Irrigating with reclaimed water

February

2009

A scoping study to investigate feasibility for the wine industry

By Arris Pty Ltd
Arris Project: H0502ds
Project Leader: Dr Daryl Stevens

For

Dr Belinda Rawnsley
Sustainable Systems - Viticulture
South Australian Research and Development Institute (SARDI)
GPO Box 397
Adelaide, South Australia 5001
Mobile 0416 892 209
rawnsley.belinda@saugov.sa.gov.au



Document Information

Revision	Status	Prepared by	Issued to	Date	Reviewed by	Approved
1	Draft	Dr Stevens	Belinda Rawnsley	1/10/2008	Jim K, Kristi W.	
2	Final	Dr Stevens	Belinda Rawnsley and Troy Fisher	17/10/08	Dr Daryl Stevens	Daryl S.
3	Final comments addressed	Dr Stevens	Belinda Rawnsley and Troy Fisher	14/4/2009	Dr Daryl Stevens	Daryl S.

Created by

Arris Pty Ltd
646A Bridge St
Richmond Vic 3121
PO Box 5143
Burnley Vic 3121
t 03 9421 1701
m 0418 802 621

Head Office
Waite Campus
University of Adelaide
PO Box 206
Highgate SA 5063

t 08 8303 6706
f 08 8303 6752
ACN 092 739 574

File name Report GWRDC v9.doc

Client Dr Belinda Rawnsley, South Australian Research and Development Institute (SARDI),
GPO Box 397, Adelaide SA 5001. Mobile: 0416 892 209
Email: rawnsley.belinda@saugov.sa.gov.au

Name of organisation SARDI

Name of project H0502ds - Belinda Rawnsley GWRDC

Name of document Irrigating with reclaimed water – a scoping study to investigate feasibility for the wine industry

Document version 2

Cover

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Abbreviations

STP	Sewage Treatment Plant
AGWR	Australian Guidelines for Water Recycling
GWRDC	Grape and Wine Research and Development Corporation
ECe	Electrical conductivity of a soils saturation paste extract
ECi	Electrical conductivity of irrigation water or recycled water
SAR	Sodium adsorption ratio
ESP	Exchangeable sodium percentage

1 EXECUTIVE SUMMARY

1.1 Background

The GWRDC recognises that the use of recycled water in the viticultural industry has the potential to increase the security of water supplies. However, there are potentially a number of issues that are not well understood regarding recycled water use in viticulture. Many of these issues relate to the external implications for the use of recycled water such as government regulations, water availability, public perceptions and human health risks.

This scoping study was undertaken to determine feasibility of irrigating with recycled water for the wine industry. It has been based on a collation of available information and current understanding of the use and associated risks and impacts of using recycled water for irrigation within Australia and overseas.

This document provides an assessment of recycled water use in the wine industry, identifies missing gaps in knowledge and issues that may arise in the expansion of its use in the viticultural sector. This knowledge will assist GWRDC to make an informed decision on future investment in this area.

1.2 Knowledge gaps identified

Four major hazard categories assessed were:

1. Guidelines and recycled water resources;
2. Human health risk;
3. Environmental (including agronomic) risk; and
4. Financial risks.

The knowledge gaps identified for each major category are summarised below with recommendations for filling these gaps (Table 1).

Table 1 Summary of hazards reviewed and knowledge gaps identified

Category	Knowledge gap identified for recycled water	Recommendation to fill knowledge gap	Page
Guidance and resources			
Guidelines	Limited specific guidance for the viticultural industry and use of recycled water in Australia.	A handbook for irrigation of grapevines with recycled water.	11
Water recycled from Sewage Treatment Plants	As of June 2006 only 12 % of water from sewage effluent was recycled, indicating there was still significant opportunity for the viticultural sector to secure this recycled water. However spatial and storage challenges (Section 7.3) make much of the water difficult to access for the viticultural industry.	An assessment of potential opportunities for the viticultural sector to secure recycled water.	19
Human health			
Human health - pathogens	No knowledge gap was identified. These risks have been extensively assessed for food production with recycled water as per the Australian Guidelines for Water Recycling (NRMMC and EPHC 2006).	Note: It is important for all users of recycled water in the viticultural sector to understand, adopt and practice using recycled water in ways that comply with the appropriate guidance and recommendations.	41

