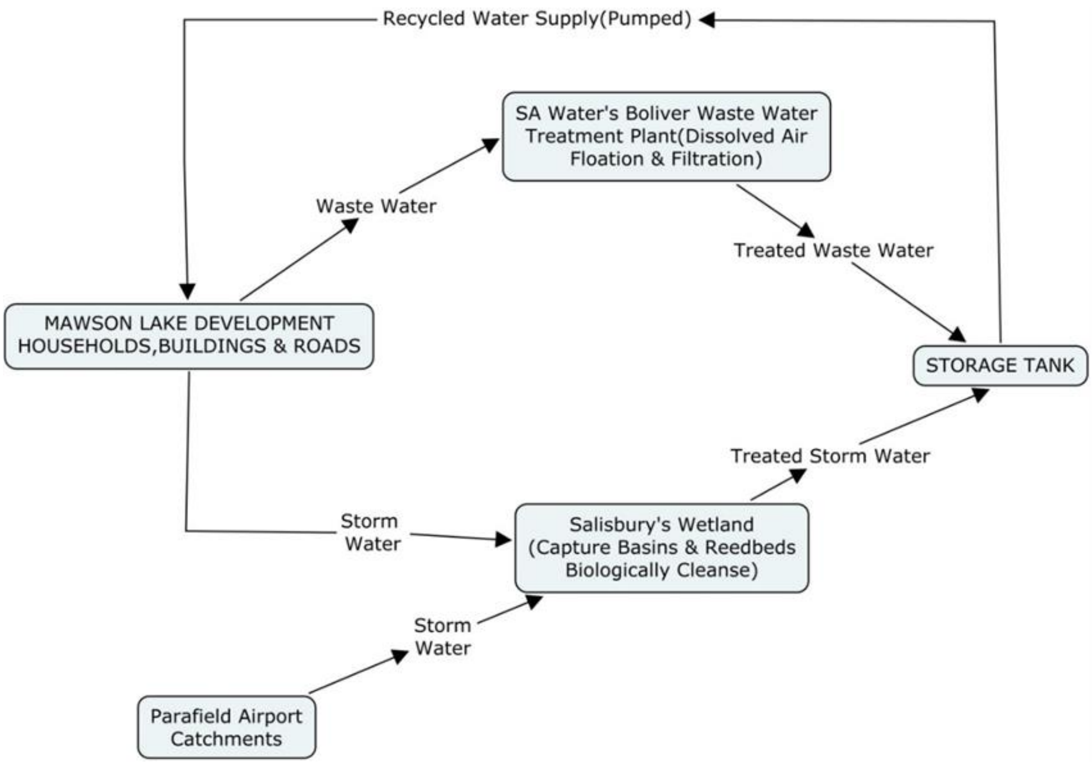


Figure 2-4: Schematic Diagram of Mawson Lakes Development recycle process

- <u>Benefits</u>

  Potable water demand is reduced by 50% and saves approximately 88,000 m^3/year. Third pipe water supply provides green open space in the Mawson Lakes development area, even over the drought period.

- Issues

  Salt content of recycled water is balanced by adding stormwater. During summer, the required quantity of stormwater is not available to achieve this.

3. Inkerman D'Lux Apartment Development project, Melbourne (Goddard, 2006, Farrelly and Davis, 2009)

- Project description

The development formerly known as Inkerman Oasis, is spread over 1.2 hectares, is a development with 236 apartments. The project on Inkerman Street in Melbourne is a joint venture between the City of Port Phillip and Inkerman Developments Pty Ltd. Two types of water (Grey water and stormwater) are partially treated before mixing. The schematic diagram of the project is shown in Figure 2.5 below. Grey water from bathrooms of the apartment complex are collected in to a storage (grey water balance tank). Stormwater from the development area is collected in to a sub-surface flow constructed wetland.

After partial treatment, both types of water (grey water and stormwater) pumped through bio reactor and UV plant to the overhead tank. Applications of the treated combined water are garden irrigation and toilet flushing.

- Benefits

  Potable demand reduced 40% in summer & 20% in winter.

  Reduce sewer loads and reduce nitrogen loads to Port Phillip Bay by approximately 14 tonnes.

- Issues

  Excess stormwater is discharged into the traditional storm water drainage system. Only part of the stormwater is re-used.

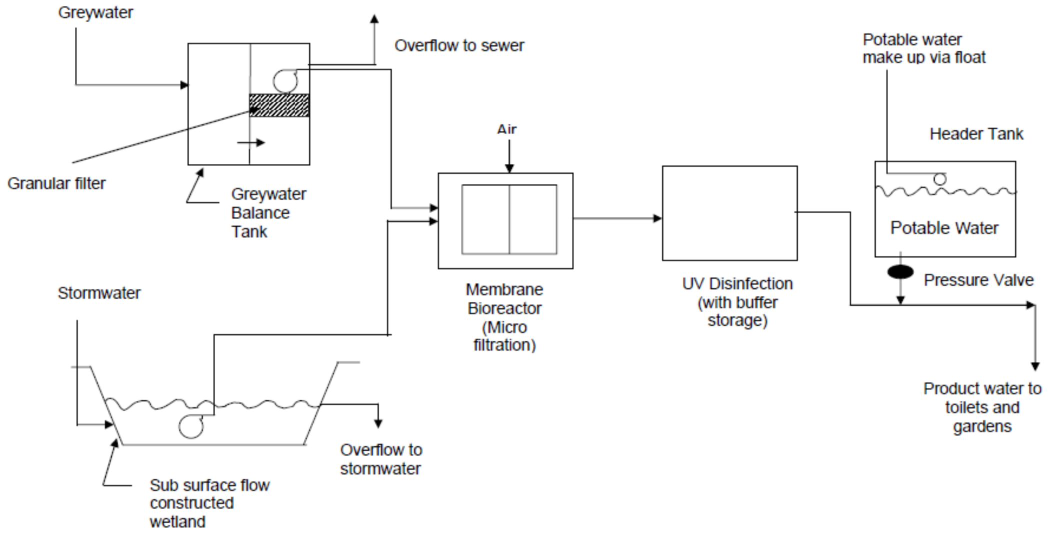


Figure 2-5: Schematic Diagram of recycle process – Inkerman D'Lux apartment development project (Adopted from Figure 1 of Coulthurst et al. (2004))

2.5 SUMMARY

This chapter provided information of the water reuse projects using recycled water and stormwater separately first and then both types of water in combination in Australia and overseas to understand the benefits and issues of these projects. The study investigated the benefits and water quality issues of these projects. This study proposes to mix recycled water and treated stormwater by injecting treated stormwater into the 'third' pipe, which carries recycled water. In this new approach, the mixing of two types of water takes place inside the recycled water pipe, compared to the conventional approach of mixing recycled water and stormwater in a dedicated chamber. There are certainly new challenges with the combination of two types of water with a novel mixing strategy proposed in this study.

The issues and challenges identified in the projects discussed in this chapter are summarised in the Table 2.1 below.

Table 2.1: Summary of issues and challenges in recycled water, stormwater and combined water projects

		Project Name	Benefits	Issues	Reference
RECYCLED WATER PROJECTS	Overseas Projects	Monterey County Water Recycling project, California, USA	Water reuse is considered as the major factor for success of agricultural industry	Salt concentration is higher in recycled water, but are within the acceptable range. Efforts are underway to reduce salt concentration in wastewater through source control.	Crook and Association(2004), Lazarova et al.(2013)
		Dan Region Sewage Reclamation and Recharge project, Israel	The largest reuse project in Israel with national importance with economic benefits	Biofouling of the effluent pipeline and lack of capacity of the Soil Aquifer Treatment (SAT) system	Goren et al.(2014), Asano et al.(2007)
		Makuhari New Central Water Recycling Project, Tokyo, Japan	Increase water security in high population density area	Higher energy consumption in treatment process	Lazarova et al. (2013)
		Orange County Water District – Water Factory 21, California, USA	Eliminated discharge of wastewater to the surface waters	N-nitrosodimethylamine (NDMA) and 1, 4-dioxane(classified as human carcinogens), were found in reclaimed water and exceeded the guideline values. Treatment train was later modified to include advanced oxidation process (AOP) to avoid this problem.	Asano et al.(2007), Crook and Association(2004)
		NEWater, Singapore	Water security of the country is increased.	winning the public acceptance was a challenge. Higher energy consumption is an issue.	Lazarova et al.(2013)
	Australian Projects	Virginia Pipeline Scheme in Adelaide, Australia	Volume of nutrient rich treated effluent entering St Vincent Gulf is reduced (approximately 75% decrease in the Nitrogen and 40% decrease in phosphorus loading from 1996 to 2003)	Higher nitrogen and phosphorus concentration in recycled water affected plant growth. This could be managed with appropriate irrigation management practice.	Asano et al. (2007),Lazarova et al. (2013), Kelly et al. (2003)
		Western Corridor Recycled Water Scheme in Queensland, Australia	Reduce nutrient loads into Brisbane and Bremer Rivers and Moreton Bay as a result of further treatment of treated wastewater in Advanced Water Treatment Plant (AWTP).	When flood water is filled in water supply storages, recycling scheme cannot operate at full capacity.	Apostolidis et al. (2011), Lazarova et al. (2013)
		Altona Recycled water project in Melbourne, Australia	The project has the effect of reducing prices to customers as potable water is replaced by recycled water.	Quality of the secondary treated water coming into the ARWP varied significantly for short periods. Operational design of the plant has been changed to address the problem.	Tedra Australia Pty Ltd (2011)
		Kooragang Recycled Water Scheme (KRWS) in New South Wales, Australia	Save up to 3.3 million m^3 of drinking water each year	Chlorine Contact time (Ct) in the chlorine contact tank had fallen below the critical limit. Error was identified and has been rectified and the faulty valve has been replaced.	https://www.hunterwater.com.au/Major-Projects/Project-Pages/Kooragang-Recycled-Water-Scheme.aspx
		Rouse Hill Recycled Water Project in New South Wales, Australia	Reduction of drinking water demand by about 40%	A cross connection was discovered in 2004 and affected 82 homes. Unauthorised plumbing work in household was the reason and it was rectified.	Asano et al., 2007 Apostolidis et al., 2011,Lazarova et al., 2013)
STORMWATER PROJECTS	Overseas Projects	Stormwater harvesting projects, Singapore	Improved water security of the country and answer to the flooding problem	Bad odour or taste exists in the treated stormwater and could be eliminated with activated carbon	Lim et al. (2011), PUB(Singapores National Water Agency) (2013)
		Berlin–Lankwitz stormwater project, Germany	First flush diversion avoids highly polluted first flush entering the stormwater treatment system. Also it provides protection of receiving waters.	After a long drought period in summer, relatively high BOD concentration (up to 45 mg/L) were reported	(Pitt et al., 2012)
		Santa Monica Urban Runoff Recycling Facility project (SMURRF) in California, USA	It eliminates pollution of Santa Monica bay caused by urban runoff during dry season (dry weather flow). Also it provides cost effective treatment and producing high quality water for reuse.	Bacteria growth inside the pipe causes colour and odour problems. To address the issue of bacteria growth, chlorination is added for the purpose of maintaining chlorine residual in the distribution system.	Crook and Association, 2004)
		Renaissance Project, West Farm Beach in Florida, USA	Increasing flood protection levels in the low-lying Pineapple Park neighbourhood and providing the required surface water management needs (water quality and quantity).	Elevated levels of lead are reported. Lead is primarily from materials and components associated with service lines and home plumbing. Customer education or awareness is done to avoid the use of plumbing materials with lead.	Pitt et al., 2012)
		Kalkallo Stormwater Harvesting Project in Melbourne, Australia	Stormwater pollutants discharging into Kalkallo Creek, was reduced with an estimated average annual reduction of 1.46 tonnes of Nitrogen.	The Kalkallo Stormwater Harvesting Project has open storages and Blue-green algae (BGA) problems are anticipated, which cause operational challenges.	Asoka Jayaratne (2011), Corbett (2012)
	Australian Projects	Troups Creek stormwater recycling project in Narre Warren North, Melbourne	Stormwater harvesting can also reduce urban flooding, improve the quality of run-off and reduce the volume of run-off flowing into creeks and waterways	Increases in turbidity between the wetland's outlet structure and the feedwater inlet to the treatment system was observed and simple monitoring was proposed to detect.	(McCarthy D, Undated,)
		Kogarah Town Square – Sydney in NSW, Australia	This project has reduced demand for drinking water in the city centre by 42% and saves over two million litres of drinking water a year.	Replacement of filter media of the LFFS is needed quarterly, because of oily crust form layer due to first flush.	Kus and Kandasamy, 2009)
		Lochiel Park residential development, South Australia, Australia	Potable water use in Lochiel Park household is reduced by 78% from the South Australia average usage.	The Gross Pollutant Trap (GPT), which filters stormwater, is not functioning well and cost to maintain the GPT has been higher than the cost anticipated	Blaess et al., 2006, Leonard et al., 2014)
COMBINED WATER PROJECTS	Overseas Projects	Combined water use in Singapore	Potable water demand was reduced by 30% and is expected to reduce 55% by 2060.	Higher energy consumption was an issue and continuous research work is being conducted to investigate low energy consumption for water treatment methods	Lim et al., 2011, PUB (Singapores National Water Agency), 2013)
		Atlantis MAR (Management of Aquifer Recharge) in Cape Town, South Africa	Recharge system has been in operation for more than 20 years and ensure the sustainability of the Atlantis water supply being in Arid Region. Also evaporation is minimised	Managing the salinity level of water is one of the toughest challenges inthis system. Also clogging of boreholes, slow recharge rate and high cost of extraction are some other issues	Tredoux et al., 2011
	Australian Projects	Sydney Olympic Park combined water project	Potable water demand is reduced by 50% and 800,000 m^3/year sewage are treated and reused. Also 700,000	Metallic corrosion & Biological growth are observed in the cooling systems, as warm and moist environment promotes biological growth.	Chapman, 2006 Phuntsho et al., 2011)
		Mawson Lakes Development Project	Potable water demand is reduced by 50% and saves approximately 88,000 m^3/year.	Salt content of recycled water is balanced by adding stormwater. During summer, the required quantity of stormwater is not available to achieve this	Anda et al., 2006, Hurlimann, 2008)

3 DEVELOPMENT OF THE WATER QUALITY GUIDELINE FOR COMBINED WATER USE

3.1 INTRODUCTION

The available literature on major combined water projects in Australia for mixing of recycled water and stormwater in a third pipe system was reviewed in the preceding chapter to identify how water quality is controlled and managed to ensure the safety of the end users. However, it is understood that there is no guideline common to the three projects reviewed to control and manage the water quality of the combined water distributed to the public; rather the three projects are operated through three separate license agreements to ensure the safety of water users.

The recycled water system of the Mawson Lakes development is owned and operated by SA Water. The Department of Human Services (DHS) audits health risks while the Environmental Protection Agency (EPA), South Australia controls and manage the risks related to the environment. Therefore, separate approvals are needed from DHS and the EPA, South Australia in relation to the quality of combined water. Concentration limits are specified in an Environmental Management Plan by EPA, South Australia for salinity, BOD, Turbidity, Faecal Coliforms and pathogens (Page et al., 2013).

In the Sydney Olympic Park project, an Environmental Protection License has been established by EPA, NSW which the quality of combined water discharged to the environment was specified. In the Environmental Protection License, Chlorine, Oil and Grease, pH, Nitrogen (total), Phosphorus (total), Faecal Coliforms, BOD and Total suspended solids were specified with their allowable percentile concentration limits (EPA NSW, 2011).

Quality of combined water (grey water and stormwater) in the Inkerman D'Lux apartment development was maintained as equivalent to third pipe water recommended by EPA Victoria, and the quality was controlled by the Environmental Management Plan prepared by the South East Water, a retail water company in the Melbourne metropolitan area. Initially, the operation and monitoring of the onsite treatment and reuse system was done by South East Water. However, currently South East Water has an agreement with the Body Corporate of the apartment complex for operation and maintenance of the onsite treatment and reuse system (Farrelly and Davis, 2009).

There is a need to establish a guideline for the use of combined water. The objective of the proposed guideline described in this chapter is to provide information on the minimum water quality standards that could be applied to third pipe projects which use combined water (mix of recycled water and treated stormwater). The proposed guideline can be used to prepare the license agreements in future combined water use projects.

3.2 WATER QUALITY ISSUES AND CHALLENGES

After reviewing the Australian Drinking Water Guideline (ADWG, 2013), the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC-ARMCANZ, 2000) and the Guidance for the Use of Recycled Water by Industry (ISI and CSIRO, undated), the common issues and the challenges of the use of recycled water and stormwater and the water quality parameters accountable for these issues were identified. These issues are tabulated in column 1 of Table 3.1.

Some of the issues identified in Table 3.1 are discussed here. In projects that use recycled water, stormwater or combined water (mix of recycled water and stormwater), it is important to control the presence of pathogenic microorganisms to safeguard the health of a community. Objectionable odours can result from compounds produced by certain types of algae, bacteria and sometimes protozoa (ADWG, 2013). High iron concentrations give water an undesirable rust-brown appearance and can cause staining of laundry and plumbing fittings, fouling of ion-exchange softeners, and blockages in irrigation systems. At concentrations exceeding 0.1 mg/L, manganese imparts an undesirable taste to water and stains plumbing fixtures and laundry (ADWG, 2013). When using recycled water for irrigation it is also important to monitor the salinity level and assess the salt tolerance of the crop. Usually the salinity level of recycled water is higher than that of stormwater.

The water quality parameters presented in Table 3.1 (identified as causing issues in water distribution systems) are categorised as physiochemical indicators, metals and metalloids, organic matters, bacteria indicators and pathogens, and nutrients, which were also used in Section 3.3 for the development of the proposed guideline.

Table 3.1: Water quality parameters identified for use of combined water

Issues Identified	Water quality parameters																														
	Physiochemical Indicators											Metals & Metalloids														Organic matters	Bacteria-Indicators &			Nutrients	
	Ammonia(NH3)	Chloride	Colour AppPt/Co units	Electrical Conductivity	pH	SAR(Sodium Adsorption Ratio)	Sulphate	Suspended Solids	Total Alkalinity mg CaCO3 / L	Total Dissolved Solids(TDS)	Turbidity	Aluminium	Arsenic	Barium	Boron	Cadmium	Calcium	Copper	Iron	Lead	Magnesium	Manganese	Mercury	Nickel	Sodium	Zinc	Total Organic Carbon(TOC)	Campylobacter(bacteria) #/L	E coli	Cryptosporidium #/L	Total Nitrogen	Total Phosphorus
Salinity				√		√				√															√							
Odour	√	√					√											√	√			√				√		√	√	√		
Colour			√					√			√	√						√										√	√			
Corrosion	√	√			√		√	√	√	√	√						√	√	√			√						√				
Health Issues													√	√	√	√		√		√		√	√	√			√	√	√	√		
Deposits																			√			√						√				
Scaling of pipes																	√				√											√
Fouling								√			√																	√				

3.3 PROPOSED GUIDELINE FOR COMBINED WATER USE

After identification of water quality parameters, that may cause issues related to use of combined water, the next step was to propose the limits (or thresholds) for these parameters to mitigate the identified issues. The following guidelines were used to set these limits.

- EPA Guidelines (EPA Victoria, 2003, EPA Victoria, 2005)
- Australian Guidelines for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006b) and Phase 2 (NRMMC-EPHC-NHMRC, 2009b)
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC-ARMCANZ, 2000)

Table 3.2 was then prepared considering all water quality parameters identified in Table 3.1. The columns of Table 3.2 show the thresholds used in different guidelines (ANZECC-ARMCANZ, 2000, EPA Victoria, 2003, EPA Victoria, 2005, NRMMC-EPHC-NHMRC, 2006, NRMMC-EPHC-NHMRC, 2009) which were then used in this study to develop the proposed guideline for combined water. The last column of Table 3.2 shows the thresholds for water quality parameters in the proposed guideline. The most critical value was selected as the threshold in the proposed guideline for each water quality parameter from the above guidelines. When selecting threshold values applicable to irrigation, short term trigger values were considered in the proposed guideline, as most irrigation equipment is likely to have less than 20 years design life.

Table 3.2: Proposed guideline for use of combined water

Selected Parameters for the study		Guidelines For Environmental Management (EPA Victoria 2003 & 2005)	Australian Guidelines for Water Recycling(2006) - PHASE 1 - Managing Health and Environmental Risks		Australian Guidelines for Water Recycling(2009) - PHASE 2 - Stormwater Harvesting and Reuse		Australian and New Zealand Guidelines for Fresh and Marine Water Quality(2000)			Proposed Values
		Class A	Long Term trigger Value (LTV)(mg/L)	Short Term trigger Value (STV)(mg/L)	Public,Open space irrigation,Design life up to 100 Yrs(mg/L)	Public,Open space irrigation,Design life up to 20 Yrs(mg/L)	Irrigation (Long term Use-up to 100Yrs) (mg/L)	Irrigation (Short term Use-up to 20Yrs) (mg/L)	Recreational purposes (mg/L)	
Physiochemical Indicators	Ammonia(NH3)								0.01(as N)	0.01mg/L(as N)
	Chloride						175-350(Sensitive plants)		400.0	175 - 350 mg/L
	Colour AppPt/Co units									
	Electrical Conductivity						650			650
	pH	6.0–9.0					6.0–9.0	6.0–9.0	6.5–8.5	6.0–9.0
	SAR(Sodium Adsorption Ratio)						8-18(sensitive)			8 - 18
	Sulphate								400	400 mg/L
	Suspended Solids	5mg/L			<30 mg/L	<50 mg/L				5 mg/L
	Total Alkalinity mg CaCO3 / L				< 350 mg/L	< 350m g/L	60mg/L - 350mg/L		500.0	< 350 mg/L
	Total Dissolved Solids(TDS)								1000	1000 mg/L
	Turbidity	< 2 NTU			< 25 NTU					< 2 NTU
Metals & Metalloids	Aluminium		5.0	20			5.0	20.0	0.2	0.2 mg/L
	Arsenic		0.1	2			0.1	2.0	0.05	0.05 mg/L
	Barium								1	1 mg/L
	Boron		0.5	0.5-15			0.5		1.0	0.5-15 mg/L
	Cadmium						0.01	0.05	0.005	0.005 mg/L
	Calcium									
	Copper		0.2	5					1	1.0 mg/L
	Iron		0.2	10.0	< 0.2 mg/L	< 10 mg/L	0.2	10.0	0.3	0.3 mg/L
	Lead		2.0	5			2.0	5.0	0.05	0.05 mg/L
	Magnesium									
	Manganese		0.2	10.0			0.2	1.0	0.1	0.1 mg/L
	Mercury		0.002	0.002					0.001	0.001 mg/L
	Nickel		0.2	2			0.2	2.0	0.1	0.1 mg/L
	Sodium						115-230(moderately sensitive)		300.0	115 - 230 mg/L
	Zinc		2.0	5			2.0	5.0	5.0	5 mg/L
Organic matters	Total Organic Carbon (TOC)									
Bacteria- Indicators & Pathogens	Campylobacter(bacteria) #/L				15					15 /L
	E coli	< 10/100 mL			< 10 CFU/100 mL				<126/10 mL	< 10/100 mL
	Cryptosporidium #/L				1.8					1.8/L
Nutrients	Total Nitrogen				<30 mg/L	<30 mg/L	5.0	25–125		< 30 mg/L
	Total Phosphorus				< 0.05 mg/L	< 0.8 mg/L	0.05	0.8–12		< 0.8 mg/L

3.4 APPROPRIATENESS OF THE MASS BALANCE APPROACH TO DETERMINE COMBINED WATER QUALITY

In this study, it is proposed to inject treated stormwater into the third pipe which carries recycled water. The water quality of the combined water determines the appropriateness of this water for intended uses. Recycled water is generally treated to an acceptable level of third pipe water use and the qualities of recycled water in terms of various water quality parameters are known. However, the quality of stormwater is variable both spatially and temporally, and requires treatment before injection into the third pipe. The level of treatment of stormwater (to be injected into the third pipe) depends on the quality of recycled water and the quality of the combined water downstream of the injection point. When the project for study area is implemented, then the water quality of combined water downstream of the injection point could be determined by testing water quality samples. However, it is very useful to have a desktop method to calculate the water quality of the mix in addition to laboratory testing during project in operation. Obviously, for the planning stage of a project, such as the one discussed in this thesis, laboratory testing of water quality samples is not possible. The mass balance analysis which is widely used to determine the concentration of a particular water quality parameter in a mix can be used to determine the water quality of combined water below the injection point in the third pipe. This is possible only if additional constituents (i.e. often chemicals and gases) are not generated during the mixing process, which is assumed in the mass balance analysis. Furthermore, it is assumed that that the volume of combined water after mixing is the sum of volumes of recycled water and stormwater before mixing.

In this section, the appropriateness of the mass balance method was investigated to estimate the water quality of combined water by comparing the results of the mass balance method with laboratory testing of several combined water samples. Recycled water and stormwater samples were collected from sources in the study area and tested for a set of water quality parameters. Recycled water and stormwater are then mixed to a number of pre-determined mix ratios. The water quality of the mix was then tested at the laboratory. Alternatively, using the results of water quality parameters of recycled water and stormwater, mass balance analysis was applied to obtain the water quality for the same pre-determined mix ratios. Comparison was made between the results of water quality parameters in the mix obtained from direct measurements of laboratory testing of the mix and the results obtained from the mass balance analysis of the mix. As explained in this chapter, the comparison is made taking measurement uncertainties for laboratory measurements into consideration.

3.4.1 Mass balance analysis

For a given water quality parameter, the equation describing the mass balance is given below

$$C_3 = (V_1C_1 + V_2C_2) / (V_1+V_2) \qquad (1)$$

Where V_1 is the volume of recycled water, V_2 is the volume of stormwater, C_1 (mg/L) is the concentration of water quality parameter in recycled water, C_2 (mg/L) is the concentration of water quality parameter in stormwater, and C_3 (mg/L) is the concentration of water quality parameter in combined water.

3.4.2 Collection of water samples and laboratory testing

Stormwater was collected from a wetland in Point Cook, in the western part of the Melbourne metropolitan area which is close to the study area. Also this stormwater collection point has similar catchment properties (newly developed residential areas) to those of the proposed study area. Furthermore, it was agreed that the stormwater sample collection would be better done on a day after a substantial amount of rainfall. Therefore, stormwater was collected on 17th November 2014, as the previous day had received rainfall of 31.4 mm at the Laverton rainfall station of Bureau of Meteorology (BOM), which is close to the proposed study area. A 20 litre capacity container was cleaned using potable water first and then with distilled water. Then this container was filled with stormwater from the wetland.

The same cleaning procedure used for collection of stormwater was done for the recycled water container and approximately 20 litres of recycled water was collected from a stand pipe in the Melbourne west area (Hoppers Lane).

Eight laboratory tests were planned using samples of approximately 2.0 litres of mix of stormwater and recycled water covering the entire range of mixing from 0% to 100% of stormwater and recycled water. Each sample bottle was labelled with a unique number and recorded into the chain of custody form as required by the testing laboratory. Table 3.3 below shows the mixing ratios used in this investigation. Selected water quality parameters as in the proposed guideline were tested in the laboratory for stormwater, recycled water and combined water. The tests were done on the same day of collection of samples and after 3 days of sampling. The 3-day testing was conducted assuming that it would take maximum of 3 days for water to travel from injection point to the end user in the third pipe and testing after 3 days would demonstrate this practical situation.

Table 3.3: Proposed mix ratios of stormwater and recycled water

	Sample Name	Stormwater %	Recycled water %
Testing done on the sampling day	Mix 1	0	100
	Mix 2	100	0
	Mix 3	75	25
	Mix 4	50	50
	Mix 5	25	75
after 3 days of sampling	Mix 6	75	25
	Mix 7	50	50
	Mix 8	25	75

All samples were transported to the testing laboratory. Laboratory tests were done in a National Association of Testing Authorities (NATA) accredited ALS laboratory in Scoresby. Sample mixes 1-5 were tested for selected water quality parameters on the same day of collection. The remaining samples (i.e. Mixes 6 – 8) were kept under room temperature for three days and quality was tested for selected water quality parameters.

3.4.3 Comparison of results of mass balance analysis with laboratory test results

Mixed water quality obtained by the mass balance analysis (Section 3.4.1) and laboratory tests (Section 3.4.2) for both same day samples and samples after 3 days were compared. The testing laboratory also provided the measurement uncertainties of their laboratory testing results as percentages. By using the measurement uncertainty percentages, the possible error ranges of laboratory measurements for each water quality parameter were calculated.

3.4.3.1 Samples tested on the same day

Table 3.4 shows the results of the laboratory testing for the mix water quality for Mix 3, Mix 4 and Mix 5. Using laboratory test results for 100% recycled water (Mix 1) and 100% stormwater (Mix 2), combined water quality of Mix 3, Mix 4 and Mix 5 were calculated from the mass balance analysis (i.e. using Equation (1)) and tabulated in Table 3.4.

Using the testing laboratory provided measurement uncertainty (as a percentage) along with the measurement which could be used to calculate a range where the particular

Table 3.4: Water quality of mixed water through laboratory testing and mass balance - same day samples

Selected Parameters for the study		LABORATORY EXPERIMENTS					MASS BALANCE EQUATION		
		Recycled Water Quality (mg/L)	Stormwater Quality (mg/L)	Mixed Water Quality (mg/L)			Mixed Water Quality (mg/L)		
		Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 3	Mix 4	Mix 5
Physiochemical Indicators	Ammonia (NH3), as N	0.20	<0.1	<0.1	0.10	0.20	0.13	0.15	0.18
	Chloride	420.0	10.0	120.0	210.0	300.0	112.5	215.0	317.5
	Colour AppPt/Co units	25.0	120.0	100.0	75.0	50.0	N/A	N/A	N/A
	EC at 25 °C µS/cm	1800	120	560	970	1400	N/A	N/A	N/A
	pH	7.6	7.2	7.4	7.5	7.6	N/A	N/A	N/A
	SAR (Sodium Adsorption Ratio)	9.0	0.9	4.4	6.3	7.7	N/A	N/A	N/A
	Sulphate	94.0	10.0	27.0	49.0	69.0	31.0	52.0	73.0
	Suspended Solids	2.0	14.0	10.0	6.0	4.0	11.0	8.0	5.0
	Total Alkalinity mg CaCO3 / L	120.0	38.0	57.0	78.0	99.0	58.5	79.0	99.5
	Total Dissolved Solids (TDS)	1000	100	340	550	780	325	550	775
	Turbidity (NTU)	1.9	19.0	14.0	10.0	6.3	N/A	N/A	N/A
Metals & Metalloids	Aluminium	<0.1	1.6	1.4	1.0	0.6	1.23	0.85	0.48
	Arsenic	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.1	0.1
	Barium	<0.01	0.03	0.02	0.02	0.01	0.025	0.020	0.015
	Boron	0.13	<0.05	<0.05	0.07	0.09	0.07	0.09	0.11
	Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.01
	Calcium	31.0	7.2	12.0	17.0	22.0	13.15	19.10	25.05
	Copper	<0.01	<0.01	0.01	<0.01	<0.01	0.01	0.01	0.01
	Iron	0.07	2.30	1.90	1.20	0.68	1.74	1.19	0.628
	Lead	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	0.05	0.05
	Magnesium	26.0	2.4	7.9	13.0	18.0	8.3	14.2	20.1
	Manganese	0.04	0.04	0.05	0.04	0.04	0.04	0.04	0.04
	Mercury	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.1	0.1
	Nickel	0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.01
	Sodium	280.0	10.00	81.0	140.0	200.0	77.5	145.0	212.5
	Zinc	0.02	0.01	0.01	0.01	0.01	0.013	0.015	0.018
Organic Matters	TOC	10.0	5.0	7.0	7.0	9.0	6.25	7.50	8.75
Bacteria Indicator	E coli (orgs/100mL)	0.00	460.0	280.0	200.0	93.0	345.0	230.0	115.0
Nutrients	Total Nitrogen	11.10	0.62	3.80	6.50	8.50	3.24	5.86	8.48
	Total Phosphorus	9.0	0.13	2.10	4.20	6.10	2.35	4.57	6.78

N/A -Not Applicable, since mass balance method cannot be used for physical parameters

measurement could be positioned. This range could be defined as the acceptable range of the measurement. Using the results in Table 3.4, Table 3.5 was prepared to include the acceptable range of each water quality parameter for Mix3, Mix4 and Mix 5. The acceptable range was computed using the measurement uncertainties provided by the laboratory (as a percentage) for Mix3, Mix4 and Mix 5 for; (1). direct laboratory measurements of the mix and (2). measurements obtained using the mass balance analysis.

