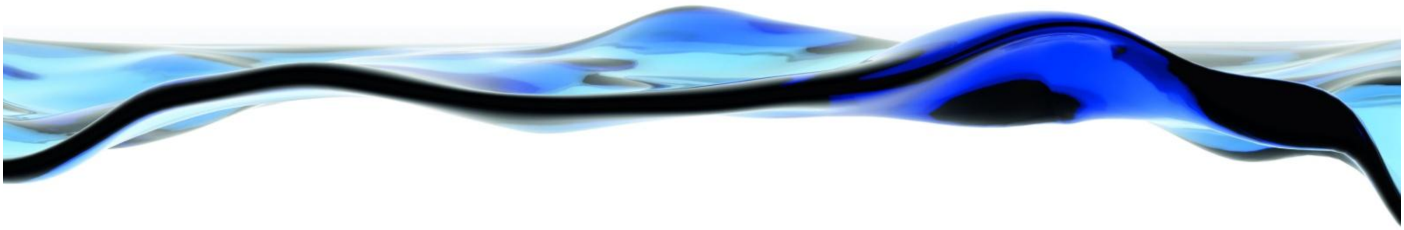
A RISK-BASED MANAGEMENT PLAN FOR MOUNT GAMBIER STORMWATER RECHARGE SYSTEM

Stormwater recharge to the Gambier Limestone aquifer

Vanderzalm, J., Page, D., Dillon P., Lawson, J., Grey, N., Sexton, D. and Williamson, D.



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Executive Summary

The majority of Mount Gambier's urban stormwater is discharged directly via drainage wells or sink holes into the unconfined, karstic Gambier Limestone aquifer. This aquifer is the dominant source of water for Blue Lake, from which Mount Gambier's drinking water supply is drawn. In addition to its value as a drinking water supply, the Blue Lake is of high environmental value to the region as a tourist attraction due to its annual colour change process and vibrant blue colour in summer.

The scope of this risk management plan covers harvesting of urban stormwater generated within the City of Mount Gambier, the processes for intentional recharge of this stormwater, the consequent groundwater quality in the Gambier Limestone aquifer and use of this groundwater via the Blue Lake for the raw water for the Mount Gambier drinking water supply. This plan also covers use of groundwater potentially affected by stormwater recharge in the City of Mount Gambier for non-potable domestic and irrigation use. Drinking water supply providers are required to develop and adopt an appropriate risk management plan under the *Safe Drinking Water Act 2011*. SA Water has an approved Water Safety Plan under the *Safe Drinking Water Act 2011.*

This report documents the application of each of the twelve elements of the National Water Quality Management Strategy risk management framework. When implemented this will assist in protection of public health and the environment in compliance with the National Guidelines for Managed Aquifer Recharge and for Augmentation of Drinking Water Supplies.

The South Australian Department of Environment, Water and Natural Resources; Environment Protection Authority, South Australia; South Australian Water Corporation; City of Mount Gambier; and District Council of Grant were consulted in preparation of 'A risk-based management plan for Mount Gambier stormwater recharge system'. At the time of writing, consultation with these key agencies was undertaken through their representation on the Blue Lake Management Committee. Since completion of this plan, the Blue Lake Management Committee has been disbanded. Nonetheless, the agencies consulted remain as the key stakeholders for management of the stormwater recharge system and protection of Blue Lake and its groundwater system. While the Blue Lake Management Committee can no longer oversee this plan, the recommendations made for management of the stormwater recharge system remain relevant.

With the shared responsibility of stakeholders in mind, proposed actions for various stakeholders are suggested to support this risk-based management plan. Appendix A presents a proposed Activities Schedule for implementation of this plan, with possible suggestions for the agency that would take responsibility for implementation of recommended actions. Measures suggested include new programs for monitoring the quality of stormwater recharge and groundwater to complement the existing water quality monitoring in Blue Lake; catchment hazard assessment and protection; regular inspection of non-licensed risk activities; improvement of existing pre-treatment of recharge; documentation and review of incident and emergency response actions; and review of training procedures for employees and contractors involved with the recharge system.

Introduction

This report documents a risk-based management plan for the Mount Gambier stormwater recharge system. It is important to acknowledge that stormwater recharge in Mount Gambier commenced in the 1880s with hand dug drainage wells as a means of stormwater disposal without understanding this would contribute to groundwater resources. However, it is now known that disposal of stormwater recharges the Gambier Limestone aquifer beneath Mount Gambier, which replenishes the Blue Lake (BLMC, 2006). Therefore, this report aims to document and provide suggested enhancements to the management for the current practice of stormwater recharge to protect human health and the environment and was developed in accordance with the Australian Guidelines for Water Recycling (Phase 1 and Phase 2) (NRMMC-EPHC, 2006; NRMMC-EPHC-NHRMC, 2008; NRMMC-EPHC-NHMRC, 2009a,b) and the Australian Drinking Water Guidelines (NHMRC-NRMMC, 2011). Once implemented the suggested enhanced operations would be recognised as Managed Aquifer Recharge (MAR). The basis of an Activities Schedule is presented in Appendix A, with the suggestions for the agency that could take responsibility for implementation of recommended actions.

Objective

The objective of a risk-based management plan for the Mount Gambier stormwater recharge system is to document a sequence of activities to manage identified water quality risks to human health and the environment to ensure that water affected by recharge of urban stormwater in the Gambier Limestone aquifer and in Blue Lake continues to meet its existing environmental values. Blue Lake is a source of drinking water supply and an oligotrophic lake of environmental importance due to its annual calcite precipitation and colour change.

Plan scope

This plan is one component of a comprehensive risk-based management plan for the Blue Lake. The water quality and quantity within Blue Lake can potentially be impacted by numerous activities within the groundwater catchment zone for Blue Lake, such as urban stormwater recharge (the current plan), leakage from on-site wastewater treatment and disposal and diffuse recharge under agricultural land use (Figure 1). This report outlines the requirements of a risk-based management plan for one of these activities, urban stormwater recharge that may contain components of industrial stormwater and sewer overflow. This plan provides a module based on each of the twelve elements of risk management that can be built upon in working toward comprehensive risk-based management for all activities that can impact on Blue Lake. The stormwater recharge risk-based management plan is based on protection of Blue Lake as a source of drinking water supply and a lake of environmental importance. While drinking water supply is considered as an end-use, this plan does not constitute a drinking water risk management plan for Blue Lake. Drinking water risk management is the responsibility of SA Water under the *Safe Drinking Water Act 2011*.

The dominant method for stormwater recharge is via drainage wells, which intersect the Gambier Limestone aquifer and bypass the unsaturated zone. Stormwater recharge also occurs through sink holes within the limestone and infiltration, including via purpose-built detention and infiltration basins. A recent guideline for stormwater management in Mount Gambier discourages direct discharge of stormwater to the aquifer, instead advocating for retention and use of stormwater or improved treatment prior to recharge utilising infiltration techniques for recharge (EPA, 2007). It should be noted that stormwater recharge plays an important role in sustaining groundwater resources in the Gambier Limestone aquifer.

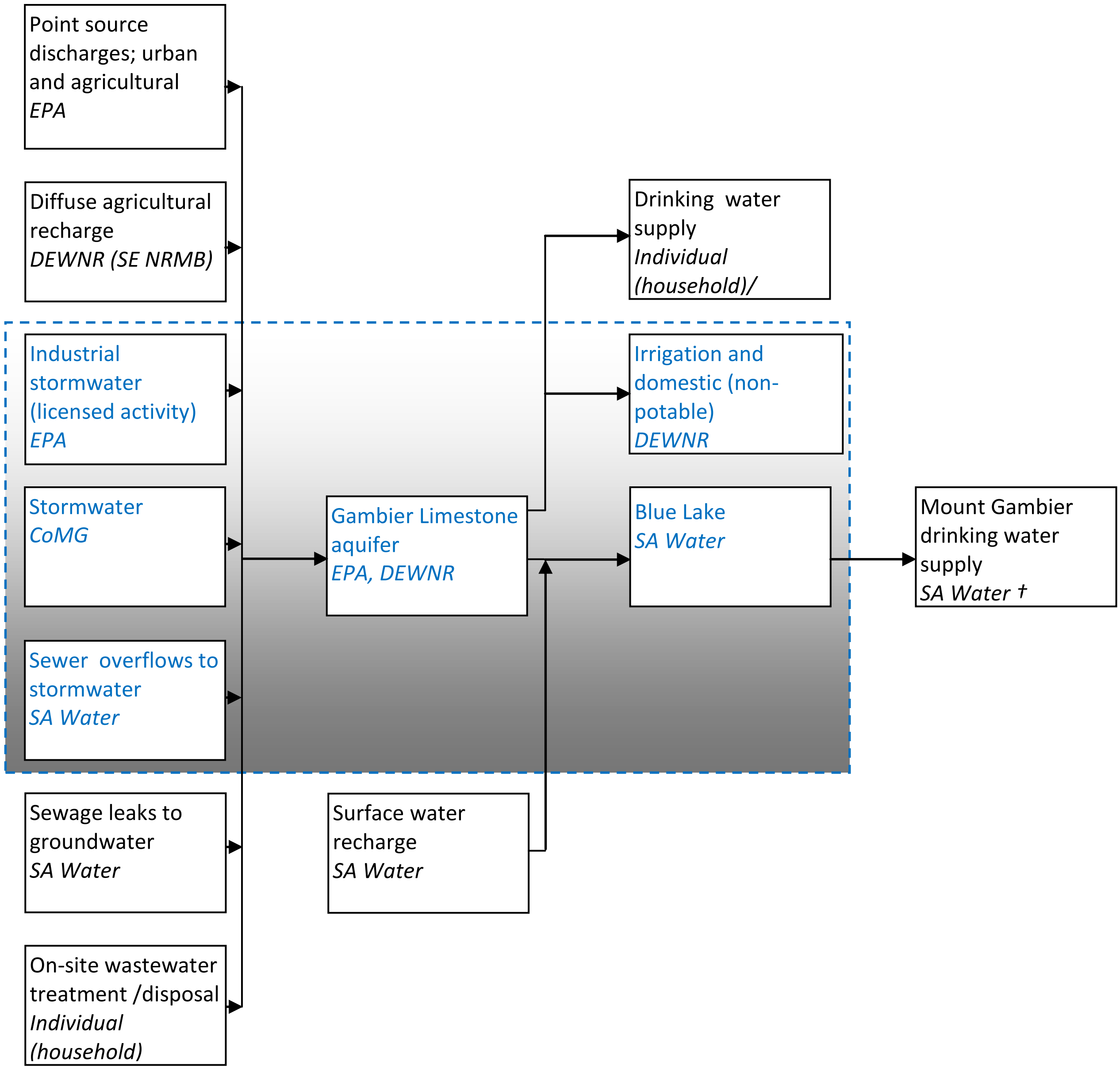

Figure 1 Water resource and use and the agency/ies responsible (italics). Area bounded by blue dashed line containing blue text signifies the components covered within the scope of this risk-based management plan. † indicates a risk management plan is required under the *Safe Drinking Water Act 2011*

This document contributes to the goals of the Blue Lake Management Plan (BLMC, 2006), specific to Outcome 2: Blue Lake water quality maintained within Water Quality Environment Protection Policy limits. Moreover, this risk management plan is relevant to the majority of the expected outcomes of the Blue Lake Management Plan (e.g. Outcome 3: Maintained quality of groundwater within the Blue Lake Protection and Capture Zones for existing beneficial used, Outcome 1: A community committed to protecting Blue Lake through changes to on-ground behaviour).

Blue Lake end-use is as a raw water source for drinking supply water in Mount Gambier and as a significant tourist attraction in the region. This plan refers to indirect potable use of stormwater via Blue Lake and groundwater use for non-potable domestic purposes via wells within the City of Mount Gambier. While the groundwater capture zone for the Blue Lake extends beyond this local government boundary, stormwater recharge is contained within this zone. Ultimately, a series of management plans including those on industrial and agricultural land use management and on-site sanitation and sewerage system management, including activities outside the City of Mount Gambier boundary could also be developed.

Specifically, this plan does not address management of the following:

- reticulated drinking water supply after water is extracted from the Blue Lake, which is the responsibility of SA Water (subject of the Mount Gambier Water Quality Safety Plan),
- drinking water supply from wells within the Gambier Limestone aquifer, if there were any, which is the responsibility of the bore owner (individual or household use),
- additional activities within the catchment, related to land use, that may lead to diffuse or point source pollution and impact on the quality of groundwater or the Blue Lake.

Overview of scheme

The majority of Mount Gambier's urban stormwater is discharged directly via drainage wells or sink holes into the unconfined, karstic Gambier Limestone aquifer, which is the dominant source of water for Blue Lake (BLMC, 2001, 2006). Discharge of urban runoff to the aquifer commenced in the 1800s as a means of stormwater drainage, but is now recognised as contributing to the drinking water supply in Blue Lake (BLMC, 2001, 2006). Therefore the Mount Gambier stormwater recharge system is an example of stormwater to potable recycling via the aquifer that has been operating for over 100 years. Recently, the potential human health and environmental risks associated with this indirect stormwater to potable recycling scheme were assessed (Wolf *et al.*, 2006; Page *et al.*, 2010; Vanderzalm *et al.*, 2009, 2011).

A risk management plan is essential to transition from historical unintentional potable reuse of stormwater recharged via drainage wells to managed aquifer recharge, where risks are identified, preventive measures are implemented to protect human health and the environment and the system is monitored to verify its ongoing performance. This document draws on and extends the risk assessment undertaken previously for the Mount Gambier stormwater recharge system as the basis for development of a risk management plan.

1 Commitment to responsible use and management of stormwater

1.1 Responsible use of stormwater

The following key agencies were consulted regarding continued operation of the stormwater recharge scheme, through their representation on the Blue Lake Management Committee:

- South Australian Department of Environment, Water and Natural Resources (DEWNR, which includes SE NRMB),
- Environment Protection Authority, South Australia (EPA),
- South Australian Water Corporation (SA Water),
- City of Mount Gambier (CoMG),
- District Council of Grant (DCG).

The management, operation and maintenance of the drainage wells and infiltration systems contributing to the stormwater recharge system are the responsibility of multiple parties. The City of Mount Gambier is the largest single agency, responsible for approximately 400 operational drainage wells for stormwater discharge as a licensed activity (Appendix B). Around 50 private drainage wells are also in operation, with approximately 30 of these associated with a licence for discharge to the aquifer issued by the EPA (Appendix B). The remaining private bores do not trigger the requirement for an EPA licence as they occupy a drainage area of less than one hectare.

SA Water is currently the sole user of water from Blue Lake for raw water supply to Mount Gambier. There are approximately 100 domestic wells for irrigation and non-potable domestic use in Mount Gambier that could be influenced by stormwater recharge. Licences to construct and withdraw water from these wells are issued by DEWNR.

Statement of commitment (Goal of the Blue Lake Management Plan)

The Blue Lake Management Plan (BLMC 2001, 2006) was a commitment from the Blue Lake Management Organisations, SA Water, DEWNR, EPA, City of Mount Gambier and District Council of Grant, to implement actions within the plan. The goal of the Blue Lake Management Plan was as follows:

"Enhancement and protection of the Blue Lake and the aquifer system as a long term water resource asset to the Mount Gambier and district community."

Since completion of this plan, the Blue Lake Management Committee has been disbanded. Nonetheless, the agencies consulted remain as the key stakeholders for management of the stormwater recharge system and protection of Blue Lake and its groundwater system.

1.2 Regulatory and formal requirements

1.2.1 Legislation, regulations and industry standards

Legislation compliance associated with the Mount Gambier stormwater recharge system includes the:

- *Environment Protection Act 1993,*
- *Environment Protection (Water Quality) Policy 2003 (under the EP Act 1993),*
- *Natural Resource Management Act 2004.*

The *Water Resources Act 1999* was in place prior to the *Natural Resource Management Act 2004.* In addition, the *Safe Drinking Water Act 2011* and Safe Drinking Water Regulations 2012 apply to all providers of drinking water supply, which includes SA Water in Mount Gambier. The *Safe Drinking Water Act* is based on implementation of the Australian Drinking Water Guidelines (NHMRC-NRMMC, 2011) and requires development and adoption of appropriate risk management plans. Drinking water providers must register with the SA Department for Health and Ageing.

The Australian Drinking Water Guidelines and the Australian Guidelines for Water Recycling (2006, 2009a,b) are key documents that provide the 'framework for the management of recycled water quality and use' (NRMMC-EPHC, 2006, p.iii). The EPA guidelines for stormwater management in Mount Gambier (EPA, 2007) provide guidance on infrastructure for stormwater management installed from 2007 onwards. This guideline is targeted toward new developments or significant redevelopments and incorporates best management practices for stormwater management and treatment. The EPA guidelines for stormwater management is based on the principle that recharge should involve infiltration rather than direct discharge via wells to the aquifer where possible, but does not rule out the use of discharge wells. It provides detail on treatment methods such as grassed swales, gravel trenches or oil separator systems that could be employed prior to well discharge.