Category	Knowledge gap identified for recycled water	Recommendation to fill knowledge gap	Page
Environmental (including agronomic)			
Nitrogen	No knowledge gap identified	Nutrient budgets and monitoring seem well understood and excesses which may lead to off-site impacts managed.	54
Phosphorus	No knowledge gap identified		57
Potassium	Excess potassium may pose a risk to grape/wine quality. Budgets for potassium applied in recycled water compared to removal in grapes suggest on average excesses will be applied in recycled water. However, concentration in recycled water is rarely reported and the data found indicates it may be highly variable.	Potassium concentrations in a range of recycled water sample from across Australia need to be identified. If significant volumes of recycled water are as high as reported, with the potential to use of vines, the identification of critical petiole nutrient concentrations needs to be understood and any changes in grape/wine quality from excess K applied quantified.	59
Salinity	The future challenges and knowledge gap for grape production will be to manage water of high salinities (with limited water) while minimising environmental impacts.	Current research projects seem to be addressing this knowledge gap.	61
Sodium and Chloride	Toxicity - no knowledge gaps identified.	Not required.	66
	Sodicity - no knowledge gaps identified	Not required.	69
Algae – Blue green toxin producers	To-date there have been no reported impacts of algae toxins in recycled water dams impacting grape quality. However, little is known with respect to the effectiveness of barrier offered from below canopy irrigation and the wine making process.	Theoretically the risk of algae toxin impacting on wine quality seems low. However, a thorough risk assessment should be undertaken to fill this knowledge gap and address any future issues that may arise.	71
Boron	No crucial knowledge gaps or future issues were identified.	Not required.	72
Chlorine disinfection residuals	Some risks from chlorine disinfection bi-products could be posed to highly sensitive plants as the number of plants tested are limited. Grapevines are not specifically assessed in the data searched for this review regarding chlorine disinfection bi-products, representing a knowledge gap.	Further research into the sensitivity of grapevines to chlorine and related disinfection bi-products should be considered. Alternatively, control measures to minimise chlorine residuals in recycled water used for irrigation of grape vines should be implemented at the treatment plant.	75
Heavy metals	No crucial knowledge gaps or future issues related to the heavy metal concentration of recycled water and irrigation of grapevines were identified.	Note: some historical use of heavy metal based pesticides can lead to increased soil concentration. These should be considered when using recycled water.	78
Organic chemicals of concern	The data reviewed above indicated the risk to contamination of berries or wines from organic chemicals of concern is low, given the multi-barriers. However, due to the range of chemicals potentially present in recycled water and the fact that recycled water with relatively low levels of treatment can be used to irrigate grapevines; a detailed environmental and human health risk assessment has been recognised as a knowledge gap.	A risk assessment focused specifically at pathways within the viticultural sector and also identifying any hazards that could pose a significant risk to soil contamination, soil microbes, aquatic systems, berry or wine quality and human health. The AGWR provide a framework for undertaking this type of risk assessment (NRMMC and EPHC 2006).	83
Plant pathogens	STP effluent water treated to a relatively low level (recycled water) can be used to irrigate vines. Therefore, recycled water with limited treatment can be exposed directly to vine roots. However, the level of plant pathogens in STP effluent is a knowledge gap.	Plant pathogens relative to the viticultural sector should be assessed in a range of recycled water qualities, to allow better assessment of this risk.	87
Financial			
Pricing,	The true cost of recycled water is a function of	A resource audit for viticulture to identify	89