Table 3.5: Acceptable ranges within brackets for same day samples calculated for direct laboratory water quality results and mass balance method water quality results

Selected Parameters for the study		Mixed Water Quality (mg/L)						Measurement Uncertainity as a % (provided by the testing laboratory)
		Mix 3 (Lab results)	Mix 3 (Mass balance)	Mix 4 (Lab results)	Mix 4 (Mass balance)	Mix 5 (Lab results)	Mix 5 (Mass balance)	
Physiochemical Indicators	Ammonia (NH3)	0.10 (0.09-0.11)	0.13 (0.12-0.13)	0.10(0.09-0.11)	0.15 (0.14-0.16)	0.20 (0.19-0.21)	0.18 (0.16-0.19)	7.1%
	Chloride	120.0 (100.2-139.8)	112.5 (93.96-131.04)	210.0 (175.4-244.6)	215.0 (179.6-250.4)	300.0 (250.6-349.4)	317.5 (265.2-369.8)	16.5%
	Colour AppPt/Co units	100.0	N/A	75.0	N/A	50.0	N/A	N/A
	EC at 25 °C µS/cm	560	N/A	970	N/A	1400	N/A	N/A
	pH	7.4	N/A	7.5	N/A	7.6	N/A	N/A
	SAR(Sodium Adsorption Ratio)	4.4	N/A	6.3	N/A	7.7	N/A	N/A
	Sulphate	27.0 (23.0-31.0)	31.0 (26.38-35.62)	49.0 (41.7-56.3)	52.0 (44.2-59.7)	69.0 (58.7-79.3)	73.0 (62.12-83.88)	14.9%
	Suspended Solids	10.0 (8.8 -11.2)	11.0 (9.6-12.3)	6.0 (5.3-6.7)	8.0 (7.0-9.0)	4.0 (3.5-4.5)	5.0 (4.4-5.6)	12.3%
	Total Alkalinity mg CaCO3 / L	57.0	58.5	78.0	79.0	99.0	99.5	N/A
	Total Dissolved Solids (TDS)	340 (313-367)	325 (299-351)	550 (506-594)	550 (506-594)	780 (718-842)	775 (713-837)	8.0%
	Turbidity (NTU)	14.0	N/A	10.0	N/A	6.3	N/A	N/A
Metals & Metalloids	Aluminium	1.4 (1.2-1.6)	1.2 (1.1-1.4)	1.0 (0.9-1.1)	0.85 (0.73-0.97)	0.6 (0.51-0.68)	0.48 (0.41-0.54)	13.6%
	Arsenic	0.10 (0.09-0.11)	0.10 (0.09-0.11)	0.10 (0.09-0.11)	0.10 (0.09-0.11)	0.10 (0.09-0.11)	0.10 (0.09-0.11)	11.5%
	Barium	0.020 (0.018-0.022)	0.025 (0.022-0.028)	0.020 (0.018-0.022)	0.020 (0.018-0.022)	0.010 (0.009-0.011)	0.020 (0.013-0.017)	11.6%
	Boron	0.05 (0.04-0.06)	0.07 (0.06-0.08)	0.070 (0.061-0.079)	0.090 (0.078-0.102)	0.090 (0.078-0.102)	0.110 (0.095-0.125)	13.4%
	Cadmium	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	10.1%
	Calcium	12.0 (9.5-14.5)	13.1 (10.34-15.91)	17.0 (13.4-20.6)	19.1 (15.1-23.1)	22.0 (17.4-26.6)	25.05 (19.79-30.31)	21.0%
	Copper	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	13.1%
	Iron	1.9 (1.6-2.2)	1.74 (1.5-2.0)	1.2 (1.0-1.4)	1.19 (1.02-1.35)	0.68 (0.59-0.77)	0.63 (0.54-0.71)	13.8%
	Lead	0.050 (0.045-0.055)	0.050 (0.045-0.055)	0.050 (0.045-0.055)	0.050 (0.045-0.055)	0.050 (0.045-0.055)	0.050 (0.045-0.055)	10.4%
	Magnesium	7.90 (6.60-9.20)	8.30 (6.93-9.67)	13.0 (10.86-15.15)	14.20 (11.86-16.54)	18.0 (15.03-20.97)	20.10 (16.78-23.42)	16.5%
	Manganese	0.050 (0.044-0.055)	0.040 (0.036-0.044)	0.040 (0.036-0.044)	0.040 (0.036-0.044)	0.040 (0.036-0.044)	0.040 (0.036-0.044)	9.6%
	Mercury	0.10 (0.08-0.12)	0.10 (0.08-0.12)	0.10 (0.08-0.12)	0.10 (0.08-0.12)	0.10 (0.08-0.12)	0.10 (0.08-0.12)	18.1%
	Nickel	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	12.6%
	Sodium	81.0 (67.3-94.7)	77.5 (64.4-90.6)	140.0 (116.3-163.7)	145.0 (120.5-169.5)	200.0 (166.2-233.8)	212.5 (176.5-248.4)	16.9%
	Zinc	0.010 (0.009-0.011)	0.013 (0.011-0.014)	0.010 (0.009-0.011)	0.015 (0.013-0.017)	0.010 (0.009-0.011)	0.020 (0.015-0.020)	14.7%
Organic Matters	TOC	7.0 (5.9-8.1)	6.3 (5.2-7.3)	7.0 (5.9-8.1)	7.5 (6.3-8.7)	9.0(7.524-10.4760	8.8 (7.3-10.2)	16.4%
Bacteria Indicator	E coli (orgs/100mL)	280.0 (193.7-404.7)	345 (238.7-498.7)	200.0 (138.4-289.1)	230 (159.1-332.4)	93.0 (64.3-134.4)	115 (79.6-166.2)	Log 0.16
Nutrients	Total Nitrogen	3.80 (3.02-4.58)	3.24 (2.58-3.90)	6.50 (5.17-7.83)	5.86 (4.66-7.05)	8.50 (6.77-10.23)	8.48 (6.75-10.21)	20.4%
	Total Phosphorus	2.10 (1.75-2.45)	2.35 (1.96-2.74)	4.20 (3.50-4.90)	4.57(3.80-5.32)	6.10 (5.08-7.12)	6.78 (5.65-7.91)	16.6%

[shaded box] Exceeding measurement uncertainty limit

N/A – Not Applicable, since measurement uncertainty is not available

The acceptable range for direct laboratory readings of combined water quality was computed by multiplication of measurement uncertainty percentages by the measured reading. The acceptable ranges for mass balance results were calculated using equation (2) below.

Uncertainty estimation (mass balance) = $[(V_1 * (\delta C_1)) + (V_2 * (\delta C_2))] / (V_1+V_2)$ (2)

Where V_1 is the volume of recycled water, V_2 is the volume of stormwater, δC_1 is the uncertainty related to recycled water quality parameter and δC_2 is the uncertainty related to stormwater quality parameter.

The acceptable range calculations are shown below for chloride in Mix 3 as an example, whose measurement uncertainty is given as 16.5% by the testing laboratory (Table 3.6).

Acceptable range for laboratory measurement

Laboratory testing reading = 120mg/L (Mix 3 - Table 3.4)

Measurement uncertainty (%) = 16.5% (Table 3.5)

Measurement uncertainty for the measurement reading 16.5%*120=19.8 mg/L

Acceptable range of this measurement reading=(120–19.8)=100.20 to (120+19.8)=139.8.

Acceptable range for mass balance analysis estimate

Mass balance estimate (Mix 3 Table 3.5) = 0.25*420 + 0.75*10 = 112.5 mg/L

For Mix 3, mix ratio of stormwater to recycled water is 75% to 25% (Table 3.3). Laboratory testing reading for recycled water = 420 mg/L (Mix 1 - Table 3.4) and for stormwater = 10 mg/L (Mix 2 – Table 3.4)

δC_1 = 16.5% * 420 (=69.3)

δC_1 = 16.5% * 10 (=1.65)

Mass balance uncertainty estimate using Equation (2) = 0.25*69.3 + 0.75*1.65 = 18.56 mg/L

Acceptable range of this measurement reading = 112.5-18.56 (=93.9) to 112.5 + 18.56 (=131.1)

The acceptable ranges are graphically shown below.

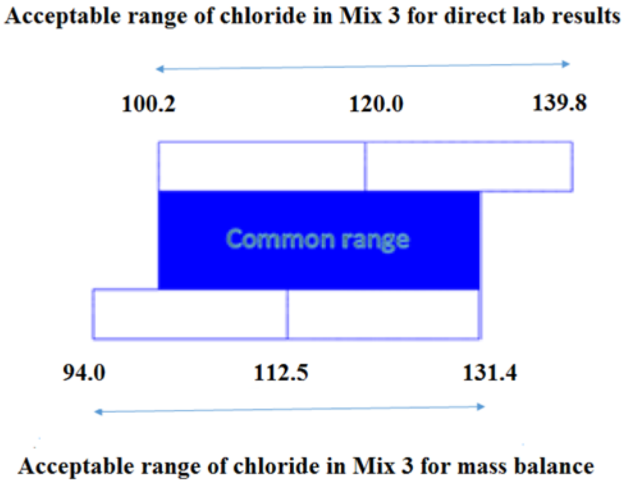


Figure 3.1: Graphical picture showing acceptable range of Chloride

It is seen from the above, that acceptable ranges for laboratory measurement and mass balance measurement has an overlap between 100.2 to 131.1. This figure indicates that the measurement of chloride in the mix 3 obtained from the laboratory and chloride in the mix 3 calculated using mass balance analysis have partially overlapped. Therefore, it could be concluded that use of mass balance analysis is an acceptable method to calculate chloride content in Mix 3. This is checked for other parameters in all the mixes listed in Table 3.4 and the results are given in Table 3.5. A discussion is given in the next chapter for the comparison of these acceptable ranges for other parameters in all three mixes.

If the acceptable range calculated for the laboratory measurement and for the mass balance analysis estimate overlap fully or partially, then it can be concluded that the results from the two approaches are similar within the measurement uncertainty given by the laboratory (as shown in the example for chloride). This is because direct laboratory measurement reading or the mass balance estimate could be any value within their respective ranges. The results in Table 3.5 satisfy this condition, except for ammonia, suspended solids, barium and zinc. For suspended solids and barium, two mixed samples satisfy this condition out of the three mix proportions considered. However, for ammonia and zinc, only one mixed ratio satisfied the condition out of three mixed proportions. It is to be noted in all cases, when the uncertainty ranges calculated for the mass balance estimate do not overlap with the uncertainty range calculated for the direct laboratory measurement reading, the estimated combined water quality parameter value using mass balance is higher than the direct laboratory measurement. This is a conservative outcome for these parameters to use the mass balance method to determine the combined water quality. Therefore, in general, based on the values in Table 3.5 it could be concluded that the mass balance method could be used as a valid tool to calculate the combined water quality.

3.4.3.2 Samples tested after 3 days

Table 3.6 below shows the results obtained from the laboratory tests for the 3 samples kept under room temperature for three days for the three mix proportions Mix 6, Mix 7 and Mix 8. These results are compared with the results of mixed water tested on the same day of sampling which are Mix 3, Mix 4 and Mix 5 respectively. Mix ratios of stormwater and recycled water of Mix 6, Mix 7, and Mix 8 are same as those of Mix 3, Mix 4, and Mix 5 respectively.

Table 3.6: Comparison of laboratory testing results of samples tested on the same day and after 3 days of collection and mixing.

Selected Parameters for the study		Results of laboratory testing					
		Mix 3 (mg/L) (Same day)	Mix 6 (mg/L) (After 3days)	Mix 4 (mg/L) (Same day)	Mix 7 (mg/L) (After 3days)	Mix 5 (mg/L) (Same day)	Mix 8(mg/L) (After 3days)
Physiochemical Indicators	Ammonia (NH3), as N	<0.1	<0.1	0.1	0.2	0.2	0.2
	Chloride	120	110	210	200	300	280
	Colour AppPt/Co units	100	80	75	70	50	25
	EC at 25 °C µS/cm	560	560	970	970	1400	1400
	pH	7.4	7.5	7.5	7.7	7.6	7.8
	SAR (Sodium Adsorption Ratio)	4.4	4.3	6.3	6.3	7.7	7.8
	Sulphate	27.0	22.0	49.0	43.0	69.0	63.0
	Suspended Solids	10.0	12.0	6.0	5.0	4.0	6.0
	Total Alkalinity mg CaCO3 / L	57	58	78	77	99	96
	Total Dissolved Solids (TDS)	340	320	550	560	780	780
	Turbidity	14.0	14.0	10.0	9.4	6.3	5.9
Metals & Metalloids	Aluminium	1.4	1.3	1.0	0.8	0.6	0.5
	Arsenic	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	Barium	0.02	0.02	0.02	0.02	0.01	0.01
	Boron	<0.05	<0.05	0.07	0.06	0.09	0.09
	Cadmium	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
	Calcium	12	12	17	16	22	22
	Copper	0.01	<0.01	<0.01	<0.01	0.01	0.01
	Iron	1.90	1.60	1.20	0.99	0.68	0.57
	Lead	<0.05	<0.05	<0.05	<0.05	0.05	<0.05
	Magnesium	7.90	7.70	13.00	13.00	18.00	19.00
	Manganese	0.05	0.03	0.04	0.03	0.04	0.03
	Mercury	<0.1	<0.1	<0.1	<0.1	0.10	<0.1
	Nickel	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
	Sodium	81.0	77.0	140.0	140.0	200.0	210.0
	Zinc	0.01	<0.01	0.01	0.01	0.01	0.02
Organic Matters	TOC	7.0	6.0	7.0	6.0	9.0	7.0
Bacteria Indicator	E coli (orgs/100mL)	280	30	200	16	93	13
Nutrients	Total Nitrogen	3.8	3.8	6.5	6.0	8.5	8.9
	Total Phosphorus	2.1	2.2	4.2	4.1	6.1	6.2

Table 3.7 shows the laboratory results of water quality parameters taken from Table 3.6 and the acceptable ranges within brackets for each water quality parameter calculated using the same procedure as explained in Section 3.4.3.1.

If the acceptable range calculated for the laboratory testing results of same day samples and 3 days samples overlap fully or partially, this means that the water quality of samples tested on the same day and after three days have not changed over a three day period.

Table 3.7: Water quality results from laboratory testing and acceptable ranges within brackets for samples of same day and after 3 days of sampling

Selected Parameters for the study		Mixed Water Quality (mg/L)						Measurement Uncertainity as a %
		Mix 3 (same day)	Mix 6 (After 3 days)	Mix 4 (Same day)	Mix 7 (After 3 days)	Mix 5 (Same day)	Mix 8 (After 3 days)	
Physiochemical Indicators	Ammonia(NH3)	0.10 (0.09-0.11)	0.10 (0.09-0.11)	0.10(0.09-0.11)	0.20 (0.19-0.21)	0.20 (0.19-0.21)	0.20 (0.19-0.21)	7.1%
	Chloride	120.0 (100.2-139.8)	110.0 (91.9-128.1)	210.0 (175.4-244.6)	200.0 (167.0-233.0)	300.0 (250.6-349.4)	280.0 (233.9-326.1)	16.5%
	Colour AppPt/Co units	100.0	80.0	75.0	70.0	50.0	25.0	N/A
	EC at 25 °C µS/cm	560	560	970	970	1400	1400	N/A
	pH	7.4	7.5	7.5	7.7	7.6	7.8	N/A
	SAR(Sodium Adsorption Ratio)	4.4	4.3	6.3	6.3	7.7	7.8	N/A
	Sulphate	27.0 (23.0-31.0)	22.0 (18.7-25.3)	49.0 (41.7-56.3)	43.0 (36.6-49.4)	69.0 (58.7-79.3)	63.0 (53.6-72.4)	14.9%
	Suspended Solids	10.0 (8.8 -11.2)	12.0 (10.5-13.5)	6.0 (5.3-6.7)	5.0 (4.4-5.6)	4.0 (3.5-4.5)	6.0 (5.3-6.7)	12.3%
	Total Alkalinity mg CaCO3 / L	57.0	58.0	78.0	77.0	99.0	96.0	N/A
	Total Dissolved Solids(TDS)	340 (313-367)	320 (294-346)	550 (506-594)	560 (515-605)	780 (718-842)	780 (718-842)	8.0%
	Turbidity	14.0	14.0	10.0	9.4	6.3	5.9	N/A
Metals & Metalloids	Aluminium	1.4 (1.2-1.6)	1.3 (1.1-1.5)	1.0 (0.9-1.1)	0.8 (0.7-0.9)	0.6 (0.5-0.7)	0.5 (0.4-0.6)	13.6%
	Arsenic	0.10 (0.09-0.11)	0.10 (0.09-0.11)	0.10 (0.09-0.11)	0.10 (0.09-0.11)	0.10 (0.09-0.11)	0.10 (0.09-0.11)	11.5%
	Barium	0.020 (0.018-0.022)	0.020 (0.018-0.022)	0.020 (0.018-0.022)	0.020 (0.018-0.022)	0.020 (0.018-0.022)	0.020 (0.018-0.022)	11.6%
	Boron	0.050 (0.043-0.057)	0.050 (0.043-0.057)	0.070 (0.061-0.079)	0.060 (0.052-0.068)	0.090 (0.078-0.102)	0.090 (0.078-0.102)	13.4%
	Cadmium	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	10.1%
	Calcium	12.0 (9.5-14.5)	12.0 (9.5-14.5)	17.0 (13.4-20.6)	16.0 (12.6-19.4)	22.0 (17.4-26.6)	22.0 (17.4-26.6)	21.0%
	Copper	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	13.1%
	Iron	1.9 (1.6-2.2)	1.6 (1.4-1.8)	1.2 (1.0-1.4)	0.99 (0.85-1.13)	0.68 (0.59-0.77)	0.57 (0.49-0.65)	13.8%
	Lead	0.050 (0.045-0.055)	0.050 (0.045-0.055)	0.050 (0.045-0.055)	0.050 (0.045-0.055)	0.050 (0.045-0.055)	0.050 (0.045-0.055)	10.4%
	Magnesium	7.90 (6.60-9.20)	7.70 (6.43-8.97)	13.0 (10.86-15.15)	13.0 (10.86-15.15)	18.0 (15.03-20.97)	19.0 (15.87-22.14)	16.5%
	Manganese	0.050 (0.045-0.055)	0.030 (0.027-0.033)	0.040 (0.036-0.044)	0.030 (0.027-0.033)	0.040 (0.036-0.044)	0.030 (0.027-0.033)	9.6%
	Mercury	0.10 (0.08-0.12)	0.10 (0.08-0.12)	0.10 (0.08-0.12)	0.10 (0.08-0.12)	0.10 (0.08-0.12)	0.10 (0.08-0.12)	18.1%
	Nickel	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	12.6%
	Sodium	81.0 (67.3-94.7)	77.0 (64.0-90.0)	140.0 (116.3-163.7)	140.0 (116.3-163.7)	200.0 (166.2-233.8)	210.0 (174.5-245.5)	16.9%
	Zinc	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.010 (0.009-0.011)	0.020 (0.017-0.023)	14.7%
Organic Matters	TOC	7.0 (5.9-8.1)	6.0 (5.0-7.0)	7.0 (5.9-8.1)	6.0 (5.0-7.0)	9.0(7.5-10.5)	7.0 (5.9-8.1)	16.4%
Bacteria Indicator	E coli	280.0 (193.7-404.7)	30.0 (20.8-43.4)	200.0 (138.4-289.1)	16.0 (11.1-23.1)	93.0 (64.3-134.4)	13.0 (9.0-18.8)	Log 0.16
Nutrients	Total Nitrogen	3.80 (3.02-4.58)	3.80 (3.02-4.58)	6.50 (5.17-7.83)	6.00 (4.78-7.22)	8.50 (6.77-10.23)	8.90 (7.08-10.72)	20.4%
	Total Phosphorus	2.10 (1.75-2.45)	2.20 (1.83-2.57)	4.20 (3.50-4.90)	4.1(3.42-4.78)	6.10 (5.08-7.12)	6.20 (5.17-7.23)	16.6%

(grey box) Exceeding measurement uncertainty limit

N/A – Not Applicable, since measurement uncertainty is not available

Then it can be concluded that the results from the two approaches are similar within the measurement uncertainty given by the laboratory. This is because laboratory reading can be any value within their respective acceptable range. The results in Table 3.7 satisfy this condition, except for ammonia, suspended solids, manganese and E coli.

For Ammonia and suspended solids, two mixed samples are within the acceptable range out of three samples. However, Manganese and E coli are not within the acceptable range for all three mixed samples. It is to be noted that E coli concentration has reduced significantly within the three days (by 86% - 92% for the three samples). This drastic reduction could be due to presence of residual chlorine in recycled water. In general, based on the values in Table 3.7, combined water quality remained unchanged even after 3 days of mixing.

3.5 SUMMARY

Combined water (i.e. mix of recycled water and stormwater) has been successfully used in the past using a third pipe, however mixing has been done prior to delivery by the third pipe. In this study, it is proposed to inject treated stormwater into the third pipe which carries recycled water. With this novel technique, mixing occurs in the third pipe. Recycled water generally less variable in quality, since it has been treated to acceptable levels of third pipe water use to control risks to human health and the environment. However, the stormwater is highly variable both temporally and spatially and there are many aspects to consider to control risks of human health and environment with the use of stormwater. Combined water also needs to satisfy appropriate standard of water quality in order to minimise risks of human health and the environment. The use of combined water as proposed in this study has its own issues and challenges especially in relation to water quality.

To address water quality issues and challenges in combined water systems, it is necessary to provide guidance regarding the required quality of combined water in the third pipe. Two important aspects are considered in this study.

(1) The development of a guideline on water quality of combined water, as such a guideline is not available in Australia or elsewhere to the authors' knowledge and

(2) The investigation of the appropriateness of the mass balance method to obtain mix water quality comparing with the laboratory testing

After reviewing the existing guidelines for recycled water and stormwater, a guideline was developed during this study for combined water use via a third pipe, considering acceptable limits for water quality parameters. Selection of the water quality parameters in the developed guideline was made by reviewing the available literature and understanding the issues such as corrosion, colour, and odour brought to the end user caused by these parameters exceeding the limits (or thresholds). Limits were developed considering the existing guidelines for recycled water and stormwater and various end use applications of combined water as proposed in this study.

The mass balance analysis could be used to estimate the water quality of combined water with respect to water quality parameters. However, this could be done only if additional chemicals or gases are not produced during the mixing process. The results from the mass balance analysis was compared against laboratory testing of samples of combined water covering a range of potential mixes of recycled water and stormwater. The results showed that the water quality obtained from the two methods are within the measurement uncertainty for all tested water quality parameters except for suspended solids, barium, (only one mixed ratio) and ammonia and zinc (two mixed ratios). Laboratory tests conducted on several combined water samples on the same day of collection and after three days of collection showed that they are also within the measurement uncertainty for all tested water quality parameters except for manganese and E coli (for all three mixed ratios) and ammonia and suspended solids (for only one mixed ratio).

Based on the laboratory tests conducted, it is concluded that mass balance method could be used to calculate the water quality of combined water with respect to water quality parameters, and that the water quality of combined water is expected to remain unchanged in the third pipe during travel time from the injection point to the consumers' end.

4 RISK MANAGEMENT FRAMEWORK FOR COMBINED USE OF RECYCLED WATER AND STORMWATER IN THIRD PIPES

4.1 INTRODUCTION

It is essential to protect the health of both public and the environment, when using combined water through a third pipe system. A proper risk management system can be used to ensure consumers' health and minimise harmful impacts on the environment. Through a proper risk management plan, developed via a sound risk management framework, it is possible to take preventive measures to mitigate risks to the public and the environment. In the planning stage of a project, through this risk management plan, it is important to identify possible hazards, consequences of these hazards and then suggest preventive measures. Monitoring the system is also important for continuous improvement in mitigating risks.

This chapter presents a risk management framework which consists of methods to identify and control risks in combined water systems, based on the existing risk management systems for recycled water and stormwater available in Australia. To identify possible hazards and preventive measures, it is necessary to consider the components of the combined water system systematically. It is also proposed to identify critical control points for monitoring, since monitoring is necessary for continuous improvement of combined water quality and the risk management methods.

4.2 RISK MANAGEMENT FRAMEWORK FOR USE OF COMBINED WATER VIA A THIRD PIPE

A generic risk management framework has been proposed in the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006) to control the risks in recycled water originating from sewage. However, these guidelines also recommended this framework to be used for recycled water originating from greywater, stormwater or combination of these sources. The same risk management framework was adopted in the Australian Guideline for Water Recycling Phase 2: Stormwater Harvesting and Reuse (NRMMC-EPHC-NHMRC, 2009). Therefore, the same risk management framework is adopted in this study for the combined use of recycled water and stormwater supplied via a third pipe. The proposed risk management framework has 12 elements as shown in Figure 4.1 below.

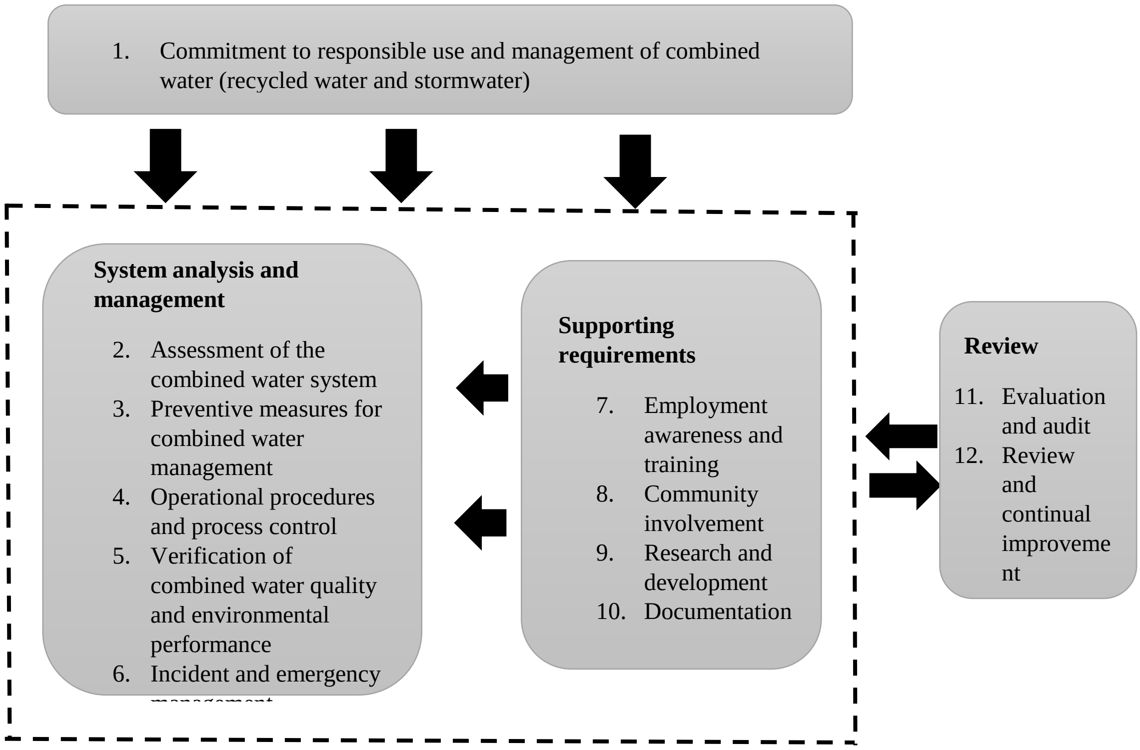


Figure 4.1: Elements of the framework for management of water quality and use (adopted from Australian Guideline for Water Recycling Phase 1 NRMMC-EPHC-NHMRC, (2006))

The 12 elements are structured within four general areas, as illustrated in the above figure and these areas as defined in the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006) are;

- Commitment to responsible use and management of recycled water (Element 1)

  This requires the development of a commitment to responsible use of recycled water and to application of a preventive risk management approach to support this use. The commitment requires active participation of senior managers, and a supportive organisational philosophy within agencies responsible for operating and managing recycled water schemes.

- System analysis and management (Elements 2 to 6)

    This requires an understanding of the entire recycled water system, the hazards and events that can compromise recycled water quality, and the preventive measures and operational control necessary for assuring safe and reliable use of recycled water.

- Supporting requirements (Elements 7 to 10)

    These include basic elements of good practice, such as employee training, community involvement, research and development, validation of process efficacy, and systems for documentation and reporting.

- Review (Elements 11 and 12)

    This includes evaluation and audit processes to ensure that the management system is functioning satisfactorily. It also provides a basis for review and continuous improvement.

Above definitions are adopted from the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006). Although these 12 elements are categorized in four general areas in the Australian Guidelines for Recycled Water, these elements are interrelated. Each element supports the effectiveness of the others. Hence all 12 elements are needed to address together to assure a safe and sustainable combined water (i.e. mix of recycled water and stormwater) supply system.

Commitment to responsible use and management of combined water (Element 1), supporting requirements (Elements 7 to 10) and review (Elements 11 and 12) are to be covered at the institutional level during the implementation stage. System analysis and management (Elements 2 to 6) are covered in the planning stage of a project and it is the core of the risk management framework. This requires an understanding of the entire combined water system, the hazards and events that can compromise mixed water quality, and the preventive measures and operational control necessary for assuring safe and reliable use of combined water. The elements in system analysis and management are listed below.

Element 2: Assessment of the combined water system

Element 3: Preventive measures for combined water management

Element 4: Operational procedures and process control

Element 5: Verification of combined water quality and environmental performance

Element 6: Incident and emergency management

In this study, only system analysis and management section (Elements 2 to 6) of the risk management framework was considered, as this is the area covered under planning stage of a project, which is the scope of this thesis.

4.3 ASSESSMENT OF THE COMBINED WATER SYSTEM (ELEMENT 2)

The assessment of the combined water system provides detailed understanding of the entire combined water supply system from source to the end user. This assessment will identify hazards that can have effect on water quality.

According to the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006), there are four components under Element 2 to assess recycled water systems, as;

- Source of recycled water, intended uses, receiving environments and route of exposure
- Recycled water system analysis
- Assessment of water quality data
- Hazard identification and risk assessment

These components used for recycled water were adopted for the combined water (recycled water and stormwater) systems as explained in the next sections.

4.3.1 Sources of combined water (recycled water and stormwater), intended uses, receiving environments and routes of exposure

4.3.1.1 Sources of water

The proposed project considered a mix of recycled water and stormwater. Therefore, this section describes both sources of recycled water and stormwater and then sources of combined water.

a) Recycled water

Sources of recycled water considered in this project are large metropolitan sewage treatment plants. With reference to the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006), identification and production of recycled water is based on 'fit-for-purpose'. This Australian guideline does not specify the recycled water into different classes. However, other guidelines used in different States in Australia still classify recycled water into various classes based on the quality of water.

b) Stormwater

Stormwater harvesting is the process of collection, treatment, storage and re-use of stormwater. The runoff in urban areas is higher than in undeveloped/predevelopment areas due to significant increase in the impervious areas such as roads, roofs and paved areas in urban areas. Stormwater is usually harvested from drains and held in storages above or below ground to balance supply and demand. The Australian Guidelines for Water Recycling Phase 2 – Stormwater Harvesting and Reuse (NRMMC-EPHC-NHMRC, 2009), recommends to incorporate a minimum 72-hour buffer time between the collection of stormwater and its release for reuse. Captured water is treated to reduce pathogen and pollution levels to ensure that water quality is fit for the purpose of its use. Treatment methods adopted depend on the end uses. Stormwater is usually treated using natural methods such as grass swales, sedimentation ponds, wetlands, etc. in addition to disinfection.

Quality of stormwater depends on catchment characteristics and human activities in the catchment. It is important to gather information about the catchment use for management of risks in stormwater reuse. Land use of the catchment affects the quality of stormwater. Also stormwater quality varies significantly between storm events.

c) Combined water (recycled water and stormwater)

Combined water (as defined in this study) runs through the first stormwater injection point to the user's end. With this stormwater injection method, mixing of two types of water takes place inside the third pipe. Recycled water is produced to quality standards as defined by responsible health and environmental authorities. The quality of combined water could be varied by changing the stormwater percentage. However, the quality of stormwater varies both spatially and temporally, and stormwater quality has to be monitored on a daily basis. When the quality of stormwater deviates to such an extent that the quality of combined water does not comply with the required water quality standards of the end use applications, there should be a facility to blend recycled water with potable water.

4.3.1.2 Intended uses

Intended uses of recycled water/stormwater are related to the various water use activities. Based on the information in the Australian Guidelines for Water Recycling: Managing Health and Environmental Risk Phase 1 (NRMMC-EPHC-NHMRC, 2006) and Phase 2 (NRMMC-EPHC-NHMRC, 2009), combined water use activities are identified and tabulated in Table 4.1 below.

Table 4.1: Identified combined water use activities

Uses of Combined Water	**Type of Activity**
Agricultural uses	Horticulture, trees/woodlots, pasture/fodder, dairy pasture, lucerne, cotton, flowers, orchard, nursery, vegetables, viticulture, hydroponics, turf farm, cane fields, grain cropping
Fire control uses	Controlling fires, testing and maintenance of fire control systems, training facilities for fire fighting
Municipal uses	Irrigation of public parks and gardens, roadsides, sporting facilities (including golf courses), road making and dust control, street cleaning
Residential and commercial property uses	Dual-reticulation schemes supply water for residential and commercial property uses, including: • in-building (toilet flushing) • garden watering, car washing • water features and systems (ponds, fountains, cascades) • utility washing (paths, vehicles, fences etc)
Industrial and commercial uses	Cooling water, process water, wash-down water

Source: Table 1.1 of NRMMC-EPHC-NHMRC (2006) and Table A6.1 NRMMC-EPHC-NHMRC (2009)

4.3.1.3 *Receiving environments*

The receiving environment or the environmental end point of combined water depends on the type of uses. Receiving environment include surface water, groundwater, plants, biota, air and soils. Environmental hazards to the receiving environment could be minimised by regular monitoring of water quality to comply with the proposed combined water quality guideline proposed in Section 3.3.

4.3.1.4 *Routes of exposure*

Assessment of exposure requires consideration of both intended and unintended uses (NRMMC-EPHC-NHMRC, 2006). The routes of exposure are related to both human health and environment. The main route of exposure for human health from microbial hazards (by recycled water or stormwater) is ingestion, including ingestion of droplets produced by sprays. The uses associated with combined water, routes of exposure for human health and exposure events are tabulated in Table 4.2.