1.2.2 Approvals and licences/permits

In the City of Mount Gambier, stormwater recharge is licensed by the EPA for a catchment area exceeding one hectare in size. The terminology 'stormwater recharge' is used throughout this document rather than 'stormwater discharge', which is used in EPA licences, as this activity augments the groundwater supply. A licence to recharge stormwater can require monitoring and reporting of stormwater and groundwater at specific points to assess compliance with the *Environment Protection Act 1993* and the *Environment Protection (Water Quality) Policy 2003* under the Act. Current EPA licences for stormwater recharge activities are given in Appendix B (EPA, 2012). A schedule for stormwater and groundwater quality monitoring is applied when stormwater recharge from an activity is deemed to be a potential risk to the water quality in the Gambier Limestone aquifer. While there is a condition that the City of Mount Gambier's stormwater quality meets the ANZECC Guidelines for Fresh and Marine Water Quality (ANZECC–ARMCANZ, 2000) prior to recharge, there is currently no schedule stipulating stormwater or groundwater quality monitoring within the licence.

Development applications, which can impact on the quality of stormwater, are subject to approval by the City of Mount Gambier in accordance with the *Mount Gambier (City) Development Plan* (Government of South Australia, 2012a). The *Greater Mount Gambier Master Plan* (Government of South Australia, 2008) has formal statutory effect (Section 22, Development Act 1993) to guide development. The *Greater Mount Gambier Master Plan* states that 'development plans should have regard to the objectives of the Blue Lake Management Plan' (p. 11).

DEWNR manages the allocation of water in accordance with the water allocation planning developed under the *Natural Resources Management Act 2004*. In this role, DEWNR issue licences to discharge water into and to extract water from the aquifer.

SA Water has a permanent licence from DEWNR (licence no. 11230) to extract up to 4,000 ML/y from the Gambier Limestone aquifer (via Blue Lake) and an obligation under the *Safe Drinking Water Act 2011* to monitor water quality in Blue Lake and in the treated water. SA Water also has a permanent licence (licence no. 11238) from DEWNR to extract up to 210 ML from the deeper confined aquifer for drinking water supply if required.

1.3 Partnerships and engagement of stakeholders

A number of agencies are involved in the stormwater recharge system at Mount Gambier. These organisations and their current roles and responsibilities in the stormwater recharge system are presented in Table 1, after modification from the Blue Lake Management Plan (BLMC, 2006). At the time of writing partnership between local and state government agencies was via the Blue Lake Management Committee. Although the Committee has now been disbanded the agencies consulted remain as the key stakeholders for management of the stormwater recharge system and protection of Blue Lake and its groundwater system. Private bore owners subject to EPA licence are engaged through contact with the EPA. Private bore owners that are not subject to EPA licence and users of Blue Lake are engaged through community engagement processes, administered through local government and DEWNR.

Table 1 Roles and responsibilities of organisations related to Mount Gambier stormwater recharge system (adapted from BLMC, 2006)

Organisation	Roles and responsibilities
Blue Lake Management Committee †	Oversee the implementation and review of the Blue Lake Management Plan.
South Australian Department of Environment, Water and Natural Resources (DEWNR, previously SE NRMB and DWLBC)	Issue permits under NRM Act. Protection and enhancement of the quality of the Blue Lake. Facilitator of input from key stakeholders. Facilitate implementation of the NRM plan. Working with Local Government on development planning matters as they relate to natural resource management. Groundwater level and salinity monitoring. Definition of boundaries to the Blue Lake Protection and Capture Zones. Continue to support the plan through provision of hydrogeological data and outcomes from research projects.
Environment Protection Authority, South Australia (EPA) ††	Maintain water quality of the lake through managing potentially polluting activities. Regulatory responsibility for protection for surface- and ground- water quality. Manage risks associated with operation of potentially polluting activities. Continue to fulfil regulatory obligations (mostly via the Prescribed Activities licensing system) and undertake target projects as internal funds are made available.
South Australian Water Corporation (SA Water)	Provide a potable water supply to Mount Gambier and district. Facilitate investigation and management of potential threats to the Lake.
City of Mount Gambier (CoMG)	Ensure protection of the resource (as representatives of the community) through the control of development in Zone 1.* Increase community awareness and manage stormwater. Managing the risk associated with stormwater and keeping others stakeholders accountable. Continue with the initiatives to provide an appropriate planning policy, support the implementation of stormwater management, community education and manage the lake as a tourist destination.
District Council of Grant	Increase community awareness and manage stormwater.

† Since the preparation of this report the Blue Lake Management Committee and its role has been terminated.
†† EPA was previously responsible for monitoring of the Blue Lake and surrounding groundwater quality (BLMC, 2006) but this is not a current role; *Zone 1 refers to the Blue Lake Protection Zone

1.4 Stormwater use policy

A position statement on stormwater should be prepared to formalise the commitment made for responsible use of stormwater. A draft statement follows which could be adopted within the Blue Lake Management Plan:

The Blue Lake Management Committee supports and promotes the responsible use of stormwater as a component of Mount Gambier's drinking water supply through the application of a management approach that consistently meets the National Water Quality Management Strategy Guidelines and regulatory requirements. To do this we will:

- *use a risk-based approach to ensure the protection of public and environmental health,*
- *maintain communication and partnerships between contributing organisations and stakeholders,*
- *recognise the importance of community involvement and engagement in protecting the quality of stormwater,*
- *develop appropriate management, including contingency planning and incident-response capability, to minimise and protect against hazards,*

- *review and continually improve activities related to the operation of the stormwater recharge system.*

2 Assessment of the stormwater use system

In the management of risks in a stormwater catchment, an initial key objective is to collect information about the stormwater catchment for hazard analysis followed by risk assessment to enable identification of risk management options to mitigate the risks.

2.1 Source of stormwater, intended uses of stormwater, receiving environments and routes of exposure

2.1.1 Source water

Stormwater is harvested within the City of Mount Gambier, a regional city with a population of ~26,000. The city area of 26.5 km^2, is comprised of ~11 km^2 impervious covers and is divided into over 400 stormwater drainage catchments, ranging in size from 0.2 to 58 ha each (Vanderzalm *et al.,* 2011; Nguyen, 2013) (Figure 2). Average annual rainfall is 713 mm and annual potential evaporation of approximately 1270 mm (Mount Gambier Aero station #026026, latitude 37.75°S, longitude 140.77°E; BOM 2013).

Residential land use is dominant (48%) followed by public open space (20%) and then industrial land use on the western and eastern fringes of the city (10%). Currently the City of Mount Gambier operates approximately 400 stormwater drainage bores as the majority of drainage catchments have at least one operational discharge bore. In addition, approximately 50 drainage bores are operated by private operators. Nguyen (2013) estimated that the average annual recharge in the period of 2007-2012 from the impervious surfaces within stormwater catchments containing a drainage well was 5,100 ML/y . There are instances where stormwater recharge occurs via infiltration basins, but recharge via drainage wells predominates. The City of Mount Gambier is situated directly north of the Blue Lake within the Blue Lake Protection Zone (Figure 3). Lawson (2014) recently revised the Blue Lake Protection and Capture Zones, to constrain the northern extent of the Capture Zone.

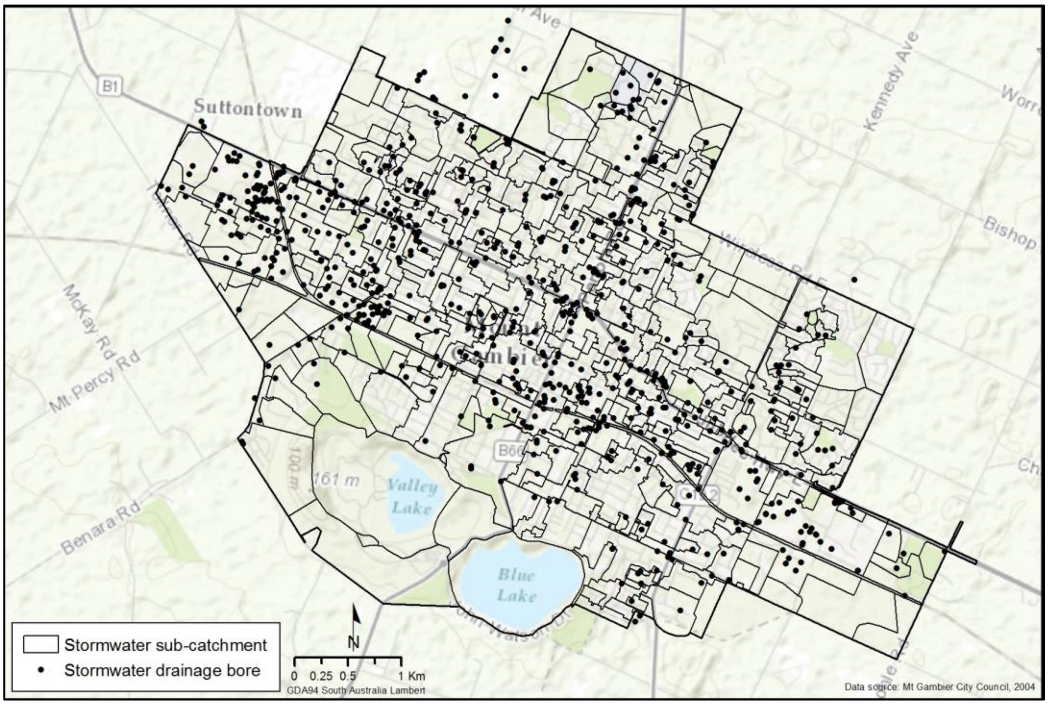

Figure 2 City of Mount Gambier illustrating stormwater drainage catchments and drainage wells

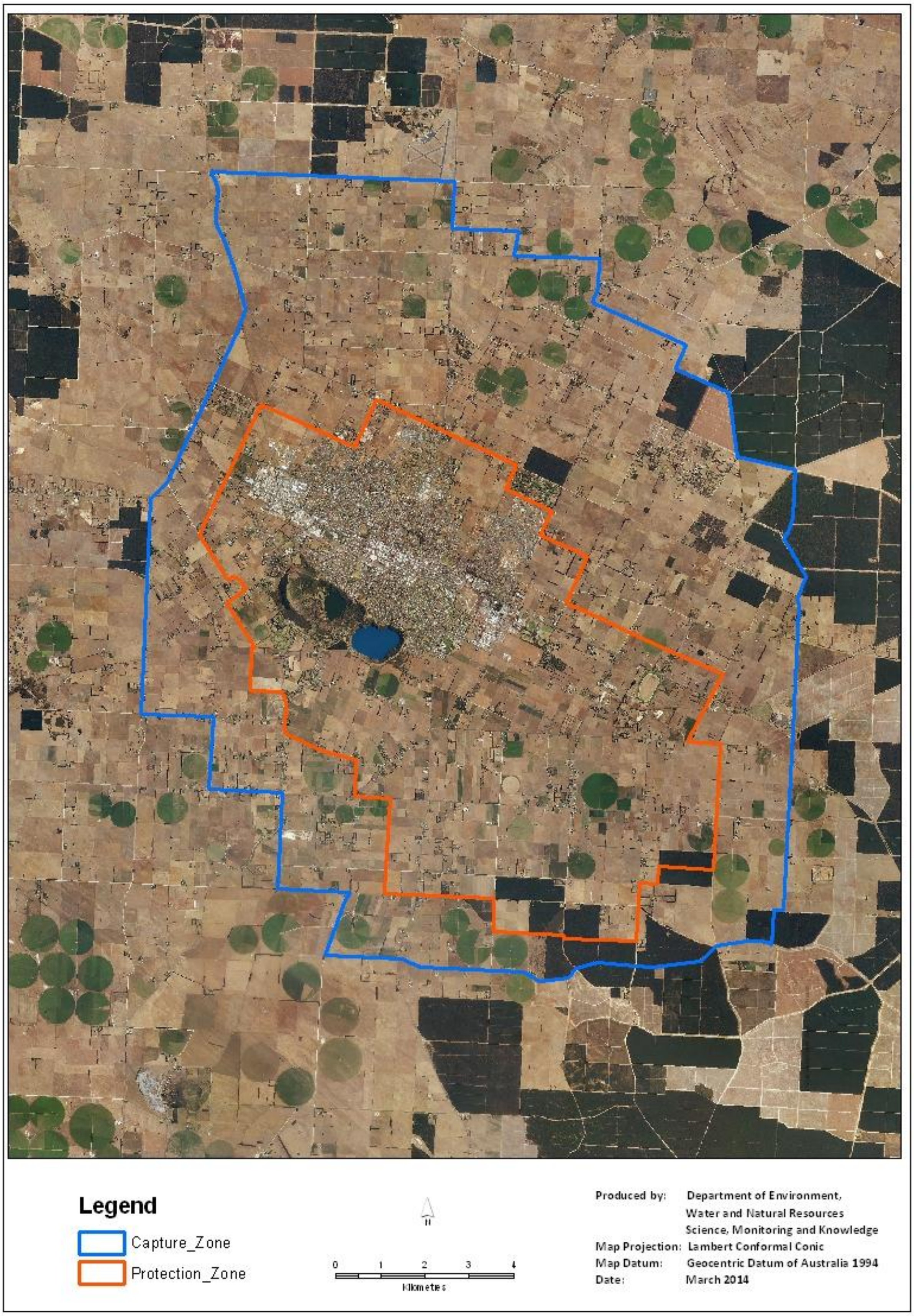

Figure 3 Groundwater management zones for protection of Blue Lake; protection zone and capture zone

2.1.2 Intended uses

Stormwater recharge contributes to groundwater in the Gambier Limestone aquifer that replenishes the Blue Lake, which provides raw water used for drinking water supply in Mount Gambier. The lake amenity including water clarity and colour is a valued tourist attraction. Annually 3,600 ML/y of water is extracted from Blue Lake for drinking water supply under SA Water's extraction licence (up to 4,000 ML/y).

The groundwater in the Gambier Limestone aquifer underlying the City of Mount Gambier, is also used as a water supply for irrigation and non-potable domestic uses. Approximately 100 domestic bores are located within the City of Mount Gambier, but it is not known how many of these are currently in use. Inadvertent or unauthorised drinking water use may occur from groundwater extraction directly, via domestic bores within the City of Mount Gambier as groundwater is likely to contain some portion of stormwater. It is unlikely that domestic bores would be used routinely for drinking water when all households have access to reticulated drinking water supplied by SA Water. If there is intent to use domestic wells for drinking water supply, the responsibility for safety of this water supply lies with the bore owner. The Department for Health and Ageing has a standard risk management plan (Government of South Australia, 2012b) that can be adopted for small systems (e.g. single bore) supplying groundwater for drinking water supply.

2.1.3 Receiving environments

The primary receiving environment for stormwater is the unconfined Gambier Limestone aquifer. Regionally, groundwater levels have declined since the 1970s, with some stabilisation of levels between 2000 and 2005 (BLMC, 2006).

The unconfined Gambier Limestone aquifer is comprised of up to six sub units, consisting of alternating beds of bryozoal limestone and marl overlying a dolomitic Camelback Member (Figure 4). Lawson (2013) reports that Unit 1 is absent to the north of Blue Lake and inflow to the lake is predominantly via Unit 3 and the Camelback Member. On the southern side of the lake inflow is via Unit 1 while outflow is via Unit 2 (Lawson, 2013).

The Gambier Limestone is a dual porosity medium with karstic flow supplementing primary intergranular flow. Regionally groundwater flows from the northeast to the southwest, but in the lake vicinity the hydraulic gradient is low (10^{-4}) and local flow systems and the karstic domain can reverse the flow direction (Wolf *et al.*, 2006). Lawson (2013) has defined a zone to the northwest of Blue Lake, from which recharge to Blue Lake is most likely to occur through primary fracture paths.

Pumping-test derived transmissivities vary over two orders of magnitude from 200 m^2/day to > 10,000 m^2/day, with porosity estimates between 30% and 50% (Love *et al*., 1993; Wolf *et al.*, 2006). While considerable variation in travel time is expected in the karstic aquifer, a minimum transit time of 2-20 years was estimated through calculation of pumping induced flow using the approach of Miller *et al*. (2002) in combination with natural and applied tracers (Vanderzalm *et al.,* 2009). The presence of X-ray contrast media in Blue Lake, identified by the detection of adsorbable organic iodine (AOI) and iopromide, confirmed that recent water (<50 years) has replenished the lake.

An applied tracer test using sulfur hexafluoride (SF_6) was undertaken in August 2005. SF_6 was injected into 24 bores, consisting of 22 stormwater drainage bores and 2 groundwater observation bores, situated 1-3 km on the northern side of Blue Lake and predominantly completed in the Camelback Member. While some injection sites were located in the direction of regional groundwater flow, the majority of injection sites were selected to enhance the opportunity for migration through primary fracture flow paths. Samples of Blue Lake collected after August 2007 had very low levels of SF_6, marginally higher than the analytical detection limit, indicating a minimum transit time of 2 years. Following this, approximately 40 per cent of samples from Blue Lake collected between August 2007 and October 2008 had detectable SF_6 concentrations. Movement from any of the injection sites to Blue Lake in 2 years indicates a groundwater flow velocity of 0.5-1.5 km/year through karstic flow. (Appendix C). Water level contours in the upper unit of the Gamier Limestone aquifer and in the Camelback Member are shown in Appendix C.