Category	Knowledge gap identified for recycled water	Recommendation to fill knowledge gap	Page
Infrastructure/ treatment, storage and reticulation	water treatment, length and size of pipe infrastructure and storage requirements. The parameters vary considerable between specific reuse schemes, and who is responsible for which component. At present there is no resource audit for viticulture to identify where opportunities could potentially exist for development or use of recycled water. This is currently a gap in the available knowledge.	where opportunities could potentially exist for development or use of recycled water.	
Public image and acceptance	The risk of rejection of wine made from berries grown with recycled water due to poor public acceptance is low; especially given the historic use and growing public support for water recycling. However, the financial impact is potentially high. To our knowledge, this has not been directly measured in the viticultural sector.	The public/consumers image of wines produced with grapes irrigated with recycled water should be assessed.	95

1.3 Priorities for filling knowledge gaps

The logical sequence for filling these knowledge gaps is outlined below. High priority activities were identified as:

- Confirm opportunities for the use of recycled water in the viticultural sector for specific sewage treatment plants and wine growing areas identified.
- Significant risk to the viticultural industry could exist without sufficient assessment of the impact of potassium, potential plant pathogens and chemicals of concern in recycled water
- Knowledge focused on viticulture to develop and use recycled water schemes is not currently easily accessible to the viticultural sector

High priority activities were considered to be crucial components in the immediate feasibility, development and use of recycled water in the viticultural sector.

High priority activities include:

1. Recycled water resource audit – A detailed specific assessment of most promising opportunities identified for specific viticultural regions to secure recycled water (i.e. volumes of recycled water still available, location (soils, vines) that recycled water could be used, estimate likely cost of treatment, storage and reticulation given relative locations, compared with cost of water that viticultural sector is able/willing to pay for water).

If significant opportunities are identified in 1, then:

2. Determine if potassium concentration in recycled water will impact on grape/wine quality.
    - Confirm K concentration in recycled water in Australia and determine excess of vine requirements will be applied with recycled water; if so
    - Determine critical K concentration in petioles, soils and recycled water related to changes in grape/wine quality from excess K applied in recycled water to help manage these impacts.

3. Plant pathogens relevant to the viticultural sector should be assessed in a range of recycled water qualities (Effluent, Classes A to D), to allow better assessment of this risks.

4. A risk assessment for chemicals of concern (e.g. endocrine disruptors and pharmaceuticals) focused specifically at pathways within the viticultural sector environment. Including identifying hazards that could pose a significant risk to vines, soil contamination, soil microbes, aquatic systems, berry or wine quality and human health. The AGWR provide a framework for undertaking this type of risk assessment (NRMMC and EPHC 2006).

5. Publication of a handbook for growers for irrigation of grapevines with recycled water including high and low priority outcomes when completed.

Some lower priority knowledge gaps and activities identified are listed below. These activities are not crucial to viticultural sector's development and use of recycled water, but may pose future risks that require a watching brief.

Low priority activities identified were:

1. The public/consumers image of wines produced with grapes irrigated with recycled water should be determined.

2. Theoretically the risk of algae toxin impacting on wine quality seems low. However, a thorough risk assessment should be undertaken to fill this knowledge gap and address any future issues that may arise.

3. Further research into the sensitivity of grapevines to chlorine and related disinfection bi-products should be considered. Alternatively, control measures to minimise chlorine residuals in recycled water used for irrigation of grapevines could be readily implemented prior to irrigation.

1.4 Conclusion

This feasibility study has identified several areas where knowledge gaps exist when using recycled water for irrigation in the viticultural sector. There are two logical stages to address these knowledge gaps.

1. Assess in details the potential for delivery and use of recycled water to the viticultural regions identified as most likely opportunities and economically feasible.

2. If point 1 above identifies significant opportunities then all high priority areas should be addressed.

With these knowledge gaps addressed the viticultural sector will understand the opportunities and feasibility of using recycled water and be adequately informed to ensure recycled water is used sustainably and safely in the viticultural industry.

2 BACKGROUND

The GWRDC committee recently acknowledged more information was required on water recycled from sewage treatment plants (STPs) if it was to be used in the viticultural industry. This water is sometimes referred to as reclaimed water. However, for this report the recommendations of the Australian Guidelines for Water Recycling (NRMMC and EPHC 2006) will be adopted (i.e. the report will refer to this as recycled water).