Table 4.2: Routes of exposures for human health with the use of combined water

Uses	Route of exposure	Exposure events
Garden irrigation	• Ingestion of sprays • Routine ingestion • Accidental ingestion	Exposure to aerosols occurs during watering Indirect ingestion via contact with plants, lawns. Infrequent event (e.g. drinking accidental)
Municipal irrigation	• Indirect ingestion	Contact with plants, lawns, etc.
Food crop consumption (home grown/commercial)	• Ingestion	Consume after watering
Toilet flushing	• Ingestion of sprays	Exposure to aerosols occurs during toilet flushing
Washing machine use	• Ingestion of sprays	Exposure to aerosols occurs when using (machines usually closed during operation).
Fire fighting	• Ingestion of water and sprays	Exposure to aerosols occurs when sprays
Dual-reticulation systems	• Ingestion	Accidental drinking when cross connection with drinking water

Note: Information above is adopted from Table 3.3 of NRMMC-EPHC-NHMRC (2006)

Based on the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006), nine environmental hazards have been identified for assessing the environmental risks associated with specific uses of recycled water are related to boron, cadmium, chlorine disinfection residuals, hydraulic loading rate, nitrogen, phosphorus, salinity, chloride and sodium. The environmental hazards identified in the Australian Guideline for Water Recycling Phase 2 - Stormwater and Reuse (NRMMC-EPHC-NHMRC, 2009) are cadmium, hydraulic loading rate, iron, nitrogen and phosphorus. Therefore, list of environmental hazards for the use of combined water is prepared by combining the environmental hazards of recycled water and stormwater. The uses associated with combined water, the routes of exposure for environment and environmental end points are tabulated in Table 4.3.

Table 4.3: Routes of exposure for environmental considerations for combined third pipe water use

Hazard	**Environmental end point**	**Exposure Route**
Boron	Soils	Irrigation
Cadmium	Plants and soils	Irrigation
Chlorine disinfection residual	Plants and surface water	Irrigation
Chloride	Plants, soils and surface water	Irrigation
Hydraulic loading rate	Soil and ground water	Irrigation
Iron	Plants and Irrigation equipment	Irrigation
Nitrogen	Soil and surface water	Irrigation
Phosphorus	Soil	Irrigation
Salinity	Soils, surface water, ground water and infrastructure	Irrigation
Sodium	Plants and soils	Irrigation

Note: Information above is adopted from Table 4.2 of NRMMC-EPHC-NHMRC (2006) and Table A4.1 of Appendix 4 of NRMMC-EPHC-NHMRC (2009)

4.3.2 Combined water system analysis

4.3.2.1 Assemble a team with appropriate knowledge and expertise

Understanding of the combined water system from source to the end user is necessary for effective management of the system. That is the understanding of the recycled water subsystem (from source to the injection point), stormwater subsystem (from source to the injection point) and then combined water subsystem (from injection point to the end user). Each part of the sub system should be characterised with respect to water quality, the factors that affect water quality, and the integrity of the supply system. The analysis of combined water requires a team with adequate knowledge.

It is proposed that the team should include management staff from the alternative water supplier or the retail water company in the relevant area, who are responsible for the recycled water system and the combined water system including the stormwater injection point. Team should also include responsible staff from the local government body for management of the stormwater system. This team should possess appropriate knowledge for quality assurance and system maintenance. Regulatory agencies for health and environment must have license agreements with both third pipe water supplier and the local government body to safeguard the third pipe water customers and the environment.

4.3.2.2 Assemble information of the combined water system and layout and process schematic

In Australia, the development, installation and operation of large scale recycled water systems are guided by the Australian Guidelines for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006). However, different States have interpreted these guidelines in different ways, as the guidelines are flexible and provide only a framework for assessing the system. For example, in Victoria, the recycled water quality should be maintained according to the EPA guidelines (EPA-Victoria, 2003, EPA Victoria, 2005) in addition to the Australian Guidelines for Water Recycling. Furthermore, the Department of Health and Human Services (DHHS) sets the water quality standards for public safety regarding the health issues in Victoria.

a) Layout and process schematic of recycled water system

Recycled water subsystem is defined in this study as from source to the stormwater injection point. It includes wastewater treatment system, recycled water storage system and transport recycled water from storage to the first stormwater injection point. Figure 4.2 is the typical process flow diagram of the wastewater treatment plant, where recycled water is produced. Treatment processes mainly focus on pathogen reduction in recycled water from the perspective of human health.

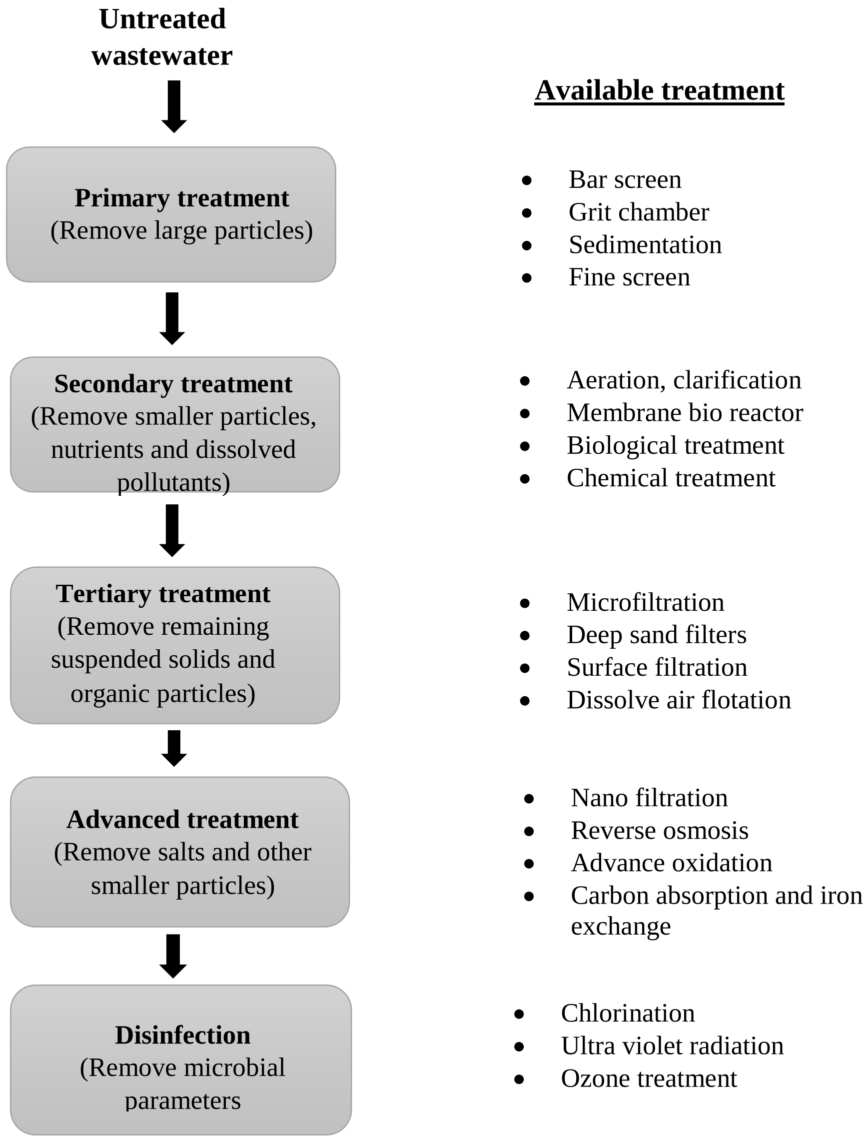


Figure 4.2: Typical flow diagram of recycled water subsystem

When wastewater arrives the treatment plant, primary treatment is the first process to undergo to remove large particles. Usually gross solids are removed by bar screens and grit is removed using grit removal chambers. Floating and settleable particles are removed through sedimentation and sometimes fine screens are used to enhance the removal of the suspended solids. After primary treatment, wastewater is directed to secondary treatment. In secondary treatment, biological and chemical treatments are used to remove nutrients and dissolved pollutants. Recycled water is usually produced to fit for the intended uses. After secondary treatment with disinfection, recycled water can be used for restricted irrigation works. In tertiary treatment, remaining suspended solids and organic matters are removed usually using a filtration process. With tertiary treatment and disinfection, recycled water can be used for watering gardens and even toilet flushing. In some cases, advanced treatment systems are used depending on the required quality of recycled water at end use level. Combination of advanced treatment methods (as mentioned in Figure 4.2) are used to reduce constituents which are not possible to remove using conventional methods. Advanced treatment can remove salts. Most of the industrial applications require advanced treatment and disinfection.

b) Layout and process schematic of stormwater sub system

The stormwater sub system is defined in this study as from source (usually stormwater catchment) to the stormwater injection point. The sub system includes diversion of low flows (usually less than 1 year ARI flow) to the bio retention system, collection of stormwater from the drain, diversion through the weir to the treatment measures (wetland)

and after treatment, storage of treated stormwater and transport up to the injection point. Figure 4.3 illustrates the typical flow diagram of stormwater sub system.

- *Stormwater availability*

Stormwater harvesting volume for a given stormwater catchment depends on many aspects. Topography of the area, land used pattern, rainfall intensity and characteristics of the soil in the area are some aspects from the many. In this study, it is proposed to harvest stormwater from the newly developed areas or urban areas. Urban development typically has major impacts on the volume, frequency and quality of run-off. Peak discharge generated from an urbanised catchment can be as much as 35 times that generated from a rural catchment. (Wong, 2000).

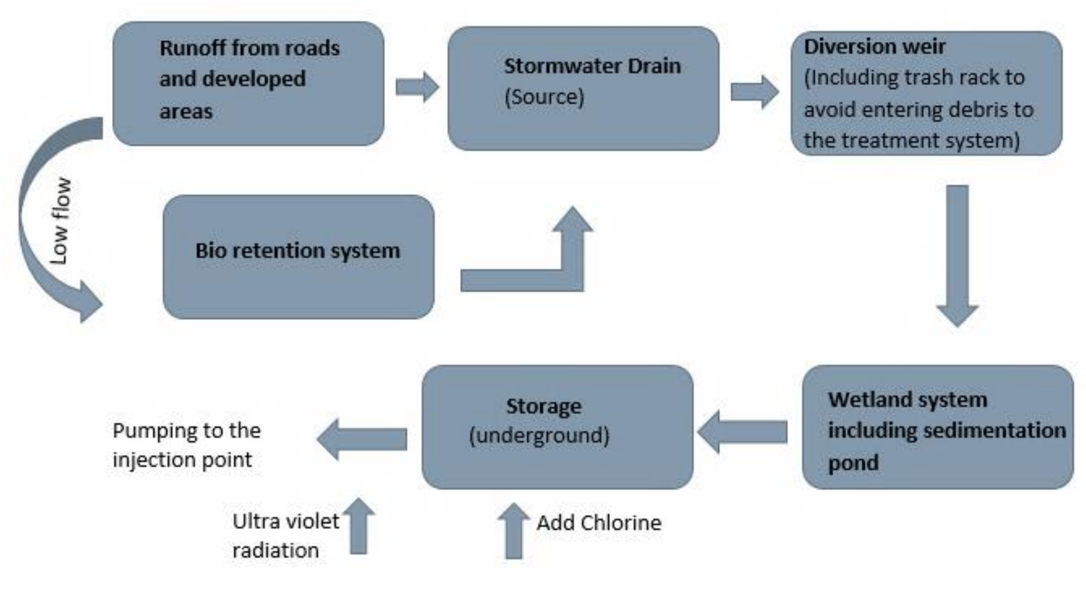


Figure 4.3*:* Typical flow diagram of stormwater sub system

Stormwater available for harvesting and reuse mostly depends on the rainfall amount received on the area considered. Variable rainfall is the most critical factor for stormwater harvesting schemes, as this influences the reliability of stormwater flows from a catchment. The extent of rainfall variability depends on local climatic conditions (DEC-NSW, 2006). For example, the mean annual rainfall recorded in Melbourne (Melbourne Regional Office station) within 50 years (1964-2014), was 648 mm, and while lowest recorded was 332 mm. For the same station, within 10 years (2004-2014) average was 572 mm and lowest recorded was 438 mm. These figures reflect the variation of the rainfall. Variable rainfall patterns can affect the viability of stormwater reuse schemes by increasing/decreasing the required storage volume and the need for back-up water supplies and/or demand management when demand cannot be met from harvested stormwater (DEC - NSW, 2006).

- *Stormwater storage and treatment measures*

Basically there are two types of storages, which can be used to store stormwater based on the location of the storage and they are on-line storages or off-line storages. When the storage is located away from the main stream or channel, it is called off-line storage, while the storage is located in the direct flow path of stream/channel, it is called on-line storage. There are advantages and disadvantages of these two types. Off-line systems have relatively low maintenance costs and has the ability to bypass the high flows. On-line storages, runoff from the whole catchment is directed through the inlet and spillway is provided for high flows. For a given storage volume, relative yield of on-line storage is higher than off-line storage, while construction and maintenance costs are high in on-line storage.

Stormwater storage can be above ground, underground or aquifer storage and recovery (ASR). Each method has specific advantages and disadvantages. Open storages usually have low capital and maintenance costs, but risk of algal bloom is high. Underground tanks have higher capital and maintenance costs than the above-ground tanks, while there are no aesthetic issues with underground tanks. Aquifer storages are cost effective, but requires suitable geology (DEC - NSW, 2006).

In new urban developments in Victoria, it is a statutory requirement to construct water-sensitive urban design (WSUD) elements such as swales and bio filters (BPEMG, 2006). These WSUD elements provide a degree of stormwater treatment while providing storage. Stormwater for harvesting and reuse is likely to need pre-treatment to remove gross pollutants, including litter, organic matter and coarse sediments before stormwater enters the WSUD elements (DEC - NSW, 2006). Sand filters, grassed swales, bio retentions and wetlands are some of the traditional WSUD elements in practice. Sand filters and bio retentions require ongoing maintenance to ensure the performance, while grass swales and wetlands require a large land footprint for adequate levels of treatment (Aryal et al., 2010).

Information in Table 4.4 was extracted from Table 6.7 of DEC – NSW (2006). This table gives pollutant retention percentages with respect to different stormwater treatment measures.

Table 4.4: Pollution retention for different stormwater treatment measures

Stormwater Treatment Measure	**Pollution retention as a percentage**				
	Suspended solids	**Total Phosphorus**	**Total Nitrogen**	**Turbidity**	**E Coli**
Swale	55 - 75 %	25 - 35 %	5 - 10 %	44 - 77 %	Negligible
Sand filter	60 - 90 %	40 - 70 %	30 - 50 %	55 - 90 %	-25 - 95 %
Bio retention system	70 - 90 %	50 - 80 %	30 - 50 %	55 - 90 %	-58 - 90 %
Pond	50 - 75 %	25 - 45 %	10 - 20 %	35 - 88 %	40 - 98 %
Wetland	50 - 90 %	35 - 65 %	15 - 30 %	10 - 70 %	-5 - 99 %

Source: Table 6.7 of DEC – NSW (2006)

Based on the figures in Table 4.4, highest E Coli reduction was recorded in ponds and wetlands, up to a maximum value of 98% and 99% respectively. Negative values recorded in the E Coli reduction range indicates that, E Coli is added during the treatment process. For example, faecal input by birds may be added in the wetlands. As outlined in the Australian Guideline for Water Recycling Phase 2 (NRMMC-EPHC-NHMRC, 2009), the monitoring data indicates that a constructed wetland or a pond could be designed to achieve a reasonable reduction in the loads of conventional stormwater pollutants and 68%-90% E. Coli reduction. The most reliable stormwater treatment measures for indicator bacterial reduction are the constructed surface-flow wetlands and wet ponds (i.e. those that have a permanent body of water) (NRMMC-EPHC-NHMRC, 2009).

No data on virus removals in wetlands was available in the Australian Guideline for Water Recycling Phase 1. However, the removal is expected to be less than 0.5 log (NRMMC-EPHC-NHMRC, 2006). A conservative approach is to assume that the conventional stormwater treatment measures do not reduce the levels of reference pathogens. The most appropriate approach for pathogen removal in stormwater for small-to-medium reuse schemes is disinfection, possibly preceded by filtration for turbidity control. Large schemes involving dual reticulation may need to incorporate more sophisticated treatment methods, such as membrane filtration, reverse osmosis or lagoon storage with disinfection (NRMMC-EPHC-NHMRC, 2009).

- *Stormwater pumping station and injection methods*

In this study, stormwater is proposed to be injected into the third pipe which carries recycled water, at different locations along the pipeline. If gravity is insufficient to inject stormwater at an adequate pressure, pumps need to be installed to boost the pressure upto the required level. Pumps can be either continuous or intermittent operational. They can be controlled by a time-switch, pressure or a water level in a tank or reservoir (Chambers et al., 2004). A back-up system (e.g. a standby pump) may be needed. All of these control valves need to be designed correctly for their application. The correct location and the size of a pump or valve can be identified using a network modelling software package such as Water CAD or EPANET. Pumps and valves should be operated to minimize surge effects (Chambers et al., 2004).

There are other aspects which need to be considered in this novel approach of using combined water via stormwater injection. The UV disinfection and chlorination of stormwater has to be done at every storage location. There will be algal blooms developed in the stormwater storages, and therefore continuous maintenance is a must to reduce risk to the public health. Also there should be a backup potable water supply system to pump potable water into the stormwater pipe, which will be injected to the third pipe using same injection point when stormwater is not available.

c) Layout and process schematic of combined water system

Combined water sub system is defined in this study as from the first stormwater injection point to the end user. It is assumed within considerable distance (for example 50 m), below the injection point, mixing of recycled water and stormwater is completed. In this study, it is proposed to monitor combined water quality at two points below considerable distance to the injection point to assure complete mixing occurs. Within the third pipe, it is not allowed to distribute combined water before complete mixing occurs. Figure 4.4 below is the typical layout of the combined water system.

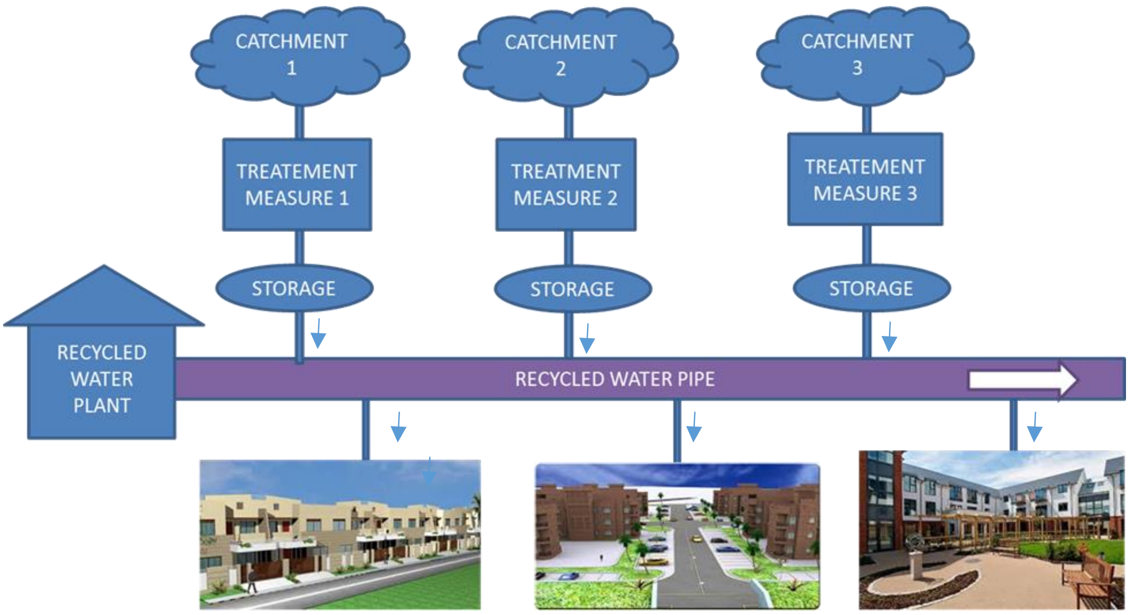


Figure 4.4: Schematic layout of the combined water subsystem

4.3.3 Assessment of water quality data

4.3.3.1 Stormwater quality data

Urbanisation has major effect on stormwater quantity generated from the catchment as well as stormwater quality. Also stormwater quality varies spatially and temporally. Hence it is a difficult task to prepare possible variation range of concentration of stormwater quality parameters in urban catchments.

Understanding the land use pattern and topography of the stormwater catchments helps to identify possible stormwater quality risks generated from the catchment. The assessment and evaluation of stormwater quality may be facilitated by breaking the large catchment into several sub catchments based on the land use pattern. (Page et al., 2013). The method proposed in this study is to have small scale stormwater systems along the third pipe and inject treated stormwater into the third pipe.

Physical and chemical urban stormwater quality summary statistics in Australia has been prepared in Australian Guideline for water Recycling phase 2 (NRMMC-EPHC-NHMRC, 2009) by combining multiple studies and presented in Table A2.3 (Appendix 2) of the guideline. As per this guideline, log-normal probability density functions for each parameter in Table A2.3 is prepared to enable these multiple studies to be combined. Table 4.5 below is prepared, adopting 95th percentile concentration of untreated stormwater quality data for urban catchments from Table A2.3 of Australian Guidelines for Water Recycling Phase 2 (NRMMC-EPHC-NHMRC, 2009).

When observing the values in Table 4.5, concentration of most of the parameters are higher than the recommended values in the proposed guideline. Hence treatment of stormwater before injection into a recycled water pipe will be required.

4.3.3.2 Recycled water quality data

Recycled water produced from large metropolitan wastewater plants (considered in this study), usually maintains consistent quality. The quality of the recycled water depends on the source water quality and the treatment processes adopted. Established plants have water quality records. It is possible to identify trends in recycled water quality data using historical records and identify improvements needed for the treatment processes.

Table 4.5: 95th percentile concentration values for selected water quality parameters in untreated stormwater – urban catchments

Selected Parameters for the study		Proposed Guideline Values	Untreated stormwater quality (95th percentile)
Physiochemical Indicators	Ammonia (NH_3)	0.01mg/L (as N)	3.28 mg/L
	Chloride	175 - 350 mg/L	13.2 mg/L
	Colour AppPt/Co units	-	N/A
	EC at 25 ^{o}C µS/cm	650	N/A
	pH	6.0–9.0	7.27
	SAR (Sodium Adsorption	8 - 18	N/A
	Sulphate	400 mg/L	N/A
	Suspended Solids	5 mg/L	254.47 mg/L
	Total Alkalinity mg $CaCO_3$ / L	< 350 mg/L	40.97 mg/L
	Total Dissolved Solids(TDS)	1000 mg/L	170.0 mg/L
	Turbidity	< 2 NTU	127.8 NTU
Metals & Metalloids	Aluminium	0.2 mg/L	2.29 mg/L
	Arsenic	0.05 mg/L	0.011 mg/L
	Barium	1 mg/L	0.038 mg/L
	Boron	0.5-15 mg/L	N/A
	Cadmium	0.005 mg/L	0.06 mg/L
	Calcium		0.1 mg/L
	Copper	1.0 mg/L	0.141 mg/L
	Iron	0.3 mg/L	5.1 mg/L
	Lead	0.05 mg/L	0.162 mg/L
	Magnesium		N/A
	Manganese	0.1 mg/L	0.197 mg/L
	Mercury	0.001 mg/L	0.411 mg/L
	Nickel	0.1 mg/L	0.017 mg/L
	Sodium	115 - 230 mg/L	15.7 mg/L
	Zinc	5 mg/L	0.57 mg/L
Organic matters	Total Organic Carbon (TOC)	-	22.8 mg/L
Bacteria-Indicators	Campylobacter(bacteria) #/L	15 /L	70.2/L
	E coli	< 10/100 mL	184382/100mL
	Cryptosporidium #/L	1.8/L	54.6/L
Nutrients	Total Nitrogen	<30 mg/L	7.46 mg/L
	Total Phosphorus	< 0.8 mg/L	1.3 mg/L

Source: Untreated stormwater quality data in Table 4.5 is adopted from Table A 2.3 of NRMMC-EPHC-NHMRC (2009)

Advanced treatment methods are needed to achieve the required quality of recycled water for third pipe use. Table 4.6 shows the log reduction targets proposed in the Australian

Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006) for dual reticulation system including toilet flushing, washing machines and garden use. Log reduction targets are defined in the guideline as minimum reduction required from raw sewage based on 95th percentile values of the concentration of water quality parameters.

Table 4.6: Recommended log reduction targets for third pipe use

Log reduction targets	Indicative treatment process
6.5 (Virus) 5.0 (Protozoa) 5.0 (Bacteria)	Secondary treatment, coagulation, filtration and disinfection or Secondary treatment, membrane filtration, UV light

Source: Table 3.8 of NRMMC-EPHC-NHMRC (2006)

4.3.3.3 Combined water quality data

It is important to maintain combined water quality in the third pipe system according to the proposed water quality guideline in this study (Section 3.3). As explained in Section 3.4, mass balance method is an appropriate method to estimate the combined water quality in the planning stage of a project. Monitoring combined water quality is a requirement in the implementation stage to safeguard users. After monitoring combined water quality for few years, it is possible to identify performance or trends of combined water quality parameters using water quality records.

4.3.4 Hazard identification and risk assessment

Hazards can be at any point in the water system from the source to the end user. In the combined water system, these hazards can be in the recycled water subsystem, stormwater subsystem and combined water subsystem. To estimate the level of risk associated with each hazard, it is necessary to identify hazards and hazardous events in each subsystem. Identification of hazards zones of each subsystem helps to identify possible hazards and hazardous events. Table 4.7 presents possible hazard zones in each subsystem.

Table 4.7: Possible hazard zones in combined water project

Recycled water subsystem	Stormwater subsystem	Combined water subsystem
Source of recycled water	Stormwater catchments	Stormwater injection point
Recycled water treatment plant	Stormwater treatment systems	Mixing zone of two types of water (recycled water and stormwater)
Storage of treated recycled water	Storage including wetland	Distribution pipes
Supply recycled water up to injection point	Supply pipe up to injection point	Application and receiving environments

4.3.4.1 Hazard identification

- Hazards

A hazard is a biological, chemical, physical or radiological agent which may harm people, animals, plants, soils or the environment. Examples are the microorganisms which are hazards to human health and the excessive amounts of potassium which are a hazard to plants. Failure of alarms and monitoring systems is a hazard in operational infrastructure (NRMMC-EPHC-NHMRC, 2006).

- Hazardous events

A hazardous event is an incident or situation which may lead to a hazard (NRMMC-EPHC-NHMRC, 2006). Generally, a hazardous event can be related to a natural event or to a man-made incident.

4.3.4.2 Risk assessment

The risk assessment method adopted here is based on the methodology defined in the Australian Guideline for Water Recycling Phase 1 and Phase 2 (NRMMC-EPHC-NHMRC, 2006,NRMMC-EPHC-NHMRC, 2009).

The aim of the risk management is to reduce identified risks to acceptable levels. Risk assessment can be either quantitative, where risks are calculated or qualitative, where risks are assigned a relative risk level (DEC - NSW, 2006).

A. Quantitative risk assessment

Quantitative risk assessment provides a numerical estimate of risks. For some contaminants, it may be possible to carry out a quantitative risk assessment to provide a numerical estimate of risks (NRMMC-EPHC-NHMRC, 2006). According to the Australian Guidelines for Water Recycling Phase 1 and Phase 2 (NRMMC-EPHC-NHMRC, 2006, NRMMC-EPHC-NHMRC, 2009), the quantitative assessment of microbial health based risks involves the following stages.

- Hazard Identification: The first part of assessment is to identify the hazards likely to be present in the source water, their concentration and their effects on human health. Three reference pathogens selected for combined use (recycled and stormwater) are cryptosporidium, campylobacter jejuni and human rotavirus (These are the same in the Australian Guideline for Water Recycling Phase 1 & Phase 2). As recommended in the guidelines, 95th percentile concentration is proposed for the risk assessment.
- Determination of dose-response: Next step is to establish the relationship between the dose of the hazard and the likelihood of the illness
- Exposure assessment: Then it is necessery to estimate the size and the nature of the population likely to be exposed to the hazard
- Risk characterization: Finally, it is necessary to combine the information on the level of the hazard, dose response and exposure, to calculate the risk.

B. Qualitative risk assessment

Qualitative risk assessment is one of the methods available to estimate the risk based on the likelihood of occurrence and severity of the impacts. Following steps are to be followed in the qualitative risk assessment method as per the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006).

- The first step is to identify and document hazards and hazardous events which are anticipated in each subsystem of combined recycled and stormwater system - these hazards and hazardous events have the potential to raise risks to public health, environment and to operational infrastructure.
- The next step is to estimate the likelihood that a hazard or a hazardous event will occur.

- Then it is necessary to estimate or to find the qualitative measurement of the consequences (i.e.: the impact) of the hazard or a hazardous event occurring.
- The final step is to characterise the overall risk by combining the hazards and hazardous events with their likelihood and consequence in a qualitative risk assessment matrix.

a) Likelihood of hazards

Understanding of the likelihood of a hazard occurring is important to assess the risk of the particular hazard. Based on the likelihood of occurring of a hazard, the hazard can be categorised to rare (A), unlikely (B), possible (C), likely (D) and almost certain (E), as given in Table 2.5 of NRMMC-EPHC-NHMRC (2006). It is reproduced in Table 4.8 below.

b) Consequences of hazards

Understanding of the consequences of a hazard occurring is important to assess the risk of the particular hazard. Based on the consequences or impacts of a hazardous event, there are 5 levels of consequences as specified in Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006). Consequences of hazardous events of the combined water project in this study are categorised as per Table 4.9 below, which is extracted from Table 2.6 of NRMMC-EPHC-NHMRC (2006).

Consequences of one identified hazard to the public health of consumers may be different from the effect to the environment or the effect to functionality of operational infrastructure. Hence in this study, it is considered consequences related to public health, environment and the operational infrastructure.

c) Assessment of risk

Qualitative assessment of risk can be estimated by combining the likelihood and consequences of hazards (Qualitative Risk = Likelihood x Consequence). The risk characterisation is assessed such as to low, moderate, high and very high based on the rating system specified in Table 2.7 of NRMMC-EPHC-NHMRC (2006). The same characterisation is proposed for the combined water system in this study as described in Table 4.10.

Table 4.8: Qualitative measures of likelihood

Level	Descriptor	Example description
A	Rare	May occur only in exceptional circumstances. May occur once in 100 years
B	Unlikely	Could occur within 20 years or in unusual circumstances
C	Possible	Might occur or should be expected to occur within a 5 to 10 years period
D	Likely	Will probably occur within a 1 to 5 years period
E	Almost certain	Is expected to occur with a probability of multiple occurrences within a year

Extracted from Table 2.5 of (NRMMC-EPHC-NHMRC, 2006)

Table 4.9: Qualitative measures of consequences

Level	Descriptor	Example description
1	Insignificant	Insignificant impact or not detectable
2	Minor	Health - Minor impact for small population Environment - Potentially harmful to local ecosystem with local impacts contained to site
3	Moderate	Health - Minor impact for large population Environment - Potentially harmful to regional ecosystem with local impacts primarily contained to on-site
4	Major	Health - Major impact for small population Environment - Potentially lethal to local ecosystem; predominantly local, but potential for off-site impacts
5	Catastrophic	Health - Major impact for large population Environment - Potentially lethal to regional ecosystem or threatened species; widespread on-site and off-site impacts

Extracted from Table 2.6 of NRMMC-EPHC-NHMRC (2006)

Table 4.10: Qualitative risk estimation

Likelyhood	Consequences				
	1- Insignificant	2 - Minor	3 - Moderate	4 - Major	5- Catastrophic
A - Rare	Low	Low	Low	High	High
B - Unlikely	Low	Low	Moderate	High	Very high
C - Possible	Low	Moderate	High	Very high	Very high
D - Likely	Low	Moderate	High	Very high	Very high
E - Almost certain	Low	Moderate	High	Very high	Very high

Extracted from Table 2.7 of NRMMC-EPHC-NHMRC (2006)

According to the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006), if the risk characterisation is low, it is considered acceptable. However, if they are characterised as moderate, high or very high, they are not acceptable, and they then will trigger the next phase of the risk assessment process, which is the residual risk assessment. The residual risk assessment will be discussed in detail in Section 4.4.

The risk assessment procedure discussed in this study, considers risks related to three separate end-points.

- Risks to public health related to human exposure to contact or ingestion of recycled water, stormwater or combined water
- Risks to the environment receiving the recycled water, stormwater or combined water
- Risks to operational infrastructure in stormwater subsystem and combined water subsystem

i. Public health risks

The most significant human health hazards in the recycled water or stormwater are microorganisms (NRMMC-EPHC-NHMRC, 2006). Microorganism's concentration in sewers are higher than in stormwater. However, the concentration of microorganisms is more variable in stormwater than in sewer. Microbial contamination is the most severe potential public health hazard associated with combined water (recycled and stormwater) use.

The Australian Guidelines for Water Recycling Phase 1 and Phase 2 (NRMMC-EPHC-NHMRC, 2006, NRMMC-EPHC-NHMRC, 2009), use a level of one-millionth of a DALY (Disability-Adjusted Life Year) per person per year as a measure of the acceptable risk to human health. DALY is a measure of overall disease burden expressed as number of years lost due to ill-health, disability or early death. Standard risk assessments determine the likelihood of infection or illness. DALYs convert these likelihoods into burdens of disease (NRMMC-EPHC-NHMRC, 2006). As per the NRMMC-EPHC-NHMRC (2006), the tolerable risk is set as 10^{-6} DALYs per person per year. To check the tolerable concentration limit, The Australian Guideline for Water Recycling Phase 2 suggests water quality criteria for the third pipe system as stated below.