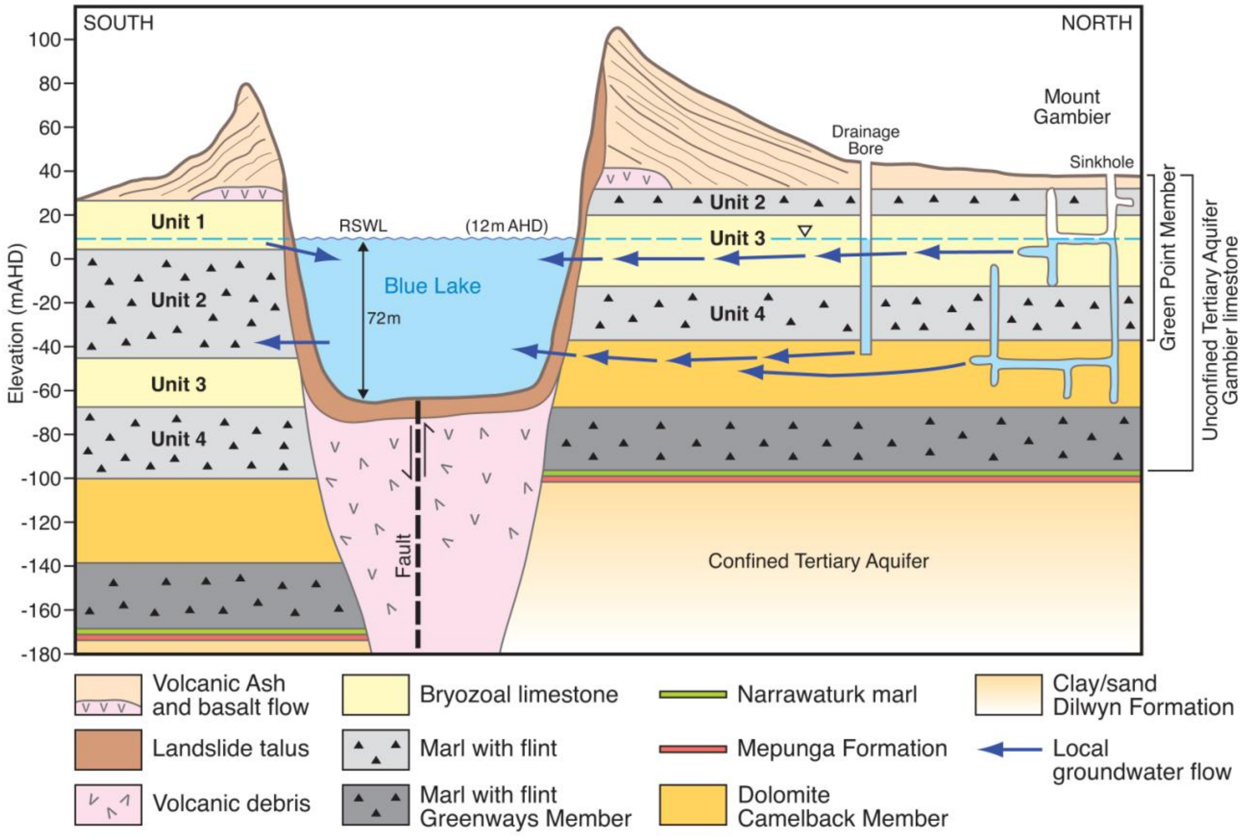

Figure 4 Conceptual diagram of stratigraphy in the vicinity of the Blue Lake

The Blue Lake receives stormwater via its contribution to groundwater in the Gambier Limestone aquifer. Groundwater is the predominant inflow to the lake (3,500-4,500 ML/y), with minimal input from precipitation (500 ML/y) due to the small surface catchment area created by the steep walls of the volcanic crater (Lamontagne and Herczeg, 2002). Groundwater outflow is limited, estimated at between 0 and 100 ML/y (Lamontagne and Herczeg, 2002).

The portion of stormwater in groundwater entering Blue Lake has been estimated at between 35 and 55% based on changes in chloride concentrations due to recharge from fresh stormwater (BLMC, 2001, 2006). However, Lamontagne and Herczeg (2002) highlighted the uncertainty in this estimate as the chloride concentration in groundwater may be declining due to other impacts of European settlement and cannot be solely explained by stormwater recharge. This possible overestimate of stormwater entering Blue Lake can still be used in a conservative assessment of the risks associated with stormwater recharge.

The Blue Lake level has also declined over time and management targets include ensuring there is no acceleration in the rate of decline (BLMC, 2001). Since the early 1900s, the Blue Lake water level declined by approximately 8 m, stabilising at around 12 m AHD in the early 2000s. This decline was attributed to a steady decline in average rainfall since the early 1900s and the impact of extraction from Blue Lake, which peaked at over 4,500 ML/y in the 1970s (BLMC, 2006). SA Water’s licence allocation of 4,000 ML/y contributes to management of the lake level. However, the most recent 10 years of lake level data continues to highlight the influence of below average rainfall, with the Blue Lake water level declining to 11 m AHD before increasing rainfall since2008 (Figure 5).

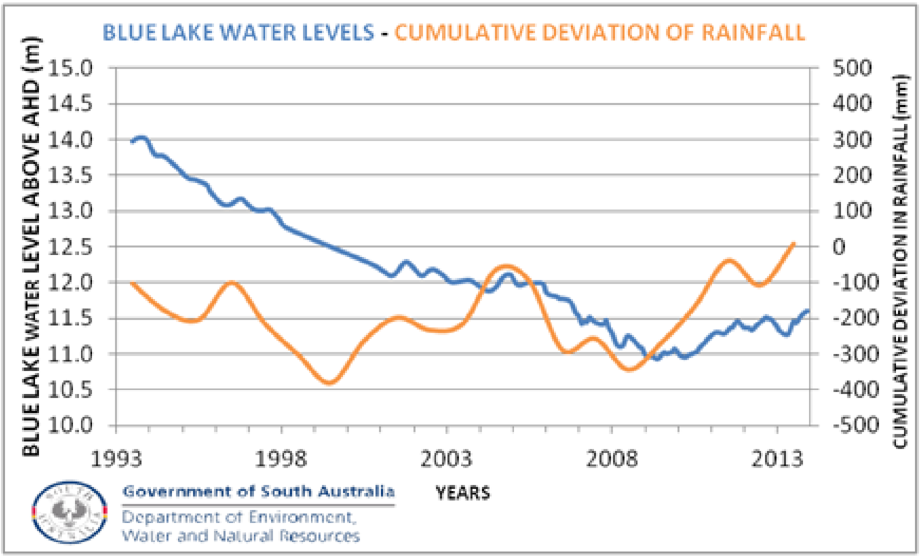

Figure 5 Comparison between Blue Lake water levels and cumulative deviation from annual rainfall since 1993

Along with the annual extraction of ~3,600 ML of water from the Blue Lake for the reticulated water supply, a further 7,000 ML groundwater is extracted annually from the unconfined aquifer within the Protection and Capture Zones (BLMC, 2006). Recent direct stormwater recharge estimates of around 5,100 ML/y (Nguyen, 2013) highlight the integral role that the stormwater recharge via drainage wells plays in sustaining groundwater beneath Mount Gambier. It follows that appropriate management measures are adopted to ensure protection of water quality in addition to water quantity.

The groundwater quality within the Gambier Limestone aquifer is variable. Historical land use has resulted in some localised contamination of groundwater. Stormwater recharge can serve to dilute some of the parameter concentrations within the groundwater. However recharge and extraction from Blue Lake can increase hydraulic gradients and induce flow toward the lake, which may mobilise contaminated groundwater.

2.1.4 Routes of exposure

The route of exposure assessed for the Mount Gambier stormwater recharge system is ingestion, directly from drinking water and indirectly from ingestion of aerosols in public open space irrigation.

2.2 System analysis

The major components of the stormwater recharge system in Mount Gambier are summarised in Figure 6 and Table 2. The distance between individual drainage wells and the Blue Lake varies from 200 m to approximately 5 km.

The major treatment for recycled stormwater is natural treatment during aquifer and lake storage. However, natural treatment remains to be validated. The passive treatment processes occurring during residence in the aquifer enhances the water quality prior to entering the lake.

Pre-treatment consists of gross pollutant removal using triple chamber silt traps prior to discharge via most drainage wells. Continuous deflective separation (CDS) units are used in a small number (<5) of catchments prior to discharge via karst features. Gross pollutant removal is intended for protection of clogging in drainage bores, rather than water quality treatment for health or environmental protection. Engineered pre-treatment devices are employed for pre-treatment where stormwater treatment is stipulated as a licence condition (Appendix B). Water sensitive urban design principles, as outlined in the EPA Guideline for stormwater management (EPA, 2007) have been incorporated prior to the triple chamber silt trap to improve stormwater quality in a small number (<5) of stormwater catchments. Stormwater recharge through infiltration basins provides passive treatment during transport through an unsaturated zone of approximately 20 to 50 m depth within the limestone. Older triple chamber silt traps constructed from limestone blocks also allow infiltration due to leakage from the base of the pits.

Water pumped from Blue Lake is chlorinated prior to reticulation in the drinking water supply. This has also been fluoridated for oral health protection since October, 2010. There is no treatment of groundwater used for public open space irrigation.

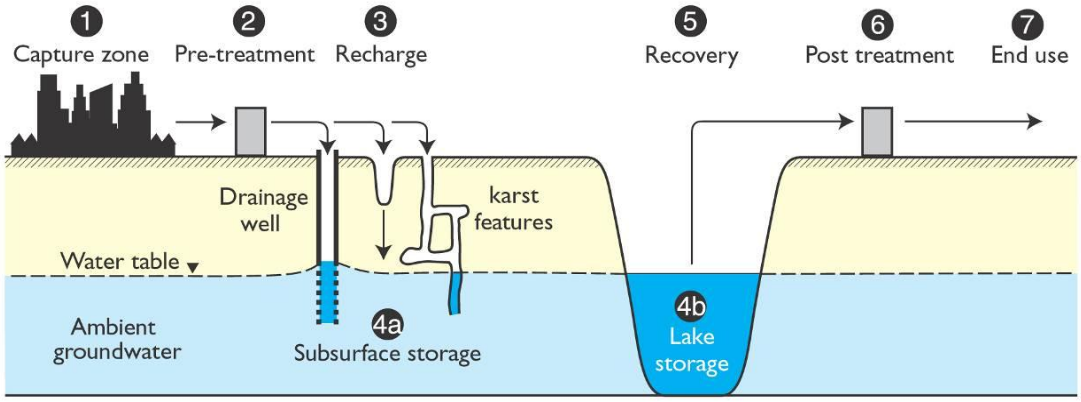

Figure 6 Mount Gambier stormwater recharge system schematic of water flow (Page *et al.*, 2010)

Table 2 Mount Gambier stormwater recharge system components

Component	Mount Gambier system
1. Capture zone	Stormwater from the City of Mount Gambier
2. Pre-treatment	Triple chamber silt traps prior to some drainage wells; continuous deflective separation (CDS) units prior to some karst features; unsaturated zone transport in infiltration systems
3. Recharge	Drainage wells (~5,100 ML/y; Nguyen, 2013); karst features e.g. sinkholes, caves; infiltration
4. Storage	a) Aquifer storage (subsurface) – Gambier Limestone aquifer; minimum 1.5-20 years (Vanderzalm *et al*., 2009) b) Lake storage – Blue Lake; 6-10 years (Herczeg *et al*., 2003)
5. Recovery	Extraction from Blue Lake (~3,600 ML/y); alternatively, irrigation wells in Mount Gambier
6. Post-treatment	Disinfection, via chlorination of water from Blue Lake; no treatment for irrigation wells
7. End use	Reticulated drinking water supply from Blue Lake; non-potable water supply from domestic and irrigation wells in Mount Gambier

2.3 Assessment of water quality data

Water quality data for the Blue Lake was obtained from seven sampling locations between 1968 until 2013. The water quality within the Blue Lake is currently monitored by SA Water from the surface of the lake at the pumping station. The frequency of this sampling is monthly and some parameters are measured each time (e.g. turbidity, colour, biology, *E. coli*, *Cryptosporidium*), other are measured quarterly (e.g. major ions, nutrients, metal(loid)s, BTEX, TPH) or annually (e.g. herbicides and pesticides) as required under the *Safe Drinking Water Act 2011*.

The EPA monitored water quality in the Blue Lake at four depths (surface, 20 m, 40 m and 60 m) on a 3 monthly basis at various sampling locations between 1974 and 2005. Water quality data preceding 1968 may be available, but reliability of historical analytical and sampling methodologies has previously been the cause for exclusion of early nitrate data (pre 1968) (Lamontagne and Herczeg, 2002).

The water quality data (EPA, unpublished data) for the unconfined aquifer within the Blue Lake Protection and Capture Zone (BLPCZ) was available between 1981 and 2005. Stormwater quality data was obtained from Emmet (1985), the City Council of Mount Gambier (URS, 2000, 2003) and a CSIRO study (Wolf *et al.,* 2006).

The risk assessment reported in Vanderzalm *et al.* (2009) utilised water quality data for the period 1968 to 2005 and this is referred to as historical Blue Lake water quality. National guideline values for drinking water quality are given in the Australian Drinking Water Guidelines (NHMRC-NRMMC, 2011). Guidelines for protection of the Blue Lake as an aquatic ecosystem are not well defined, but can be established with guidance provided in the ANZECC Guidelines for Fresh and Marine Quality (ANZECC-ARMCANZ, 2000) in combination with stakeholder consultation based on protection of the Blue Lake as a raw water supply, maintaining the annual colour change and clarity of the lake and preventing algal blooms.

As there is no local data on biological effects, the trigger value for a 95% level of protection is recommended for slightly to moderately disturbed ecosystems (ANZECC-ARMCANZ, 2000). The 80th percentile of historical Blue Lake water quality is compared to the Australian Drinking Water Guidelines (NHMRC-NRMMC, 2011) and aquatic ecosystem trigger values to examine the applicability of these trigger values to the Blue Lake scenario (Appendix D), since the recommended trigger values based on the ANZECC guidelines are very stringent. For example, the nitrogen trigger value of 1 mg/L total nitrogen is considerably lower than the health based drinking water quality guideline (50 mg/L nitrate) and historically has not been met within Blue Lake or its groundwater. The 80th percentile of historical Blue Lake water quality exceeds the recommended trigger value for Cr(VI), Cu, Ni and Zn, suggesting these trigger values are not feasible for the Blue Lake. In addition, the recommended trigger values for some parameters (Cd, Hg) cannot be met by the analytical reporting or detection limit.

As a result, a number of target indicators were proposed for protection of Blue Lake water quality and quantity, based on historical water quality data for the Blue Lake, groundwater in the unconfined aquifer and Mount Gambier's stormwater (up until 2005) and were subsequently embedded within the most recent revision of the Blue Lake Management Plan (BLMC, 2006) (Table 3). Of these, targets 1-4 relate to protection of health and the environmental protection and are adopted within this risk-based management plan.

Table 3 Targets, indicators and measurements for Blue Lake and adjacent groundwater (modified from Table 5 in BLMC, 2006)

Target	Indicator/trigger value	Current measurement †
1. Maintain a margin of safety on drinking water guidelines (aside from pathogens managed by disinfection prior to reticulation) so that action can be effective in time if monitoring shows undesirable trends.	Pumped water quality meets all NWQMS drinking water quality criteria (aside from pathogens) including a margin of safety (annual mean concentrations <80th %ile of historical values*).	SA Water monitoring program; frequency and analytes as required by the SA Department for Health and Ageing under the *Safe Drinking Water Act 2011*.
2. Maintain nutrient levels in Blue Lake within or lower than the current range of concentrations (that have been shown to support the environmental value of the lake).	Annual mean [TP] <80th %ile of historical values* (0.02 mg/L). Increase in mean [NO_3^-] <10% over a 5 year interval. [NO_3^-]$_{1997}$=3.5 mg/L, [NO_3^-]$_{2002}$= 3.4 mg/L. Annual mean [DOC] <80th %ile of historical values* (1.3 mg/L).	SA Water monitoring program, monthly.
3. Maintain or improve groundwater quality on the perimeter of the lake and in specific locations associated with contaminant sources that may adversely affect future achievement of target values, so that management can be effective before targets are infringed.	Annual mean concentrations <80th %ile of historical values*. Increase in mean [NO_3^-] <10% over a 5 year interval.	Nil, but a monitoring program will be reinstated in the future #.
4. Maintain lake in oligotrophic state. Maintain biotic species and numbers within lake within range pertaining to targets 1 and 2.	Chlorophyll *a* <5 µg/L (based on historical data* and ANZECC-ARMCANZ, 2000).	SA Water monitoring program, fortnightly.
5. No acceleration in decline in lake level. No target has yet been set for maximum annual pumping volume or minimum desirable lake level.	Decline in lake level <10% of depth over a 10 year period.	SA Water monitoring program, continuous monitoring; DEWNR water licences.