The GWRDC committee regarded the following issues as imperative to understand the future use of recycled water in the viticultural sector:

- Financial feasibility of collecting and treating water for distribution;
- Potential health impacts;
- Current status of existing schemes using recycled water;
- Consideration of using recycled water around regional centres;
- Acknowledgement of existing work performed in recycling water and the risks of using recycled water;
- Deliverance of recycled water through existing infrastructure at a reasonable cost; and
- Potential for the project outcomes to be applied within the viticultural industry as well as other industries.

Many of these issues are not research based, but explore external implications for the use of recycled water such as government regulations, water availability and human health risks. To ensure the scoping study is informative, feasible and accurate, Arris was commissioned to determine feasibility of irrigating with recycled water for the wine industry.

This feasibility study was based on collation of available information and current understanding of the use and associated risks and impacts of using recycled water for irrigation within Australia and overseas.

This review provides an assessment of the feasibility of recycled water use in the viticultural sector and identifies missing gaps in knowledge and issues that may arise in the expansion of its use in the viticultural sector. This knowledge will assist GWRDC to make an informed decision on future investment in this area.

3 INTRODUCTION AND OPPORTUNITIES

3.1 Guidelines for recycled water

Australia's water industry is one of the world leaders in water recycling. They use some of the most developed and robust treatment technology and have a strong commitment to water recycling. Australia has traditionally had some of the most comprehensive guidelines in the world with respect to irrigation with recycled water. Recent publication of the Australian Guidelines for Water Recycling (AGWR - NRMMC and EPHC 2006) has set a new benchmark for managing risk associated with recycled water use (human health and the environment).

Many state/territory guidelines have adopted this approach in recently released guidelines or now default to these guidelines (i.e. NSW). How these guidelines are implemented across Australia and the fundamentals that underline them are discussed below.

Currently most state/territory health and environment protection departments have individual guidelines (Table 2) to ensure the health and safety of people working with recycled water, exposed to recycled water (parks, gardens and turf areas) and eating food grown with recycled water. Every recycled water scheme requires the approval of these departments and must show that appropriate safeguards are in place (before the recycling scheme is commissioned) to guarantee a particular water quality to users. These extensive safeguards should guarantee protection of human health and the environment.

In most states/territories the quality of recycled water varies depending on the source of the water and the recycling process used. Generally Class A, B and C recycled water is used in viticulture in Australia. The class of recycled water used for irrigation can range in quality depending on the specific use, irrigation method and restrictions during irrigation (discussed below in this chapter).

It should be noted that the Class of water usually refers to the level of treatment to remove pathogens from the water (Figure 1). It does not guarantee the water is suitable for a specific amenity horticulture crop or species. The physical and chemical properties of the recycled water also need to be checked to ensure that the water is suitable for the soil and plant species to be irrigated.