Turbidity (95th percentile value) < 2 NTU

E Coli < 1/100 mL

The main route of exposure to microbial hazards from combined water is ingestion, as mentioned in Table 4.2. It is important to consider both intended and unintended uses, when exposure assessment is done. As per the information in Table 3.3 of the Australian Guideline for water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006), it is necessary to consider both frequency and volume of usage of application, when calculating exposure assessment.

ii. Environmental risks

Environmental hazards for the use of combined water is identified as explained in Section 4.3.1.3. These hazards associated with specific uses of combined water are related to boron, cadmium, chlorine disinfection residuals, hydraulic loading rate, iron, nitrogen, phosphorus, salinity, chloride and sodium.

Table 4.11 is prepared to show environmental impacts due to the water quality parameters mentioned above, based on the information in Appendix 4 of the Australian Guideline for Water Recycling Phase 2 (NRMMC-EPHC-NHMRC, 2009) and Section 4.2 of the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006).

iii. Operational risks

Operational risks can be minimized by setting operational procedures and processes to monitor the performance of the combined water system. By monitoring the performance at critical control points, it is possible to give advance warning, if water quality deviates from the specified limits of proposed guideline of this study (Section 3.3). The effectiveness of operational monitoring depends on equipment capabilities, maintenance and calibration.

In the Australian Guideline for Water Recycling Phase 2 (NRMMC-EPHC-NHMRC, 2009), it is proposed stormwater treatment criteria for managing operational risks. Same criteria are proposed for the combined water to control operational risks. Table 4.12 is prepared adopting the information in Table 3.2 of Australian Guideline for Water Recycling Phase 2 (NRMMC-EPHC-NHMRC, 2009)

Table 4.11: Environmental end point and effects on the environment

Hazard related to	Environmental end point	Effects or impact on the environment
Boron	Soils	Toxicity to plants
Cadmium	Plants	Toxic to plants
Chlorine disinfection residual	Plants and surface water	Toxicity to plants and aquatic biota
Chloride	Plants, soils and surface water	Toxicity to plants when spray on leaves and via uptake through roots, Toxicity to aquatic biota
Hydraulic loading rate	Soil and ground water	Water logging of plants and secondary effect on soil salinity
Iron	Plants	May be toxic to plants
Nitrogen	Soil and surface water	Nutrition imbalance and disease in plants, Eutrophication of soils and surface water
Phosphorus	Soils	Toxic effects on phosphorus sensitive plants
Salinity	Soils, surface water, ground water and infrastructure	Plants stressed from soil salinity, Increasing the salinity of surface & ground waters, corrosion of assets
Sodium	Plants and soils	Toxicity to plants when spray on leaves and via uptake through roots, Soil structure decline due to sodicity

Note: Information above is adopted from Table 4.2 of NRMMC-EPHC-NHMRC (2006) and Appendix 4 of NRMMC-EPHC-NHMRC (2009)

Stormwater treatment criteria proposed in this study is "design life up to 20 years", as most irrigation components and pumps have design life less than 20 years.

It is possible to avoid some operational risks, when combine stormwater with recycled water. Usually iron concentration in stormwater is higher than in recycled water. High iron concentrations potentially block irrigation systems over time and impairs the effectiveness of the disinfection system. In combined water, as stormwater in mixed with recycled water, iron concentration in stormwater can be diluted and operational risk due to high iron concentration is also low.

Table 4.12: Stormwater treatment criteria to manage operational risks

Parameter	Stormwater treatment criteria	
	Design life up to 20 years	Design life up to 100 years
Suspended solids	< 50 mg/L	< 30 mg/L
Coarse particles	< 2 mm diameter	< 1 mm diameter
Iron (total)	< 10 mg/L	< 0.2 mg/L
Phosphorus	< 0.8 mg/L	< 0.05 mg/L
Hardness (CaCo3)	< 350 mg/L	< 350 mg/L

Note: Adopted fromTable3.2 of (NRMMC-EPHC-NHMRC, 2009)

4.4 PREVENTIVE MEASURES FOR COMBINED WATER MANAGEMENT (ELEMENT 3)

This section describes the actions to be taken to prevent potential hazards or to reduce the hazards to acceptable levels that may encounter in the use of combined water for the intended uses. As explained in Section 4.3.4.2, identified risks characterised as moderate, high or very high in risk matrix, has to be reduced to acceptable level with the implementation of preventive measures.

According to the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006), there are two components under Element 3 to prevent potential hazards. They are;

- Preventive measures and multiple barriers
- Critical control points

4.4.1 Preventive measures and multiple barriers

Prevention of water quality hazards or the reduction of the risk to acceptable levels is needed to safeguard the combined water user. Preventive measures are those actions, activities and processes used to prevent hazards from occurring or reduce them to acceptable levels (ADWG, 2013). It may be possible to control more than one hazard from one preventive measure. In certain instances, to prevent a hazard or to reduce the risk to acceptable level, it is required to have more than one preventive measures, and these multiple preventive measures are called multiple barriers.

4.4.1.1 Preventive measures

Planning of preventive measures are usually site specific. There may be preventive measures already in place in parts of the system. For example, in this proposed study, recycled water is supplied from an existing recycled water plant where the preventive measures are already available for that part of the system. Stormwater treatment, injection of treated stormwater into the third pipe and distribution of combined water are new parts of the proposed study. Identifying preventive measures already in place for the existing part of the system and proposing preventive measures for new parts of the system for already identified hazards is the first step of assessment of preventive measures.

There exist two types of preventive measures in the recycled water treatment systems, according to the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006).

1. Exclusion barrier – prevents entry or removes hazard
2. End use restriction barrier – controls exposure

Standard recycled water treatment processes that are often used for treating sewage (e.g. primary, secondary, tertiary treatment, storage lagoons and disinfection), can be considered as “exclusion barrier” type preventive measures. The preventive measures proposed in the stormwater subsystem are mainly the catchment management processes for source protection and treatment processes. These also can be considered as “exclusion barrier” type preventive measures, namely treatment measures such as wetlands and bio retention systems and disinfection to reduction of pathogens by chlorination and UV protection

Monitoring of water quality parameters as per the proposed guideline, residual chlorine monitoring and pressure monitoring are also “exclusion barrier” type preventive measures. Some of the preventive measures proposed in the combined water system are “exclusion barrier” type preventive measures, while some are “end-use restriction barriers”. Maintaining buffer distances, maintaining proper drainage systems and nutrient budgeting in irrigation areas using combined water are some of the “end-use restriction barriers”.

As per the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006), the preventive measures chosen will be determined considering concerns such as cost, intended uses, existing treatment facilities, technical expertise, availability of land (if buffer zones are to be used), public access and perception requirements.

It is important to evaluate identified preventive measures are effective in reducing risks, which are characterised as moderate, high or very high in risk matrix to acceptable levels. If further improvement is required, additional preventive measures must be identified. Finally, the preventive measures should be properly documented.

4.4.1.2 Multiple barriers

Multiple barriers consist of more than one preventive measures to prevent one hazard. They are mainly applied on the pathogens. There are multiple actions taken to protect the consumers from pathogens such as filtration, chlorination and UV protection in multiple locations along the combined water system.

4.4.2 Critical control points (CCP)

A critical control point is defined as an activity, procedure or process for which control can be applied and which is essential to prevent a hazard or reduce the risk to an acceptable level (ADWG, 2013).

The Australian Guidelines for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006) suggests following decision tree (Figure 4.5) to identify if a certain preventive measure constitutes a critical control point (CCP). The CCPs relevant to the proposed combined water project in this study are identified and listed in Section 5.4.

4.5 OPERATIONAL PROCEDURES AND PROCESS CONTROL OF COMBINED WATER USE (ELEMENT 4)

This section describes the operational procedures and the process control methods which are essential for continuous supply of combined water to the consumers.

According to the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006), there are five components under Element 4, these are;

- Operational procedures

- Operational monitoring
- Operational corrections
- Equipment capability and maintenance
- Materials and chemicals

Each of the components will be described in Sections 4.5.1 to 4.5.5.

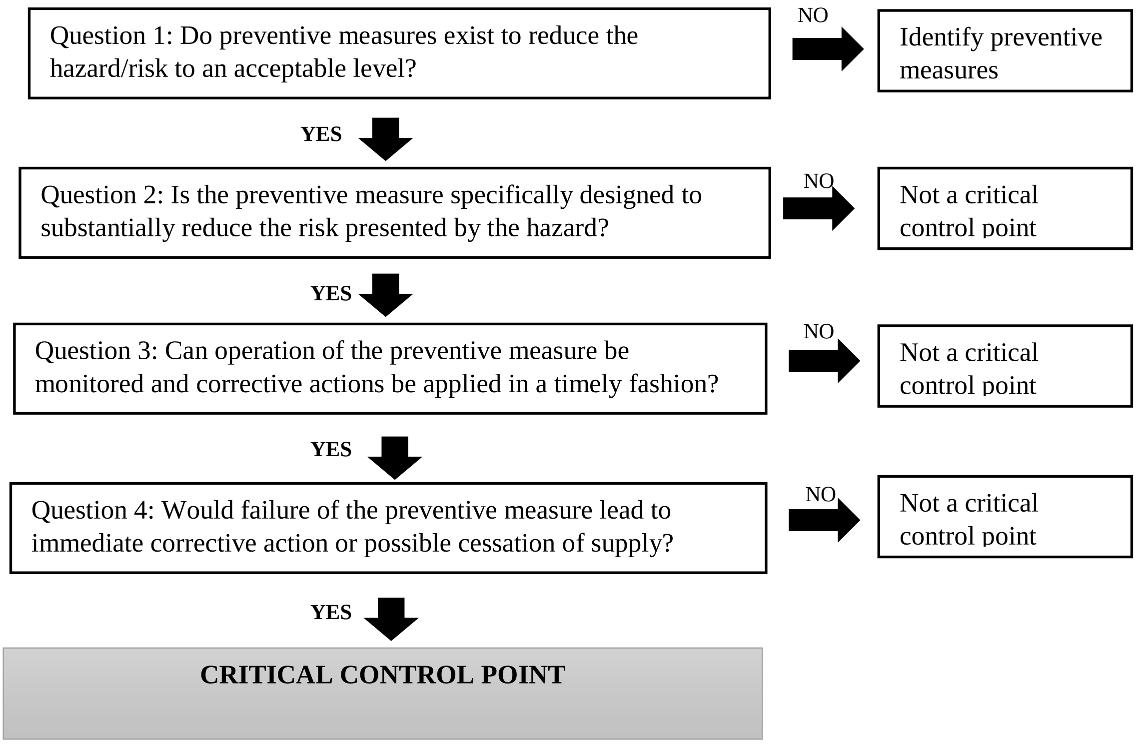


Figure 4.5: Critical control point decision tree (Adopted from Figure 2.2 of NRMMC-EPHC-NHMRC (2006))

4.5.1 Operational procedures

Operational procedures should be prepared for each step of the combined water treatment process to make sure all the processes are working as planned and the preventive measures are functioning as planned. This involves identification of operations in the combined water system and document them in an operational manual including listing of all risks and preventive measures. Daily checklists including locations and corrections to processes when target criteria are not met also included in the operational procedures. It is recommended to prepare operational manual consisting operational procedures, including day to day activities and periodic activities.

Skills and training of operations staff are needed for effective implementation of the operational procedures. There should be online access to the operational manual for all responsible staff in relevant organisations to understand and control of all operations.

4.5.2 Operational monitoring

Operational monitoring is different from water quality monitoring. Operational monitoring is the routine monitoring of control parameters identified in the catchment, treatment system and distribution system. Operational monitoring is used to confirm that preventive measures implemented to control hazards are functioning properly and effectively (NRMMC-EPHC-NHMRC, 2006). The operational monitoring plan should include operational monitoring of critical control points, including operational parameters, critical control limits, monitoring frequency and responsible party (NSW Department of Primary industries, 2015). To reflect the effectiveness of each process or activity, operational parameters have to be selected. As an example, the operational monitoring of chlorination plant of stormwater treatment unit should be continuously monitored for turbidity, free chlorine, pH and temperature. Short-term corrective actions are taken according to the operational monitoring of data. The main elements of operational monitoring as per the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006) include:

- Preparation of operational monitoring plan; this will ensure establishment of the preventive measures are functioning properly
- Identification of the parameters and criteria to be used to measure operational effectiveness of each process
- Review and interpretation of results to confirm operational performance

4.5.3 Operational corrections

When the target criteria or the critical limits are not met in the system, there should be a procedure in place to make corrective actions. The documented procedure should include changes to the process control methods and the requirements for additional monitoring. There should also be an effective communication system to deal with the unexpected situations. The documented procedure will include the relevant authorities and their responsibilities in such situations. When there is a failure of water quality targets, the corrective actions should include possible changes required for the treatment processes to bring the system back to normal operating conditions in each operational level.

4.5.4 Equipment capability and maintenance

This section discusses the adequacy of equipment performance within the combined water project. It is also required to establish the regular inspection and maintenance programmes for the equipment used in the combined water project. All equipment shall be adequately designed for the intended use in terms of sizes, volumes and efficiencies to handle the peak and off-peak supply of water. Special attention needs to be given for seasonal variations expected in the use of stormwater.

Proper design procedures will ensure the successful equipment performance in the recycled water and stormwater facilities. Further to the design, monitoring of equipment performance will ensure the necessary modifications and changes are done in a timely manner to ensure continuous performance of supply of combined water. Online measurements of equipment performance using modern devices, use of alarm systems and provision of backup systems will be useful to ensure the successful performance of the combined water project.

Establishment of routine equipment performance monitoring is required. Calibration of measuring equipment in a timely manner and training of operators are also required.

4.5.5 Materials and chemicals

It is essential that the certified materials and chemicals in accordance with Australian and ISO standards are used in the process of production of combined water. Procedures for the procurement of materials and chemicals and the procedures for the delivery and storage of chemicals must be documented. Following are some of the guidelines proposed in the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006) to control quality of products and materials used in the dual water supply system.

- Australian and New Zealand Standard AS/NZS 3500 (Plumbing and Drainage) (Standards Australia/Standards New Zealand 2003)
- WSAA Sewerage Code Version 2.1 (WSAA 2002)
- WSAA Water Supply Code (Dual Water Supply Supplement Version 1.1) (WSAA 2002).

4.6 VERIFICATION OF COMBINED WATER QUALITY AND ENVIRONMENTAL PERFORMANCE (ELEMENT 5)

Verification monitoring is undertaken to confirm the compliance with the water quality management plan. As per the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006), verification monitoring assesses;

- The overall performance of the combined water system
- The ultimate quality of combined water being supplied
- The quality of the receiving environment

There are six components included under Element 5 in Australian Guidelines for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006), They are;

1. Recycled water quality monitoring
2. Application site and receiving environment monitoring
3. Documentation and reliability
4. Satisfaction of users of recycled water
5. Short-term evaluation of results
6. Corrective responses

They also can be applied to combined water verification monitoring. All components under Element 5 must be addressed to complete the verification monitoring process. The combined water verification monitoring process is basically divided into three sections (i.e. monitoring of the recycled water subsystem, stormwater subsystem and combined water subsystem). Sections 4.6.1 to 4.6.6 describe the above mentioned components under Element 5.

4.6.1 Combined water quality monitoring

The parameters to be included under combined water quality monitoring will be based on the parameters listed in the proposed guideline in Section 3.3. It is not economically viable to test all the parameters listed in the guideline at all monitoring points. Monitoring parameters have to be selected carefully to represent the complete list and should be reliable. Usually monitoring parameters include microbial indicator organism, disinfectant residual, parameters related to aesthetic impact (e.g. colour) and potential contaminants identified under hazard identification. The frequency of testing is high at the start of a project implementing these monitoring processes and the frequency will be less as the system is established with time. Microbial constituents are tested more frequently during this verification monitoring. However, from the environmental perspective, checking of chemical parameters is more important than microbial testing. As per Table 5.5 of the NRMMC-EPHC-NHMRC (2006), the verification monitoring points can be at treatment plants, at the point of supply immediately downstream of the completion of final disinfection and at the point of use.

4.6.2 Application site and receiving environment monitoring

Verification monitoring for environmental risks involve assessing the overall performance, the quality of the combined water being supplied or discharged and the quality of the receiving environment (NRMMC-EPHC-NHMRC, 2006). As part of the application, combined water will be applied to the land and this water may be discharged to the surface water and groundwater. Hence monitoring of the environment needs to be carried out to ensure that there will be no harmful impacts on the environment by long term use of combined water. Areas requiring monitoring are soil, plants, surface water and groundwater. Environmental monitoring can be visual observation of vegetation characteristics or laboratory testing of physical and chemical parameters of soil and water (surface or ground).

4.6.3 Documentation and reliability

Documentation is done for the verification of combined water quality and the environmental performance, as part of the submission to the regulating authorities and to the satisfaction of the monitoring parties. The documents shall include the parameters to be tested, locations of tests and frequency of testing of each of the parameter. The testing personnel should be fully qualified with adequate experience. The testing methods shall be the most appropriate and the testing equipment shall be modern and fully calibrated. Industry recognised laboratories should be used for testing to the satisfaction of all parties concerned.

4.6.4 Satisfaction of users of combined water

There should be a method for the combined water users to communicate with the water authority for inquiries about the supply of combined water and the quality of water. The staff involved in the help desk shall be trained properly to answer the complaints of the public. The responses for the inquiries shall be satisfactory to the public.

4.6.5 Short-term evaluation of results

It is important to evaluate monitoring data regularly and frequently (within a short time period, for example once a week), to make sure the quality of combined water supplied to the customers are within the established targets. Responsible officers, who evaluate and interpret recording results must have good understanding of the established guideline values, regulatory requirements and the trends of previous results.

4.6.6 Corrective responses

It is necessary to review short term evaluation results (Section 4.6.5) to identify deviations of water quality targets. Immediate corrective responses should be made when there is a deviation of water quality targets from the recommended guideline value. Failure to take immediate actions may lead to emergency situations. Also there may be situations to make corrective responses based on comments by combined water users. Quick actions to implement corrective responses are needed to maintain the public confidence on the water authority.

4.7 MANAGEMENT OF INCIDENTS AND EMERGENCIES (ELEMENT 6)

Any incident or emergencies that can compromise combined water quality has to be controlled immediately to protect public and environmental health and as well as to maintain confidence of customers. Hence, it is important to plan for emergency situations.

Most of the incidents to interruption to the supply of combined water are not anticipated. Also they are very unlikely to occur or frequency is very low. Preventive measures to avoid such incidents would be too costly. Those type of hazards are covered under Element 6. Some of the examples as per the Australian Guideline for Water Recycling phase 1 (NRMMC-EPHC-NHMRC, 2006), are as stated below;

- Breakdown of equipment
- Power outages
- Extreme weather including floods
- Natural disasters
- Human errors that may cause erroneous dosages of chemicals in the treatment plants
- Illegal and accidental cross-connections

As per the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006), there are two sections under Element 6.

1. Communication
2. Incident and emergency response protocols

4.7.1 Communication

Effective communication is essential in dealing with emergency situations. The operators of the combined water supply schemes shall be fully aware of how to contact the key people and the relevant regulatory bodies including health and environment in emergency situations. Development of a contact list including name, work number and after-hours telephone number including media is vital. The contacts lists shall be updated as often as possible (e.g. six-monthly) to ensure the most current contact details are available with the relevant people. Media communication shall be done by personnel with a good knowledge of the outcomes of media release. Publicity of wrong or distorted information may be more harmful than no information of the situation. The reputation and the confidence on the water authority will depend on how the unexpected situations are handled and communicated.

4.7.2 Incident and emergency response protocols

Incident and emergency response protocols are needed to effectively handle the emergency situation. In emergency situations, there will be no time to prepare plans and procedures. Hence, plans and procedures should be available in advance of the incident or emergency. The response plans need to comply with regulations of relevant authorities and the government. Following are some of the incidents reported in literature (EPA Victoria, 2005, NSW Department of Primary industries, 2015).

- Non-compliance with health related water quality objectives (microbiological monitoring results)
- incidents that increase the levels of potentially harmful contaminants or cause failure of treatment systems (such as spills, illegal discharges or incorrect dosing of chemicals)
- Suspected or identified cross connections with drinking water systems
- Cyanobacterial (blue-green algae) blooms in storages
- Post treatment contamination of recycled water
- Customer or community health complaint concerning water quality

Identified incidents should be classified based on the severity. Following is the classification given in Australian Guideline for Water Recycling Phase 1(NRMMC-EPHC-NHMRC, 2006):

Type 1 — potentially serious, with either human health or environmental risks

Type 2 — lesser incidents representing a low risk to human health, or possible low impact and localised environmental harm.

Based on the classification of the incident, the communication and notification protocol has to be defined. This will ensure that the incidents are communicated to all relevant authorities and to ensure that message of the incident is communicated to the public in the quickest and the most efficient manner.

All relevant employees should be trained to use the incident notification and response protocol. Also the protocol has to be updated frequently.

4.8 SUMMARY

The risk management framework proposed in this chapter could be implemented in any project using combination of recycled water and stormwater within Australia or overseas with required modifications to suit local conditions. This is a framework with shared responsibilities among all the stakeholders and the water users. The framework consists of 12 Elements of which some are to be considered during project implementation stage. This study only discussed Elements 2 to 6 which are relevant to a project at planning stage. These five Elements cover system analysis and management of the combined water system.

Under Element 2 which is assessment of combined water system, there are four sections which discuss about the water sources, water system analysis, assessment of water quality data and hazard identification and risk assessment. To cover the first three sections of Element 2, a comprehensive study was made on identification of the best available recycled water and stormwater sources, water quality assessment and treatment measures to achieve the required water quality. Intended uses were important to be identified as the water should be treated to fit for purpose.

Hazard identification and risk assessment is a very important component of Element 2. Possible hazards that are anticipated to happen in the life cycle of the whole system and their vulnerabilities (consequences or impacts) are identified as the first step of this process. In doing so, the whole combined water supply system is divided into three subsystems (i.e. recycled water subsystem, stormwater subsystem and combined water subsystem). There are two types of risk assessments namely; quantitative risk assessment and qualitative risk assessment. The quantitative risk assessment provides a mechanism to obtain a numerical estimate of disease burden on the water users due to pathogenic microorganisms present in the combined water. This condition could only be fulfilled on a project in operation. Therefore, quantitative risk assessment is not applicable to the current study. The qualitative risk assessment is an estimation of the level of risk on the third pipe water users due to the anticipated hazards on the water quality.

For the assessment of the qualitative risk, hazards and hazardous events which are anticipated in each subsystem of the combined water system which have the potential to raise risks to public health, environment and operational infrastructure need to be identified. The likelihood of occurring of each of these hazards or hazardous events are estimated. The impacts or the consequences these hazards or hazardous events making on the public, environment and the operational infrastructure are then estimated. A qualitative risk matrix is built combining the likelihood and consequences of the hazards or hazardous events. When there is a higher chance of a hazard to occur and when there are significant impacts due to the hazards, the expected risk is high. On this basis, the risks are categorised into four classes namely low, moderate, high and very high. If the risk characterisation is low, it is considered as acceptable. However, if they are characterised as moderate, high or very high, they are not acceptable. This situation will require the framework to consider the preventive measures to reduce the level of risks which is Element 3 of the framework.

Element 3 is the preventive measures for the combined water system, which has two components namely, (1) preventive measures and multiple barriers and (2) critical control points. Certain hazards may have more than one preventive measure. These multiple preventive measures are called multiple barriers. Identification of critical control points (CCP) which is defined as an activity, procedure or process for which control can be applied and which is essential to prevent hazard or reduce the risk to an acceptable level is an important area to exclude hazards. During the application of this framework to the study area the CCPs will be nominated throughout the whole system.

A general discussion is made on the operational procedures and process control of combined water use which is Element 4 of the framework. Verification monitoring of the third pipe water supply will be undertaken to confirm the compliance with the water quality management plan which is Element 5 of the framework. This Element spreads beyond the internal verification to an extent to the satisfaction of users of combined water, short term evaluation of results to identify deviations of water quality targets and how to make immediate corrective responses when there is such a deviation from the recommended guideline is encountered.

There exists incidents and emergencies in a water supply scheme, which will compromise combined water quality. Element 6 discusses about communication, and incident and emergency response protocols during such incidents and emergencies which are inevitable to occur.

The Elements 7 to 10 (supporting requirements) and Elements 11 and 13 (review of the process) are not dealt in this study. Those elements have to be addressed during the implementation of the projects. Supporting requirements include basic elements of good practice, such as employee training, community involvement, research and development, validation of process efficacy, and systems for documentation and reporting. Review includes evaluation and audit processes to ensure that the management system is functioning satisfactorily. It also provides a basis for review and continuous improvement.

This risk management framework is next applied to the Black Forest Road South study area to demonstrate the site specific details.

5 APPLICATION OF RISK MANAGEMENT FRAMEWORK TO BLACK FOREST ROAD SOUTH STUDY AREA

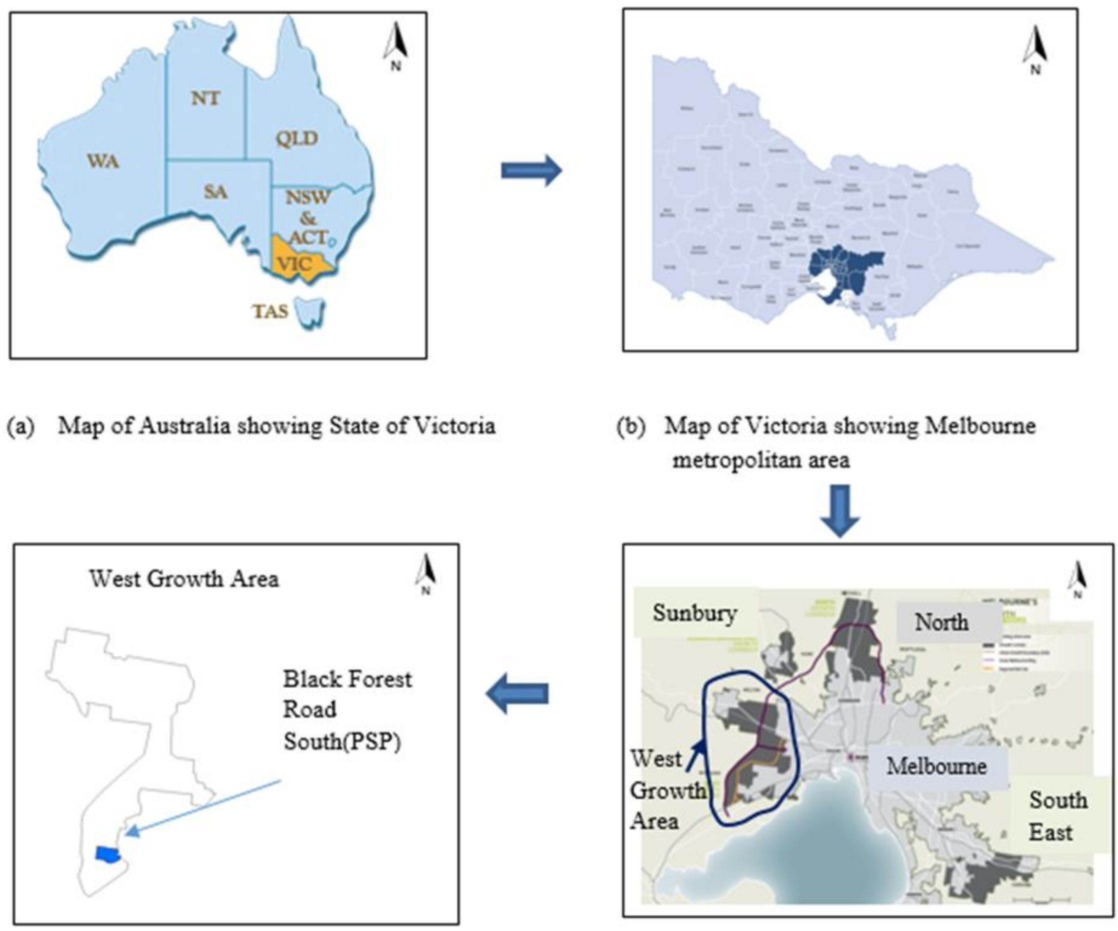
5.1 INTRODUCTION

This chapter details the application of the risk management framework described in Chapter 4, to the Black Forest Road South study area. A description of the study area is presented in Section 5.2. The application of the framework follows the same sequence of events and steps used in Chapter 4 to describe the elements of the risk management framework, and they are presented in the subsequent sections.

5.2 DESCRIPTION OF BLACK FOREST ROAD SOUTH STUDY AREA

There are several infrastructure development projects planned to address the population growth in Melbourne, (Australia) over the next 30 to 40 years. In this planning process, the Metropolitan Planning Authority of Victoria has identified four Growth Corridors extending the current Melbourne metropolitan area as North Growth Corridor, South East Growth Corridor, Sunbury Growth Corridor and West Growth Corridor. With this extension of the urban growth boundaries, the Growth Areas Authority (GAA) has produced Growth Corridor Plans for each growth corridor, which is further divided into Precincts. Individual Precinct Structure Plans (PSPs) are the formal planning requirements for the development of Growth Corridors (Corbett, 2012). The Black Forest Road South study area refers to one such Precinct Structure Plan (PSP 42.2) and it is one of the PSPs in the West Growth Corridor as shown in Figure 5.1 and has been selected as the study area to apply the risk management framework of this study.

The Black Forest Road South PSP is located about 40 km to the West of Melbourne and it is approximately 500 hectares in area. As shown in Figure 5.2, the Black Forest Road South PSP area (or study area) is bounded by McGrath Road to the east, Bulban Road to the south-east, Black Forest Road to the north and future urban lands to the west (PSP 93.1) and south west (PSP 93). The Black Forest Road South PSP contains approximately 5000 lots, when it is fully developed (Growth Areas Authority, 2010).



(a) Map of Australia showing State of Victoria

(b) Map of Victoria showing Melbourne metropolitan area

(c) Urban Growth Areas within Melbourne Metropolitan area

(d) Black Forest South PSP (study area)

Figure 5.1 : Maps showing the Black Forest Road South PSP (study area)

The introduction of Precinct Structure Planning for Melbourne's growth areas, and the requirements for an Integrated Water Management (IWM) Plan for each precinct, have been of considerable benefit to link urban planning and water planning (Corbett, 2012). At the subdivision level, within all precincts, there is scope for incorporation of water sensitive design initiatives and water quality treatment within streets and open spaces in accordance with Clause 56.07 of the Victoria Planning Provisions (Victoria Planning Provisions, 2015). City West Water (CWW), the water supply authority in the study area is responsible for providing reticulated sewerage, water supply and recycled water supply to the proposed PSP area. Recycled water from the Western Treatment Plant is further treated by CWW and stored in West Werribee tank for distribution in the Melbourne west area. CWW has plans to use combination of recycled water and stormwater for the PSP area. This combination is proposed with the injection of treated stormwater into the third pipe which carries recycled water is a novel approach. To the author's knowledge, this approach has not been used anywhere in the world. Figure 5.2 shows the study area, the proposed third pipe system and wetland locations (W1,W2 & W3) within the study area. Treated stormwater injection to the third pipe which carries recycled water takes place from locations downstream to the wetlands.

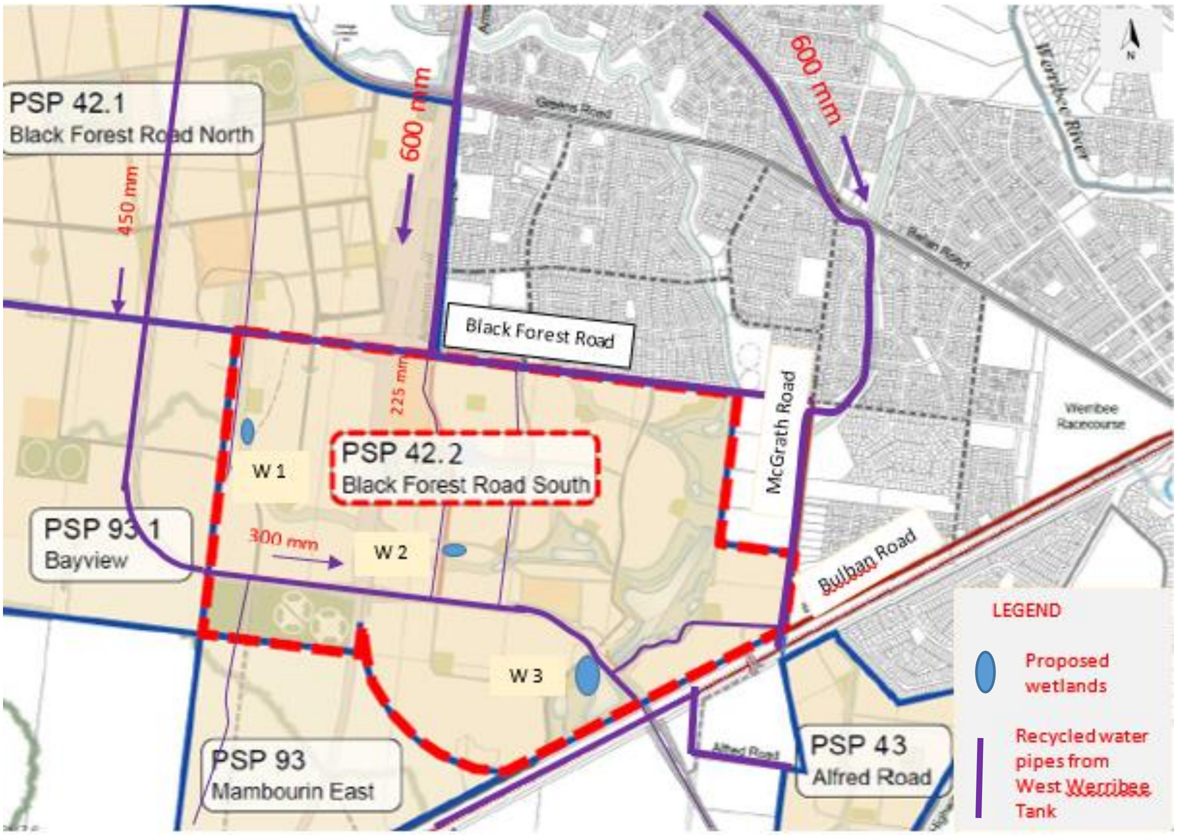


Figure 5.2: Black Forest Road South PSP (study area) with recycled water pipe network and wetland locations Source: Growth Areas Authority (2010)

5.3 ASSESSMENT OF COMBINED WATER SYSTEM (ELEMENT 2)

In the process of risk management of combined water system in the Black Forest Road South study area, it is important to understand the catchment characteristics of the area, the operational scenarios of the third pipe system and the end user requirements.