† proposed changes to measurement are detailed in verification monitoring (section 5.1); * historical values are for the period 1968 to 2005; # Previously assessed within the EPA groundwater monitoring program, monitoring will be reinstated after a state-wide review of monitoring is completed

2.4 Hazard identification and risk assessment

Land use activities within the City of Mount Gambier that could pose a risk to Blue Lake water quality via stormwater recharge were informed by a preceding qualitative risk assessment (S&G, 2004). The land use pattern and the pathway/s (infiltration, surface runoff, spill) within the urban area that could pose a risk to stormwater quality are summarised in Table 4. The 16 stormwater catchments (> 400 stormwater catchments in total) deemed to pose the highest risk for stormwater runoff quality based on the number and nature of the chemical hazards contained are shown in Figure 7. One additional stormwater catchment (number 408) was deemed high risk to stormwater quality via spills only, which is due to a high risk of traffic accidents. The location of sampling associated with existing stormwater quality data in relation to these 17 highest risk catchments is illustrated in Figure 8. Stormwater suspended solids (SS), total phosphorus, chromium, copper, lead, zinc and total petroleum hydrocarbon (TPH) concentrations were significantly different in samples from high and low risk catchments (Appendix D; Vanderzalm *et al.*, 2009). Note that this assessment of high risk catchments is based purely on land use and the risk activities contained within and it does not take into account preventative measures.

Table 4 Urban land use and associated risk activities incorporated into urban area GIS.

Land Use	Risk activity	Chemicals of concern	Qualitative risk assessment (S&G, 2004)	Pathway[‡]
Sewers	Sewer leak or overflow	pathogens, inorganic chemicals (metals), nutrients, organic chemicals (solvents)	L-M	I, SP (overflow)
Bulk fuel storage	Fuel storage	organic chemicals (hydrocarbons)	M-H	I, SR, SP
Service stations	Fuel storage	organic chemicals (hydrocarbons)	M-H	I, SR, SP
Timber industry	Timber treatment	inorganic chemicals (copper chrome arsenic; CCA[†]), organic chemicals (creosote[†])	M-H	I, SR, SP
	Fuel storage	organic chemicals (hydrocarbons)	M	I, SR, SP
Dry cleaners	Chemical storage	organic chemicals (perchloroethylene; PCE, tetrachloroethylene; TCE)	H	I, SR, SP
Works depots	Bitumen storage	organic chemicals (polycyclic aromatic hydrocarbons; PAH)	M	I, SR
	Fuel storage	organic chemicals (hydrocarbons)	M	I, SR, SP
Road transport	High density traffic	inorganic chemicals (metals), organic chemicals (hydrocarbons)	not assessed	SR
	High risk traffic accidents	organic chemicals (hydrocarbons, solvents)	not assessed	SP

[†]Specific to site and nature of timber treatment, [‡] I=infiltration, SR=surface runoff, SP=spill

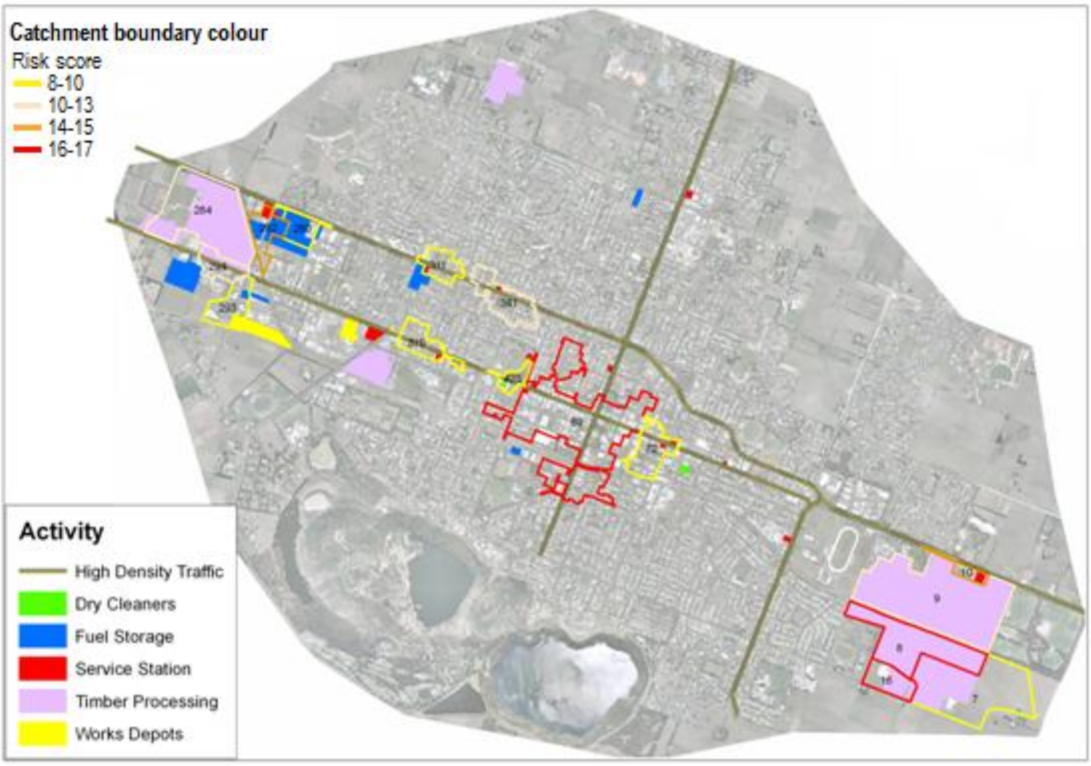

Figure 7 Stormwater catchments of highest potential risk for stormwater runoff quality based on risk activities contained (catchment number shown for highest risk catchments) (Vanderzalm *et al*., 2009)

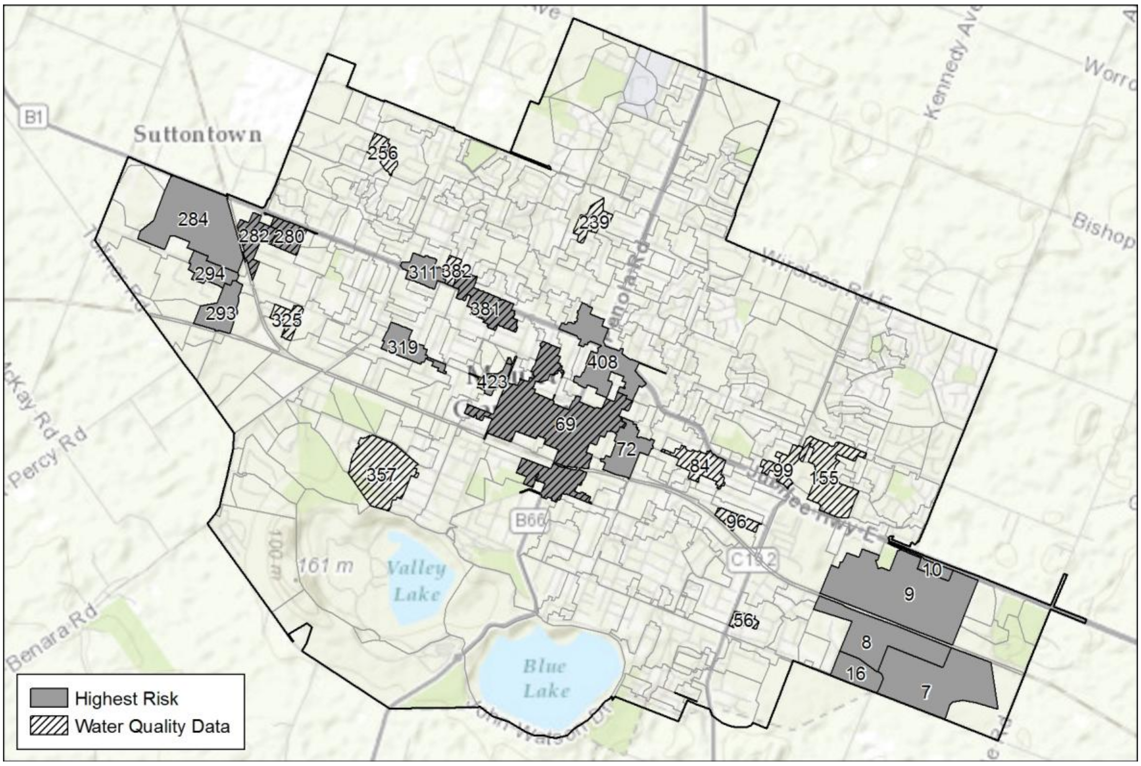

Figure 8 Location of existing stormwater quality data for Mount Gambier in relation to highest risk catchments (catchment number shown for highest risk catchments)

2.4.1 Maximal risk assessment

The Mount Gambier stormwater recharge system was assessed against the hazard categories identified within the Managed Aquifer Recharge Guidelines (NRMMC-EPHC-NHMRC, 2009b). A semi-quantitative risk assessment was performed for each of the hazards (NRMMC-EPHC-NHMRC, 2009b) for human health and environmental endpoints, with green, orange and red indicating low, uncertain and high risks respectively. Hazards 1 to 7 apply to the human endpoint, while all are relevant to the environmental endpoint. The maximal risk assessment is based on untreated stormwater quality in the absence of any preventative measures (Table 5). Historical water quality data for the stormwater, groundwater in the unconfined Gambier Limestone aquifer and the Blue Lake is presented in Appendix D.

Table 5 Maximal risk assessment summary for Mount Gambier stormwater recharge system

	MAR Hazards	Drinking water from Blue Lake	Protection of aquifer and lake
1.	Pathogens – no data for pathogens in Mount Gambier's stormwater, but enteric pathogens can be present in stormwater due to sewer blockages and overflows (5 blockages/y/100 km sewer; NWC, 2013); non potable use of urban groundwater could result in ingestion of aerosols with pathogen	U	U
2.	Inorganic chemicals – maximum stormwater concentration exceeds drinking water guideline values for As, Pb, Ni and exceeds the 80th %ile of historical lake concentrations for As, Cr, Cu, Pb, Zn	H	H
3.	Salinity and sodicity – both stormwater (TDS ~ 50 mg/L) and groundwater (TDS ~390 mg/L) are fresh, low risk for sodicity when used in irrigation as sodium adsorption ratio (SAR) is low (<1)	L	L
4.	Nutrients: nitrogen, phosphorous and organic carbon – Blue Lake is oligotrophic with P thought to limit algal biomass growth, stormwater TP exceeds the 80th %ile of historical lake concentrations	L	H
5.	Organic chemicals – potential for presence of organic chemicals in stormwater, in particular industrial stormwater	H	H
6.	Turbidity and particulates – untreated stormwater can be turbid	H	L
7.	Radionuclides – low potential for release from aquifer sediments or presence in the source stormwater	L	L
8.	Pressure, flow rates, volumes and groundwater levels – gravity drainage in an unconfined aquifer, stormwater recharges helps to sustain groundwater levels		L
9.	Contaminant migration in fractured rock and karstic aquifers – many karstic features in aquifer identified		H
10.	Aquifer dissolution and stability of well and aquitard – drainage wells observed to be stable after 100 years		L
11.	Aquifer and groundwater-dependent ecosystems – potential for stormwater impact		H
12.	Energy and greenhouse gas considerations – lower than alternatives for drinking water supply to Mount Gambier		L

L low risk; **U** uncertain risk; **H** high risk.

2.4.2 Residual risk assessment

The residual risk assessment for the Mount Gambier stormwater recharge system was performed using the same approach as for the maximal risk assessment, but with inclusion of natural treatment during storage and transfer in the aquifer and the lake and regulated extraction from the Blue Lake. With the potential for natural treatment by biodegradation and adsorption in the aquifer and the lake (Vanderzalm *et al.* 2009, 2013), supported by historical water quality data for the Blue Lake (reported in Section 5), the residual risks can be considered acceptable. Water quality data for Blue Lake (1968-2012) illustrates compliance with guidelines for protection of human health. Pathogen data was not available for this assessment. *Cryptosporidium* monitoring is undertaken without an incidence requiring public notification (G. Ashman, pers. comm.). Historical water quality for Blue Lake (1968-2005) was used in conjunction with guidance provided in the ANZECC Guidelines for Fresh and Marine Quality (ANZECC-ARMCANZ, 2000) to establish target indicators for protection of environmental end points and more recent lake water quality data (2006-2012) illustrates compliance with these targets. Each of the health based hazards is discussed below.

Chlorination after extraction provides another treatment barrier prior to reticulated supply of drinking water.

Public health risks

The exposure pathway of greatest public health risk for stormwater use in Mount Gambier is via drinking water supply. Based on the typical volume and frequency of ingestion of spray, routine ingestion or accidental ingestion due to use in garden irrigation or home grown food crop consumption, exposure through inadvertent or unauthorised use would be substantially lower than for drinking water (NRMMC-EPHC, 2006).

The potential pathogen risk from untreated sewage entering the stormwater system via sewer overflows is the most uncertain public health concern as there is no data on pathogens in Mount Gambier's stormwater (Table 5). The previous risk assessment (Vanderzalm *et al*., 2009) preceded the Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1) (NRMMC-EPHC-AHMC, 2006) and the Phase 2 Guidelines for Augmentation of Drinking Water Supplies (NRMMC-EPHC-NHMRC, 2008) and did not assess the pathogen risk. It had been assumed the residual risk from pathogens in the chlorinated, reticulated water supply was acceptable, based on the continued operation with approval by the Department for Health and Ageing. However, this current evaluation considers the potential for pathogen inactivation during aquifer and lake storage (Appendix E), in addition to chlorination. Chlorination is associated with reticulated water supply, managed by SA Water and provides additional protection against bacterial and viral hazards, but not against *Cryptosporidium*.

Natural treatment steps within the Mount Gambier stormwater recharge system include aquifer and lake storage and transfer. A minimum residence time of 1.5 years in the aerobic aquifer (Vanderzalm *et al*., 2009) enhanced by lake residence of 6 years (Herczeg *et al.*, 2003) was adopted for the purpose of assessing the risk from pathogens from stormwater sources. Applying the inactivation rates reported for a warm, oxic, limestone aquifer (Toze *et al.*, 2010) suggests the aquifer can provide adequate protection against pathogens. However, these rates have not been validated in the Gambier Limestone aquifer, which experiences cooler temperatures along with anoxic conditions and hence, lower inactivation rates are expected (Page *et al.,* 2013).

The Managed Aquifer Recharge Guidelines (NRMMC-EPHC-NHMRC, 2009b) requires that where the aquifer is relied on for pathogen removal the removal rate must be validated *in situ.* While the guidelines currently address only the inactivation rate, it is likely that they will be updated to also include net attachment when this can be reliably determined in a risk assessment context, similar to the procedure adopted in the Netherlands. Determination of local pathogen inactivation rates and net attachment, if required, should be used to validate the aquifer's capacity for natural treatment (Section 9).

Higher concentrations of metal(loid)s in stormwater are often associated with particulates, rather than as soluble species. This is illustrated by considerably higher 'total' concentrations than 'soluble' (filtered through 0.45 μm) concentrations (e.g. As, Cr, Cu, Fe, Pb, Ni, Zn) in Appendix D. Therefore considerable removal can occur by sedimentation in the triple chamber silt traps prior to recharge, filtration during aquifer passage or sedimentation during lake storage. Verification monitoring reported annual mean concentrations of trace metal(loid) concentrations in the Blue Lake for the period from 2006 to 2012, below the drinking water guideline values and the 80th percentile of historical values (1968-2005).

A quantitative risk assessment was previously undertaken for a suite of hydrocarbons and a dry-cleaning solvent (benzene, ethylbenzene, toluene, xylene, phenanthrene, fluoranthene, pyrene and tetrachloroethene) that were considered as potential risks to the quality of stormwater and groundwater in Mount Gambier (Vanderzalm *et al.,* 2009). Stormwater monitoring has reported all hydrocarbon concentrations as below the limit of analytical reporting, while tetrachloroethene has not been measured. In the absence of data on the concentration of these organic chemicals in Mount Gambier's stormwater, an organic chemical risk assessment was based on a uniform distribution of concentration between zero and the solubility limit of each chemical. The solubility limit was greater than concentrations reported in the literature for these species in urban stormwater. This assessment incorporated a range of minimum aquifer residence time (1.5-20 years) and 45-65% dilution in groundwater. Median groundwater quality was below the target values for drinking water and aquatic ecosystem, illustrating the treatment capacity of the aquifer for substances analysed. Lake storage was shown to provide an additional level of protection, as water quality could be prone to processes such as degradation, volatilisation, sorption and sedimentation.

Pre-treatment via three-chambered settling pits, filtration in the aquifer and sedimentation in the Blue Lake provide adequate protection against turbidity and particulates. The annual average turbidity from 2006-2012 ranged from 0.19-0.27 NTU, well below the drinking water guideline value of 5 NTU.

Environmental risks

Environmental targets aim to maintain the condition of the lake water quality, in particular the nutrient status, by adopting the 80th percentile of historical lake concentrations as targets for annual mean water quality.

Verification monitoring confirmed that the annual mean of trace metal(loid) concentrations in the Blue Lake from 2006-2012 (Table 8) was generally lower than the 80th percentile of historical lake concentrations. Examination of the lake floor sediment did not reveal any increase in the accumulation of anthropogenic inorganic chemicals due to stormwater recharge (Vanderzalm *et al.*, 2013), but did highlight an increase in the accumulation rate of lithogenic elements due to land clearing and soil erosion around the time of settlement.

The annual average concentrations of both total phosphorus and dissolved organic carbon remain below the 80th percentile of historical water quality at 0.02 mg/L and 1.3 mg/L respectively. In addition, the annual mean nitrate concentrations remain within the target of less than 10% increase in a 5 year period. Thus, nutrient concentrations within Blue Lake are not increasing at a rate that requires intervention. Furthermore, the median nitrate-N concentration in stormwater of 0.12 mg/L is lower than the median concentrations within the Gambier Limestone aquifer in the vicinity of the city of 9 mg/L (Vanderzalm *et al.*, 2009), suggesting stormwater recharge dilutes nitrate concentration in groundwater that replenishes the Blue Lake.