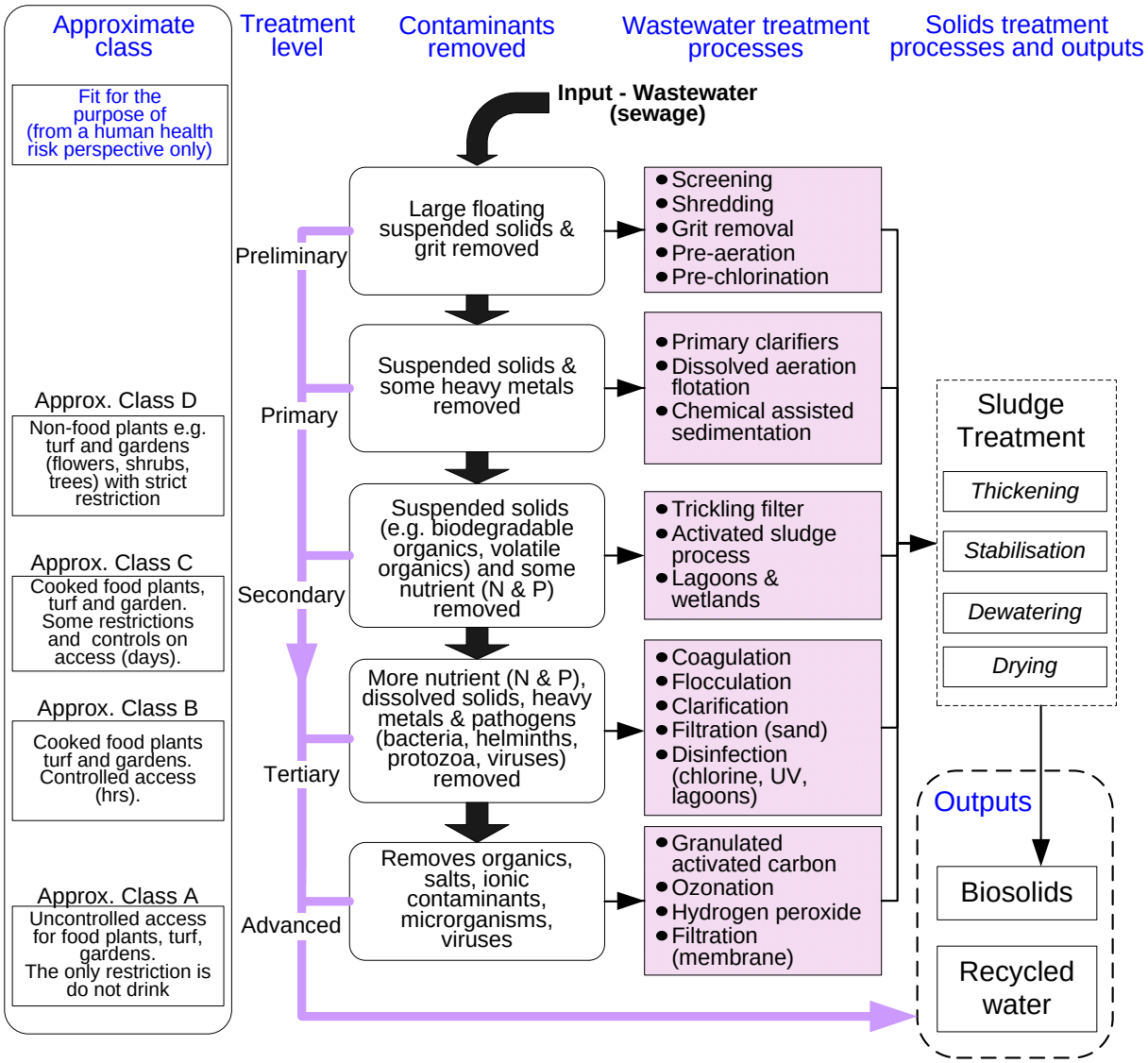


Figure 1 **Treatment levels and processes typically used to treat wastewater. This diagram gives a general indication of parameters; it is not a substitute for specific guidelines and verification processes (preliminary treated = limited treatment, advanced = extensive treatment).**

3.1.1 State and territory guidelines for recycled water

Many of the state/territory guidelines (Table 2) refer to recycled water as Class A, B, C or D (Table 3); depending on the level of treatment. Class A usually has the highest level of treatment (note: Qld has a Class A+). In most states/territories, sewage treatment plants are subject to works approvals and licensing by EPA or equivalent (this may very depending on the flow treated (e.g. Victoria > 5KL/day; EPA Victoria 2003b; Stevens 2006). There are usually exemptions from these statutory processes if effluent reuse schemes meet the requirements specified in the state/territory guidelines.

Table 2 Guidelines relating to the use of recycled water for irrigated agriculture in Australia