As outlined in Section 4.3, there are four components under this assessment (Element 2), as

- Sources of combined water, intended uses, receiving environments and routes of exposure

- Combined water system analysis
- Assessment of water quality data
- Hazard identification and risk assessment

5.3.1 Sources of combined water (recycled water and stormwater), intended uses, receiving environments and routes of exposure

5.3.1.1 Sources of combined water (recycled water and stormwater)

a) Recycled water

Source of recycled water considered in this study is the recycled water produced by Western Treatment Plant (WTP) in Werribee, Melbourne. The WTP is owned and operated by Melbourne Water, which is the wholesale supplier of recycled water to the retail water companies, who then distributes it to the customers. High quality recycled water is produced by WTP, which has unique treatment processes.

According to the website of Melbourne Water, (http://www.melbournewater .com.au/ whatwedo/ treatsewage /wtp/Pages/ Sewage-treatment-process.aspx), the WTP produces about 110 million liters of recycled water per day using domestic and industrial sewage. In the WTP, treatment of raw sewage to Class "C" recycled water standard is done by using a massive lagoon system. Sewage flows slowly through this lagoon system, gradually becoming cleaner as bacteria breaks down the organic material in the water. This process usually takes around 30 to 35 days. After treatment in the lagoon system, the treated effluent is either treated to Class "A" standard using disinfection or is discharged to Port Phillip Bay, under strict EPA Victoria licence requirements

According to EPA Victoria (2005), recycled water classified as Class "A" in dual pipe schemes should satisfy the following microbial criteria.

Bacteria	< 10 E. coli/100 mL
Viruses	7-log reduction from raw sewage to recycled water
Protozoa	6-log reduction from raw sewage to recycled water

b) Stormwater

Stormwater will be collected from the newly developed areas in the Black Forest Road South study area (PSP 42.2). Stormwater is planned to be harvested at various locations along the recycled water pipe and treated stormwater will be injected into the third pipe which carries recycled water.

The Best Practice Environmental Management Guidelines for Urban Stormwater (BPEMG, 2006) establish stormwater quality objectives to help determine the level of stormwater management necessary to meet the State Environment Protection Policy (Waters of Victoria) objectives. To meet current BPEMG objectives it is compulsory under the Sustainable Neighbourhoods Clause 56 of the Victoria Planning Provisions to design and manage urban stormwater management systems for all new residential subdivisions (BPEMG, 2006). According to Table 2.1 of BPEMG, the current objectives for environmental management of stormwater are 80% retention of Total Suspended solids (TSS), 45% retention of Total Phosphorus (TP), and 45% retention of Total Nitrogen (TN) of the typical urban annual load. Also it is recommended to maintain 1.5-year Annual Recurrence Interval (ARI) stormwater flow at pre-development levels (BPEMG, 2006). To achieve these targets, it is required to construct stormwater treatment measures in new residential subdivisions. Growth Areas Authority already identified open waterways linked to a network of wetland / retarding basins, as stormwater treatment measures. These open waterways also can be used as recreational purposes in urban growth areas (Growth Area Authority, 2013).

As per the plan from the Growth Areas Authority, the stormwater catchment in the Black Forest Road South PSP (study area) will have 5,319 lots including over 800 lots less than 300 square metres by the time this PSP is fully developed (Growth Area Authority, 2013). Based on an average household size of 2.8 persons (State Government Victoria, 2014), the future population of the PSP is estimated at approximately 15,000 people. Based on the data available for allocated land used areas in Growth Area Authority (2013) and the information from Melbourne Water (2010) regarding fraction imperviousness of urban areas, the fraction imperviousness for different land use areas in the Black Forest Road South study area are calculated and tabulated in Table 5.1.

Table 5.1: Proposed land use areas and their pervious/impervious details of the study area

Description	Allocated Area (ha)	Pervious Area		Impervious Area	
		%	Area (ha)	%	Area (ha)
Transport (roads & rail reserve)	38.6	20	7.7	80	30.9
Community facilities	0.8	30	0.2	70	0.6
Education	13.9	30	4.2	70	9.7
Open space	126.2	90	113.6	10	12.6
Developable area	330.4	30	99.1	70	231.3
Total area	**509.9**	**44.1**	**224.8**	**55.9**	**285.1**

Sources: 1. Allocated areas; from Growth Area Authority (2013);

2. Pervious area and impervious area percentage; from Melbourne Water (2010).

Based on Table 5.1, there are 224.8 ha of pervious areas and 285.1 ha of impervious areas in the Black Forest Road South study area and the overall fraction imperviousness of the study area is 0.56.

5.3.1.2 Intended uses

Intended uses of recycled water were identified by CWW. Same intended uses are proposed for the combined water for the study area and they are listed below (City West Water, 2012).

- Toilet flushing
- Garden watering (including use on vegetable gardens)
- Municipal irrigation (parks, sporting fields and other public open spaces)
- General outdoor use, including pressure cleaning and washing cars
- Filling fountains
- Dust suppression
- Washing Pets
- Dedicated cold water taps for washing machines

Following uses are not permitted by CWW for using recycled water and the same list is not recommended for the use of combined water for the study area.

- Human consumption
- Human washing or bathing

- Filling swimming pools
- Any and all uses involving pigs
- Any and all uses involving milking machinery

5.3.1.3 Receiving environment and routes of exposure

As identified in the Australian Guidelines for Water Recycling Phase 1 and Phase 2 (NRMMC-EPHC-NHMRC, 2006, NRMMC-EPHC-NHMRC, 2009), the environmental hazards may be caused due to exceeding allowable limits of boron, cadmium, nitrogen, phosphorus, salinity, chloride, sodium, iron, disinfection residuals of chlorine and hydraulic loading rate. However, when recycled water is combined with stormwater, it is likely to avoid some of the environmental hazards as some of the concentrations are reduced.

Possible routes of exposure to the environment can be through irrigation, surface storage and infiltration. Probable routes of exposure for human health may be due to ingestion or inhalation as a result of accidental misuse of third pipe water. In dual reticulation systems, there is a possibility of accidental cross connections with potable water system, which can be avoided using proper colour code and signage on third pipe systems, and using proper education for plumbing. Also there is a possibility of deliberate misuses such as filling swimming pools with third pipe water etc., which can be avoided using proper public awareness. Although these are general comments with regards to possible routes of exposure for human health, they are equally applicable to the Black Forest Road South study area.

5.3.2 Combined water system analysis

Each part of the combined water system should be characterised with respect to water quality, the factors that affect water quality, and the reliability of the supply system. Such characterisation promotes the understanding of the combined water system.

5.3.2.1 Assemble a team with appropriate knowledge and expertise

The third pipe water supply scheme from the Western Treatment Plant (WTP) to the consumers in the Black Forest Road South study area is under the authority of City West Water. It consists of two sections; third pipe from the WTP to the first stormwater injection point (recycled water only) and the third pipe from the first stormwater injection point to the consumer (combined water). The collection of stormwater, storage, and treatment is handled by the local council. However, the injection of treated stormwater to the third pipe will be under the authority of City West Water. As there is a license agreement already in place for the production and distribution of recycled water, two new license agreements for production of treated stormwater and distribution of combined water are required.

5.3.2.2 Assemble information of combined water system and layout and process schematic

The study area is within the drainage catchment of the Lollypop Creek. As shown in Figure 5.3, possible stormwater harvesting sites within the drainage catchment have also been identified by Melbourne Water. Based on the stormwater harvesting locations identified by Melbourne Water, three stormwater harvesting sites are proposed for this study area, as a demonstration of the risk management framework to the study area.

a) Layout and process schematic of recycled water system

The recycled water to the study area is supplied from the WTP, which is located about 5 km Southeast to the study area. The process flow diagram of the WTP is shown in Figure 5.4. A low-energy process is used in the WTP using an existing lagoon system. The first stage of lagoon treatment is anaerobic. In the remaining ponds, oxygen is naturally available in the lagoon system (aerobic) and ultraviolet from sunlight helps natural disinfection. After 30 –35 days, water reaches the end of the lagoon system and considered as Class “C” recycled water. Then disinfection using UV technology and chlorine, Class “A” recycled water is produced.

b) Layout and process schematic of stormwater harvesting system

It is proposed to have a bio retention system and a wetland as the stormwater treatment measures in each identified stormwater harvesting location of the Black Forest Road South study area. Each stormwater harvesting system has similar functional layout, but with different capacities and sizing of the components.

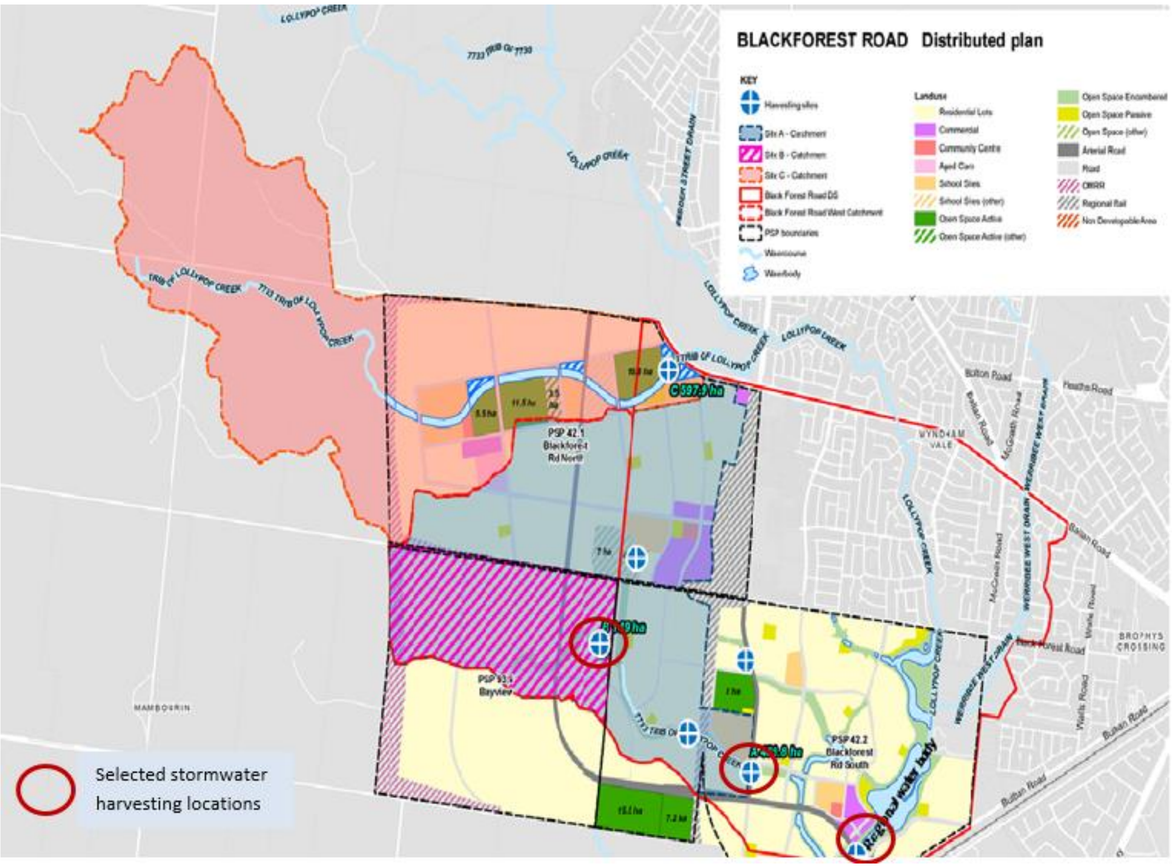


Fig 5.3: Proposed stormwater harvesting sites by Melbourne water (Map is supplied by CWW)

c) Stormwater availability

The annual average rainfall (considering the last 10 years, 2004 - 2014) of the weather station at Laverton, which is about 13 km to the northeast of the study area, was 469 mm. Lowest recorded annual rainfall within the same period was 335.6 mm. The Melton weather station, which is located about 20 Km to the northwest of the study area recorded 459 mm as the average rainfall during 2004-2014, while the lowest recorded annual rainfall was 301.8 mm.

Based on the above figures, it is reasonable to assume average annual rainfall for the study area as 450 mm and minimum annual rainfall as 300 mm.

Considering the stormwater harvesting locations proposed by Melbourne Water in the Lollypop Creek drainage area, three places were selected as stormwater harvesting locations as mentioned in Section 5.3.2.2. Stormwater injection locations in this study area are assumed to be located within the same site.

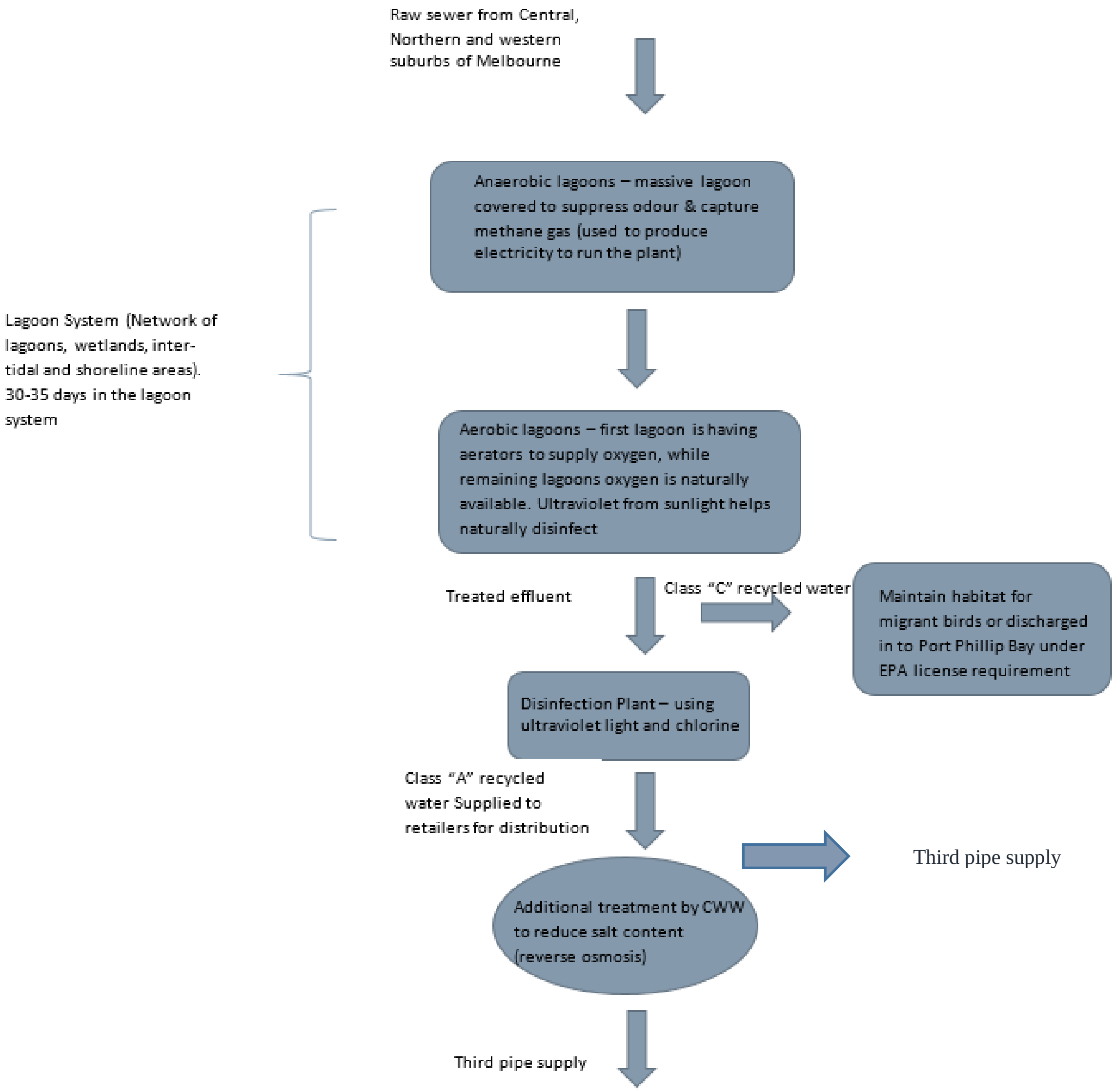


Figure 5.4: Process flow diagram of WTP

Source: Melbourne Water (undated)

Studies done on Cobbler Creek and Parafield stormwater catchments in Adelaide (Page et al., 2013) found that percentage of annual rainfall harvested (as stormwater) from annual rainfall varies between 4% to 12% within 9 years (2003-2011) of records. Therefore, it was assumed that 10% of the annual rainfall volume could be reused for the Black Forest Road South study area. Based on this assumption and the catchment area, the potential volume of rainfall reuse from first stormwater catchment (i.e. from outlet of wetland 1) is estimated and is shown in Figure 5.5.

Wetland 1

Average annual rainfall (2004 – 2014) - 450 mm

Minimum recorded annual rainfall (2004 – 2014) - 300 mm

Catchment area of Wetland W1 - 145 ha

Assuming 10% of the volume reused

Average volume of reuse - 0.1 * 0.45 * 145 * 10^4

- 65250 m^3
- 65.25 ML

Minimum volume of water reuse - 0.1 * 0.3 * 145 * 10^4

- 43.5 ML

Figure 5.5: Rainfall reuse volume calculation for stormwater catchment 1 (outlet of wetland 1)

Similar calculations were done for the proposed stormwater catchments (i.e. outlet of wetlands 2 and 3), and are tabulated in Table 5.2 below.

Table 5.2: Potential annual harvested stormwater volumes in wetlands

Wetland	Catchment Area (ha)	Average annual harvested Volume (ML)	Minimum annual harvested Volume (ML)
W1	145	65.3	43.5
W2	74	33.3	22.2
W3	306	137.7	91.8

The values in Table 5.2, are anticipated to be extracted as the average annual harvested volumes through wetlands, W1, W2 and W3 for the study area. In the worst case scenario, the wetlands are capable of harvesting the minimum annual volumes, and then the balance volumes to cater for the demand needs to be added through alternate water supplies (e.g. addition of potable water).

d) Stormwater treatment measures and storage

Stormwater treatment measures are required to minimise health, environmental and operational risks. The treatment arrangements for a stormwater reuse project should relate to the adopted stormwater quality criteria for the project (DEC - NSW, 2006). It is proposed to maintain combined water quality (recycled and stormwater) according to the guideline proposed in Section 3.3 of this study. The stormwater treatment measures considered for the study area are bio retention systems along the nature strip area and the offline wetland system in suitable locations. In addition, disinfection through chlorination and UV technology are proposed to control the microbial risk. It is proposed to construct a low level weir across the drainage path which will allow high flows to follow the drainage path. The weir diverts only low flows to the wetland. The water extraction to the wetland needs to be fitted with a trash rack to avoid gross pollutants entering the wetland.

For initial sizing of wetlands, the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) version 6.1 software was used. In the MUSIC software, there is a facility to size the treatment measures to achieve stormwater quality requirements of Best Practice Environmental Management Guidelines (BPEMG, 2006). Current Best Practice performance objectives are as follows.

80% retention of Suspended Solids (TSS)

45% retention of Total Phosphorus (TP)

45% retention of Total Nitrogen (TN)

Maintain discharges for the developed 1.5 year ARI at pre-development level

The MUSIC model for the Black Forest Road South study area was prepared based on a previous MUSIC model developed for the Lollypop Creek by CWW. The catchment of Black Forest Road South study area is geographically located within the Lollypop Creek catchment at the downstream end. Most of the upper catchments are being developed for urban use. When developing MUSIC model for the Black Forest Road South study area, it is assumed stormwater from upstream catchments to the study area have achieved the water quality specified by Best Practice Environmental Management Guidelines. Generic node is used in the MUSIC model to represent upper catchments to the study area. However, according to the previous MUSIC model supplied by the CWW, there are few catchments outside the Black Forest Road South study area catchments which are connected to the wetlands in the Black Forest Road South study area without treatment.

Following data were used for the MUSIC model in this study.

- 6 minutes' rainfall data at the Melton station (Latitude: 37.66° S Longitude: 144.57° E)
- Monthly average evapotranspiration data of Melton.
- Fraction of imperviousness of the catchments according to the previous MUSIC model of CWW (Table 5.3).

Following are the properties (input) used in bioretention system and the wetlands in the MUSIC model.

Bioretention system

Extended detention depth 0.3 m

Filter Depth 0.6 m

Saturated Hydraulic Conductivity 150 mm/hr

Wetland

Extended detention depth 0.3

Detention time 72 hrs

Figure 5.6 shows the layout diagram of MUSIC model set up for the Black Forest Road South study area.

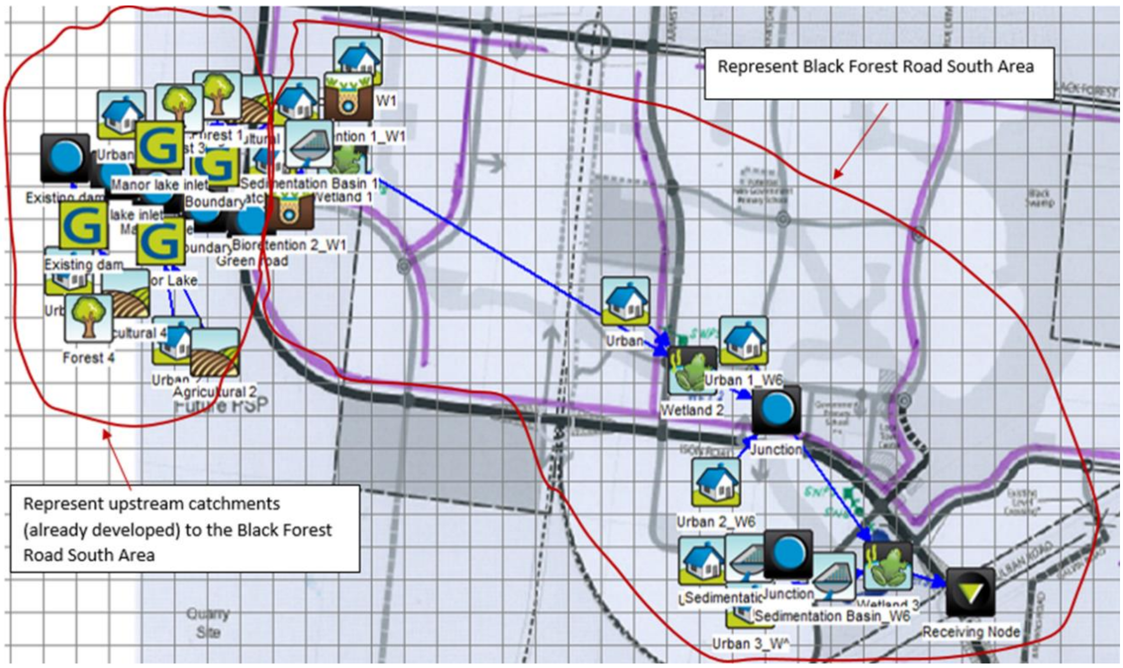


Figure 5.6: Layout of MUSIC Model prepared for the Black Forest Road South area

The best practice treatment targets are achieved in outlets of wetlands. Table 5.3 provides a summary of data used in the MUSIC model, the required wetland and bioretention areas and their performances (derived from MUSIC model), in terms of Total Suspended Solids (TSS), Total Phosphorus (TP) and Total Nitrogen (TN) pollutant reduction targets.

Table 5.3: Data used for bio retention and wetland preliminary design and results from MUSIC model

WETLAND	W1			W2			W3		
Catchment Area (Total) (ha)	145			74			306.3		
Catchment Area (within Black Forest Road South) (ha)	35			74			87		
Catchment Area (outside Black Forest Road South - connected to the wetland without treatment) (ha)	110			-			219.3		
Catchment Area (Impervious) (ha)	80			29.6			125.22		
Catchment Area (Pervious) (ha)	65			44.4			181.08		
Wetland Area (m^2)	3500			6300			58800		
Inlet pond volume (m^3)	2100			1350			4900		
Bio Retention Area (m^2)	2000			-			-		
Pollutant Name	TSS	TP	TN	TSS	TP	TN	TSS	TP	TN
Treatment Area Performance (% reduction)	**77.8**	**47.2**	**44.8**	**77.4**	**47.8**	**44.4**	**81.7**	**57.1**	**47.5**

e) Layout and process schematic of combined water system

The third pipe feeds recycled water to the study area with pipes of appropriate sizes depending on the demand of area. Nominal diameters of the pipes have been shown on the layout diagram (Figure 5.2). The layout and process schematic diagram for a combined water system is shown in the Figure 5.7. The third pipe recycled water distribution pipes to the area receives treated stormwater at the injection point (IP). The third pipe carrying recycled water is fitted with a non-return valve (NRV) (Figure 5.7) upstream to the injection point to ensure that the stormwater injection pressure will not back pressure the third pipe.

The first sampling point (SP1) in Figure 5.7 is located at the exit of the wetland before water enters to the stormwater storage. The second sampling point (SP2) in Figure 5.7 is located between the stormwater storage and UV treatment. Third sampling point (SP3) in Figure 5.7 is located between the UV treatment and injection point to monitor the water quality of treated stormwater. The injection point, (IP) where stormwater is injected to the recycled water pipe plays a key role in this whole system. In stormwater pipe, immediately upstream to the injection point (IP), pressure of stormwater is remotely measured with a SCADA facility to ensure that the predetermined pressure is maintained for proper injection and mixing of two types of water. It is also important to monitor the water pressure of the recycled water pipe before the injection point. There is a sampling point on the recycled water pipe just upstream to the stormwater injection point, SP4 to monitor the recycled water quality.

Monitoring of the water quality after mixing of two types of water is achieved by fitting adequate number of sampling points (SP) after the injection point before the mixed water reaches to the consumer. For example, sampling point 5 (SP_5) in Figure 5.7 is located 50 m downstream of the injection point where it is assumed that adequate mixing has taken place in the third pipe. Next sampling point, SP_6 in Figure 5.7, located 50 m downstream to SP_5 will confirm adequate mixing has taken place at SP_5 if the readings for water quality parameters of SP_6 are same as those of SP_5, and thus mixed water downstream of SP_6 is now ready for distribution. The backup plan for any failure in the stormwater supply will be handled by alternative potable water supply to the system between the UV treatment and the injection point marked as APWS (Alternate Potable Water Supply) on the layout diagram (Figure 5.7).

Stormwater system can fail due to non-availability of adequate quantity of stormwater because of drought or unacceptable quality. Furthermore, when salinity level is higher in stormwater and if specified combined water quality cannot be achieved, stormwater can be replaced with potable water.

Detailed discussion on the sampling points and pressure monitoring points is discussed in Section 5.4.2.

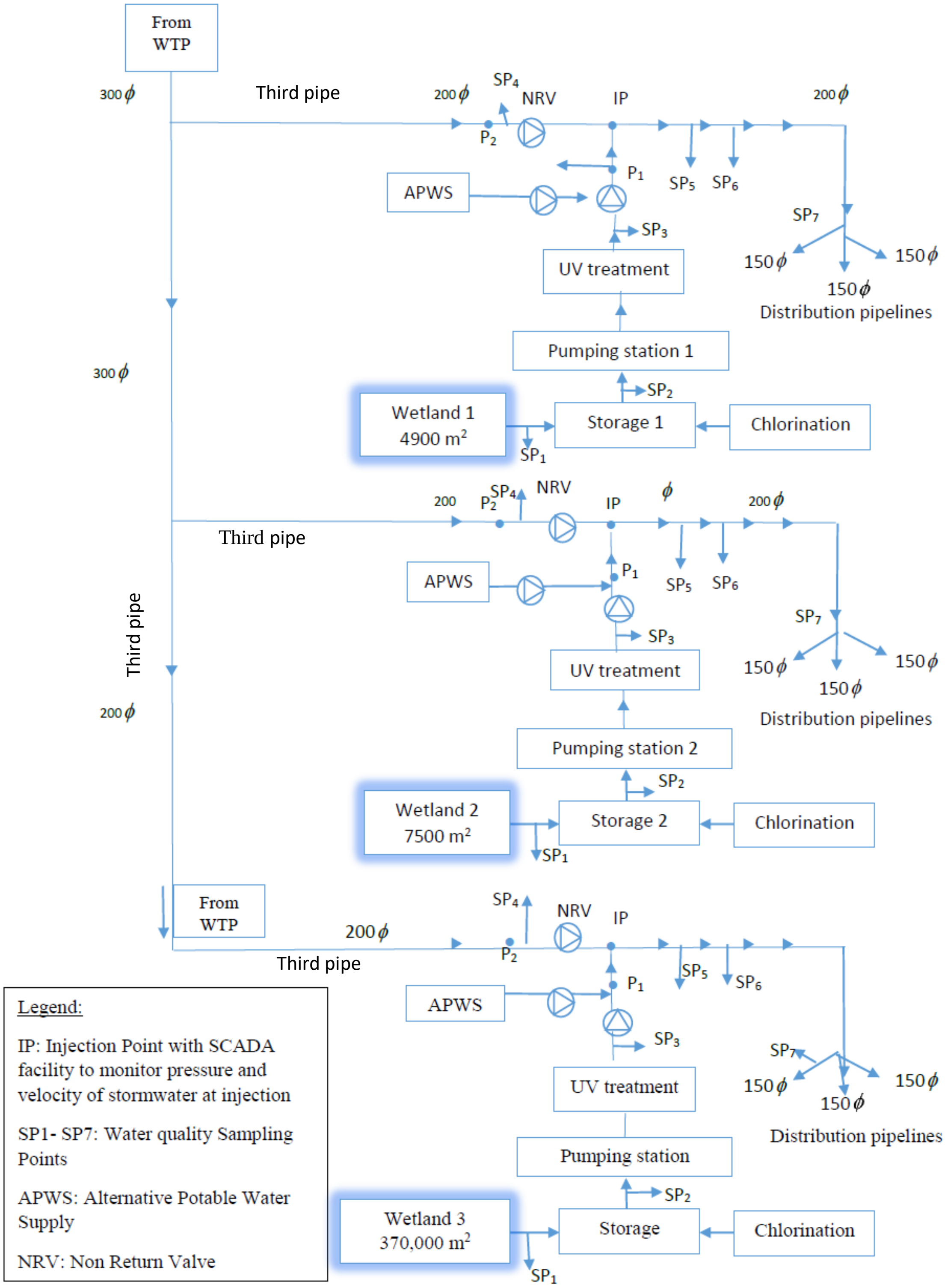


Figure 5.7: Schematic and instrumentation diagram of the combined water system

5.3.3 Assessment of water quality data

5.3.3.1 Stormwater quality data

Raw stormwater quality data were obtained from City West Water (CWW) which had been collected from their stormwater harvesting points (as shown in Figure 5.8). About 60 data sets were available from 10 stormwater harvesting points. About 50 water quality parameters were monitored in each stormwater harvesting points including physiochemical parameters, metals and metalloids, organic matters, bacteria indicators and microorganisms and nutrients.

Figure 5.8: Stormwater harvesting points of CWW (Figure is obtained from CWW)

Stormwater quality varies spatially and temporally (between stormwater harvesting points and the different sampling time in the same stormwater harvesting point). Hence as per the guidance of Australian Guideline for Water Recycling Phase 2 (NRMMC-EPHC-NHMRC, 2009), the 95th percentile concentration values are used. Parameters, namely SAR (Sodium Absorption Ratio), sulphate, calcium, magnesium, and sodium are not available in the data set provided by the CWW. Hence missing parameters from the data sets are filled using the data from literature, as highlighted in Table 5.4.

5.3.3.2 Recycled water quality data

Post disinfection recycled water quality data of the Western Treatment Plant were available as monthly mean values in Southern Rural Water Corporation web site (Southern Rural Water, 2015). Annual average values are selected for the study and tabulated in Table 5.5.