A quantitative risk assessment for organic chemical risks, outlined above in Public Health Risks, reported median groundwater quality was below the target values for aquatic ecosystem protection (Vanderzalm *et al.,* 2009).

Recharge cannot result in excessive groundwater pressure or mound height as recharge occurs via gravity drainage, the depth to watertable beneath Mount Gambier is 20 to 50 m and transmissivity estimates are at least 200 m^2/day. A limit to the volume of extraction from Blue Lake along with monitoring of the lake and groundwater levels provides a measure to protect groundwater levels. In fact without stormwater recharge, groundwater and Blue Lake levels would decline at a greater rate than recently observed (~ 1.5 m from 1996-2006, BLMC, 2006).

Many karstic features have been identified within the proximity of Blue Lake leading to considerable uncertainty regarding aquifer residence time. Minimum residence time between the discharge point and the Blue Lake has been estimated at 1.5-20 years based on a applied tracer test using SF_6 and estimates of pumping induced flow (Wolf *et al*., 2006; Vanderzalm *et al*., 2009). This residence time in the aquifer provides an opportunity for natural treatment and also provides an opportunity for response to water quality concerns identified by groundwater quality monitoring, both of which can lower the risk associated with rapid migration through karstic features. EPA licensees undertake groundwater monitoring associated with known pollution plumes. However, currently there is no designated groundwater quality monitoring to provide early warning of pollutants migrating through karstic features toward Blue Lake.

A pilot study of biodiversity of stygofauna in stormwater recharge wells (Dillon *et al.,* 2009) reported reduced diversity when compared with data from the broader region of the lower South East of South

Australia. Elevated organic carbon was identified as a contributing factor and therefore this should be minimised in stormwater recharge to protect the groundwater-dependent ecosystems.

Summary

In the absence of targeted pre-treatment of stormwater prior to discharge, passive or natural treatment during residence in the aquifer is an important treatment barrier for water quality entering the Blue Lake. While verification monitoring has been undertaken within this system (section 5), treatment of pathogens, trace organics and metal(loid)s during aquifer storage has not been validated (section 9) and there is currently no standard methodology to validate the natural treatment systems. Residence time within the Blue Lake itself is assumed to provide additional time for treatment processes (Appendix E; Vanderzalm *et al.*, 2009), but reservoir storage time can be discounted as a barrier by health authorities if there is the possibility of short-circuiting.

3 Preventive measures for urban stormwater quality management

Preventive measures for stormwater quality management include all actions, activities and processes used to prevent hazards from being in stormwater or to reduce the hazards to acceptable levels.

3.1 Preventative measures and multiple barriers

The existing barriers or buffers within the Mount Gambier stormwater recharge system for the protection of human health and the environment include measures within the catchment, in the stormwater recharge system and in the water supply system. Measures within the catchment include EPA and SafeWork SA regulations concerning stormwater quality and management of hazardous substances by industry. These include storage of hazards under cover, use of bunds to contain hazards and procedures for product accounting to minimise the possibility of undetected loss or leakage.

Preventative measures in the stormwater recharge system include:

- triple chambered silt trap (predominant pre-treatment),
- engineered pre-treatment devices (limited use),
- water sensitive urban design through grassy swales/infiltration (limited use in pre-2007 stormwater management),
- unsaturated zone passage,
- aquifer storage,
- lake storage.

Chlorination of water drawn from Blue Lake is the main preventative measure within the drinking water supply system (a preventative measure within the SA Water drinking water risk management plan).

3.2 Critical control points

A critical control point is an activity, procedure or process where control can be applied and thus is essential for preventing hazards that represent high risks or reducing them to acceptable levels. Critical control points require operational parameters that can be measured and responded to in a timely manner with procedures for correction e.g. chlorine residuals for disinfection.

However, owing to the decentralised nature of the Mount Gambier stormwater recharge system, there are no existing critical control points, prior to extraction from the lake for drinking water supply. The chlorine residual in the drinking water supply after chlorination is a critical control point operated by SA Water.

4 Operational procedures and process control

Operational processes and procedures formalise the activities in place to ensure stormwater is of adequate quality.

4.1 Operational procedures

An Activities Schedule (Appendix A) has been developed identifying the activities required to be undertaken to support the risk management plan for Mount Gambier's stormwater recharge system. This schedule covers all elements of the risk management framework.

Operational procedures related to stormwater discharge under a SA EPA licence are documented by the licensee. Those with monitoring requirement on their licences report to the EPA on an annual basis.

4.2 Operational monitoring

Operational monitoring should assess and confirm the performance of preventative measures through a planned sequence of observations and measurement. Measurement of operational parameters is used to confirm that the preventative measures are functioning properly and can be used as triggers for corrective actions.

It is not feasible to employ continuous operational monitoring throughout this decentralised stormwater recharge system, prior to extraction from the lake. However, continuous operational monitoring (e.g. turbidity, electrical conductivity, total organic carbon or UV_{254}) could be adopted within one or two stormwater catchments containing risks activities to evaluate the performance of preventative measures within the stormwater recharge system.

Operational monitoring performed by the City of Mount Gambier includes documentation of maintenance of the stormwater recharge system, e.g. cleaning of triple chamber pits.

Current operational monitoring undertaken by SA Water includes the volume extracted from Blue Lake, the lake level and the chlorine residual following chlorination.

4.3 Operational corrections

Operational corrections address the conditions when the system is operating outside normal conditions, as revealed by operational monitoring.

Therefore corrections include initiation of triple chamber pit maintenance if not undertaken in the preceding 5 years and adjustment of the chlorine dosing or pumped extraction from the lake.

4.4 Equipment capability and maintenance

The City of Mount Gambier operates the majority of stormwater discharge bores and has a program for inspecting and maintaining stormwater pre-treatment devices. Bore and silt trap maintenance occurs on an ad-hoc basis as required to maintain drainage and cleaning is undertaken at approximately 5 year intervals. Bore and silt trap cleaning or maintenance is recorded in the City of Mount Gambier drainage plan.

It may be more effective to modify the annual maintenance regime to include a selection of bores and silt traps for programmed maintenance (e.g. ~50 systems/y), a smaller number for upgrade to the pre-treatment system based on annual water quality monitoring and an additional number for ad-hoc maintenance as required to maintain drainage, based on potential impact from hazardous activities such as building construction, or from records of previous maintenance (~50 systems/y).

4.5 Materials and chemicals

No chemicals are used to treat the City of Mount's Gambier's urban stormwater prior to recharge. Chemical treatment of industrial stormwater may be required to meet licence conditions. Any materials to be used in improving the pre-treatment provided to existing drainage bores or in establishment of new drainage systems must be authorised or approved to ensure compliance with industry standards.

5 Verification of water quality and environmental performance

Water quality data collected for the stormwater recharge system until 2005 was previously assessed within Vanderzalm *et al.* (2009) and Wolf *et al.* (2006). The current assessment extends the previous assessment by incorporating more recent data for the water quality of the Blue Lake, from 2006 to early 2013 (SA Water, unpublished data) and by incorporating *E. coli* as a microbial indicator.

All water quality monitoring is consistent with the procedures outlined in *Standard Methods for the Examination of Water and Wastewater* (APHA-AWWA-WEF, 1998). Water quality samples are sent to a laboratory for analysis and measured according to standard NATA accredited procedures.

5.1 Stormwater quality monitoring

Currently there is no monitoring for the City of Mount Gambier's stormwater quality and industrial stormwater monitoring is limited to licence requirements. EPA licensee data for industrial stormwater was not accessed for this assessment. Therefore, there was no additional data for the City of Mount Gambier's stormwater to extend the previous assessment of stormwater quality (Vanderzalm *et al.,* 2009; data in Appendix D). The current and historical water quality monitoring relevant to the Mount Gambier stormwater recharge system is given in Table 6.

Table 6 Monitoring history for water sources and end use alternatives within the Mount Gambier stormwater recharge system

Component or activity	Current water quality monitoring	Previous water quality monitoring
Industrial stormwater	✓	✓
Stormwater	✗	✓ (1978-1982, 1999-2002, 2004)
Gambier Limestone aquifer	✗	✓ (1981-2005)
Blue Lake	✓	✓
Non-potable groundwater uses at point of use	✗	✗

The monitoring program objectives refer back to the overarching management goal of "*enhancement and protection of the Blue Lake and the aquifer system as a long term water resource asset to the Mount Gambier and district community*". Therefore, water quality monitoring should provide evidence to determine if Blue Lake and the aquifer system are being enhanced and protected. Specifically, the monitoring objectives are:

- Describe and assess the quality of stormwater recharge in sufficient detail to confidently understand the potential pollutant inputs to the aquifer system and the Blue Lake.
- Describe and assess the water quality in the Blue Lake and its groundwater system with respect to their environmental values (and water quality guidelines), with reference to the potential hazards from stormwater recharge.
- Assess changes in stormwater quality and groundwater quality that are anticipated as a consequence of land use and/or stormwater management initiatives consistent with enhancement and protection of the Blue Lake and the aquifer system.

The monitoring program should aim to inform these objectives. A brief outline to support development of a verification monitoring program for the Mount Gambier stormwater recharge system is given in Table 7. The detail of the monitoring program, including sampling location, methodology and frequency and the suite of parameters to be measured may be constrained by the resources available. Using the risk assessment framework allows available resources to be allocated to the highest priory risks.

If multiple agencies take responsibly for individual components of the verification monitoring program, it is recommended that the suite of parameters measured and the analytical detection limits reported remain consistent. Furthermore, coordination and oversight of the individual components of the verification monitoring program is required.

The monitoring data should be reviewed regularly and used to revise the monitoring program where necessary. For example, verification that a hazard poses an acceptable risk may lead to a reduction in the sampling frequency. Conversely, an increasing trend may require investigation through targeted monitoring.

Table 7 Outline for development of a verification monitoring program for the Mount Gambier stormwater recharge system

Component	Monitoring suggestions	Methodology	MAR Hazards to be monitored
Stormwater	Catchments vulnerable to hazards, including catchments categorized as high risk based on the existing land use. Catchments with existing water quality data, available for comparison/analysis of trends.	Continuous, online monitoring of indicator parameters if feasible. Grab-sample, frequency and location to be determined.	• Pathogens • Inorganic chemicals • Nutrients, • Organic chemicals • Turbidity and particulates
Groundwater	Monitoring bores likely to intersect the pathway/s of potential hazard/s towards the Blue Lake. Number of samples sufficient to assess performance of aquifer treatment barrier.	Grab-sample, frequency and location to be determined.	• Pathogens • Inorganic chemicals • Nutrients, • Organic chemicals • Turbidity and particulates
Blue Lake	Representative lake water quality, taking into account stratification regime.	Continuous, online monitoring of indicator parameters if feasible. Grab-sample, frequency and location to be determined.	• Pathogens • Inorganic chemicals • Nutrients, • Organic chemicals • Turbidity and particulates

5.2 Application site and receiving environment monitoring

The receiving environment is the limestone aquifer and ultimately the Blue Lake. Verification of the recovered water quality assesses the overall performance of the system in relation to specific uses of the water as a drinking water supply and a lake of environmental importance. Blue Lake water quality monitoring currently undertaken by SA Water (details in Table 8), formerly in conjunction with monitoring by the EPA, contributes to verification monitoring.

The current water quality assessment compares annual mean water quality for the Blue Lake, from 2006 onwards (Table 8), for comparison with the targets outlined in Table 3. An increasing trend was not evident. There were isolated occasions when the annual mean concentration was in excess of the 80th percentile of historical concentrations in Blue Lake. However, in all cases the indicator value is far more stringent than the drinking water guideline value and provides time for intervention if an increasing trend is evident. The indicator value for barium may need to be revised as it was derived on a small sample size (n=21). The annual average *E. coli* in Blue Lake was generally greater than the drinking water guideline value. However the monitoring location is prior to chlorination, which provides protection against microbial hazards prior to reticulation. Specific bacteria and virus are not monitored as these risk are managed through chlorination. SA Water also monitors *Cryptosporidium* (data not presented), without any incidence that would trigger public notification.

Following the previous risk assessment reported by Vanderzalm *et al*. (2009), monitoring for trace organic chemicals in Blue Lake was undertaken by SA Water from 2008-2013. This monitoring program has focused on pesticides, with additional monitoring for petroleum based hydrocarbons in 2013. On all occasions trace organic chemical concentrations were reported as below the analytical limit of reporting, which is consistently lower than the health based ADWG value (NHMRC, 2011) and indicates stormwater recharge does not lead to an immediate high risk with respect to organic chemical hazards. The analytical limit of reporting for a small number of organic chemicals exceeds the 95% level of protection trigger value, but in general the recent data for trace organic chemical concentrations in Blue Lake complies with the aquatic ecosystem protection target values. Minor modifications to the current monitoring are suggested in the proposed verification monitoring program (Table 7).

General groundwater water quality or groundwater-dependent ecosystem monitoring is not currently undertaken on a routine basis. Groundwater quality monitoring is limited to licence requirements (Appendix B) and infrequent investigations of contaminated sites, but data was from these programs was not accessed for the current assessment. The EPA is developing a revised groundwater monitoring program for this area, which is expected to be reinstated in the future.

The existing Blue Lake groundwater observation well network has limited observation wells completed within the Camelback Member, which is believed to convey stormwater and groundwater to Blue Lake. Therefore, grab sampling to assess groundwater quality may need to utilise a combination of groundwater observation bores and stormwater drainage bores.

Table 8 Mount Gambier stormwater quality (1978-1982;1999-2002;2004) and annual mean water quality for Blue Lake (2005-2012) in comparison to drinking water guideline values and 80th percentile of historical water quality data (1968-2004)

mg/L unless alternate units are given	ADWG	Stormwater		80th %ile historical Blue Lake (1968-2005)	Annual mean						
		Median	95th %ile		2006	2007	2008	2009	2010	2011	2012
Total Dissolved Solids	600 [a]	51	92	370	350	350	350	360	360	350	350
Turbidity (NTU)	5 [a]	81	135	0.25	0.24	0.25	0.25	**0.27**	0.19	0.20	0.19
True Colour (HU)	15 [a]	-	-	1	1	<1	<1	<1	<1	<1	<1
Sulfate	500 [h], 250 [a]	8.2	14	20	17	17	18	17	16	15	16
Sodium	180 [a]	8.0	11	60	59	58	55	59	55	55	57
Nitrate as N	11.3 [h]	0.12	1.1	3.6	3.57	3.63	3.50	3.42	3.55	3.45	3.48
Total Phosphorus	-	0.28	1.9	0.02	0.0065	0.0063	0.0031	0.011	0.0072	0.011	0.0063
Dissolved Organic Carbon	-	8.8	19	1.3	1.2	0.94	0.96	0.99	0.93	0.90	0.87
Chlorophyll *a* (µg/L)	-	-	-	1.8 (indicator =5) [#]	0.27	0.32	0.53	0.44	0.55	0.51	0.32
Antimony - Total	0.003 [h]	-	-	<0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic - Total	0.01 [h]	<0.005	0.009	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.001
Barium - Total	2 [h]	-	-	0.005	0.004	0.005	0.005	0.005	0.039 *	0.006	0.005
Beryllium - Total	0.06 [h]	-	-	<0.001	<0.0005	<0.0005	<0.0005	<0.0003	<0.0003	<0.0003	<0.0003
Boron - Soluble	4 [h]	0.12	0.13	0.09	<0.04	<0.04	<0.04	0.034	0.027	0.030	0.029
Cadmium - Total	0.002 [h]	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0001	<0.0001	<0.0001
Chromium - Total	0.05 as Cr(VI) [h]	<0.005	0.025	0.010	<0.0003	<0.0003	<0.0003	<0.0003	<0.0001	<0.0001	<0.0001
Copper - Total	2 [h], 1 [a]	0.013	0.070	0.01	<0.03	0.02	0.01	0.001	0.003	0.001	0.002
Iron - Total	0.3 [a]	0.68	2.0	0.04	<0.03	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Lead - Total	0.01 [h]	0.014	0.25	0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0001	<0.0001	<0.0001
Manganese - Total	0.5 [h], 0.1 [a]	-	-	0.005	<0.005	<0.001	<0.001	<0.001	0.007 *	<0.0001	0.0001
Mercury - Total	0.001 [h]	-	-	<0.001	<0.0003	<0.0003	<0.0003	<0.0003	0.00002	0.00002	0.0001
Molybdenum - Total	0.05 [h]	-	-	0.001	0.0008	0.0005	0.0007	0.0007	0.0005	0.0007	0.0006
Nickel - Total	0.02 [h]	0.002	0.029	0.06	<0.0005	<0.0005	<0.0005	0.0005	0.0002	0.0001	0.0001
Selenium - Total	0.01 [h]	-	-	0.003	0.004	<0.003	<0.003	<0.003	0.0003	0.0004	0.0003
Zinc - Total	3 [h]	0.10	0.58	0.04	0.009	0.006	0.002	0.003	0.004	0.002	0.002
E. coli (n/100 mL)	0 [h]	-	-	-	2	13	3	<1	<1	7	1

ADWG = Australian drinking water guideline (NHMRC, 2011) [h]=health based guideline; [a]=aesthetic based guideline, * average affected by one high value; - no data; [#] indicator value set using historical values and ANZECC and ARMCANZ, 2000

5.3 Documentation and reliability

The revised monitoring program (Table 7) requires establishment and documentation of the location and frequency of sampling, ensuring that monitoring data is reliable and representative of spatial and temporal variability.