State/Territory	Guideline	Reference
National	Australian Guidelines for Water Recycling. Managing Health and Environmental Risks. Phase 1. National Water Quality Management Strategy 21.	NRMMC and EPHC 2006
Australian Capital Territory (ACT)	ACT Wastewater Reuse for Irrigation — Environment Protection Policy.	ACT 1999
Northern Territory (NT)	Default to Australian Guidelines for Water Recycling.	
New South Wales (NSW)	Environmental Guidelines: Use of effluent by irrigation[A].	NSW DEC 2004
Queensland (Qld)	Queensland Water Recycling Guidelines.	Qld EPA 2005
South Australia (SA)	South Australian Reclaimed Water Guidelines.	DHS SA and EPA SA 1999
Tasmania (Tas)	Environmental Guidelines for the use of Recycled Water in Tasmania.	Dettrick and Gallagher 2002
Victoria (Vic)	Use of reclaimed water. Guidelines for environmental management (Part of the 2 guidelines below are relevant to this guideline).	EPA Victoria 2003b
	EPA Vic (2005) 'Guidelines for Environmental Management: Dual pipe water recycling schemes - Health and environmental risk management.' EPA Victoria, Melbourne, Australia.	EPA Victoria 2005
	EPA Victoria. (1991). "Guidelines for wastewater irrigation. Publication no 168." 168, EPA Victoria, Melbourne.	EPA Victoria 1991
Western Australia (WA)	Irrigation with nutrient-rich wastewater. Water Quality Protection Note.	DofW 2006

[A]It is still to be confirmed that these guidelines will be discarded and replaced with the Australian Guidelines for Water Recycling (NRMMC and EPHC 2006). However, to date (2008 09 05) NSW Health now recommends the use of the Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (phase 1) (2006) for the development of recycled water schemes and in this regard, the Australian Guidelines have replaced the 1993 NSW Recycled Water Co-ordination Committee's NSW Guides for Urban and Residential Use of Reclaimed Water for use with dual reticulation schemes. The NSW Department of Water and Energy (DWE) have also released the guideline document Management of Private Recycled Water Schemes. This guideline aligns the principles outlined in the Australian guideline to the approvals process for private recycled water schemes (requiring section 68 approval) in NSW. The guideline replaces the NSW Health Interim Guidance for Greywater and Sewage Recycling for Multi-Unit Dwellings and Commercial Premises (GL 2005/051 previously Circular 2004/71).

Australian Guidelines for Water Recycling should also be considered (see below). These guidelines provide a framework for the management of recycled water, sets performance objectives, establishes the obligations of suppliers and users of recycled water, and suggests best practice measures for treatment, quality, site selection, application, site management, and monitoring and reporting in order to meet the performance.

Table 3 Victorian classifications of recycled water and permitted uses

Class	Overview of recycling process	Permitted Uses (fit for purpose)
A	This is the highest quality of recycled water and is achieved after a tertiary treatment process is combined with pathogen removal. Class A recycled water is classified as safe for use on irrigation for food plants - including those eaten raw. Indicative objectives: < 10 E.coli org/100 mL, Turbidity < 2 NTU, < 10 / 5 mg/L BOD / SS, pH 6 – 9.5 and 1 mg/L Cl_2 residual (or equivalent disinfection). In addition to this, the guidelines for dual pipe recycled water scheme indicate that 7-log removal of viruses and 6-log removal of protozoa with helminth control if required (EPA Victoria 2005, Table 5.1).	• residential garden watering • closed system toilet flushing • process/cooling water for industry • fire protection stores and reticulation systems • irrigation of municipal parks and sports grounds • water for contained wetlands or ornamental ponds • food plants that are consumed raw • all of the uses listed for classes B, C and D
B	A secondary treatment process, combined with some pathogen reduction is used to produce Class B recycled water. With strict management practices it may be used for the following: <100 E.coli org/100 mL pH 6 – 9.5 < 20 / 30 mg/L BOD / SS	• irrigation of dairy cattle grazing fodder • livestock drinking water (not including pigs) • wash down water for dairy sheds and stockyards (not including milking equipment) • urban (non-potable) uses with restricted public access • closed industrial systems • all of the uses listed for classes C and D
C	A secondary treatment process combined with minor pathogen reduction is used to produce Class C recycled water. With strict management practices it may be used for the following: <1000 E.coli org/100 mL pH 6 – 9.5 < 20 / 30 mg/L BOD / SS	• cooked/processed human food plants • selected (raw/unprocessed) plants not directly exposed to recycled water (e.g. apples) • grazing/fodder for cattle, sheep, horses, goats etc. • grazing for dairy cattle (subject to a five day withholding period after irrigation) • urban (non-potable) uses with restricted public access • closed industrial systems • all of the uses listed for Class D
D	A secondary treatment process is used to produce water of this quality. Class D recycled water may be used for the following uses: <10000 E.coli org/100 mL pH 6 – 9.5 < 20 / 30 mg/L BOD / SS	• non-food plants such as woodlots, turf growing and flowers