Table 5.4: Untreated stormwater quality data (95th percentile value)

Selected Parameters for the study		Proposed Guideline Values	Untreated stormwater quality (95th percentile)
Physiochemical Indicators	Ammonia (NH_3)	0.01mg/L (as N)	1.2 mg/L
	Chloride	175 - 350 mg/L	140 mg/L
	Colour AppPt/Co units	-	160
	EC at 25 ^{o}C µS/cm	650	1001
	pH	6.0–9.0	8.66
	SAR (Sodium Adsorption Ratio)	8 - 18	1.9
	Sulphate	400 mg/L	63.2 mg/L
	Suspended Solids	5 mg/L	280 mg/L
	Total Alkalinity mg $CaCO_3$ / L	< 350 mg/L	210 mg/L
	Total Dissolved Solids(TDS)	1000 mg/L	470 mg/L
	Turbidity	< 2 NTU	290 mg/L
Metals & Metalloids	Aluminium	0.2 mg/L	7.5 mg/L
	Arsenic	0.05 mg/L	0.01 mg/L
	Barium	1 mg/L	0.11 mg/L
	Boron	0.5-15 mg/L	0.31 mg/L
	Cadmium	0.005 mg/L	0.002 mg/L
	Calcium		83.2 mg/L
	Copper	1.0 mg/L	0.06 mg/L
	Iron	0.3 mg/L	6.3 mg/L
	Lead	0.05 mg/L	0.01 mg/L
	Magnesium		59.1 mg/L
	Manganese	0.1 mg/L	0.19 mg/L
	Mercury	0.001 mg/L	0.001 mg/L
	Nickel	0.1 mg/L	0.01 mg/L
	Sodium	115 - 230 mg/L	15.72 mg/L
	Zinc	5 mg/L	0.54 mg/L
Organic matters	Total Organic Carbon (TOC)	-	22.8 mg/L
Bacteria-Indicators	Campylobacter(bacteria) #/L	15 /L	9.6/L
	E coli	< 10/100 mL	18300/100mL
	Cryptosporidium #/L	1.8/L	1.58/L
Nutrients	Total Nitrogen	<30 mg/L	11.7 mg/L
	Total Phosphorus	< 0.8 mg/L	1.8 mg/L

Data from literature Page and Levett (2010)

Data from Table 2.3 - NRMMC-EPHC-NHMRC (2009)

Table 5.5: Western Treatment Plant Recycled Water Quality data (yearly mean) – Post disinfection

Selected Parameters for the study		Proposed Guideline Values	WTP recycled water quality (post disinfection-yearly mean (2014-2015 August)
Physiochemical Indicators	Ammonia(NH_3)	0.01mg/L(as N)	N/A
	Chloride	175 - 350 mg/L	408 mg/L
	Colour AppPt/Co units	-	12
	EC at 25 ^oC µS/cm	650	1756
	pH	6.0–9.0	7.48
	SAR(Sodium Adsorption Ratio)	8 - 18	9
	Sulphate	400 mg/L	N/A
	Suspended Solids	5 mg/L	3.55 mg/L
	Total Alkalinity mg $CaCO_3$ / L	< 350 mg/L	N/A
	Total Dissolved Solids(TDS)	1000 mg/L	1020 mg/L
	Turbidity	< 2 NTU	N/A
Metals & Metalloids	Aluminium	0.2 mg/L	0.033 mg/L
	Arsenic	0.05 mg/L	0.022 mg/L
	Barium	1 mg/L	0.005 mg/L
	Boron	0.5-15 mg/L	0.16 mg/L
	Cadmium	0.005 mg/L	0 mg/L
	Calcium	-	27 mg/L
	Copper	1.0 mg/L	0.033 mg/L
	Iron	0.3 mg/L	0.048 mg/L
	Lead	0.05 mg/L	0.001mg/L
	Magnesium	-	23 mg/L
	Manganese	0.1 mg/L	0.036 mg/L
	Mercury	0.001 mg/L	0 mg/L
	Nickel	0.1 mg/L	0.009 mg/L
	Sodium	115 - 230 mg/L	253 mg/L
	Zinc	5 mg/L	0.04 mg/L
Organic matters	Total Organic Carbon (TOC)	-	N/A
Bacteria-Indicators	Campylobacter(bacteria) #/L	15 mg/L	N/A
	E coli	< 10/100 mL	0.5
	Cryptosporidium #/L	1.8/L	N/A
Nutrients	Total Nitrogen	<30 mg/L	17.9 mg/L
	Total Phosphorus	< 0.8 mg/L	8.34 mg/L

N/A: Not Available

5.3.3.3 Combined water quality data

As explained in Section 3.4, the mass balance analysis is a valid methodology to be adopted for calculating water quality of combined water in the third pipe. Using existing stormwater quality data and Western Recycled Plant water quality data, combined water quality is calculated for pre-determined mix proportions and tabulated in Table 5.6.

Table 5.6: Combined water quality using mass balance equation with existing untreated stormwater quality data and Western Treatment Plant recycled water data

Selected Parameters for the study		Proposed Guideline Values	Untreated stormwater quality (95^{th} percentile)	WTP Recycled Water Quality – Post disinfection-Yearly mean 2014 August - 2015 August	Mix Water Quality (mg/L) for different ratios of volume of Recycled water to volume of untreated stormwater				
					9:1	7.5:2.5	5:5	2.5:7.5	1:9
Physiochemical Indicators	Ammonia (NH_3)	0.01mg/L(as N)	1.2	N/A	-	-	-	-	-
	Chloride	175 - 350 mg/L	140	408.0	381.20	341.00	274.00	207.00	166.80
	Colour AppPt/Co units	-	160	12.0	N/A	N/A	N/A	N/A	N/A
	EC at 25 $^{\circ}$C µS/cm	650	1001.00	1756.0	N/A	N/A	N/A	N/A	N/A
	pH	6.0–9.0	8.66	7.480	N/A	N/A	N/A	N/A	N/A
	SAR (Sodium Adsorption Ratio)	8 - 18	1.9	9.0	N/A	N/A	N/A	N/A	N/A
	Sulphate	400 mg/L	63.2	N/A	-	-	-	-	-
	Suspended Solids	5 mg/L	280	3.550	31.20	72.66	141.78	210.89	252.36
	Total Alkalinity mg $CaCO_3$ / L	< 350 mg/L	210	N/A	-	-	-	-	-
	Total Dissolved Solids (TDS)	1000 mg/L	470	1020.0	965.00	882.50	745.00	607.50	525.00
	Turbidity	< 2 NTU	290	N/A	-	-	-	-	-
Metals & Metalloids	Aluminium	0.2 mg/L	7.5	0.033	0.78	1.90	3.77	5.63	6.75
	Arsenic	0.05 mg/L	0.01	0.022	0.0208	0.0190	0.02	0.01	0.01
	Barium	1 mg/L	0.11	0.005	0.02	0.03	0.06	0.08	0.10
	Boron	0.5-15 mg/L	0.31	0.160	0.18	0.20	0.24	0.27	0.30
	Cadmium	0.005 mg/L	0.002	0.0	0.0002	0.0005	0.00	0.00	0.00
	Calcium		83.2	27.0	32.62	41.05	55.10	69.15	77.58
	Copper	1.0 mg/L	0.06	0.033	0.0357	0.0398	0.05	0.05	0.06
	Iron	0.3 mg/L	6.3	0.048	0.67	1.6110	3.17	4.74	5.67
	Lead	0.05 mg/L	0.01	0.001	0.0019	0.0033	0.01	0.01	0.01
	Magnesium		59.1	23.0	26.61	32.03	41.05	50.08	55.49
	Manganese	0.1 mg/L	0.19	0.036	0.0514	0.07	0.11	0.15	0.17
	Mercury	0.001 mg/L	0.001	0.0	0.0001	0.0003	0.0005	0.00	0.0009
	Nickel	0.1 mg/L	0.01	0.009	0.0091	0.0093	0.01	0.01	0.01
	Sodium	115 - 230 mg/L	15.72	253.0	229.272	193.680	134.360	75.040	39.448
	Zinc	5 mg/L	0.54	0.040	0.0900	0.17	0.29	0.42	0.49
	Total Organic Carbon (TOC)		22.8	N/A	-	-	-	-	-
Bacteria-Indicators & Pathogens	Campylobacter(bacteria) #/L	15 /L	9.6	N/A	-	-	-	-	-
	E coli	< 10/100 mL	18300	0.5	1830.45	4575.38	9150.25	13725.13	16470.05
	Cryptosporidium #/L	1.8/L	1.58	N/A	-	-	-	-	-
Nutrients	Total Nitrogen	<30 mg/L	11.70	17.9	17.28	16.35	14.80	13.25	12.32
	Total Phosphorus	< 0.8 mg/L	1.8	8.34	7.69	6.71	5.07	3.44	2.45

N/A: Not Applicable

Data from literature Page and Levett (2010)

Data from Table 2.3 - NRMMC-EPHC-NHMRC (2009)

Concentration exceeds guideline value

Mix proportions are selected to cover possible mix ratios from low stormwater ratio (10%) to high stormwater ratio (90%). It is to be noted here, mass balance is not applicable for physical parameters.

There are some important observations made from the Table 5.6 regarding the combined water quality. Values highlighted in yellow exceed the values of the proposed guideline in the study; namely chloride, suspended solids, aluminium, iron, E coli and total phosphorus which are explained in detail below.

a) Suspended solids

The 95th percentile value of suspended solids from the data set used for the study is 280.0 mg/L for untreated stormwater, while annual average value of suspended solids in Western Treatment Plant recycled water is 3.55 mg/L. Recommended value of suspended solids for combined water quality in the proposed guideline is 5 mg/L. Therefore, it is required to remove more than 90% of suspended solids from stormwater before injection of stormwater into the recycled water pipe. Based on the literature, 90% removal efficiency of suspended solids is possible using dry swales, about 59% using bioretention system and about 72% removal efficiency using wetlands (C.F.W.P., 2007). Using more than one treatment measure (or combining several treatment measures), it is possible to achieve the 90% of removal efficiency.

Treated stormwater quality data are not available for Black Forest Road South study area currently, as the project is in the planning stage. Therefore, a MUSIC software model, developed for the study area was used to get treated stormwater quality. Stormwater treatment measures used in the MUSIC model was bioretention system and wetland. MUSIC software outputs are available as 90th percentile values, although the proposed guideline values for stormwater quality are required as 95th percentile values. The Table 5.7 presents the outputs of the MUSIC software model as 90th percentile of the concentrations of suspended solids of the three wetland outlets of the Black Forest Road South study area and can be considered as treated stormwater quality data.

Using treated stormwater quality data (from MUSIC model) as shown in Table 5.7 and recycled water quality data as shown in Table 5.5 for the suspended solids, the combined

Table 5.7 - Suspended solids concentration at the outlets of the proposed wetlands according to the results of MUSIC model for the study area

Location	90th percentile value of suspended solids concentration (mg/L)
Outlet of wetland 1	15.9
Outlet of wetland 2	16.9
Outlet of wetland 3	8.0

water quality is calculated using mass balance analysis for pre-determined mix proportions. Results of suspended solids concentrations for combined water are given in Table 5.8.

Table 5.8: TSS concentration of mix water using the mass balance analysis using the Wetland outlet concentration values of MUSIC model and recycled water quality data of WTP

V1 = Volume of Recycled water			V1 (ML)	9	7.5	5	2.5	1
V2 = Volume of treated stormwater			V2 (ML)	1	2.5	5	7.5	9
Selected parameters for the study	Proposed Guideline Values	Treated stormwater quality (90th percentile)	WTP Recycled Water Quality – yearly mean(2014 to 2015 August)	Mix Water Quality (mg/L)	Mix Water Quality (mg/L)	Mix Water Quality (mg/L)	Mix Water Quality (mg/L)	Mix Water Quality (mg/L)
Suspended Solids	5 mg/L	15.9 mg/L (Wetland 1 outlet)	3.55	4.79	6.64	9.73	12.81	14.67
Suspended Solids	5 mg/L	16.9 mg/L (Wetland 2 outlet)	3.55	4.89	6.89	10.23	13.56	15.57
Suspended Solids	5 mg/L	8.0 mg/L (Wetland 3 outlet)	3.55	4.00	4.66	5.78	6.89	7.56

Concentration exceeds guideline value

The allowable limit for suspended solid concentration in the proposed guideline is 5 mg/L. The highlighted figures in Table 5.8 are the suspended solids concentrations calculated using mass balance analysis which are higher than the suspended solid concentration value of the proposed guideline. It can be seen that only the lower percentages of stormwater in the mix comply with the proposed guideline limits of suspended solid concentration in the mix (i.e.; only suspended solid concentrations for treated stormwater: recycled water ratio 1:9 for all three wetlands and treated stormwater: recycled water ratio 2.5:7.5 for wetland 3 comply with the guideline). The treatment measures for stormwater used in the MUSIC model are wetlands and bioretention system. Therefore, it is seen that for use of higher percentage of stormwater in the mix requires further treatment for suspended solids. Filtration may be a good option to further remove suspended solids from stormwater.

b) Aluminium

The 95^{th} concentration of Aluminium in untreated stormwater is 7.5 mg/L, from the data set used for this study. This Aluminium concentration is not a hazard for irrigation purposes. However, the third pipe water is proposed to be used for recreational activities. Based on the proposed guideline, Aluminium concentration should be less than 0.2 mg/L to avoid aesthetic problems which is a feature in the use of combined water for recreational activities. To bring the Aluminium concentration of 7.5 mg/L in the untreated water down to 0.2 mg/L in the combined water, stormwater requires further treatment measures in addition to the conventional stormwater treatment of wetlands and bioretention systems. Literature recommends the use of activated carbon particles to remove aluminium from water and it is a fast, simple and cheap method to use (Takassi and Hamoule, 2014).

c) Iron

The 95th percentile value of iron exceeds the trigger values of guideline of combined water quality. High amounts of iron influence colour, odour and turbidity of mix water. This is an issue when third pipe water is used for toilet flushing and washing clothes. Presence of Iron compounds may also cause health risks. The recommended options for managing iron risks are to implement stormwater treatment measures like wetland (Page and Levett, 2010) or bioretention systems (NRMMC-EPHC-NHMRC, 2009). As the project at this planning stage has already proposed wetland and bioretention systems to achieve the required water quality of the list of the parameters in the proposed guideline, it is anticipated that the percentage of iron removal using the wetland and bioretention system could be sufficient to achieve the required iron concentration targets of the proposed guideline. Therefore, the actual iron concentrations of treated stormwater exiting the wetland and bioretention system need to be assessed during the implementation stage of the project through water sampling. In the event of further iron removal is required, it will be possible to introduce advanced filtration system in addition to the wetland and bioretention systems.

d) E coli

In this study, E Coli is considered as a representative for all bacterial indicators or considered as a microbial surrogate. The goal of selecting a sufficiently representative surrogate is to improve public health through a health-based risk assessment framework (Sinclair et al., 2012). Combined water quality data in Table 5.6 show concentration of E Coli is very much higher than the trigger value. The 95th percentile value for E Coli of untreated stormwater is 18300 /100ml. The trigger value for E Coli in the guideline is 10/100ml. Wetlands have been used to reduce pathogen populations with varying but significant degrees of effectiveness (Kadlec and Wallace, 2008). For Black Forest South study area, wetlands and bioretention systems have been proposed as stormwater treatment measures. These two treatment measures alone may not be capable to bring the E coli to the target levels. Disinfection is required for reduction for microorganisms to the target levels further to these two stormwater treatment measures. For the disinfection methods to be effective, turbidity needs to be brought down to a lower level. Wetlands and bioretention systems will reduce turbidity of stormwater. Therefore, stormwater disinfection needs to be added to the stormwater after stormwater has undergone treatment for turbidity through wetlands and bioretention system. For most small to medium sized stormwater treatment schemes, ultraviolet (UV) disinfection is the most practical and commonly used disinfection technique for achieving the required log reductions. Disinfection by chlorine is also suitable for stormwater reuse schemes, particularly for larger schemes (NRMMC-EPHC-NHMRC, 2009). Combination of chlorine and ultraviolet (UV) treatment as disinfection methods for the Black Forest South study area which will treat stormwater for E-coli to a level suitable for all intended uses is proposed in this study.

It is possible to assume in the risk assessment, that if the microbial health targets are met and the aesthetic targets of colour and turbidity are also met, then the stormwater will be suitable for non-potable water use (Page and Levett, 2010). Therefore, stormwater treatment for E coli is one of the key requirements to be considered in the risk management framework which will be discussed in the next chapters.

e) Total phosphorus

As for the suspended solids, total phosphorus concentrations at the outlets of wetlands were calculated using MUSIC software. MUSIC software outputs are available as 90th percentile values, albeit the proposed guideline values for stormwater quality are required as 95th percentile values. Table 5.9 presents the outputs of the MUSIC software model as 90th percentile of the concentrations of total phosphorus of the three wetlands of the Black Forest Road South study area. This can be considered as phosphorus concentration in treated stormwater through bio retention and wetland.

Table 5.9: Total phosphorus (TP) concentration at the outlets of the proposed wetlands according to the results of MUSIC model for the study area

Location	90th percentile value of TP concentration (mg/L)
Outlet of wetland 1	0.120
Outlet of wetland 2	0.118
Outlet of wetland 3	0.073

Proposed guideline target value for total phosphorus concentration in combined water is 0.8 mg/L. Though treated stormwater has less total phosphorus concentration than the proposed guideline value, recycled water has higher total phosphorus concentration (8.48 mg/L). Hence it is not practically possible to obtain the guideline target value for total phosphorus by mixing stormwater (with low concentration of total phosphorus ranging from 0.073mg/L to 0.12mg/L) with recycled water (with high total phosphorus concentration of 8.48mg/L) as the total phosphorus concentration of recycled water is comparatively higher. It is therefore necessary to implement treatment measures to reduce total phosphorus concentration in recycled water system to obtain required guideline limit for total phosphorus in the combined water.

Presence of high concentrations of total Phosphorus in the combined water could be harmful to irrigation equipment and the receiving environments of plants and soils. Alternatively, it can be proposed to have no treatment for recycled water for total phosphorous reduction, then the risks associated with the irrigation equipment, plants and soils need to be assessed. Monitoring of the irrigation system regularly after 20 years to assess any bio clogging is suggested (NRMMC-EPHC-NHMRC, 2009). It is also required to make site specific assessments to make sure that there will be no adverse effects for the receiving soils and plants due to high concentrations of phosphorus in combined water. Also phosphorus level of soil can be controlled by adjusting the application rate of fertilizers. It is also not allowed any movement of significant concentrations of phosphorus from soils into water bodies.

5.3.4 Hazard identification and risk assessment

Hazard identification and risk assessment of the Black Forest Road South study area were performed and discussed in this section. Effective risk management needs to identify all potential hazards and hazardous events, and assess the level of risk of these hazards and hazardous events present to public health, environmental health and operational infrastructure arising from the activities carried out to produce and use of combined water (NRMMC-EPHC-NHMRC, 2006).

5.3.4.1 Hazard identification

All potential hazards and hazardous events for the Black Forest Road South study area were identified and documented for each component of the stormwater subsystem and combined water subsystem. The Western Treatment Plant is already supplying recycled water, and a risk management system is already established for recycled water. Hence there is no discussion given on the hazard identification and risk management made for recycled water subsystem in this study. Hazards and hazardous events related to stormwater subsystem and combined water subsystem were identified based on the information in Table 2.4 of NRMMC-EPHC-NHMRC (2006). Hazards and hazardous events in stormwater subsystem are given identification numbers (Hazard IDs) in chronological order starting from 1 in Table 5.10. Hazards or hazardous events in stormwater subsystem are further divided into four categories depending on the location or zone hazard or hazardous event is present as shown in column 1 of Table 5.10 namely; stormwater catchments, treatment systems, storage including wetlands and supply pipe up to injection point. Hazards and hazardous events in combined water subsystem are given identification numbers (Hazard IDs) in chronological order starting from 101 in Table 5.11. Hazards or hazardous events in combined water subsystem are further divided into three categories depending on the location or zone hazard or hazardous event is present as shown in column 1 of Table 5.11 namely; stormwater injection point, mixing zone of two types of water and distribution system.

5.3.4.2 Risk assessment

Only the qualitative risk assessment was conducted for the Black Forest Road South study area. This is because the study area is currently in the planning stage and as a result the

Table 5.10: Qualitative measures of likelihood – Stormwater subsystem

Hazard Zone	Hazard description	Hazard ID	Qualitative measure of likelihood	Hazaard Zone	Hazard description	Hazard ID	Qualitative measure of likelihood
Stormwater catchments	Chemical use in catchment areas	1	E	Storage including wetlands	Birds and vermin	22	E
	Climate and seasonal variations	2	E		Bushfires and natural disasters	23	C
	Flushing of pipes and internal discharge	3	D		Climatic and seasonal variations (heavy rainfalls, droughts)	24	D
	Inadequate buffer zones	4	B		Cyanobacterial blooms	25	D
	Industrial discharges	5	C		Leakage from storage to groundwater	26	C
	Leachingfrom existing waste disposal	6	A		Livestock access	27	B
	Major fires (firefightingchemicals)	7	C		Inadequate buffer zones and vegetation	28	B
	Major spills and accidential spillage	8	B		Inadequate storage	29	D
	poorly vegetated riparianz ones and soil erosion	9	D		Public roads and accidental spillage	30	E
	Road washing	10	E		Sabotage	31	A
	Sewage overflows	11	B		Short-circuiting of wetland	32	D
	Unrestricted livestock	12	B				
Treatment systems	Disinfection malfunctions	13	B	Supply pipe upto injection point	Biofilms, sloughing and resuspension,regrowth	33	C
	Equipment malfunctions	14	C		Buildup of sediments and slimes (eg following period of low use)	34	E
	Failure of alarms and monitoring equipment	15	B		Flow variability, inadequate pressures	35	D
	Formation of disinfection byproducts	16	D		Formation of disinfection byproducts	36	E
	Inadequate mixing of treatment chemicals	17	C		Groundwater intrusion (salinity)	37	C
	Inadequate filter operation and backwash	18	C		Human or livestock access, absence of exclusion	38	B
	Power failures	19	E		Lack of seperation between storm water and drinking water systems	39	B
	Sabotage and natural disaters	20	A		Inappropriate materials and coatings or material failure	40	B
	Significant flow variations through water treatment systems	21	D		Pipe bursts or leaks	41	D
					Sabotage and natural disaters	42	A

Key
A Rare B Unlikely C Possible D Likely E Almost certain

required stormwater/combined water quality monitoring data are not available for the project area to conduct a quantitative risk assessment.

A. Qualitative risk assessment

Once potential hazards or hazardous events have been identified, the qualitative risk level associated with each of the hazard or hazardous event should be estimated. Thereby risk management can be established and documented. Every hazard or hazardous event will not require the same degree of attention. Risk assessment helps to pay attention directly to the most threatening hazards or hazardous events and provide resources to minimise the effects of these hazards or hazardous events (NRMMC-EPHC-NHMRC, 2006).

Table 5.11: Qualitative measures of likelihood – Combined water sub system

Hazard zone	Harard Description	Hazard ID	Qualitative measure of likelihood
Stormwater injection point	Wear and tear of stormwater injectors leading change of injection pressure	101	B
	Variability of stormwater injection pressure due to variations of presssure of recycled water	102	C
	Faulty pressure gauges / expiration of calibration certificates	103	C
	Blockages of injectors/nozzles with debris	104	C
	Physical damages to injector equipment	105	A
	Malfunction of injector pressure pumps	106	C
	Pressure variations due to extreme temperature variations (seasonal)	107	B
	Malfunction of air release valves leading to difficulty in maintaing of pressures	108	C
	Power failures	109	D
	Human errors during pressure monitoring	110	D
Mixing zone of two types of water(recycled water and stormwater)	Pressure variations of mixing of two types of water	111	E
	Temperature variations (seasonal)	112	D
	Pipe settlements in poor soil conditions	113	C
	Leaking pipes and pipe joints	114	B
	Malfunction of air release valves leading to difficulty in maintaing of pressures	115	C
	Power failures	116	D
	Human errors during monitoring	117	D
Distribution system, application and receiving environments	Biofilms,sloughing and resuspension,regrowth	118	D
	Buildup of sediments and slimes (eg following period of low use)	119	E
	Change in biodiversity from increased nutrients applied in combined water	120	B
	Deliberate or inadvertent misuse of combined water	121	D
	Eutrophication of receiving waters	122	D
	Failure to identify recycled water systems(below and above ground components)	123	B
	Flow variability, inadequate pressures	124	D
	Formation of disinfection byproducts	125	D
	Groundwater intrusion (salinity)	126	C
	Human or livestock access, absence of exclusion	127	C
	Inadequate repair and maintenance, inadequate system flushing	128	C
	Lack of seperation between recycled water and drinking water systems	129	B
	Inappropriate materials and coatings or material failure	130	B
	Pipe bursts or leaks	131	D
	Poor cross-connection control and backflow protection of higher quality water sources (eg drinking water)	132	B
	Poor cross-connection control and backflow protection of recycled water from lower quality water sources	133	B
	Raised water tables, salination, soil structure decline	134	C
	Sabotage and natural disaters	135	A
	Soil, groundwater or surface water contamination by combined water	136	B
	Toxicity to plants, terrestrial or aquatic biota	137	C
	Waterlogging of plants	138	C

Key

A Rare B Unlikely C Possible D Likely E Almost certain

a) Likelihood of hazards and hazardous events

As a first step of the risk assessment, the likelihood of happening of a hazard or hazardous event was assessed. It was categorised as rare (A), unlikely (B), possible (C), likely (D) and almost certain (E) as explained in Section 4.3.4.1. Likelihood assigned to a particular hazard or hazardous event depends on the better understanding of the study area and perspective of the person who undertakes the risk assessment (the author of this thesis in this case). The hazards or hazardous events occurring and the likelihood of these occur in the stormwater subsystem and combined water subsystem for the study area were identified as shown in Tables 5.10 and 5.11 respectively.

As an example, "chemical use in catchment area (Hazard ID – 1)" was given the likelihood of "E" in this study. The chemical use in the study area depends on the local industrial characteristics such as the availability of chemical producing factories in the area and the magnitude of such factories. Therefore, the "chemical use in catchment area (Hazard ID-1)" in the Black Forest Road South study area is expected to occur multiple times within a year. Therefore, the likelihood of "chemical use in catchment area (Hazard ID-1)" was assigned with "almost certain (E)".

b) Consequences of hazards

Understanding of the consequences of a hazard occurring is important to assess the risk of the particular hazard. Consequences are categorised as insignificant (1), minor (2), moderate (3), major (4) and catastrophic (5). Explanations of these categories are given in Table 4.7.

Consequences of each identified hazard were categorised for the stormwater subsystem and combined water subsystem of the study by the author of the thesis based on the current knowledge of the study area and tabulated in Tables 5.12 and 5.13 respectively. It is proposed to modify the assessment during the implementation stage with better understanding of the study area.

Table 5.12: Measures of consequences – Stormwater sub system

Hazard zone	Hazard Description	Hazard ID	Public health risks	Environmental risks					Operational risks				
			Pathogens	Cadmium	Nitrogen	Phosphorus	Iron	Hydraulic loading rate	Suspended solids	Coarse particles	Hardness	Phosphorus	Iron
Stormwater catchments	Chemical use in catchment areas	1	1	4	3	3	3	-	1	-	3	3	3
	Climate and seasonal variations	2	3	3	3	3	3	5	4	3	3	3	3
	Flushing of pipes and internal discharge	3	3	3	3	3	3	3	3	3	3	3	3
	Inadequate buffer zones	4	4	4	3	3	3	-	1	-	3	3	3
	Industrial discharges	5	3	5	2	2	3	-	1	-	3	2	3
	Leaching from existing waste disposal	6	5	5	4	4	3	-	2	-	2	4	3
	Major fires (firefighting chemicals)	7	1	2	2	2	1	2	2	-	-	2	1
	Major spills and accidential spillage	8	5	5	3	3	3	-	3	-	3	3	3
	poorly vegetated riparianzones and soil erosion	9	1	1	2	2	2	2	4	3	-	2	2
	Road washing	10	3	3	2	2	2	2	3	3	2	2	2
	Sewage overflows	11	5	3	3	3	1	2	3	-	2	3	1
	Unrestricted livestock	12	5	2	2	2	2	-	2	-	-	2	2
Treatment systems	Disinfection malfunctions	13	5	1	1	1	1	1	1	1	1	1	1
	Equipment malfunctions	14	4	2	2	2	2	1	2	2	2	2	2
	Failure of alarms and monitoring equipment	15	5	4	2	2	2	1	3	2	2	2	2
	Formation of disinfection byproducts	16	1	2	2	2	2	1	1	-	2	2	2
	Inadequate mixing of treatment chemicals	17	4	1	1	1	1	1	1	1	1	1	1
	Inadequate filter operation and backwash	18	1	2	2	2	2	1	4	2	2	2	2
	Power failures	19	4	1	1	1	1	1	1	1	1	1	1
	Sabotage and natural disaters	20	5	4	3	3	3	3	3	3	3	3	3
	Significant flow variations through water treatment systems	21	1	3	3	3	3	1	3	1	1	3	3
Storage including wetlands	Birds and vermin	22	3	1	2	2	1	1	2	1	2	2	1
	Bushfires and natural disasters	23	3	4	3	3	3	3	3	2	2	3	3
	Climatic and seasonal variations (heavy rainfalls, droughts)	24	3	3	3	3	3	3	3	3	2	3	3
	Cyanobacterial blooms	25	5	3	2	2	1	1	1	1	1	2	1
	Leakage from storage to groundwater	26	3	2	2	2	2	2	1	1	1	2	2
	Livestock access	27	4	1	1	1	1	1	1	1	1	1	1
	Inadequate buffer zones and vegetation	28	4	3	3	3	3	2	3	2	1	3	3
	Inadequate storage	29	1	1	1	1	1	2	2	1	1	1	1
	Public roads and accidental spillage	30	4	4	3	3	3	3	3	1	2	3	3
	Sabotage	31	2	2	3	3	3	1	2	1	1	3	3
	Short-circuiting of wetland	32	3	3	3	3	3	1	3	2	1	3	3
Supply pipe up to injection point	Biofilms,sloughing and resuspension,regrowth	33	2	2	3	3	2	1	3	2	2	3	2
	Buildup of sediments and slimes (eg following period of low use)	34	1	1	2	2	2	1	3	3	3	2	2
	Flow variability, inadequate pressures	35	1	1	1	1	1	1	2	1	1	1	1
	Formation of disinfection byproducts	36	1	1	1	1	1	1	2	1	2	1	1
	Groundwater intrusion (salinity)	37	1	3	2	2	2	2	1	2	2	2	2
	Human or livestock access, absence of exclusion	38	2	1	1	1	1	1	1	1	1	1	1
	Lack of seperation between storm water and drinking water systems	39	3	3	2	2	2	1	2	1	2	2	2
	Inappropriate materials and coatings or material failure	40	1	4	2	2	1	1	3	2	2	2	1
	Pipe bursts or leaks	41	4	4	3	3	2	2	3	1	2	3	2
	Sabotage and natural disaters	42	5	4	3	3	3	3	4	2	2	3	3

Key

1 Insignificant 2 Minor 3 Moderate 4 Major 5 Catastrophic

Each of these hazards or hazardous events may be a risk to the public health, environment and operations. Therefore, the consequences of the hazards or hazardous events to the public health, environment and operations had been assessed separately. When considering the public health risks, the selected water quality parameter is pathogens (E coli as surrogate parameter) (NRMMC-EPHC-NHMRC, 2006). There is then only one assessment required to make sure the safety of public health which is for the pathogens. Hence, the consequences for the hazards on public health were selected based on pathogen concentrations.

The consequences to the environment due to certain hazards or hazardous events have to be assessed by considering multiple water quality parameters such as phosphorus, iron, salinity, sodium, chloride, chlorine disinfection residuals and hydraulic loading rate. This is because these hazards or hazardous events may have different consequences on different parameters. For example, "chemical use in catchment area (Hazard ID – 1)" is given "major impact (4)" for cadmium as cadmium is harmful to the environment than the other parameters selected as causing environmental hazards. The highest consequence out of different consequences is selected as the consequence of the particular hazard or hazardous event on the environment ignoring the lower consequences. Therefore "chemical use in catchment area (Hazard ID – 1)" is given the consequence "major impact (4)".

Similarly, each hazard or hazardous event is assessed for consequences on the operational risks by choosing the highest consequence of the hazard or hazardous event making on suspended solids, coarse particles, phosphorous and hardness.

c) Assessment of risk

Combining likelihood and consequences (Qualitative Risk=Likelihood X Consequence), the qualitative risks were assessed for the stormwater subsystem. Tables 5.14, 5.15 and 5.16 show the results of the risk assessment of the stormwater subsystem related to public health, environment and the operational infrastructure for already identified hazards or hazardous events. The have been allocated different risk levels as low, moderate, high and very high. Only the hazard identification numbers are written in Table 5.14 to Table 5.16, and therefore it is necessary to refer to Table 5.10 to recognise the hazard description related to hazard identification numbers.