5.4 Satisfaction of users and customer feedback

The pathway for feedback regarding the quality and appearance of the Blue Lake is via the City of Mount Gambier, while the pathway for feedback regarding customer satisfaction of drinking water supply is SA Water. Consideration of relevant feedback should be undertaken on an annual basis.

5.5 Short-term evaluation of results

Data from the Mount Gambier scheme are reviewed in accordance with the EPA or SA Water reporting requirements. SA Water provide results to the Department for Health and Ageing on a quarterly basis. As of March 2014 this is a requirement under the *Safe Drinking Water Act 2011*. Management is by exception, where a water quality guideline or licence condition is exceeded follow-up corrective responses will be initiated. Suggested annual review of the combined water quality report (summaries prepared by EPA and SA Water) by the Blue Lake Management Committee is proposed (Appendix A).

5.6 Corrective responses

Corrective responses in relation to verification monitoring parameters depend upon the specific parameter. Verification monitoring is used to demonstrate that treatment barriers are performing as required. Water quality monitoring within Blue Lake is verification monitoring for the natural treatment barriers, the aquifer and the lake itself.

6 Incident and emergency management

Considered responses to incidents or emergencies that can compromise the Mount Gambier stormwater recharge system are essential.

Some of the potential hazards and events that can lead to emergency situations are:

- human actions such as waste disposal via a drainage well,
- accident-spill of hazardous material,
- sewer overflows.

6.1 Communication

Clearly defined protocols are required for both internal and external communications, including a contact list and notification procedure. Licence exceedances should be reported to the EPA.

6.2 Incident and emergency response protocols and procedures

The City of Mount Gambier, SA Water and major industry have emergency and incident response plans.

All chemical spills must be reported directly to the EPA. Sewer issues are reported to SA Water, who in turn report the incident to the EPA.

The City of Mount Gambier implement the following emergency response procedure for hazardous material spills:

- assess the nature of the spill,

- refer to Material Safety Data Sheet (MSDS) for chemical information, if relevant,
- notify MFS and/or EPA if relevant, depending on the nature of the spill,
- contain spill, using inflatable plugs on pipes and bores in catchment area and/or sandbags,
- apply appropriate absorbent material to spill, such as Spill Stop, Bitumen Plus or crusher dust for large scale spills, and/or apply soil sorbent boom socks within water,
- employ vacuum truck (available 24 hours) to dispose of any sludge/absorbent to contaminated waste disposal,
- use street sweeper for a final clean of road surface within 12 hours of spill.

The Water/Wastewater Notification and Communication Protocol was established between SA Water, EPA and the Department for Health and Ageing (coordinator) in 1999. This Protocol is a requirement of the *Safe Drinking Water Act 2011*. As a result, SA Water implement emergency response procedures that are approved by the Department for Health and Ageing. These procedures include the response to sewer spills that may enter the groundwater via stormwater drainage wells, and water quality incidences within Blue Lake.

The EPA responds to water quality incidences within licence reports on a needs basis determined by the nature of the activity and associated risk, with actions including repeat sampling and analysis or detailed site investigation.

Water quality incidences should trigger verification at wells affected by incidents in the next groundwater monitoring event.

7 Operator, contractor and end user awareness and training

This element involves awareness and training for operators, contractors and end users of stormwater.

7.1 Operator awareness and training

City of Mount Gambier employees must be appropriately skilled and trained in the management and operation of the stormwater recharge system, including incident and emergency response procedures. This requires on-the-job training in the methods and skills required to perform their tasks efficiently and competently, as well as knowledge and understanding of the impact their activities can have on water quality. Training is also relevant to City of Mount Gambier’s employees not working directly on the stormwater recharge system, but on tasks that could impact on stormwater quality e.g. building approvals, road resurfacing/line painting, weed spraying (to be undertaken in dry weather).

Workplace risk assessments undertaken by the City of Mount Gambier effectively assess occupational health and safety risks and preventive measures. Inclusion of risks to the environment within workplace risk assessment and management is a means of communicating the importance of environment protection to the organisation, in this instance focusing on protection of water quality in stormwater, groundwater and the Blue Lake.

7.2 Contractor awareness and training

City of Mount Gambier contractors must be appropriately skilled to understand the impact their activities can have on stormwater quality or the stormwater recharge system. All contractors must have an accredited ‘White Card’, which is a legal requirement nationally for construction work and indicates a person has undertaken induction for all aspects of safety related to construction, including hazards and control measures. In addition to this, the City of Mount Gambier provides induction to requirements for specific tasks as required.

7.3 End user awareness and training

The contribution of stormwater to Mount Gambier's drinking water supply is acknowledged within the Blue Lake Management Plan (BLMC, 2006), which is available from the South East Natural Resources Management Board (http://www.senrm.sa.gov.au/Water/BlueLakeManagementPlan.aspx, accessed June 19, 2013).

8 Community involvement and awareness

This element involves consultation and engagement and aims to develop a community that is actively involved in the stormwater use system.

8.1 Consultation with users of stormwater and the community

The Mount Gambier Stormwater Recharge System has been established incrementally since the 1880s, without the level of community involvement that would be expected in the current developmental process. However this importance of community involvement and awareness is acknowledge as an expected outcome of the Blue Lake Management Plan (BLMC, 2006) as follows:

"*A community committed to protecting the Blue Lake through changes to on-ground behaviour".*

Local government, the City of Mount Gambier and the District Council of Grant, is largely responsible for community engagement in relation to stormwater use and protection of Blue Lake.

8.2 Communication and education

The Blue Lake Water Care Program commenced in 2000, with funding from the South East Natural Resources Management Board (SE NRMB) and the City of Mount Gambier to work with industry, community groups and schools to improve awareness and management practices. Initially, this program included a SE NRMB funded staff member located within the City of Mount Gambier offices. While this position has ceased, the City of Mount Gambier Environmental Sustainability Officer and Sustainability sub-committee now undertake this role. Current community communication and education initiatives include:

- signage including around the lake to explain how the groundwater-fed lake changes colour and stencilling of the stormwater drainage system with 'drains to Blue Lake' to promote awareness of the presence of stormwater in Blue Lake
- websites, including Blue Lake Watercare http://www.senrm.sa.gov.au/Communityvolunteering/BlueLakeWatercare/Watercare.aspx,
- community displays,
- programs for education in schools,
- media releases,
- environment week promotion,
- environmental awards (previously Blue Lake protection awards).

Educational initiatives have been successful in raising community awareness in relation to Blue Lake programs, but additional effort is required continue to develop this awareness as the community changes and to influence behaviour (BLMP, 2006). New residents within the City of Mount Gambier could be educated on the stormwater recharge system through an information brochure, dispatched after the sale of a property. Similarly, continuing education material, such as a report on stormwater quality or upgrade of stormwater treatment, could be included with council rate notices on an annual basis.

Socioeconomic analysis reported in Wolf *et al*. (2006) indicated that both the public and stakeholders are concerned about the potential to pollute Blue Lake or its groundwater and that Blue Lake is a highly valued resource to the region.

9 Validation, research and development

This element covers validation monitoring, research and development. It is important that corporations, regulators and resource managers are committed to research and development activities on stormwater quality issues in order to manage current and emerging issues effectively. This would include investigation of innovative processes and solutions, and validation of processes affecting the fate of contaminants in the stormwater system, the aquifer and Blue Lake.

9.1 Validation of process

Validation monitoring is defined as the monitoring undertaken to demonstrate that the preventive measures/barriers, critical limit set-points, operational configuration and operating procedures implemented will achieve the required water quality.

Due to the karstic nature of the unconfined Gambier Limestone aquifer, the lake represents the terminus for stormwater extracted for drinking water supply. CSIRO studies in assessing the minimum residence time in the aquifer (Vanderzalm *et al.*, 2009), in conjunction with DEWNR investigations of hydrostratigraphy in the vicinity of Blue Lake (Lawson, 2014) provide some elementary information on the hydraulics of the natural treatment barrier.

Published rates of biodegradation for the organic chemicals suggest there is potential for considerable degradation during residence in an aerobic aquifer. However, due to the presence of organic chemical contamination in the groundwater beneath Mount Gambier it would be advisable to confirm the site specific potential for degradation of organic chemicals in the Gambier Limestone aquifer.

However, the capacity of the aquifer to treat pathogens has not been validated. As there are currently no standard validation techniques for natural treatment, this activity would require development of an experimental program for validation. Initially this could be undertaken using a site specific pathogen inactivation study to determine pathogen viability and infectivity. If aquifer inactivation alone does not provide adequate treatment of pathogens, a complementary study could address the potential for additional treatment through net attachment to the aquifer matrix. Validation of in-lake treatment is also warranted if lake storage is relied upon for the treatment, again with pathogen inactivation as the highest priority for such validation. Dilution in the aquifer and the lake may also reduce the risk from microbial pathogens.

9.2 Design of equipment

Research should be undertaken when designing new equipment and infrastructure, or when implementing design changes to improve plant performance and control systems. Adaption, such as the use of granular activated carbon sorbent for removal of organic chemical hazards within the triple chamber silt trap, or short-term use of UV disinfection for pathogen hazards, could be considered.

Stormwater pre-treatment techniques employing commercially available devices should have satisfied design requirements according to the relevant industry code.

9.3 Investigative studies and research monitoring

The Blue Lake Management Committee has been successful in securing more than $600,000 in Australian Government funding, through the Natural Heritage Trust and the National Action Plan for Salinity and Water Quality, for research related to Blue Lake and the underlying aquifers in response to the 2001 plan (BLMC, 2006). Research relevant to this document includes investigation of hazards to stormwater quality related to urban land use (S&G, 2004), management of these hazards, natural treatment in the aquifer and Blue Lake (Vanderzalm *et al*., 2009, 2013), groundwater flow in sub-units within the unconfined Gambier Limestone aquifer recharging the Blue Lake, including the influence of secondary porosity (Love, 1993; Lawson, 2013, 2014).

Complementary studies have also been undertaken, including the impacts of diffuse land use on groundwater quality (Harvey, 1979; Dillon, 1988; Fleming, 2006; Levett *et al*., 2009); groundwater and lake levels (BLMC, 2006); the fate of nitrate in groundwater and the Blue Lake (Lamontagne, 2002; Lamontagne and Herczeg, 2002); processes resulting in Blue Lake's annual colour change (Telfer, 2000; Turoczy, 2002); age, residence time and origin of water in Blue Lake (Tamuly, 1970; Waterhouse, 1977; Turner, 1979; Leaney *et al.*, 1995, Herczeg *et al.*, 2003); and catchment hydrological modelling (Nguyen, 2013).

However, ongoing research is required to validate the natural treatment provided by the aquifer and possibly also the lake, particularly for pathogens and most notably *Cryptosporidium*.

In addition, the hydraulic gradient induced by stormwater recharge and extraction from Blue Lake for drinking water supply may impact on the movement of groundwater in the Gambier Limestone aquifer that has been contaminated by previous land use activities. Increasing the hydraulic gradient in the direction of the lake may cause contaminated groundwater to move toward the Blue Lake at a faster rate. There are several locations in the City of Mount Gambier where groundwater has been contaminated by organic chemicals (total petroleum, hydrocarbons, polycyclic aromatic hydrocarbons, monocyclic aromatic hydrocarbons, phenols, dioxins, organochlorine pesticides) or inorganic chemicals (arsenic, copper, chromium). The current status of groundwater quality in the vicinity of contamination sites is not known, which necessitates monitoring to assess the quality of groundwater. Research to establish the current quality of groundwater in the Gambier Limestone aquifer arising from historical land use or contamination events is required. This may be informed by historical water quality monitoring undertaken by EPA licensees.

10 Documentation and reporting

This element of the framework for management of stormwater quality and use is part of the general area of 'supporting requirements'. Appropriate documentation provides a foundation for establishing and maintaining effective water quality management systems. It is intended that this report provides suitable documentation for the Mount Gambier stormwater recharge scheme.

10.1 Management of documentation and records

The suggested Activities Schedule in Appendix A documents the activities to be undertaken to manage the Mount Gambier stormwater recharge system. Already there is substantial effort undertaken by the numerous agencies involved and some refinement of current activities, with reinforcement in high priority areas for risk mitigation are included.

10.2 Reporting

Reporting includes scheme performance based on water quality criteria as outlined in Appendix A. Data needs to be interpreted and reported on an annual basis and recorded in a secure electronic archive for future evaluation.

11 Evaluation and audit

Long-term evaluation of Mount Gambier stormwater recharge system quality results and audit of stormwater quality management are required to determine whether preventive strategies are effective and whether they are being implemented appropriately. This long-term evaluation allows performance to be measured against objectives and helps to identify opportunities for improvement.

11.1 Long-term evaluation

Long-term evaluation would ideally be achieved through the five-yearly review of the data reported annually. It should record changes to hazards (change in land use, urban development), preventative measures and water quality. It is suggested that long-term evaluation be undertaken in conjunction with revision of the Blue Lake Management Plan with the relevant State government agencies taking responsibility for their relevant jurisdictions.

11.2 Audit of water quality management

It is advised that the Mount Gambier stormwater recharge system management plan be integrated with the revised Blue Lake Management Plan. It may be possible for audit of management of the stormwater recharge system to be combined with future audits of the drinking water quality management.

12 Review and continuous improvement

12.1 Review by senior managers

It is recommended that, in accordance with the Australian Guidelines for Water Recycling, senior managers from relevant agencies review the effectiveness of the risk management plan and amend or revise as necessary to improve operation of the stormwater recharge system and ensure ongoing protection of Blue Lake and its groundwater system on a regular (or five-yearly) basis.

12.2 Stormwater quality management improvement plan

Proposed modifications to the agreed Activities Schedule including monitoring requirements, infrastructure (pre-treatment) maintenance programs and community education activities could be developed annually after review of the previous year’s performance.

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Glossary

AHD	Australian Height Datum
ANZECC	Australian and New Zealand Environment Conservation Council
aquifer	A geological formation or group of formations capable of receiving, storing and transmitting significant quantities of water. Aquifer types include confined, unconfined and artesian.
aquitard	A geological layer that has low permeability and confines or separates aquifers.
Australian Drinking Water Guidelines	The Australian Drinking Water Guidelines undergoes rolling revision to ensure it represents the latest scientific evidence on good quality drinking water.
AWQC	Australian Water Quality Centre
Campylobacter	A genus of bacteria that is a major cause of diarrhoeal illness.
catchment	Area of land that collects rainfall and contributes to surface water (eg streams, rivers, wetlands) or to groundwater.
critical control point (CCP)	A step or procedure at which controls can be applied and a hazard can be prevented, eliminated or reduced to acceptable (critical) levels.
critical limit	A prescribed tolerance that must be met to ensure that a critical control point effectively controls a potential health hazard; a criterion that separates acceptability from unacceptability.
Cryptosporidium	Microorganism that is highly resistant to disinfection; commonly found in lakes and rivers. *Cryptosporidium* has caused several large outbreaks of gastrointestinal illness with symptoms such as diarrhoea, nausea and stomach cramps. People with severely weakened immune systems are likely to have more severe and more persistent symptoms than healthy individuals (adapted from United States Environmental Protection Agency).
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEWNR	Department for Environment, Water and Natural Resources, South Australia
DWLBC	Department of Water Land and Biodiversity Conservation
Disability adjusted life years (DALY)	DALYs are used to set health-based targets and assess risks for human health in relation to pathogens. DALYs are used to convert the likelihood of infection or illness into burdens of disease; one DALY represents the loss of one year of equivalent full health.
disinfection	The process designed to kill most microorganisms, including essentially all pathogenic bacteria. There are several ways to disinfect; chlorine is most frequently used in water treatment.
Drinking water	potable water for the Mount Gambier mains distribution system
E. coli	*Escherichia coli*; bacterium found in the gut. Used as an indicator of faecal contamination of water.
EPA	Environment Protection Authority, South Australia
guideline value	The concentration or measure of a water quality characteristic that, based on present knowledge, either does not result in any significant risk to the health of the consumer (health-related guideline value), or is associated with good-quality water (aesthetic-guideline value).
hazard	A biological, chemical, physical or radiological agent that has the potential to cause harm.
hazard control	The application or implementation of preventive measures that can be used to control identified hazards.
hazard identification	The process of recognising that a hazard exists and defining its characteristics.
hazardous event	An incident or situation that can lead to the presence of a hazard (what can happen, and how it can happen).
indicator	Measurement parameter or combination of parameters that can be used to assess the quality of water; a specific contaminant, group of contaminants or constituent that signals the presence of something else.
injectant	The water injected (pumped or fed by gravity) into an ASR or ASTR injection well.
irrigation	Provision of sufficient water for the growth of crops, lawns, parks and gardens; can be by flood, furrow, drip, sprinkler or subsurface water application to soil.
log reduction or removal	Logarithmic (base 10) concentration reductions, effectively reduction by a factor of 10. Used in reference to the physical–chemical treatment of water to remove, kill, or inactivate microorganisms such as bacteria, protozoa and viruses.
managed aquifer recharge (MAR)	The intentional recharge of water to aquifers for subsequent recovery or environmental benefit.
MARSUO	Managed Aquifer Recharge Stormwater Use Options
maximal risk	The level of risk in the absence of preventive measures.