Source: EPA Victoria 2003b, p 20

Environment Improvement Plans (EIP) form a critical component of the exemption process. EIPs need to demonstrate that the performance objectives of the guideline can be complied with by detailing the procedures and practices that will be implemented to manage risk and ensure sustainability.

Suppliers and users of recycled water must ensure that:

1. All reuse schemes have an appropriate EIP
2. For Class A recycled water schemes, approval from EPA Victoria and the Department of Human Services (DHS) is required
3. For all non-Class A schemes involving greater than 1 ML per day of recycled water or industrial process waters, approval from EPA or an appointed auditor is required
4. Endorsement from the Department of Primary Industries is also required for water with significant quantities of animal effluent (EPA Victoria 2003b)

5. Reuse schemes that use more than 1 ML per day should be annually audited to verify compliance with these guidelines
6. Reuse schemes that use less than 1 ML per day must be audited at least every three years (EPA Victoria, 2003).

All monitoring, reporting and auditing procedures and programs should be documented in the EIP. Audit programs for schemes that use greater than 1 ML per day should comply with the principles in *ISO 14010's Guidelines for Environmental Auditing*. The proponent of the reuse scheme should ensure that an appropriately qualified independent auditor or internal expert undertakes the audit (EPA Victoria 2003b).

3.1.2 Australian Guidelines for Water Recycling

The new Australian Guidelines for Water Recycling (AGWR) have recently set the standard for managing risks posed to human health and the environment in Australia (NRMMC and EPHC 2006). They do not supersede Victorian State Guidelines (EPA Victoria 2003b). However, it would be considered best practice to use the framework and information in the AGWR within the context of the Victorian Guidelines.

There are two components of the AGWR that should be considered:

1. **The Australian Guidelines for Water Recycling** [1]

Full reference: NRMMC, EPHC (2006) 'Australian Guidelines for Water Recycling. Managing Health and Environmental Risks. Phase 1. National Water Quality Management Strategy 21.' Natural Resource Management Ministerial Council. Environment Protection and Heritage Council Australian Health Ministers' Conference, Canberra, Australia.

2. **National Chemical Reference Guide - Standards in the Australian Environment**[2]

This website provides information analysed to derive safe concentration values that should be achieved in order to protect ecosystems and human health in Australia.

3.1.2.1 Key parameters of AGWR

The framework for management of recycled water quality and use given in the Australian Guidelines for Water Recycling (NRMMC and EPHC 2006) is based on and follows the same principles as the framework used in the 2004 *Australian Drinking Water Guidelines* (NHMRC and NRMMC 2004) and the Australian Standards for Risk Assessment (Standards Australia 2004a; b).

The framework describes a generic process for developing and implementing preventive risk management systems for recycled water use. Such systems can be applied to all combinations of water source and end use, including applications not specifically addressed in this document, such as stormwater recycling and use of recycled water to augment drinking water sources. The aim is to provide a measurable and ongoing assurance that performance requirements are met and that, as far as possible, faults are detected before recycled water is supplied, discharged or applied, so that corrective actions can be implemented proactively.

Risk assessment frameworks provide a structured approach to allow the systematic assessment of the complicated systems (e.g. the grape growing and wine production systems).

[1] www.ephc.gov.au/ephc/water_recycling.html
[2] www.deh.gov.au/chemicals-guide

3.1.2.2 Recycled water - "Fit for purpose"

One of the major differences between many state/territory guidelines and the Australian Guidelines for Water Recycling (NRMMC and EPHC 2006) is the concept of identifying and producing recycled water of a quality that is **'fit-for-purpose'** from a pathogen and chemical hazard perspective. To be consistent with this approach, these guidelines do not include a classification system for recycled water like in many state/territory guidelines.