Table 5.13: Measures of consequences – Combined water sub system

Hazard zone	Hazard Description	Hazard ID	Public health risks	Environmental risks							Operational risks				
			Pathogens	Phosphorus	Iron	Salinity	Sodium	Chloride	Chlorine disinfection residuals	Hydraulic loading rate	Suspended solids	Coarse particles	Iron	Phosphorus	Hardness
Stormwater injection point	Wear and tear of stormwater injectors leading change of injection pressure	101	1	2	2	2	2	2	1	1	2	1	2	2	2
	Variability of stormwater injection pressure due to variations of presssure of recycled water	102	1	2	2	2	2	2	1	1	2	1	2	2	2
	Faulty pressure gauges / expiration of calibration certificates	103	1	2	2	2	2	2	1	1	2	1	2	2	2
	Blockages of injectors/nozzles with debris	104	1	2	2	2	2	2	1	1	2	1	2	2	2
	Physical damages to injector equipment	105	1	2	2	2	2	2	1	1	2	1	2	2	2
	Malfunction of injector pressure pumps	106	1	2	2	2	2	2	1	1	2	1	2	2	2
	Pressure variations due to extreme temperature variations (seasonal)	107	1	2	2	2	2	2	1	1	2	1	2	2	2
	Malfunction of air release valves leading to difficulty in maintaing of pressures	108	1	2	2	2	2	2	1	1	2	1	2	2	2
	Power outages	109	1	2	2	2	2	2	1	2	2	1	2	2	2
	Human errors during pressure monitoring	110	1	2	2	2	2	2	1	2	2	1	2	2	2
Mixing zone of two types of water(recycled water and	Pressure variations of mixing of two types of water	111	1	2	2	2	2	2	1	1	2	1	2	2	2
	Temperature variations (seasonal)	112	1	2	2	2	2	2	1	1	2	1	2	2	2
	Pipe settlements in poor soil conditions	113	1	2	2	2	2	2	1	1	2	1	2	2	2
	Leaking pipes and pipe joints	114	1	2	2	2	2	2	1	1	2	1	2	2	2
	Malfunction of air release valves leading to difficulty in maintaing of pressures	115	1	2	2	2	2	2	1	1	2	1	2	2	2
	Power outages	116	1	2	2	2	2	2	1	1	2	1	2	2	2
	Human errors during monitoring	117	1	2	2	2	2	2	1	2	2	1	2	2	2
Distribution system, application and receiving environments	Biofilms,sloughing and resuspension,regrowth	118	3	3	2	1	1	1	3	1	3	2	3	3	2
	Buildup of sediments and slimes (eg following period of low use)	119	1	2	2	2	2	2	2	1	3	3	2	2	3
	Change in biodiversity from increased nutrients applied in combined water	120	1	4	1	1	1	1	1	1	1	1	1	4	1
	Deliberate or inadvertent misuse of combined water	121	4	1	1	1	1	1	1	1	2	1	1	1	2
	Eutrophication of receiving waters	122	3	4	1	1	1	1	1	1	1	1	1	4	1
	Failure to identify recycled water systems(below and above ground components)	123	4	1	1	1	1	1	1	1	1	1	1	1	1
	Flow variability, inadequate pressures	124	1	1	1	1	1	1	1	2	2	1	1	1	1
	Formation of disinfection byproducts	125	1	1	1	1	1	1	1	1	2	1	1	1	2
	Groundwater intrusion (salinity)	126	1	1	1	2	2	2	1	2	1	1	1	1	2
	Human or livestock access, absence of exclusion	127	2	1	1	1	1	1	1	1	1	1	1	1	1
	Inadequate repair and maintenance, inadequate system flushing	128	2	2	2	2	2	2	1	1	2	2	2	2	2
	Lack of seperation between recycled water and drinking water systems	129	4	1	1	1	1	1	1	1	1	1	1	1	1
	Inappropriate materials and coatings or material failure	130	1	2	1	1	2	2	2	1	3	2	1	2	2
	Pipe bursts or leaks	131	4	3	2	2	2	2	2	2	3	1	2	3	2
	Poor cross-connection control and backflow protection of higher quality water sources (eg drinking water)	132	5	1	1	1	1	1	1	1	1	1	1	1	1
	Poor cross-connection control and backflow protection of recycled water from lower quality water sources	133	4	2	2	2	2	2	2	1	2	1	2	2	2
	Raised water tables, salination, soil structure decline	134	1	1	1	2	2	2	1	2	1	1	1	1	1
	Sabotage and natural disaters	135	5	3	3	3	3	3	1	3	3	2	3	3	2
	Soil, groundwater or surface water contamination by combined water	136	4	2	2	2	2	2	2	2	2	2	2	2	2
	Toxicity to plants, terrestrial or aquatic biota	137	1	3	1	2	2	2	2	1	1	1	1	3	1
	Waterlogging of plants	138	1	2	2	2	2	2	2	3	1	1	2	2	1

Key

1 Insignificant 2 Minor 3 Moderate 4 Major 5 Catastrophic

As an example, hazard ID number 21 in Table 5.10 is “significant flow variations through water treatment system”. Likelihood is D which is likely to occur (Table 5.10). The consequence is insignificant related to public health. Therefore, hazard ID-21 is given the consequence number 1 which is assigned to hazards making “insignificant” consequences (Table 5.12). Combination of likelihood (which is D in Table 5.10) with the consequence (which is 1 in Table 5.12) in the risk matrix (Table 5.14) hazard ID-21 is put into the low risk category related to public health. This is further elaborated below.

Table 5.14: Qualitative risk estimation – Public health – Stormwater sub system

Likelyhood	Consequences				
	1- Insignificant	2 - Minor	3 - Moderate	4 - Major	5- Catastrophic
A - Rare		31			6,20,42
B - Unlikely	40	38	22,39	4,27,28	8,11,12,13,15
C - Possible	7,18,37	33	5,26,23	14,17	
D - Likely	9,16,21,29,35		3,24,32	41	25
E - Almost certain	1,34,36		2,10	30,19	

Key

Low Moderate High Very high

Hazard ID-21:

Hazard ID-21: Significant flow variations through water treatment system Table 5.10

Likelihood is “Likely to occur which is D” Table 5.10

Consequence is “Insignificant which is 1” Table 5.12

Qualitative Risk level is “ Low ” Table 5.14

Similarly, qualitative risk assessment for hazard ID-8 is expanded below.

Hazard ID-8: Major spills and accidental spillage Table 5.10

Likelihood is “Possible to occur which is B” Table 5.10

Consequence is “Catastrophic which is 5” Table 5.12

Qualitative Risk level is “ Very High ” Table 5.14

Tables 5.15 and 5.16 were prepared for environmental health and operational infrastructure respectively.

The risks identified for stormwater subsystem in Tables 5.14, 5.15 and 5.16 as low are acceptable. For the hazards or hazardous events making moderate, high and very high risks have to be further considered to take preventive measures as explained in Element 3. Table 5.17 summarises moderate, high and very high risks on public health, environmental health and operational infrastructure in stormwater subsystem taking the highest level of risk into consideration.

Table 5.15 Qualitative risk estimation – Environmental health - Stormwater subsystem

Likelyhood	Consequences				
	1- Insignificant	2 - Minor	3 - Moderate	4 - Major	5- Catastrophic
A - Rare		31		20	6,42
B - Unlikely	13,27,38	12	11,28,39	4,15	8,40
C - Possible	17	7,14,18,26	33,37	23	5
D - Likely	29,35	9,16	3,21,24,32	25	41
E - Almost certain	19,22,36	34	2,10	1	30

Key

Low   Moderate   High   Very high

Table 5.16 Qualitative risk estimation – Operational infrastructure - Stormwater subsystem

Likelyhood	Consequences				
	1- Insignificant	2 - Minor	3 - Moderate	4 - Major	5- Catastrophic
A - Rare		6,31	20	42	
B - Unlikely	13,27,38	12,39	4,8,11,15,28,40		
C - Possible	17,26,37	7,14	5,23,33	18	
D - Likely	16,25	29,35	3,21,24,32,41	9	
E - Almost certain	19	22,36	1,10,30,34	2	

Key

Low   Moderate   High   Very high

Similar to the above exercise carried out for stormwater subsystem, by combining likelihood and consequences (Qualitative Risk=Likelihood X Consequence), the qualitative risks are assessed for combined water subsystem. Tables 5.18, 5.19 and 5.20 give the risk assessment of combined water subsystem related to public health, environment and the operational infrastructure for already identified hazards. They are allocated different risk levels as low, moderate, high and very high.

The risks identified for combined water subsystem in Tables 5.18, 5.19 and 5.20 as low are acceptable. For the hazards or hazardous events making moderate, high and very high risks have to be further considered to take preventive measures as explained under Element 3. Table 5.21 summarises moderate, high and very high risks on public health, environmental health and operational infrastructure in combined water subsystem taking the highest level of risk into consideration.

Table 5.17: Qualitative risks in Stormwater subsystem (moderate, high and very high)

RISK ID		RISK DESCRIPTION
MODERATE	7	Major fires (firefighting chemicals)
	16	Formation of disinfection byproducts
	22	Birds and vermin
	29	Inadequate storage
	35	Flow variability, inadequate pressures
	36	Formation of disinfection byproducts
	39	Lack of seperation between storm water and drinking water systems
MAJOR	3	Flushing of pipes and internal discharge
	4	Inadequate buffer zones
	6	Leaching from existing waste disposal
	10	Road washing
	20	Sabotage and natural disaters
	21	Significant flow variations through water treatment systems
	24	Climatic and seasonal variations (heavy rainfalls, droughts)
	26	Leakage from storage to groundwater
	27	Livestock access
	28	Inadequate buffer zones and vegetation
	32	Short-circuiting of wetland
	33	Biofilms, sloughing and resuspension,regrowth
	34	Buildup of sediments and slimes (eg following period of low use)
	37	Groundwater intrusion (salinity)
	42	Sabotage and natural disaters
CATASTROPHIC	1	Chemical use in catchment areas
	2	Climate and seasonal variations
	5	Industrial discharges
	8	Major spills and accidential spillage
	9	poorly vegetated riparianzones and soil erosion
	11	Sewage overflows
	12	Unrestricted livestock
	13	Disinfection malfunctions
	14	Equipment malfunctions
	15	Failure of alarms and monitoring equipment
	17	Inadequate mixing of treatment chemicals
	18	Inadequate filter operation and backwash
	19	Power failures
	23	Bushfires and natural disasters
	25	Cyanobacterial blooms
	30	Public roads and accidental spillage
	40	Inappropriate materials and coatings or material failure
	41	Pipe bursts or leaks

Table 5.18: Qualitative risk estimation – Public health – Combined water sub system

Likelyhood	Consequences				
	1- Insignificant	2 - Minor	3 - Moderate	4 - Major	5- Catastrophic
A - Rare	105				135
B - Unlikely	101, 107, 120, 130			114,123, 129, 133, 136	132
C - Possible	102, 103, 104, 106, 108, 113, 115, 126, 134, 137, 138	127, 128			
D - Likely	109, 110, 112,117, 124, 125		118, 122	116,121, 131	
E - Almost certain	111, 119				

Key

Low Moderate High Very high

Table 5.19: Qualitative risk estimation – Environmental health Combined water subsystem

Likelyhood	Consequences				
	1- Insignificant	2 - Minor	3 - Moderate	4 - Major	5- Catastrophic
A - Rare		105	135		
B - Unlikely	123, 129, 132	101, 107, 114, 130, 133, 136		120	
C - Possible	127	102, 103, 104, 106, 108, 126, 128, 134	113,115,137, 138		
D - Likely	121, 125	109, 110, 124	112,116, 117, 118, 131	122	
E - Almost certain		119	111		

Key

Low Moderate High Very high

Table 5.20: Qualitative risk estimation – Operational infrastructure - Combined water subsystem

`	Consequences				
	1- Insignificant	2 - Minor	3 - Moderate	4 - Major	5- Catastrophic
A - Rare		105	135		
B - Unlikely	123, 129, 132	101, 107, 114, 133, 136	130	120	
C - Possible	127, 134	102, 103, 104, 106, 108, 113, 115, 126, 128, 138	137		
D - Likely		109, 110, 112, 116, 117,121, 124, 125	118, 131	122	
E - Almost certain		111	119		

Key

Low Moderate High Very high

5.4 PREVENTIVE MEASURES FOR COMBINED WATER MANAGEMENT (ELEMENT 3)

In the process of risk management of combined water system in the Black Forest Road South study area, it is important to identify preventive measures, which is defined as Element 3 of the risk management framework. The necessary actions to prevent significant hazards or to reduce hazards to acceptable levels in the combined water system of the study area resulting from the use of combined water are dealt with in this section. As outlined in Section 4.4, there are two components under this section as;

- Preventive measures and multiple barriers
- Critical control points

5.4.1 Preventive measures and multiple barriers

The following preventive measures were considered in this study:

- Exclusion of hazards (prevent entry or remove hazard)
- Proposed treatment measures to eliminate or reduce hazards
- Manage water usage

The proposed preventive measures are discussed seperately under recycled water subsystem, stormwater susystem and combined water subsystem.

a) Recycled water subsystem

The recycled water to the study area is planned to be supplied from the Western Treatment Plant (WTP). The treatment process already established in WTP can be considered as exclusion barriers for the recycled water subsystem. As explained in the process flow diagram of WTP in Figure 5.4, the treatment process consists of a lagoon system and a disinfection system. The lagoon system consists of a network of lagoons, wetlands, inter-tidal and shoreline areas. The detention time is 30 – 35 days. Lagoon detention can substantially reduce the numbers of pathogenic bacteria, protozoa and viruses. Detention can also lead to reductions in turbidity. Presence of vegetation in wetlands facilitates the removal of suspended solids, BOD, heavymetals and nutrients (NRMMC-EPHC-NHMRC, 2006). Before distribution of recycled water in the study area, the CWW will use the reverse osmosis process to reduce dissolved salt content of recycled water. All

Table 5.21: Qualitative risks in Combined water subsystem (moderate, high and very high)

Hazard ID		Hazard Description
Moderate	102	Variability of stormwater injection pressure due to variations of presssure of recycled water
	103	Faulty pressure gauges / expiration of calibration certificates
	104	Blockages of injectors/nozzles with debris
	106	Malfunction of injector pressure pumps
	108	Malfunction of air release valves leading to difficulty in maintaing of pressures
	109	Power failures
	110	Human errors during pressure monitoring
	124	Flow variability, inadequate pressures
	125	Formation of disinfection byproducts
	126	Groundwater intrusion (salinity)
	127	Human or livestock access, absence of exclusion
	128	Inadequate repair and maintenance, inadequate system flushing
	130	Inappropriate materials and coatings or material failure
	134	Raised water tables, salination, soil structure decline
High	111	Pressure variations of mixing of two types of water
	112	Temperature variations (seasonal)
	113	Pipe settlements in poor soil conditions
	114	Leaking pipes and pipe joints
	115	Malfunction of air release valves leading to difficulty in maintaing of pressures
	117	Human errors during monitoring
	118	Biofilms,sloughing and resuspension,regrowth
	119	Buildup of sediments and slimes (eg following period of low use)
	120	Change in biodiversity from increased nutrients applied in combined water
	123	Failure to identify recycled water systems(below and above ground components)
	129	Lack of seperation between recycled water and drinking water systems
	133	Poor cross-connection control and backflow protection of recycled water from lower quality water sources
	135	Sabotage and natural disasters
	136	Soil, groundwater or surface water contamination by combined water
	137	Toxicity to plants, terrestrial or aquatic biota
	138	Waterlogging of plants
Very High	116	Power failures
	121	Deliberate or inadvertent misuse of combined water
	122	Eutrophication of receiving waters
	131	Pipe bursts or leaks
	132	Poor cross-connection control and backflow protection of higher quality water

these treatment measures can be considered as preventive measures in the recycled water sub system.

b) Stormwater subsystem

In the proposed method of this study, it is planned to have small scale stormwater harvestiing sites along the third pipe in the study area. Proper catchment management can be considered as one of the exclusion barriers of stormwater subsystem. The bioretention system and wetlands proposed as stormwater treatment measures will eliminate the hazards that may cause to humans and environment. Vegetation in wetlands enables removal of suspended solids, BOD, heavy metals and nutrients (NRMMC-EPHC-NHMRC, 2006). Further treatment of stormwater using chlorine and UV treatment will eliminate the microbial hazards remaining after stormwater treatment in the wetlands and bio retentions.

c) Combined water subsystem

The guideline for combined water quality was proposed under Section 3.3 to specify the combined water quality requirements which is based on end user requirements. As this is a general guideline, the license agreements for specific applications will have to be made. The water quality of the combined system will be monitored along the pipeline before and after mixing of two types of water which will act as barriers or preventive measures for combined water use.

Table 5.22 shows the preventive measures, risks managed by the preventive measures, where these measures will be applied in the combined water system and the responsible agency of implementation of those measures. At the feasibility stage of the project, stakeholder risk management workshop needs to be organised when these items will be discussed and further modifications will be made to finalise this list.

5.4.2 Critical control points

5.4.2.1 General

In this section following activities are considered to identify and understand the critical control points of the combined water system.

- Specify critical control points to monitor water quality along the pipelines.
- Specify necessary testing regimes, points and frequencies for water quality
- Specify the minimum injection pressures for injection based on network modelling

- Specify the maximum pressures in the recycled water pipelines based on network modelling

Table 5.22: Summary of preventive measures

Preventive measures	Risks managed	Where applied	Responsibility	Comments
Adherence to license agreement on recycled water quality	Water quality issues reported from literature as listed in Section 3.2	Western Treatment Plant	City West Water	Water quality compliance of recycled water to the licence agreement based on proposed combined water guideline
Adherence to license agreement on stormwater quality	Water quality issues reported from literature as listed in Section 3.2	Outlet of Wetlands	Local council	Water quality compliance of stormwater to the proposed guideline derived by mass balance analysis
Potable water supply pipeline	Failure to produce stormwater of required quality	Stormwater injection point	Local council and City West Water	There is a variation of quantity and quality of stormwater. In the event of failure of stormwater quantity or quality, potable water will be injected to the third pipe to maintain the required quality to the end users.
SCADA monitoring system	Water quality deficiencies which would result in health hazard to humans and the environment	Stormwater storage, injection point and combined water pipeline downstream of injection point	Local council and City West Water	Continuous monitoring of the process of stormwater storing, injection and combined water pipeline

Preventive measures	Risks managed	Where applied	Responsibility	Comments
Certified plumbing services	Cross connections of pipework and fittings along the transmission, distribution and injection points	Pipe network	City West Water	Installation, operation and maintenance of two types of pipework and pipes and fittings within the injection point area needs to be done carefully
Signage for pipes and fittings	Cross connections resulting health hazards to humans and the environment	Storage, injection point and the pipe network	City West Water	The hazards resulting from cross connection will be addressed by proper signage to specify different pipelines and fittings
Signage for users of water in public places	Hazards by using third pipe water for human consumption	End use	End users/ Local Council	Third pipe water needs to be used for the purposes water is designed. There will be adequate signage at public places to show that this water is not suitable for human consumption and to show the purposes it is designed for.
Purple coloured pipe work and fittings	Health hazards due to accidental human consumption of third pipe water	End Use	End users and plumbers	To avoid misuse and cross connection of third pipe water by the consumers
Education programs for householders and plumbers	Health hazards to humans and environment	End Use	Local council and City West Water	To educate the consumers and plumbers for the application limitations of third pipe water

5.4.2.2 Critical Control Points Schematic diagram

The critical control points could be identified using the critical control point decision tree as outlined in the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006). The procedure is to ask questions for each hazard in Element 2 (as listed in Tables 5.17 and 5.21) as making a moderate or high or very high risk which require removal or reduction to assure the supply of safe combined water to the consumers. Proposed critical control points (CCPs) for the Black Forest Road South study area are shown in Figure 5.9 below (although only one wetland is shown for clarity). There are 9 CCPs identified in study area. Furthermore, the hazards have been categorised into zones as explained in Table 5.23 in the next section. Therefore, the CCPs are introduced to take control of hazards in these separate zones.

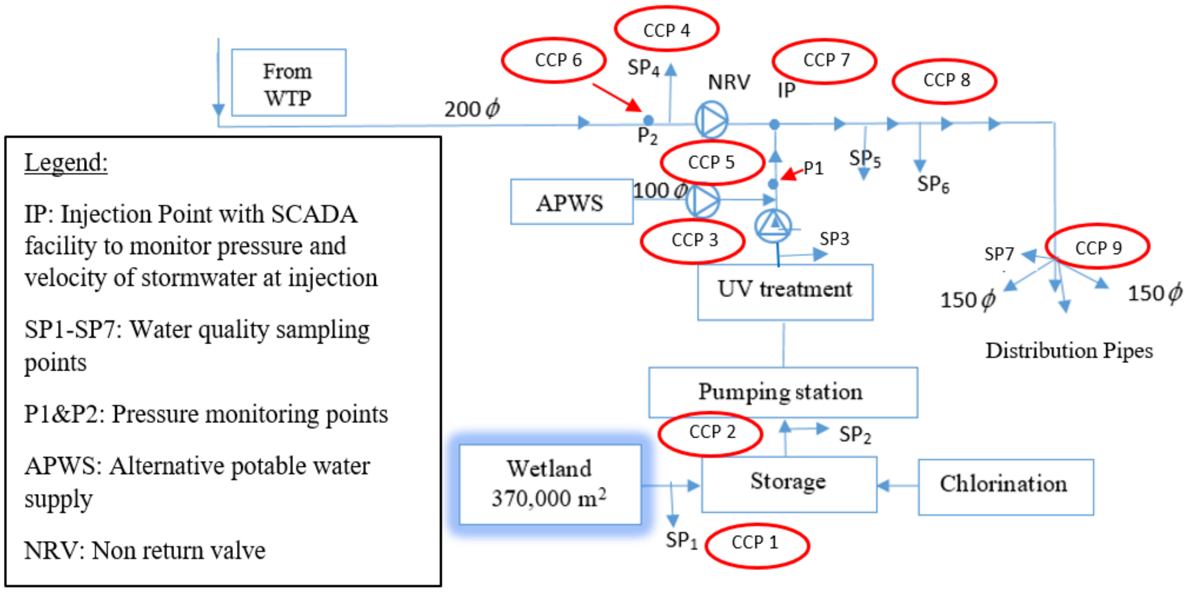


Figure 5.9: Proposed critical control points in Black Forest Road South study area

5.4.2.3 Critical Control Points (CCPs), Sampling Points (SPs), Pressure Monitoring Points (Ps) and the hazards

Critical Control Points and associated hazards are listed in Table 5.21 below. Each CCP is associated with a sampling point (SP) or a pressure monitoring point (P) as given within brackets next to the CCP number in Table 5.21. Monitoring water quality at the sampling point (SP) or monitoring pressure at pressure monitoring point (P) will enable to take the controls at CCPs. Each CCP is connected to a hazard zone. The hazards associated with each CCP are further divided as making hazards to public health, the environment and the operational infrastructure. The moderate, high and very high hazards or hazardous events as identified in Section "5.3.4 Hazard identification and Risk Assessment" and as listed in Tables 5.17 and 5.21 for stormwater subsystem and the combined water subsystem respectively, will be combined with respective CCPs as shown in Table 5.23 below.

Table 5.23: Critical Control Points and identified hazards in both stormwater subsystem and combined water subsystem

CCP	Zone (defining hazards)	Risk Level		
		Very High (Hazard ID)	High (Hazard ID)	Moderate (Hazard ID)
CCP1(SP1)	Stormwater catchments and treatment systems	1,2,5,8,9,11,12	3,4,6,10,28	7,12
CCP2(SP2)	Storage including wetlands	13,14,15,17,18,19,23, 25,30	20,21,24,26,27,32	16,18,22,29,35,36
CCP3(SP3)	Stormwater pipe from UV treatment to injection point	40,41	33,34,37,42	39
CCP4(SP4)	Recycled water pipe just before stormwater being injected	-	-	-
CCP5(P1)	Stormwater pipe just before stormwater being injected	-	-	103,104,106,108,109, 110
CCP6(P2)	Recycled water pipe just before stormwater being injected	-	-	102,103,104,108,109, 110
CCP7(SP5)	Combined water pipe at the end of mixing zone	116	111,112,113,115,117	-
CCP8(SP6)	Combined water pipe 50m downstream to mixing zone	116	111,112,113,115,118	-
CCP9(SP7)	Combined water pipe - Consumers' end	121,122,131,132	114,118,119,120,123, 129,133,135,136,137, 138	124,125,126,127,128, 130,134

CCP1: The sampling point, SP1 is located just after the wetland to make sure the stormwater catchments are not contaminated with excessive amounts of pollutants which would be beyond the level of dilution by mixing with recycled water. SP1 also ensures that sufficient treatment is carried out in the wetlands. The hazards taking place within the catchments may be chemical uses, industrial discharges, sewage overflows or unrestricted livestock in the catchments. The hazards or hazardous events denoted by hazard identification numbers under CCP 1 in Table 5.23 above are given in Tables 5.17 and 5.21. SP1 is identified as CCP1.

CCP 2: The sampling point, SP2 is placed to monitor the water quality of the storages including the wetlands to identify any potential hazards taking place in the storages including wetlands such as livestock access or accidental spillages. CCP2 is assigned to SP2. The hazards or hazardous events denoted by hazard identification numbers under CCP 2 in Table 5.23 above are given in Tables 5.17 and 5.21.

CCP 3: The sampling point, SP3 is placed to monitor the water quality of the treated stormwater ready for injection into the third pipe. The hazards or hazardous events denoted by hazard identification numbers under CCP 3 in Table 5.23 above are given in Tables 5.17 and 5.21. CCP3 is assigned to SP3.

CCP 4: The sampling point, SP4 is placed to monitor the water quality of the recycled water coming in the third pipe at a location just before treated stormwater is injected. CCP4 is assigned to SP4. As seen from Table 5.23, there are no hazards listed against CCP 4 as CCP 4 is identified in the recycled water pipe before stormwater is injected. The project uses recycled water from already operating recycled water plant (WTP). Therefore, the hazards assumed to have been assessed and managed in this system. However, all the parameters in the proposed guideline (Table 3.2) needs to be monitored at CCP 4.

CCP 5 and CCP 6: The injection pressure of treated stormwater and pressure inside recycled water pipe before mixing are important for proper mixing of two types of water. These two pressures are measured at P1 and P2 respectively, and the locations of P1 and P2 are shown in Figure 5.10. The CCPs related to these two pressure monitoring points are identified as CCP5 and CCP6 respectively. The hazards or hazardous events denoted by hazard identification numbers in Table 5.23, for CCP 5 and CCP 6 are given in Tables 5.17 and 5.21.

CCP 7 and CCP 8: This project has the most significant feature in mixing of treated stormwater with recycled water inside the third pipe. There should be a thorough mechanism to monitor the proper mixing of the two types of water within the third pipe. It was assumed, mixing of two types of water would be completed within 50 m of pipe length. 50 m of third pipe length downstream to the injection point was called as 'mixing zone'. Sampling point, SP5 is located at the end of this mixing zone, 50 m downstream to the injection point. Sampling point, SP6 is located 50 m downstream to sampling point SP5 in the third pipe as the second sampling point after mixing of two types of water. There should be no water distribution to consumers upstream of SP6. Checking of water quality parameters at these 2 sampling points (at SP5 and SP6) ensures that there is no significant change in water quality between the readings of the two sampling points. This will ensure adequate mixing has taken place inside the pipe when water reaches sampling point, SP 5. SP5 and SP6 are identified as CCP7 and CCP8 respectively. The hazards or hazardous events denoted by hazard identification numbers in Table 5.23 above for CCP7 and CCP8 are given in Tables 5.17 and 5.21.

CCP 9: The sampling point, SP7 is placed to monitor the water quality of water distribution at the consumer end. CCP 9 is assigned to SP7. The hazards or hazardous events denoted by hazard identification numbers under CCP 9 in Table 5.23 are given in Tables 5.17 and 5.21. CCP9 is assigned to SP7.

5.4.2.4 Setting limits to Turbidity, Salinity, Ecoli and water pressure monitoring

This section proposes how the controls are done in the CCPs by means of setting limits for the monitoring parameters at the CCPs. There are two limits defined here namely; the critical limits and the alert limits. The critical limits are based on the proposed guideline values. Exceedance of a critical limit indicates that the corrective actions will be in place immediately and may result in automatic closure of the combined water supply to the consumers through the Supervisory Control and Data Acquisition (SCADA) system. Alert limits are assumed to be 80% of the critical limits which will give adequate time to enforce the preventive measures. If the monitoring is done by taking water samples for checking water quality to comply with the proposed guideline values, an alert limit and a critical limit have to be defined to ensure sufficient time is available to take actions so that the particular hazard or hazardous event would be reduced to an acceptable level or eliminated completely. Similarly, if the monitoring is done by means of measuring minimum water pressure, an alert level and a critical level for pressure readings are to be defined to ensure there is adequate time to take actions against falling the water pressure below the minimum required water pressure which is needed for proper mixing of two types of water. The discussion below describes the role of the CCPs in terms of alert limits and critical limits.

Checking of the complete list of water quality parameters in the proposed guideline (Table 3.2) is required for operational and verification monitoring as explained in the next sections in this chapter (i.e. operational procedures and process control in Section 5.6 and verification monitoring in Section 5.7). For this purpose, there are frequencies of monitoring proposed in these sections. This operational and verification monitoring is done in the CCPs and the relevant schedules of monitoring are included in these sections. However, continuous monitoring of certain parameters are required to establish the risk management of the system. Those parameters are turbidity, salinity (Electrical conductivity) and Ecoli. Table 5.24 below is the list of critical control points (CCPs), alert limits and the critical limits for combined water use.

There are number of variables contributing to proper mixing of two types of water namely; diameters of recycled water pipe and treated stormwater pipe, pressures of treated stormwater and recycled water at the point of injection, and mix proportion of treated stormwater to recycled water. As given in Table 5.24 below, there is a lower limit for treated stormwater injection pressure and an upper limit for recycled water pressure for adequate mixing of the two types of water. These pressure values in the table will be used as initial values which will be verified by network modelling and will be adjusted at the time of implementation of the project to achieve proper mixing of the two types of water. These two points are critical control points as fluctuations of these pressures will lead to inadequate mixing of two types of water.

Colour is one of the monitoring parameters identified in this study. Monitoring colour is an important characteristic for customer acceptance. Colour of combined water could be monitored by visual inspection of water samples at the monitoring laboratory. Samples of combined water could be compared with previously prepared water samples of known Hazen Units (HU). The Australian Guideline for Water Recycling Phase 1 and 2 does not specify acceptable limits for colour. However, the Australian Drinking Water Guidelines 6 (2013) specifies 15 HU as the limit on aesthetic point of view. Therefore, it is suggested that three water samples of colour of 15 HU, 20 HU and 25 HU would be made available at the monitoring laboratory. Then it is possible to compare the colour of combined water samples taken at any time visually using these pre-defined samples.

Table 5.24: Critical Control Points, alert limits, critical limits and corrective actions for Black Forest Road South study Area

SP/P/CCP	Monitoring Parameter	Alert limit	Critical limit	Corrective action
SP2 (CCP2) SP4 (CCP4) SP5 (CCP7) SP6 (CCP8)	Turbidity	<1.6 NTU	<2 NTU	Consideration for inclusion of a filtration system
SP3 (CCP3) SP4 (CCP4) SP5 (CCP7) SP6 (CCP8)	Salinity	EC at 25^{0}C 520 µS/cm	EC at 25^{0}C 650 µS/cm	Adjustments to mixing ratios *and/or* Replace stormwater with potable water
P1 (CCP 5)	Treated stormwater injection pressure	< 375 kPa	< 300 kPa	Adjustments to pumps
P2 (CCP 6)	Pressure of recycled water before mixing	>160 kPa	>200 kPa	Throttling of valves
SP3 (CCP 3) SP4 (CCP 4) SP5 (CCP7) SP6 (CCP8)	Ecoli	8/100 ml	10/100 ml	Adjust Chlorination levels at treatment plant / stormwater storage
SP7(CCP9) Consumer points	Ecoli	8/100 ml	10/100 ml	Adjust Chlorination levels at treatment plant / stormwater storage

5.5 OPERATIONAL PROCEDURES AND PROCESS CONTROL OF COMBINED WATER USE (ELEMENT 4)

It is important to ensure all operations are continuously monitored and preventive measures are functional. Unexpected deviation of performance even for a shorter period may cause a risk to public health or the environment. The operational procedures and process control of the Western Treatment Plant (WTP) has already been established. Therefore this study has not discussed the operational procedures and process control of the Western Treatment Plant (WTP).

There are five components under Element 4 as explained in Section 4.5. Following sections describe these components for the combined water project in Black forest Road South study area.

5.5.1 Operational procedures

The preventive measures and the critical control points with regard to the recycled water subsystem, the stormwater subsystem and the combined water subsystem were discussed in detail under Element 3 in Section 5.4. However, an operational activity schedule needs to be prepared covering all activities in the whole combined water system. Table 5.25 which is operational activivity schedule includes the frequencies of monitoring of operational activities in the combined water system. This table has been prepared refering to the Appendix B of (Page et al. 2013).

5.5.2 Operational monitoring

Operational monitoring is routine monitoring of selected water quality parameters (NRMMC-EPHC-NHMRC, 2006). However, pressures in recycled water and treated stormwater upstream of the injection point are monitored as the mixing takes place inside the third pipe. Operational monitoring provides a timely warning, allowing corrective actions to be taken before combined water goes to the consumers. The monitoring will be done in different ways.

- Visual inspections
- Sampling and testing in the lab
- On-line monitoring using SCADA system

Table 5.26 indicates the operational monitoring parameters in the combined water project. Operational monitoring procedures of the WTP have already been established and therefore this study has not included discussion on operational monitoring procedures of the WTP. Other monitoring steps are listed in Table 5.26.