monitoring	Systematically keeping track of something, including sampling or collecting and documenting information.
multiple barriers	Use of more than one preventive measure as a barrier against hazards.
pathogen	A disease-causing organism (e.g. bacteria, viruses, protozoa).
pre-treatment	Any treatment (e.g. detention, filtration) that improves the quality of water before injection.
preventive measure	Any planned action, activity or process that is used to prevent hazards from occurring, or reduce them to acceptable levels of risk.
quality	The totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs; the term 'quality' should not be used to express a degree of excellence.
quality assurance	All the planned and systematic activities implemented within the quality system, and demonstrated as needed, to provide adequate confidence that an entity will fulfil requirements for quality.
quality control	Operational techniques and activities that are used to fulfil requirements for quality.
quantitative microbial risk assessment (QMRA)	A method for assessing risks from microbial agents in a framework that defines the statistical probability of an infection from the environmental.
recharge	Surface water replenishing groundwater.
residual risk	The risk remaining after consideration of existing preventive measures.
reuse	Using water that would otherwise be discharged to wastewater or stormwater systems, for domestic, commercial, agricultural or industrial purposes.
risk	The likelihood of a hazard causing harm to exposed populations in a specified timeframe; includes the magnitude of that harm.
risk assessment	The overall process of using available information to predict how often (likelihood) hazards or specified events may occur and the magnitude of their consequences.
risk management	The systematic evaluation of the water supply system, the identification of hazards and hazardous events, the assessment of risks, and the development and implementation of preventive strategies to manage the risks.
runoff	Surface overland flow of water resulting from rainfall or irrigation that exceeds the soil's infiltration capacity.
SA Water	South Australian Water Corporation
salinity	The presence of soluble salts in soil or water. Electrical conductivity and total dissolved salts are measures of salinity.
SE NRMB	South East Natural Resources Management Board
sewage or wastewater	Material collected from internal household and other building drains; includes faecal waste and urine from toilets, shower and bath water, laundry water and kitchen water.
sodicity	A condition in which positively charged sodium ions cause the soil particles to repel each other, resulting in soil swelling, dispersion and reduced soil permeability.
stakeholder	A person or group (eg an industry, a government jurisdiction, a community group, the public) that has an interest or concern in something.
stormwater	Rainwater that runs off all urban surfaces such as roofs, pavements, car parks, roads, gardens and vegetated open space.
target criteria	Quantitative or qualitative parameters established for preventive measures to indicate performance; performance goals.
Thermotolerant coliforms	Coliform bacteria that originate from the gut of warm-blooded animals and whose presence in drinking water can be used as an indicator for operational monitoring.
turbidity	The cloudiness of water caused by the presence of fine suspended matter.
virus	Protein-coated molecules of nucleic acid (genetic material) unable to grow or reproduce outside a host cell.

Appendix A Activities Schedule

A suggested activities schedule that could be utilised to support implementation of the Mount Gambier Stormwater Recharge System risk-based management plan is outlined in Table 9.

Table 9 Suggested activities to support the risk-based monitoring plan

Frequency	Activity	Element	Activity in place
Continuously	Online monitoring of stormwater quality	4	✗
Monthly	Respond to any customer complaints or enquiries as required, document relevant feedback	5	✓
	All incident and emergency response actions to be reported to BLMC for review	6	✗
Monthly-Annually	Water quality sampling (Blue Lake) as per water quality monitoring plan, send samples to laboratory and collate sample results into a database (frequency varies with parameter)	5	✓
Annually	Review commitment and budget to manage the operation of the stormwater recharge system	1	✗
	Add a position statement on stormwater use to the Blue Lake Management Plan	1	✗
	Perform evaluation of yearly compiled water quality data and compliance conditions	2	✗
	Plan upgrade program for stormwater pre-treatment	3	✗
	Assessment of licensee reports	4	✓
	Plan stormwater recharge infrastructure maintenance program (within drainage plan)	4	✗
	Water quality sampling (groundwater) as per water quality monitoring plan, send samples to laboratory and collate sample results into a database	5	✗
	Water quality sampling (stormwater) as per water quality monitoring plan, send samples to laboratory and collate sample results within database	5	✗
	Consolidation of relevant customer feedback and report to BLMC	5	✓
	Review the effectiveness of incident and emergency response activities	6	✗
	Review staff training procedure for employees and contractors	7	✗
	Undertake regular inspection of non-licensed industrial sites to promote best practice with respect to stormwater quality	8	✗
	Communicate with the larger community and stakeholders via corporate websites including an update on water quality and risk management activities for the year	8	✓
	Review communication activities based on reports from CoMG, SA Water, DEWNR	8	✗
	Audit of activities schedule, water quality monitoring program and incidences and emergencies for review by BLMC	11	✗

Frequency	Activity	Element	Activity in place
Five-yearly	Update position statement on stormwater use	1	×
	Review stormwater hazard assessment in relation to catchment land use changes	2	×
	Review suitability of water quality indicator values	2	×
	Review City of Mount Gambier drainage plan	4	×
	Review community attitudes and behaviours and revise community engagement strategy accordingly	8	×
	Perform long-term evaluation of yearly compiled results and compliance condition and, review suitability of indicator values	11	×
	Review City of Mount Gambier drainage plan including infrastructure maintenance	11	×
	Update risk-based management plan based on annual reviews, sign off on revised plan by senior manager (BLMC chair)	12	×
As required	Periodic notification of water well owners in CoMG (e.g. with sale of property) that well is not to be used for drinking water supply untreated	2	×
	Establishment of monitoring requirements	5	×
	Environmental risks to be addressed within workplace risk assessments	7	×
	Engage research to validate treatment performance of aquifer for pathogens, organic chemicals and metals (listed in order of decreasing priority)	9	×
	Engage research to evaluate spatial variability of groundwater quality due to previous land use or contamination events	9	×
	Nominate responsible agency for activities to support plan	10	×

Appendix B EPA Licences

Table 10 EPA Licences related to stormwater recharge (EPA, 2012)

Licence No	Licensee	Activities	Conditions	Term of licence
EPA 2387	City of Mount Gambier	Discharge of stormwater to underground aquifers – in City of Mount Gambier or western industrial zone of District Council of Mount Gambier (various locations)	Implement Environment Improvement Plan (EIP). Stormwater quality and treatment requirement, but no monitoring schedule.	1/1/11-31/12/15
EPA 10010	Peter Whitehead Pty Ltd	Discharge of stormwater to underground aquifers – in City of Mount Gambier or western industrial zone of District Council of Mount Gambier	Nil.	1/6/11-31/5/16
EPA 1109	Carter Holt Harvey Wood Products Pty Ltd	Various including: Discharge of stormwater to underground aquifers – in City of Mount Gambier or western industrial zone of District Council of Mount Gambier	Environment Management Plan. Stormwater and groundwater quality monitoring schedule.	1/7/09-30/6/14
EPA 12306	Whiteheads Timber Sales Pty Ltd	Various including: Discharge of stormwater to underground aquifers – in City of Mount Gambier or western industrial zone of District Council of Mount Gambier	Stormwater and groundwater quality monitoring schedule.	1/12/09-30/12/14
EPA 12765	Carter Holt Harvey Wood Products Australia Pty Ltd	Various including: Discharge of stormwater to underground aquifers – in City of Mount Gambier or western industrial zone of District Council of Mount Gambier	Stormwater and groundwater quality schedule.	1/11/11-31/10/16
EPA 12766	Carter Holt Harvey Wood Products Australia Pty Ltd	Various including: Discharge of stormwater to underground aquifers – in City of Mount Gambier or western industrial zone of District Council of Mount Gambier	Drainage bore maintenance requirement. Stormwater and groundwater quality monitoring schedule.	1/12/11-30/11/16
EPA 14479	A.A. Scott Pty Ltd	Discharge of stormwater to underground aquifers – in City of Mount Gambier or western industrial zone of District Council of Mount Gambier	Drainage bore maintenance requirement.	1/2/12-31/1/17
EPA 14804	K & S Freighters Pty Ltd	Discharge of stormwater to underground aquifers – in City of Mount Gambier or western industrial zone of District Council of Mount Gambier	Drainage bore maintenance requirement.	1/5/12-30/4/17
EPA 1986	Gambier Earth Movers Pty Ltd	Discharge of stormwater to underground aquifers – in City of Mount Gambier or western industrial zone of District Council of Mount Gambier	Drainage bore maintenance requirement.	1/7/11-30/6/16
EPA 23442	Carter Holt Harvey Wood Products (Southern Region) Pty Ltd	Various including: Discharge of stormwater to underground aquifers – in City of Mount Gambier or western industrial zone of District Council of Mount Gambier	Stormwater and groundwater quality monitoring schedule.	1/5/12-30/4/17

Table 11 Details of stormwater and groundwater monitoring as EPA licence conditions

Licence No	Licensee	Stormwater monitoring	Groundwater monitoring
EPA 1109	Carter Holt Harvey Wood Products Pty Ltd	5 locations, after first rainfall event for month exceeding 10mm TPH, COD, pH, TKN, NO3 – all samples Total Cu, Total Cr, Cr(VI), Total As, PAH – wood preservation areas	10 locations, twice per year Total As, Total Cu, PAH, TPH, COD, TKN, NO3, Cr(VI), pH, temperature, EC, redox potential
EPA 12306	Whiteheads Timber Sales Pty Ltd	2 locations, after first rainfall event for month exceeding 10mm, once at least in each of Jan-Mar, Apr-June, Jul-Sep, Oct-Dec or at least 3 samples per year pH, TPH, TOC, Total Cu, Total As, Total Cr	3 locations, twice per year pH, TPH, TOC, temperature, EC, redox potential or DO
EPA 12765	Carter Holt Harvey Wood Products Australia Pty Ltd	5 locations, after first rainfall event for month exceeding 10mm, once at least in each of Dec-Feb, Mar-May, Jun-Aug, Sep-Nov TPH, TOC, TKN, NO3, Total Pb, Total Zn	6 locations, twice per year pH, TPH, TOC, Total Pb, Total Zn, temperature, EC, redox potential, DO
EPA 12766	Carter Holt Harvey Wood Products Australia Pty Ltd	10 locations, after first rainfall event for month exceeding 10mm, once at least in each of Dec-Feb, Mar-May, Jun-Aug, Sep-Nov TPH, TOC, TKN, NO3, oil and grease, SS, EC	5 locations, twice per year TPH, TOC, formaldehyde, pH, temperature, EC, redox potential
EPA 23442	Carter Holt Harvey Wood Products (Southern Region) Pty Ltd	Stormwater discharge points, after first rainfall event for month exceeding 10mm, once at least in each of Dec-Feb, Mar-May, Jun-Aug, Sep-Nov TPH, oil and grease, TOC, pH, Total Cu, Total Cr, Cr(VI), Total and Dissolved As, EC	4 locations, annually Total and Dissolved As, Total and Dissolved Cu, Total Cr, Cr(VI), TKN, NO3, pH, temperature, EC, redox potential

Appendix C Water level contours in the vicinity of Blue Lake

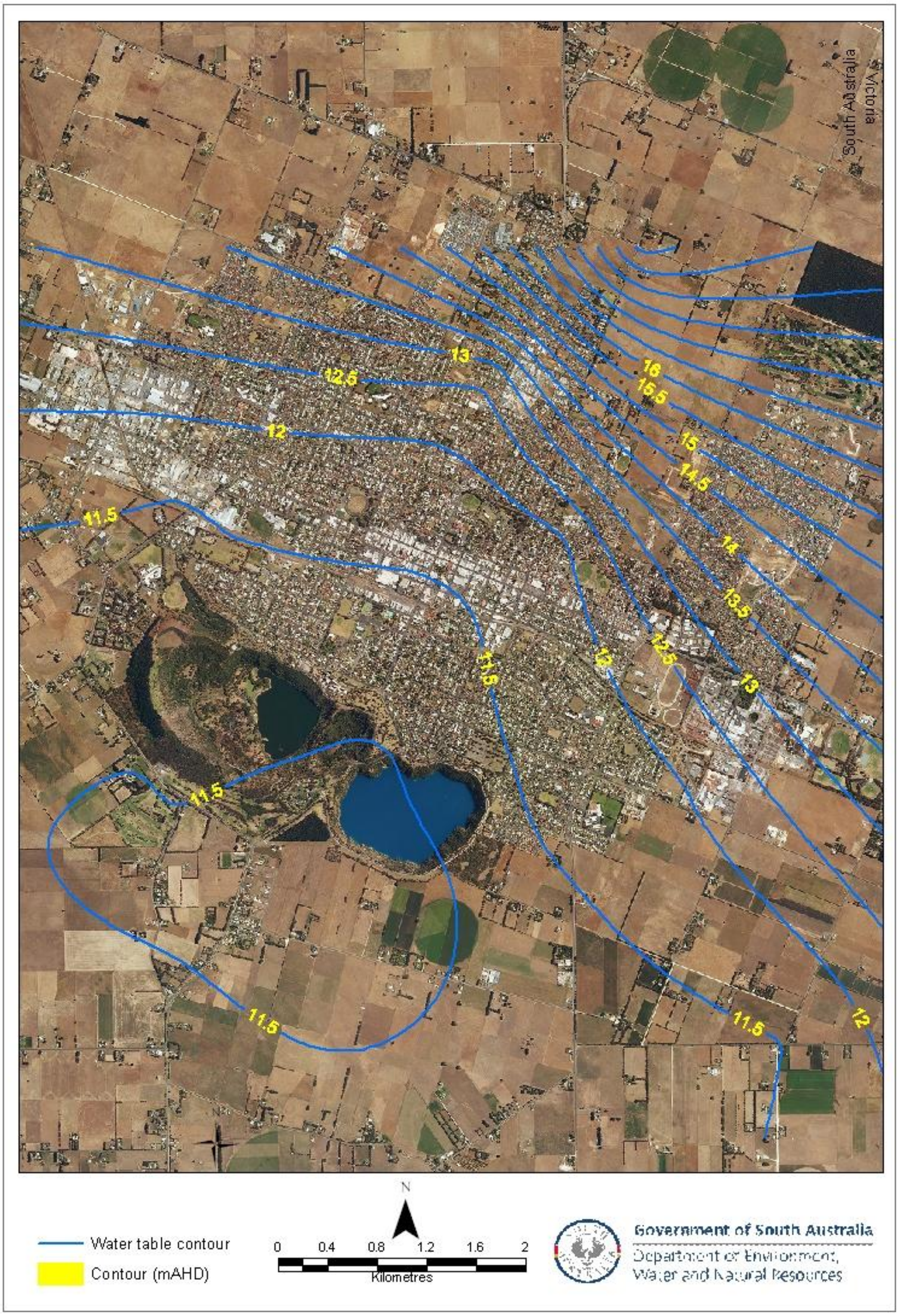


Figure 9 Water level contours in the upper unit of the Gambier limestone aquifer

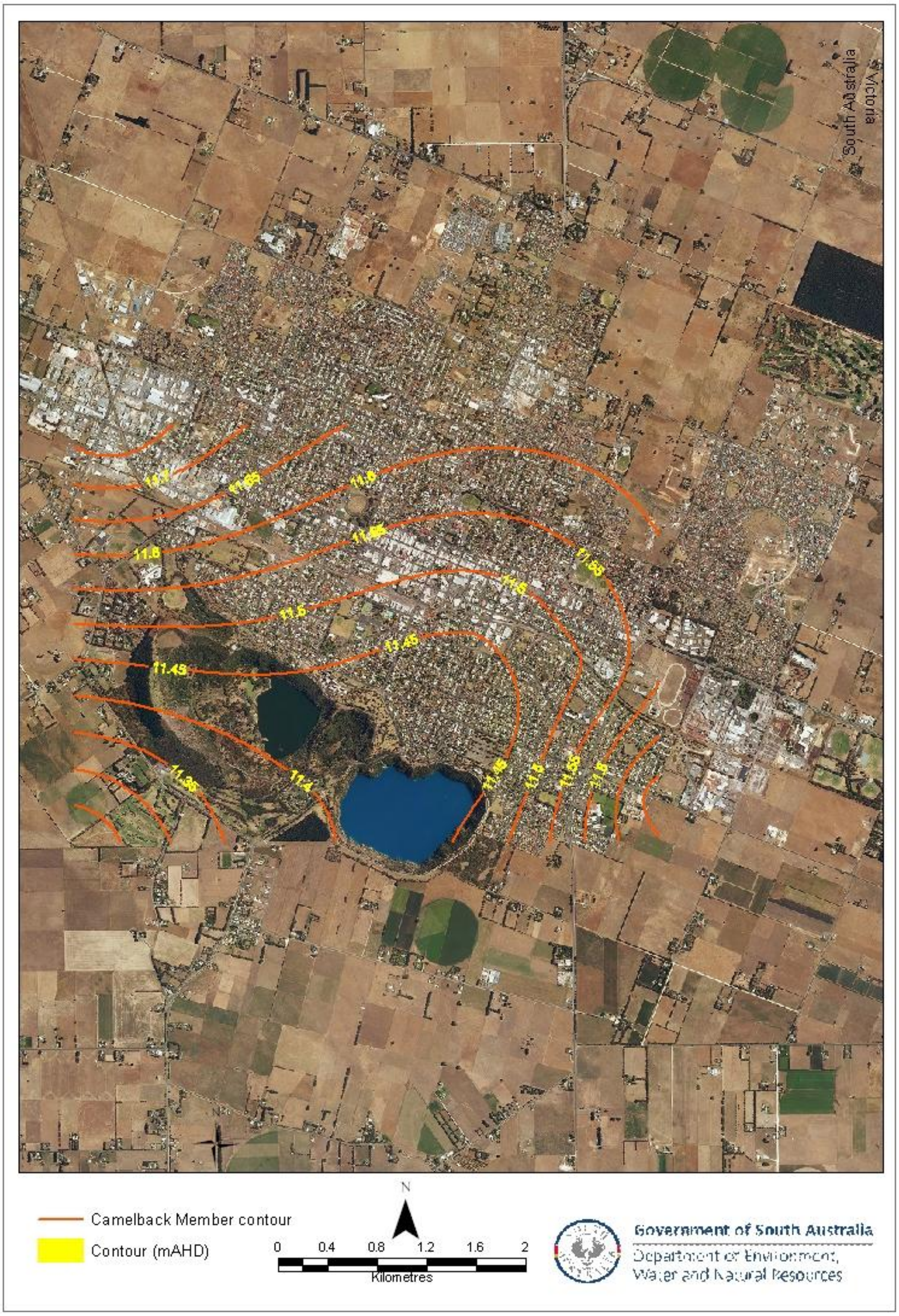


Figure 10 Water levels contours in the Camelback Member of the Gambier limestone aquifer