Table 5.25: Operational activity schedule in the combined water system

Operational activity	Freequency	Elements covered
Send samples to laboratory for testing and store resullts in to a database of all the water quality parameters in the proposed guideline in section 3.3	Monthly	2,3,4,5
Review of mechanical performance of stormwater injection equipment		
Cleaning any blockages to diversion structure		
Maintenance of pumps according to manufacturer's recommendations		
Compliance of materials and chemicals to the relevant Australian Standards		
Inspection of wetland flora health and plant health in irrigation areas		
Fixing of any pipe leaes or breakages		
Visual inspection of stormwater storage		
Preparation of water quality report comparing water quality of parameters against the threshholds in the proposed guideline (section 3.3) and observing the trends	Quarterly	2,3,4,5
Calibration of flow meters, pressure gauges and water quality probes	6 monthly	2,3,4,5,6
Cleaning of any screens and filters in irrigation schemes		
Inspection and maintenance of disinfection equipment		
Ensuring the safety of any fences around the stormwater storage or around the injection point facility		
Visual inspection of sources of recycled water and stormwater		
Education program for operators on operations and maitenance of the scheme		
Review of incidents log		
Review of equipment performance	Annually	2,3,4,5,6
Removal of accumilated sediments in stormwater storage and sedimentation/wetland basin		
Review of customer complaints log		
Review of land use in the new developments		
Customer education		
Submit annual report on performance to relevant authorities		
Staff training		
Actions regarding the customer complaints on water quality	As and when complaints are received from water users	2

Source: Activity schedules in Appendix B of Page et al. (2013)

Table 5.26 - Operational monitoring proposed for the Black Forest Road South study area

Process step to be monitored	Parameter	Monitoring freequency	Monitoring type	Operational monitoring	Responsibility
Recycled water treatment process (CCP6)	Pressure	Continuous	Online	Pressure should be maintained within the allowable range. This may require throttling of valves or pressure boosting at required locations	CWW
Wetlands performance (W1, W2 & W3) outlets	pH Turbidity	Weekly Weekly	Field/Lab Field/Lab	According to the constructed wetland guideline by Melbourne Water,maintenance must be implemented according to the operations plan for a minimum period of two years, at a cost to the developer, and to the satisfaction of the local council and Melbourne Water	Local council
Chlorination unit of stormwater treatment	Turbidity	Continuous	Online	Use of a SCADA system to monitor turbidity before adding chlori	Local council
	Flow rate to calculate Ct	Continuous	Online	Use of a SCADA system to monitor flowrate before add chlorine	
	Free chlorine, temperature and pH	Continuous	Online	Free chlorine monitoring using digital colorimeters at downstream monitoring point (CCP3)	
Ultraviolet unit of stormwater treatment	Turbidity	Continuous	Online	Using SCADA system to monitor turbidity upstream of UV plant	Local council
	UV transmttance	Continuous	Online	UVT monitor system and SCADA system	
	Flow rate	Continuous	Online	Using SCADA system to monitor flowrate upstream of UV plant	
	Lamp power	Continuous	Online	Using UV power meter	
Combined water performance	Turbidity	Continuous	Online	Turbidity level monitoring at sample points (CCP7,CCP8&CCP9)	CWW/Local Council
	Salinity	Continuous	Online	Salinity level monitoring at sample points (CCP7,CCP8&CCP9)	
	Colour	Daily	Visual inspection	Visual observation of colour at sample points (CCP7,CCP8&CCP9)	
	Pressure	Continuous	Online	Pressure monitoring at sample points (CCP5&CCP6)	
Cross connection hydraulic control	Pressure	Continuous	Online	Install devices for the prevention of backflow and back-siphonage. It is possible to install residential dual check backflow device for every new home.	CWW
Cross connection plumbing control	-	Annually	Visual inspection	Educate public and plumbers regarding the prevention methods of cross connection and possible hazards due to cross connection. Random plumbiing checks on existing homes.	CWW

Source: Table 5.4 and 5.6 of NRMMC-EPHC-NHMRC (2006), Table 3.5 of NRMMC-EPHC-NHMRC (2009) and Melbourne Water (2010)

5.5.3 Operational corrections

The corrective actions need to be taken when the combined system is operating outside the normal operating conditions. After implementing a corrective action, its effectiveness will need to be verified through additional monitoring. Following control methods are proposed for the Black Forest Road South study area as the operational corrections in the combined water system.

- Wetland level controls: Automatic water level control can be set to stop pumping water from the wetland, when wetland water level reaches to 100 mm below Normal Water Level (NWL), as per the guidance of Constructed wetlands design manual by Melbourne Water (Melbourne Water, 2010).

- Treated stormwater tank level controls: When the water level in the storage tank is at minimum level, it is possible to stop pumping automatically (pumps are used to inject stormwater into the recycled water pipe).
- Treated stormwater pressure (injection pressure) controls: Injection pressure is proposed to be controlled automatically by pump flow rate through online sensors. Injection pressure can be monitored through critical control point CCP5.
- Treated stormwater turbidity controls: When turbidity level at CCP3 is higher than 2 NTU for longer than 30 minutes continuously, it is proposed to set up automatic stop of stormwater injection.
- Salinity control: When salinity level of stormwater exceeds the recommended value (i.e. 1000 mg/L of TDS) at CCP3, it is proposed to automatic switch to potable water to replace stormwater supply.

After implementing a corrective action, it is necessary to verify its effectiveness through additional monitoring. Possible corrective actions at critical control points are listed in Table 5.24. Also it is important to identify cause of the problem and implement measures to avoid future occurrence of the same.

5.5.4 Equipment capability and maintenance

All equipment used in the combined water project should be purchased from reputed manufacturers and should be calibrated in a timely manner. The equipment performance should be monitored to ensure the satisfactory operations. Regular assessments are made to verify the equipment are working in good order and to the targets they are designed for. Maintenance of all equipment in the stormwater subsystem is the responsibility of the local government council. It is the responsibility of the local government council to appoint qualified staff for maintaining equipment in the stormwater subsystem and proper training must be given to the staff. Also it is the responsibility of CWW for maintaining equipment in the combined water subsystem.

Guidance on maintenance can be obtained from the following documents.

- Australian Guideline for Water Recycling phase 1 (NRMMC-EPHC-NHMRC, 2006)

- WSUD Maintenance Guideline by Melbourne Water (Melbourne Water, 2013)
- Constructed Wetlands Guideline by Melbourne Water (Melbourne Water, 2010)
- Guidelines for validating treatment processes for pathogen reduction by Department of Health (DoH), Victoria (DOH-VIC, 2013)
- Pump maintenance handbook by manufacturers (For example: GRUNDFOS Handbook)

5.5.5 Materials and chemicals

Selection of materials and chemicals used in the combined water system is very important, as it may have an adverse impact on combined water quality. Good quality materials and chemicals, and their correct dosages used in the Western Treatment Plant process has been already identified and therefore this study has not discussed about the materials and chemicals used in the Western Treatment Plant. Therefore, this section discusses the use of good quality materials and chemicals, and their dosages to be used only in the stormwater subsystem. It is important to calculate the correct dosages of materials and chemicals to be used in the stormwater subsystem, and it is the responsibility of the local government council to adhere to these rules. Only materials and chemicals certified according to the AS/NZS ISO9001 (2008) should be used in the stormwater subsystem. All chemicals used in treatment processes have to be stored securely to avoid any spills or leakages to the environment.

5.6 VERIFICATION OF COMBINED WATER QUALITY AND ENVIRONMENTAL PERFORMANCE (ELEMENT 5)

Under Element 5, verification of the combined water quality is made to assure the public safety and to make sure there are no detrimental effects on the environment where the combined water is used. Overall performance of the system and combined water quality received by the end user is assessed through verification monitoring. Microbial monitoring is used to verify that water quality meets the targets for microbial indicators (NRMMC-EPHC-NHMRC, 2009). Verification monitoring for environmental risks involves assessing the final quality of combined water discharged on the receiving environment, which includes soil, plants, groundwater and surface water. There are six components included under Element 5 in the Australian Guidelines for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006), as given below.

1. Recycled water quality monitoring
2. Application site and receiving environment monitoring
3. Documentation and reliability
4. Satisfaction of users of recycled water
5. Short-term evaluation of results
6. Corrective responses

5.6.1 Combined water quality monitoring

Table 5.27 specifies the proposed selected parameters for combined water quality verification monitoring from the listed parameters in the proposed guideline in Section 3.3. The water quality of the combined system depends on the water quality of the two individual subsystems (i.e. the recycled water subsystem and the stormwater subsystem). The testing of water samples should be carried out at accredited laboratories. Table 5.27 provides information on combined water quality monitoring proposed for the Black Forest Road South study area, including selected monitoring parameters, proposed locations and freequency of monitoring.

It is necessery to audit calibration activities and operational monitoring activities monthly and audit preventive maintenance activities annually as part of the verification monotoring program.

5.6.1 Application site and receiving environment monitoring

End point of the combined water may be soil, surface water and/or groundwater. Garden watering (including use on vegetable gardens), municipal irrigation (parks, sporting fields and other public open spaces) and general outdoor use (including pressure cleaning and washing cars, construction and wash down) are some of the intended uses of recycled water as identified by CWW. Same intended uses have been selected for the use of combined water. Therefore, monitoring of the environment including plants, soils, surface water and groundwater to check any adverse effects by using combined water is important. Soil analysis is needed to verify that the soil continues to remain fit for its intended uses. As per the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006), the type of soil testing required and the sample depth depend on

- Land used or plants to be grown
- Water quality
- Soil properties and type

Table 5.27 - Verification monitoring program for the combined water project Black Forest Road South study area

Location	**Sample Point**	**Frequency**	**Analysis method**	**Selected parameter**	**Responsibility**	**Remarks**
Recycled water pipe before injection of stormwater	SP4/CCP4	Monthly	Grab sample	Turbidity, Electrical Conductivity and Ecoli	CWW	As per the proposed guideline in Section 3.3
Stormwater outlet pipe before injection	SP3/CCP3	Monthly	Grab sample	Nutrients, Metals, TDS and Ecoli	Local City Council	As per the proposed guideline in Section 3.3
Combined water pipe 50m downstream to SP5	SP6/CCP8	Continuous	On-line analyser	Chlorine disinfection residual, Salinity (EC / TDS)	CWW	As per the proposed guideline in Section 3.3
Combined water pipe 50m downstream to SP5	SP6/CCP8	Weekly	Grab sample	Ammonia, Fe, colour and Ecoli	CWW	As per the proposed guideline in Section 3.3
Combined water pipe 50m downstream to SP5	SP6/CCP8	Monthly	Grab sample	All parameters included in the proposed guideline in section 3.3 [a]	CWW	As per the proposed guideline in Section 3.3
Consumer points	SP7/CCP6	Monthly	Grab sample	Ecoli, Chlorine disinfection residual Colour and turbidity	CWW	As per the proposed guideline in Section 3.3

Source: Table 5.6 and 5.8 of NRMMC-EPHC-NHMRC (2006) and Table 20 of Page et al. (2013)

[a] - Parameters included in the guideline in Section 3.3 are ammonia(NH3) chloride, colour App Pt/Co units, EC at 25 oC µS/cm, pH, SAR (Sodium Adsorption Ratio), sulphate, suspended solids, total Alkalinity mg CaCO3 / L, total dissolved solids (TDS), turbidity, aluminium, arsenic, barium, boron, cadmium, calcium, copper, iron, lead, magnesium, manganese, mercury, nickel, sodium, zinc, total organic carbon (TOC), campylobacter (bacteria), E coli, cryptosporidium, total Nitrogen, total phosphorus

As a tributary of the Lollypop Creek is running across the Black Forest Road South study area, it is recommended to do surface water monitoring in this tributary. Based on the information in Table 5.9 and Table 5.11 of (NRMMC-EPHC-NHMRC, 2006), it is recommended to do soil sampling and surface water sampling annually in the study area as outlined in Table 5.28 below.

Table 5.28: Sampling program for verification monitoring of environmental hazards in soil and surface water in Black Forest Road South study area

Selected parameter		Frequency	Location	Responsibility
Soil sampling	pH	Annually	Randomly selected areas of Black Forest Road South PSP	CWW
	Salinity (electrical conductivity)			
	Sodium absorption ratio (SAR)			
	Cadmium			
	Nitrogen (total)			
	Phosphorus			
	Boron			
Surface water sampling	pH	Quarterly (pH and phosphorus after intense rainfall event as well)	Tributary of Loiiypop Creek close to Black Forest Road South area	CWW
	Salinity (electrical conductivity)			
	Nitrogen (total)			
	Phosphorus			
	Aluminium			
Groundwater sampling	pH	Annually (Once in four years for chloride, sodium, magnesium, sodium absorption ratio (SAR), iron and aluminium)	Randomly selected areas of Black Forest Road South PSP	CWW
	Salinity (electrical conductivity)			
	Nitrogen (total)			
	Phosphorus			
	Nitrate			

Source: Table 5.9, 5.10 and 5.11 of NRMMC-EPHC-NHMRC (2006)

There is no direct application of combined water into groundwater in the Black Forest Road South study area. Hence it is possible to decrease the sampling frequency than what is recommended in Table 5.10 of (NRMMC-EPHC-NHMRC (2006) which is annual sampling.

5.6.2 Documentation and reliability

Monitoring data has to be representative and reliable (NRMMC-EPHC-NHMRC, 2006). Once water quality parameters and sampling locations have been identified (Table 5.28), it is necessary to document these properly. Procedures for sampling and testing should also be documented. The details of testing agencies and their accreditations, details of testing equipment, calibration certificates of the equipment and the capabilities of the testing personnel should be included in the documentation.

5.6.3 Satisfaction of users of combined water

Customer satisfaction and feedback from the customers are key factors for the success of a combined water project. Also from the customer's complaints, it is possible to identify the water quality issues, which may not have been identified during the risk assessment of the combined water project.

Existing customer request management system of recycled water projects by CWW can be extended to combined water project. The procedures for dealing with customer complaints in the Black Forest Road South study area should be documented. Customer complaints have to be compiled annually and reviewed for the improvements of the combined water project.

5.6.4 Short-term evaluation of results

Procedures for performance evaluation and recording of water quality results should be established and documented (NRMMC-EPHC-NHMRC, 2006). The monitoring data from the study area should be entered and processed into a suitable database software to check the variations and trends of water quality parameters. The results should be reviewed by CWW within appropriate timeframes (e.g. once a week) and reported to regulatory agencies such as EPA Victoria and Department of Health and Human Services, if the combined water quality is not within the target criteria.

5.6.5 Corrective responses

When short term (e.g. weekly) evaluation of verification monitoring of water quality data indicates non-conformance to the proposed combined water quality guideline values, reasons causing the issues should be investigated. If necessary, corrective actions should be implemented immediately (NRMMC-EPHC-NHMRC, 2006). Corrective actions have to be taken in consultation with relevant regulatory agencies such as EPA Victoria and Department of Health and Human Services, and other stakeholders.

5.7 MANAGEMENT OF INCIDENTS AND EMERGENCIES (ELEMENT 6)

When unexpected incidents or emergency situations occur, there must be a process to respond to them efficiently. The incidents and the emergencies of the combined water system are categorised into different types based on the severity of those incidents and emergencies. As per the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006), there are two areas to cover under Element 6.

1. Communication
2. Incident and emergency response protocols

5.7.1 Communication

The time taken for the responses for incidents and emergencies will determine how efficient the communications are. The reputation and confidence on the water authority from the public will greatly depend on how the unexpected situations are handled and communicated. Following are the guiding principles for the effective communication according to the Australian Guideline for Water Recycling Phase 1 (NRMMC-EPHC-NHMRC, 2006), which can be used for the combined water project in this study.

- Be truthful and empathic, to reduce the risk of negative public perceptions.
- Put public health and the water recycling customers first.
- Deal with the crisis as quickly as possible.
- Speak with one voice — the face of the spokesperson may change, but all messages about the crisis must be consistent and come from a coordinated communications effort.
- If appropriate information is not available to answer questions accurately, say so.
- Inform customers about the crisis and the water recycling organisation's actions to resolve it.
- Do not guess.

It is important to prepare contact list including regulatory agencies, emergency services and media. Table 5.29 shows the proposed emergency contacts for the Black Forest Road South study area. Contact list should include relevant officers name and contact number including after working hours contact and the contact list should be updated regularly (e.g.once in three months).

It is necessery to appoint a trained and authorised person in CWW to handle all communications during the incident or emergency. Until the crisis is properly resolved or contained, the communications strategy must be of high organisational priority. The confidence on the water authority from the consumers will greatly depend on how the unexpected situations are handled and communicated (NRMMC-EPHC-NHMRC, 2006).

Table 5.29: Proposed Emergency contact list for the Black Forest Road South study area

Emergency Services	Authorised organisations and Regulatory agencies	Other relevant organisations
Werribee Police station	City West Water	Media including local newspaper, radio and TV
Metropolitan Fire & Emergency Services Board	Wyndham City Council	Service providers including electricity, gas, water and sewer
Victoria State Emergency Service	Environmental Protection Authority (EPA) Victoria	Emergency Relief and Recovery Victoria
Ambulance Victoria	Department of Health and Human Services	Emergency Services Telecommunications Authority (ESTA)

5.7.2 Incident and emergency response protocols

All possible incidents and emergiencies as explained in Section 4.7.2, have to be identified for the Black Forest Road South study area. All identified incidents and emergencies, and response protocols should be developed to ensure public and environmental safety. These protocols should be developed in consultation with the relevant regulatory authorities and other key agencies, and should be consistent with existing government emergency response arrangements (EPA Victoria, 2005). The communication and notification of protocols are also important. Table 5.30 shows the identified incidents and the proposed emergency response protocols for the Black Forest Road South study area.

As seen from the Table 5.30, CWW and the local council are responsible to report the incidents to the responsible aencies. Both type 1 and type 2 incidents should be recorded in incident recording logs. It is necessery to review emergency response protocols periodically. Training of employees is important to handle emergency situations effectively.

Table 5.30- Emergency response protocols for the Black Forest Road South study area

Incident Identified		Indication	Classification	Response actions	Responsibility
1	Non-compliance with health related water quality objectives (microbiological monitoring results)	E coli > 1000	Type 1	Report immediately to Department of Health & Human Services	CWW
		E coli > 100	Type 2	Report within 24 hours to Department of Health & Human Services	CWW/Local Council
2	Incidents that increase the levels of potentially harmful contaminants or cause failure of treatment systems (such as spills, illegal discharges or incorrect dosing of chemicals)	Non-conformity with proposed guideline values	Type 2	Report within 24 hours to EPA Victoria	CWW/Local Council
3	Sewage overflows/spills discharged to the wetland through stormwater catchment	Sewage spills ≥ 100 kL	Type 1	Report immediately to Department of Hea	CWW/Local Council
		Sewage spills < 100 kL	Type 2	Report within 24 hours to Department of H	CWW/Local Council
4	High or Low pH in wetland outlet	Non-conformity with proposed guideline values	Type 2	After monitoring some time, if unacceptable, report EPA Victoria within 24 hrs	CWW/Local Council
5	Cyanobacterial (blue-green algae) blooms in storages	Visual observation	Type 2	After monitoring some time, if unacceptable, report EPA Victoria	Local Council

Source: Table 21 of Page et al. (2013)

5.8 SUMMARY

The Black Forest Road South Study Area in West Werribee (PSP 42.2) in Victoria, Australia is demarcated by City West Water to implement a third water supply project using the risk management framework proposed in this study. Recycled water produced by the existing Western Treatment Plant is used to combine with treated stormwater. Stormwater will undergo a process of treatment and disinfection to a level the risks of combined water to humans and environment are reduced to acceptable limits. The hazards of all stages of combined water production and distribution were identified, the associated risks were assessed, and risk management strategies were proposed. They were documented in this chapter. However, the risks of the recycled water system were not discussed as Western Treatment Plant is an existing plant and the associated risks to the intended uses were assumed to be identified and managed already to acceptable levels.

The risk management framework proposed for the study area consisted 12 Elements which were further categorised into four interrelated components. First component was commitment to responsible use and management of combined water which consisted only one element (Element 1). The second component was system analysis and management which consisted five elements (Elements 2 to 6). Third component was supporting requirements which consisted Elements 7 to 10. The fourth component was review (Elements 11 and 12).

Component 2 of the risk management framework which consisted of Elements 2 to 6 relates to a project at the planning stage. Other components of the framework relates to a project during implementation stage. Therefore, during this thesis only the component 2 of framework (which consisted Elements 2 to 6) was studied in detail which was explained in this chapter.

The sections under Element 2 of the framework discussed in detail for application to the study area were; the water sources, water system analysis, assessment of water quality data and hazard identification and risk assessment.

The Western Treatment Plant (WTP) in Werribee, Melbourne which is owned and operated by Melbourne Water, is the recycled water source. High quality "Class A" recycled water is produced by the WTP, which has a unique treatment process. Stormwater will be collected from the newly developed areas in the Black Forest Road South Study Area. Stormwater is planned to be harvested at various locations along the recycled water pipe (i.e. third pipe) and treated stormwater will be injected into the third pipe which carries recycled water.

All potential hazards and hazardous events for the Black Forest Road South Study Area were identified and documented for each component of the stormwater subsystem and combined water subsystem. The likelihood of happening of hazards and hazardous events was assessed. Then the impacts or the consequences of these hazards (if happens) were assessed. The likelihood and consequences of the hazards were combined into a risk matrix to estimate assessment of the risks in the two subsystems. From this risk matrix it is possible to identify the hazards leading to high and very high risk.

Element 3 of the framework described the preventive measures and multiple barriers and the Critical Control Points (CCPs) to remove or reduce the hazards leading to high risks in the system. CCPs are essential to prevent hazards or reduce the risk to an acceptable level were identified throughout the whole system. There are four CCPs identified in the stormwater subsystem in different zones within the subsystem. The water quality parameters and water injection pressure are monitored to at these CCPs to reduce the risks as identified from the risk matrix. In terms of the recycled water subsystem, there are two CCPs identified upstream to the stormwater injection point where recycled water quality and pressure are monitored. There are three CCPs identified in the combined water subsystem in different zones of the combined water subsystem, two of which will ensure adequate mixing. The key factors for proper mixing of treated stormwater with recycled water are the stormwater injection pressure and the pressure of recycle water immediately before the treated stormwater injection point.

Element 4 of the risk management framework (which is the operational procedures and process control) has identified the operational activities in the whole system which are to be monitored for successful and continuous combined water supply to the customers. Verification of combined water quality and environmental performance was Element 5 of the risk management framework. A verification monitoring program was prepared to include the monitoring parameters, frequencies of monitoring and the responsible agency in monitoring. Water sampling program was prepared. The Element 6 described how the incidents and emergencies are managed. This element included the communication requirements and incident and emergency response protocols during such incidents and emergencies. List of emergency services and the agencies to take actions during such occasions were listed. All contact details of the relevant personnel are needed to be included during project implementation stage and updated frequently to have the most up to date information

6 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY

6.1.1 General

The use of combination of recycled water and treated stormwater with injection of treated stormwater into the ‘third’ pipe, which carries recycled water was studied in this thesis. This injection strategy is a novel approach for mixing two types of water which has significant benefits compared to the conventional dedicated enclosed mixing spaces. A guideline for use of combined water was developed which could be used in any project with amendments suitable for the local conditions. A risk management framework was developed which could be used for the combined water system to eliminate or reduce the hazards to acceptable levels anticipated in the water system from source to the user. Only the elements which are relevant to the combined water systems at the planning stage have been considered in this study. The other elements have been listed which need to be considered at the time of project implementation. The salient points in this process of development of water quality guideline and the risk management framework for combined water use are summarized below.

6.1.2 Literature review

The literature review of projects using recycled water and treated stormwater separately in Australia and overseas were considered as the starting point in this thesis. There were few projects using both types of water in combination overseas. However, this study reviewed three combined water projects operating in Australia in detail. They were Sydney Olympic Park Project, Mawson Lakes Project and Inkerman D'Lux Apartment Development project, which were reviewed to identify the benefits, and the issues and challenges of use of two types of water in combination.

The most common benefit of the three Australian projects mentioned above using both types of water in combination is the reduction in potable water demand which saves production cost to the water authority which will then be passed to the consumer. Obviously, saving the high quality drinking water for higher level applications is contributing to the global water use. In the Sydney Olympic Park project and the Mawson

Lakes project, the potable water demand is reduced by 50%, whereas in the Inkerman D'Lux Apartment Development project has a potable water reduction by 40% in summer and 20% in winter. The issues identified in these projects were important to consider for the development of the proposed guideline.

6.1.3 Development of the guideline for combined water quality

This study developed a guideline on water quality of combined water, as such a guideline was not available in Australia or elsewhere to the authors' knowledge. However, it was required to propose a method to calculate the water quality of the mix, using the individual water quality of recycled water and stormwater. Therefore, this study also completed investigation of the appropriateness of the mass balance analysis to calculate water quality of the mix.

Selection of the water quality parameters in the developed guideline was made by reviewing the available literature and understanding the issues such as corrosion, colour, and odour brought to the end user caused by these parameters exceeding the limits (or thresholds). Limits were developed considering the existing guidelines for recycled water and stormwater, but considering various commonly used end use categories.

The mass balance analysis could be used to estimate the water quality of combined water with respect to water quality parameters. This was proved by doing laboratory testing on samples of combined water covering the whole range of potential mixes of recycled water and stormwater and comparing the results with results obtained from the mass balance analysis for the same mixes. The results showed that the water quality obtained from the two methods were within the measurement uncertainties for all tested water quality parameters except for very few variances. Based on the laboratory tests conducted, it was concluded that the mass balance method could be used to calculate the water quality of combined water with respect to water quality parameters.

6.1.4 Development of risk management framework

A risk management framework was proposed which could be implemented in any project using combination of recycled water and stormwater within Australia or overseas with required modifications to suit the local conditions. This is a framework with shared responsibilities among all parties involved including the water users. This framework has

13 elements which could be further grouped into four major sections; Commitment to responsible use and management, system analysis and management, supporting requirements and review. This study focused only on the section of system analysis and management (Elements 2 to 6) which was relevant to a project at the planning stage. The study area which was selected to apply this risk management framework as explained in the next section is in the planning stage at the time of this study. In the course of this study, risks anticipated in the entire combined water system were identified and preventive measures necessary to assure safe and reliable use of recycled water were proposed. The other three sections of the framework are to be dealt with during the implementation stage of the projects. This risk management framework was then applied to Black Forest Road South Study Area.

6.1.5 Application of risk based framework to Black Forest Road South Study Area

The Black Forest Road South Study Area is demarcated to implement the proposed risk management framework by City West Water. Recycled water produced by the Western Treatment Plant is used to combine with stormwater which will undergo a process of treatment and disinfection to a level where the risks to humans and environment are reduced to acceptable limits. The hazards of all stages of combined water production and distribution were identified, the associated risks were assessed and risk management strategies were proposed and documented in this study. However, the risks of the recycled water system were not discussed as the Western Treatment Plant is an existing plant and the associated risks to the intended uses are assumed to be identified and managed already to acceptable levels.

Stormwater has the uncertainties in availability and broader fluctuations in the quality. Stormwater is proposed to be collected from the newly developed areas in the Black Forest Road South Study Area. Stormwater is planned to be harvested at various locations along the recycled water pipe.

To manage the risks of non-availability of stormwater or highly polluted stormwater beyond treatment to acceptable level, it was proposed to provide the facility of replacement of stormwater with potable water in this study. Potable water supply facility was made available within the system to inject into the recycled water pipe to mix with recycled water to produce combined water until stormwater supply of acceptable quality is restored.

Preventive measures to mitigate hazards and Critical Control Points which constitute conditions where immediate attention from the operators of the combined water supply system were presented in this study. The study further discussed about the operational procedures and process control, the verification of combined water quality and environmental performance, and how to manage incidents and emergencies.

6.2 CONCLUSIONS

6.2.1 Development of the guideline for combined water quality

There is no guideline available to control the water quality of the combination of recycled water and treated stormwater although combined water is widely used in Australia and overseas. The water authorities who supply combined water have prepared their own license agreements to suit to local conditions. Therefore, the guideline proposed by this study would be used as the basis for preparing the license agreements by water authorities who intend to supply combined water. However, there are limitations in the adoption of this guideline. The guideline could be used for projects using water only for the purposes as listed under this study. If there are applications other than those specified in this study, the steps taken to develop the guideline in this study have to be repeated to revise the guideline by considering the issues related to those applications.

6.2.2 Risk management framework for combined water use

The risk management framework developed in this study could be used for any combined water project which is in the planning stage of development. The hazard identification and risk assessment is the core of the risk management framework. Possible hazards that are anticipated to happen in the life cycle of the whole system and their vulnerabilities (consequences or impacts) are identified to form the risk matrix. However, this list needs to be updated with the better knowledge of the combined water system during operations. The most important part of the risk management framework is application of this framework to the study area. For this study it is Black Forest Road South Study Area. When this risk management framework is applied to another site, the aspects inherent to the new site have to be incorporated to framework. Preventive measures for the combined water system to mitigate the hazards, the critical control points (CCP) and procedures or processes controls which are essential to prevent hazards or reduce the risks to acceptable levels are given as part of the framework.

6.2.3 Application of risk management framework to the Black Forest Road South Study Area

The Black Forest Road South Study Area in West Werribee (PSP 42.2) which is approximately 500 hectares in area is demarcated by City West Water to implement a third water supply project. The Western Treatment Plant (WTP) in Werribee, Melbourne which is owned and operated by Melbourne Water, is the recycled water source. High quality “Class A” recycled water is produced by the WTP, which has a unique treatment processes. The use of water produced by the WTP has been successfully distributed as ‘third pipe water’, although this water has a high salt content which is an issue specifically irrigation applications. Addition of treated stormwater to recycled water produced by WTP will solve this issue which will enable wider use of combined water for irrigation applications.

Stormwater will be collected from the newly developed areas in the Black Forest Road South Study Area. Stormwater is planned to be harvested at various locations along the recycled water pipe, and treated stormwater will be injected into the third pipe which carries recycled water. Based on the rainfall data for the last 10 years, it is reasonable to assume average annual rainfall for the study area as 450 mm and the minimum annual rainfall as 300 mm. Considering the stormwater harvesting locations proposed by Melbourne Water in the Lollypop Creek drainage area, three wetlands were identified within this Study Area.

All potential hazards and hazardous events for the Black Forest Road South Study Area had been identified and documented for each component of the stormwater subsystem and combined water subsystem. Western Treatment Plant is currently supplying recycled water to consumers and the associated risks to the intended uses are assumed to be identified and managed already to acceptable levels. Hence there is no discussion on the hazard identification and risk management made for recycled water subsystem in this study.

The major area with high risks for public health and environment in the combined water subsystem was the mixing zone. As two types of water mixes inside the third pipe (as opposed to dedicated mixing chambers in the traditional combined water system), special attention needs to be paid to activities leading to mixing of two types of water. The 50m length of pipe downstream to the mixing point is assumed to be adequate for proper mixing of two types of water. There are two water quality monitoring points beyond the mixing zone to ensure that adequate mixing is warranted inside the pipe. During the oprations mixing zone length may have to be adjusted based on the water quality monitoring results.

Next element of risk management framework is operational procedures and process control which has identified the operational activities in the entire combined water system. These procedures and controls are to be monitored for successful and continuous combined water supply to the customers. Frequency schedule of monitoring of operational activities in the combined water system has been prepared to achieve this. Operational monitoring may be done by visual inspection, sampling and testing in the lab or on-line monitoring using the SACDA system. There are operational corrections or set of controls proposed for the study area to achieve this. The capability of equipment used in different areas of the system and the use of good quality materials and chemicals in the system are important for successful operations of the system in practice.

The risk management framework for Black Forest Road South Study Area was developed with the data and information available at the time of this study. At the implementation stage of this project, further design data and information will be made available and appropriate amendments and revisions could be made to the risk management framework accordingly.

6.3 RECOMMENDATIONS

- It is recommended that the proposed guideline for combined water quality to be reviewed by Standards Australia and other organisations responsible for developing statutory documents in the water industry for wider acceptance of this guideline so that it will be a recognised document to be used for combined water projects in future.

- The risk management framework proposed in this study could be implemented in any project using combination of recycled water and stormwater within Australia or overseas with required modifications to suit the local conditions. This is a framework with shared responsibilities among all the parties involved including the water users.
- The maximum benefits of the project could be obtained if all elements of the framework are implemented as proposed. Obviously, there may be modifications to be made to this document as and when the framework is physically implemented and constructive feedback is received to the implementing authorities from the stakeholders. The hazards registers proposed in this study need to be updated at the project implementation stages. There is no hazards register prepared for the recycled water supply subsystem during this study which needs to be developed for completeness of the risk management framework.
- As stormwater quality varies spatially and temporally (between catchments and the different sampling time in the same catchment), collection of rainfall data for longer duration is recommended for better results.
- The stormwater treatment measures for the study was carried out using the MUSIC software. This software was used to demonstrate the treatment train effectiveness only for Total Suspended Solids (TSS), Total Phosphorus (TP) and Total Nitrogen (TN). However, the software use could be extended to demonstrate the treatment train effectiveness for Iron and E coli, provided water quality monitoring data for Iron and E coli are available at the inlets and outlets of stormwater treatment measures. Therefore, it is recommended to use the MUSIC software to demonstrate treatment train effectiveness of Iron and E coli in future.
- It is recommended that a numerical model is developed in future to further demonstrate the mixing of treated stormwater and recycled water inside the third pipe and to improve the efficiency of mixing.
- The testing of water samples at the sampling points proposed in this chapter is done more frequently at the commencement of the project. Once the system operates smoothly, the frequency of testing could be reduced. The Operations and Maintenance Manual should be updated based on the information at the time when the system operates smoothly. Operational procedures and process control of the combined water system also have to be updated.

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