Appendix D Historical Blue Lake, stormwater and groundwater quality data

Table 12 Historical Blue Lake water quality and stormwater quality in comparison to guideline values

mg/L unless alternate units are given	ADWG [†]	Ecosystem protection [#]	Historical Blue Lake (1968-2005)		Stormwater		
			n	80^{th} %ile	n	median	95^{th} %ile
pH (pH units)	6.5-8.5 [a]	6.5-9.0	913	8.3	47	7.8	8.3
Total Dissolved Solids	600 [a]	-	1073	370	37	51	92
Salinity (µS/cm)	-	300-1000	1073	680	10	84	100
Turbidity (NTU)	5 [a]	1-100	615	0.25	10	81	135
True Colour (HU)	15 [a]	-	134	1	-	-	-
Chloride	250 [a]	-	770	92	35	5.0	15
Sulfate	500 [h], 250 [a]	-	750	20	10	8.2	14
Sodium	180 [a]	-	760	60	10	8.0	11
Nitrate as N	11.3 [h]	0.1	1500	3.6	114	0.12	1.1
Total Nitrogen	-	1	-	-	110	1.2	4.9
Total Phosphorus	-	0.025	890	0.02	123	0.28	1.9
Total Organic Carbon	-	-	-	-	27	25	57
Dissolved Organic Carbon	-	-	295	1.3	11	8.8	19
Chlorophyll *a* (µg/L)	-	5	418	1.8	-	-	-
Aluminium – Soluble	0.2 [a]	0.055	113	0.028	7	0.12	0.42
Antimony - Total	0.003 [h]	ID	38	<0.001	-	-	-
Arsenic - Total	0.01 [h]	-	108	0.001	47	<0.005	0.009
Arsenic - Soluble	0.01 [h]	-	-	-	30	<0.005	<0.005
Arsenic(III)	-	0.024	-	-	-	-	-
Arsenic(V)	-	0.013	-	-	-	-	-
Barium - Total	2 [h]	-	21	0.005	-	-	-
Beryllium - Total	0.06 [h]	ID	11	<0.001	-	-	-
Boron - Soluble	4 [h]	0.37	13	0.09	10	0.12	0.13
Cadmium - Total	0.002 [h]	0.0002	56	<0.001	10	<0.0005	<0.0005
Chromium - Total	0.05 as Cr(VI) [h]	-	149	0.010	91	<0.005	0.025
Chromium – Soluble	0.05 as Cr(VI) [h]	-	-	-	32	<0.001	0.008
Chromium(III)	-	ID	-	-	-	-	-
Chromium(VI)	0.05 [h]	0.001	-	-	-	-	-
Copper - Total	2 [h], 1 [a]	0.0014	150	0.01	99	0.013	0.070
Copper – Soluble	2 [h], 1 [a]	0.0014	-	-	32	0.003	0.006
Iron – Total	0.3 [a]	ID	698	0.04	10	0.68	2.0
Lead – Total	0.01 [h]	0.0034	43	0.001	99	0.014	0.25
Lead - Soluble	0.01 [h]	0.0034	-	-	32	<0.001	0.003
Manganese - Total	0.5 [h], 0.1 [a]	1.9	32	0.005	-	-	-
Mercury - Total	0.001 [h]	-	57	<0.001	-	-	-
Mercury - Inorganic	-	0.0006	-	-	-	-	-
Mercury - Methyl	-	ID	-	-	-	-	-
Molybdenum - Total	0.05 [h]	ID	30	0.001	-	-	-
Nickel - Total	0.02 [h]	0.011	30	0.06	85	0.002	0.029
Nickel - Soluble	0.02 [h]	0.011	-	-	32	<0.001	<0.001
Selenium - Total	0.01 [h]	0.011	30	0.003	-	-	-
Zinc - Total	3 [h]	0.008	121	0.04	100	0.10	0.58
Zinc - Soluble	3 [h]	0.008	-	-	32	0.033	0.17
TPH C6-C9 Fraction (µg/L)	-	-	-	-	75	<20	<20
TPH C10-C14 Fraction (µg/L)	-	-	-	-	75	<50	72
TPH C15-C28 Fraction (µg/L)	-	-	-	-	75	224	566

mg/L unless alternate units are given	ADWG †	Ecosystem protection #	Historical Blue Lake (1968-2005)		Stormwater		
			n	80^{th} %ile	n	median	95^{th} %ile
TPH C29-C36 Fraction (μg/L)	-	-	-	-	75	129	367
TPH C10-C36 Fraction (μg/L)	-	-	-	-	75	395	991
Atrazine (μg/L)	20 [h]	13	53	<0.5	73	<0.5	0.90
Simazine (μg/L)	20 [h]	3.2	53	<0.5	73	<0.5	1.5

† ADWG = Australian drinking water guideline (NHMRC, 2011) [h]=health based guideline; [a]=aesthetic based guideline;
# ANZECC-ARMCANZ, 2000, slightly disturbed system for freshwater lakes and reservoirs south central Australia or 95% level of protection for metal(loid) species

Table 13 Summary of historical water quality data for groundwater in the unconfined Gambier Limestone aquifer

	Unconfined Gambier Limestone aquifer		
	n	Median (mg/L)	Range (mg/L)
Total Dissolved Solids	238	390	96-890
Chloride	206	75	6-230
Sodium	73	58	4-99
Potassium	82	2	0.1-23
Sulfate	67	12	2-33
Total Kjeldahl Nitrogen	165	0.2	<0.05-3
Nitrate as N	180	9	0.3-88
Total Phosphorus	240	0.1	0.006-3.5
Filterable Reactive Phosphorus	240	0.01	<0.005-3
Boron	22	<0.04	<0.05-0.08
Arsenic - Total	205	0.002	<0.001-0.02
Chromium - Total	209	0.005	<0.003-0.8
Copper - Total	149	0.005	<0.001-3
Lead - Total	208	0.004	<0.0005-0.06
Zinc - Total	204	0.03	<0.003-1
Dissolved Organic Carbon	210	1.1	0.1-8
Atrazine (μg/L)	140	<0.5	<0.5-1
Simazine (μg/L)	140	<0.5	<0.5-0.5

n=number of samples

Table 14 Results of Mann-Whitney rank sum test comparing stormwater quality for high and low risk catchments

	High risk catchments			Low risk catchments			P-value	Significant difference
	n	Median (mg/L)	Range (mg/L)	n	Median (mg/L)	Range (mg/L)		
Suspended Solids	30	108	4-1680	64	31	0.5-4840	<0.001	✓
Total Phosphorus	32	0.41	0.02-7	64	0.19	0.01-9.2	0.003	✓
Total Nitrogen	32	1.14	0.09-5.3	55	0.79	0.02-9.0	0.09	×
Nitrate as N	30	0.17	0.02-4.8	56	0.09	0.02-5.3	0.68	×
Chromium - Total	24	0.011	<0.001-0.059	61	0.002	<0.001-0.053	<0.001	✓
Copper - Total	27	0.033	0.009-0.23	61	0.009	<0.001-0.13	<0.001	✓
Lead - Total	27	0.034	0.01-0.88	60	0.008	0.0008-0.064	<0.001	✓
Nickel - Total	20	0.004	0.001-0.048	54	0.002	<0.001-0.059	0.007	×
Zinc - Total	27	0.34	0.084-2.4	62	0.076	0.007-0.43	<0.001	✓
Total Petroleum Hydrocarbons	20	620	70-2890	37	295	70-1570	<0.001	✓

n=number of samples

Appendix E Microbial risk assessment

This microbial risk includes assessment of the potential for pathogen inactivation during aquifer and lake storage. Chlorination is associated with reticulated water supply, managed by SA Water and provides additional protection against microbial hazards.

The Stormwater Harvesting and Reuse guidelines recommend that the 95th percentile numbers of pathogens in source waters and the minimum validated removal rates be used for each preventative measure when used in risk assessments (NHMRC-EPHC-NHMRC, 2009a). As there is no data for pathogen and faecal indicators in stormwater for Mount Gambier, the default values for reference pathogens and compiled data for the Parafield hub site, where intensive pathogen monitoring has been undertaken, are reported in Table 15. The Parafield data is from a sewered catchment with a mean value of 17 blockages/y/100 km sewer. Reported blockages for Mount Gambier from 2008-2012 are considerably lower with up to 5 blockages/y/100 km sewer, suggesting the 95th percentile values adopted may be an over-estimate (NWC, 2013).

Table 15 Summary of pathogen and faecal indicators in Australian urban stormwater (after Page *et al.*, 2013)

	Default values for reference pathogens (raw stormwater)* Log normal 95th percentile	**Parafield stormwater harvesting system (PDS untreated stormwater only)**** Log normal 95th percentile
Adenovirus (n/L) ***	1	2
Cryptosporidium (n/10L)	18 (= 1.8/L)	14
Campylobacter (n/L)	15	11
E. coli (n/100mL)		64,000
Enterococci (n/100mL)		2,900

* Default values recommended for non-potable use risk assessment after Table A3.1 from NRMMC-EPHC–NHMRC, 2009a; ** Data set only includes sampling of untreated stormwater from the Parafield Data Station to 30/11/2012; *** Default value for rotavirus adopted

Health-based performance targets for microbial quality in stormwater can be used to ensure compliance with the tolerable risk of 10^{-6} DALYs (Disability Adjusted Life Years)/person/y (NRMMC–EPHC–AHMC, 2006). The basic principle of the DALY is to weight each health impact in terms of severity within the range of zero, for good health, to one, for death. The weighting is then multiplied by the duration of the effect and the proportion of people affected. In the case of death, duration is regarded as the years lost in relation to normal life expectancy (Page *et al.*, 2013). Microbial performance targets are usually expressed in terms of required $\log_{10}$ reductions.

The two parameters required for calculation of performance targets are pathogen concentrations (Table 15) and exposures associated with identified uses of urban stormwater. To assess the Mount Gambier stormwater recharge system, the assumption that urban stormwater contains 2 virus, 1.4 *Cryptosporidium* and 11 *Campylobacter* per litre was used, based on monitoring data from the Parafield catchment. The indicative exposure associated with drinking water supply is 2 L, 365 days per year (NRMMC–EPHC–AHMC, 2006), which then results in performance targets for removal which are 5.8 $\log_{10}$ virus, 4.8 $\log_{10}$ *Cryptosporidium*, and 5.3 $\log_{10}$ *Campylobacter*, (Table 16) derived from the following equation:

The target $\log_{10}$ reduction (TLR; equation 1) is the number of organisms ingested in a year if the water was untreated ($n_{Y;}$ equation 2), divided by the dose equivalent to 10^{-6} DALY (n_{MD}).

n_{MD} is derived from NRMMC–EPHC–AHMC 2006, for rotavirus = 2.5×10^{-3} n/L, *Cryptosporidium* = 1.6×10^{-2} n/L and *Campylobacter* = 3.8×10^{-2} n/L.

$TLR = \log_{10} \frac{n_Y}{n_{MD}}$ (equation 1)

$n_Y = C \times E \times F$ (equation 2)

where C is the number of organisms per litre in raw water

E is the number of litres per day of consumption (exposure) by an individual

f is the number of exposures received each year

The Drinking Water Guidelines (ADWG) (NHMRC–NRMMC, 2011) give indicative $\log_{10}$ removals for treatment processes, provided that they are validated. SA Water employ chlorination for Mount Gambier's reticulated drinking water supply following extraction from Blue Lake. This can typically provide an additional 3 $\log_{10}$ removal for virus, greater than 4 $\log_{10}$ removal for bacteria, but no removal for protozoa. Therefore, the performance targets for natural treatment prior to chlorination are 2.8 $\log_{10}$ virus, 4.8 $\log_{10}$ *Cryptosporidium*, and 1.3 $\log_{10}$ *Campylobacter*, (Table 16).

Table 16 Performance targets for removal of enteric pathogens by chlorination and natural treatment for drinking water

	Virus	Protozoa	Bacteria
Overall $\log_{10}$ removal target	5.8	4.8	5.3
$\log_{10}$ removal chlorination	3	0	>4
$\log_{10}$ removal target natural treatment	2.8	4.8	1.3

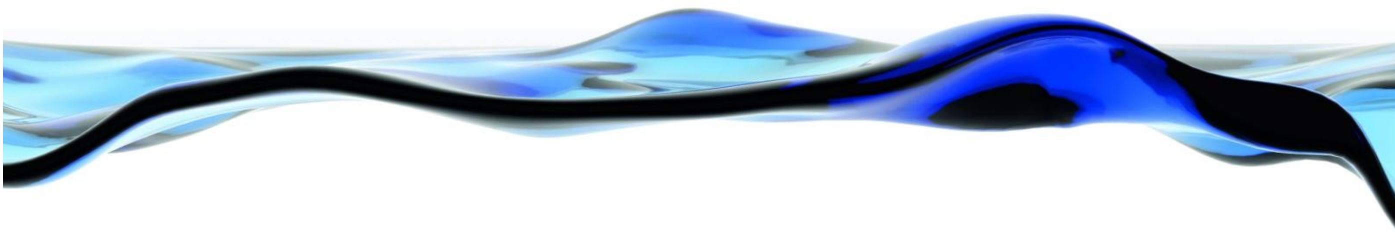
For the Mount Gambier stormwater recharge system, natural treatment steps include aquifer and lake storage and transfer. To substitute for site specific data for the Gambier Limestone aquifer or the Blue Lake, one $\log_{10}$ removal times (T90) determined in either a) a warm (>20°C) aerobic limestone aquifer in Perth (Toze *et al.*, 2010) or b) in a cool (<20° C) anoxic limestone aquifer in Adelaide (Page *et al.*, 2013) and in a lake (Wivenhoe Dam, Toze *et al.*, 2012) were applied to the Mount Gambier system to evaluate the potential for pathogen removal (Table 17). Aquifer inactivation rates varied considerably between warm, oxic conditions and cool, anoxic conditions. A residence time of 1.5 years in the aerobic aquifer could provide adequate protection against enteric pathogens, based on pathogen inactivation rates determined in a warm, oxic limestone aquifer (Toze *et al*., 2010), which is then enhanced by lake residence of 6 years (Herczeg *et al*., 2003). However, these pathogen inactivation rates have not been validated in the Gambier Limestone aquifer, which experiences cooler temperatures. Adoption of much lower rates of *Cryptosporidium* and virus inactivation reported in a cool, anoxic, limestone aquifer (Page *et al.*, 2013) results in a reduced potential of the aquifer to provide protection against these pathogens.

Note that the current level of drinking water treatment provided by SA Water is approved by the Department for Health and Ageing under the *Safe Drinking Water Act 2011*.

Table 17 $\log_{10}$ removal rate (T90) and potential $\log_{10}$ removals of enteric pathogens that can be applied to Mount Gambier stormwater recharge system, based on minimum residence time of 1.5 year in the aquifer and 6 years in the lake

	Virus	Protozoa	Bacteria
Mean T90 aquifer (days) oxic conditions, ~23°C*	42	31	2
Mean T90 aquifer (days) anoxic conditions, ~19°C[†]	>90	>90	<7
Mean T90 lake (days), surface 16-19°C[‡]	26	29	<5
Potential $\log_{10}$ removal aquifer oxic conditions, ~23°C	>12	>12	>12
Potential $\log_{10}$ removal aquifer anoxic conditions, ~19°C	<6	<6	>12
Potential $\log_{10}$ removal lake	>12	>12	>12

*****Based on Toze *et al.*, 2010, aerobic limestone aquifer; [†] Based on Page *et al.*, 2013, anoxic limestone aquifer; [‡] Based on Toze *et al.*, 2012, Wivenhoe dam



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