The framework in the Australian guidelines also relates specifically to the quality of the recycled water, ensuring any hazards to human health or the environment (including the horticultural system) do not pose a significant risk. That is, the level of risk is low and acceptable and the recycled water is fit for the intended use from an environmental and human health perspective.

The commonly used Class A, B C, D system used by states/territories of Australia often didn't relate specifically to recycled water and impacts on the environment, but was historically used from a pathogens and human health perspective. The fit-for-purpose classification overcomes the misunderstandings of the Class systems and ensures that the environment, agronomic and human health perspectives are considered when developing and using recycled water.

3.1.3 General Australian guidance

A number of guidelines or handbooks for use of recycled water have been developed for specific commodities grown with recycled water. For example:

- Guidelines for developing recycled water schemes in horticulture (HAL and NPSI 2006) www.environment.gov.au/water/publications/urban/guidelines-hort.html
- Using Recycled Water in Horticulture (Jarwal *et al.* 2006) http://products.lwa.gov.au/files/PX061131.pdf
- Irrigation of Amenity Horticulture with Recycled Water (Stevens *et al.* 2008 (In press))
- Sustainable Effluent-Irrigated Plantations: An Australian Guideline (Myers *et al.* 1999) www.ensisjv.com/ResearchCapabilitiesAchievements/SocialandEnvironmentalEffectsofForestry/EnvironmentalRemediation/SustainableEffluentIrrigatedPlantations/tabid/385/Default.aspx
- GWRDC has also completed some research in the area of winery wastewater treatment and reuse:
- Standardised protocol for management of winery production waste (Not water recycled from sewage systems) (Chapman 1999) www.gwrdc.com.au/rtopics.asp?ID=45
- Impact of winery wastewater on ecosystem health - an introductory assessment. (Kumar and Kookana 2006) www.gwrdc.com.au/downloads/researchtopics/csl%2002-03.pdf

There are also some viticulture/winery focused books written there is limited reference to the use of recycled water management:

- Grapevine Management Guide 2007-2008 (Somers and Quirk 2006)
- Guide to growing wine grapes in Australia (Davidson 1999)
- Winery utilities: planning, design and operation (Storm 1996)

There are also several fact sheets developed by different government entities across Australia (www.crcv.com.au/links/factsheets.asp) for grapevine production. However, none have a focus on the use of recycled water to irrigate grapevines. The Viticare Environmental Risk Assessment tool[3] and environmental management systems developed across Australia provide useful best practice information that will help in the sustainable environmental development of recycled water in the viticultural sector (e.g. Nind and Taylor 2002 (Reviewed 2007)).

3.1.4 International guidance

Examples of international guidance for use of recycled water include:

- WHO Guidelines for the safe use of wastewater, excreta and greywater (3rd Edition) (WHO 2006)
- US EPA guidelines for water reuse (EPA US 2004)
- Florida, USA. Department of Environmental Protection – Wastewater. CHAPTER 62-610 Reuse of reclaimed water and land application (FDEP 2007).

3.1.5 Plumbing requirements/regulations

When irrigating with recycled water one of the biggest risks to the viticultural operation is cross connection of water not suitable for drinking with drinking water supplies. To minimise this risk, all plumbing regulations should be complied with and irrigation reticulation systems for recycled water kept as separate as possible with potable water supplied and labelled correctly.

Accidental incorporation of recycled water, that is not fit for drinking, into the wine processing and production areas (e.g. washing or wine making process) could potentially lead to risks to human health.

The overarching document from plumbing of recycled water systems is the Plumbing and drainage code (AS/NZS 2003). State/territory guidelines have been developed with a specific interpretation of this standard and local context added (PIC 2005; SA Water 2006; Sydney Water 2005).

Examples of the types of recommendations (from the Victorian 'Recycled Water Plumbing Guide 2005; PIC 2005) are summarised below[4]:

General

- All plumbing work must be carried out by a licensed plumber
- A "Compliance Certificate" must be submitted to the consumer upon completion of all work
- On the Compliance Certificate Item 5 "cold water" and item 91 "recycled water" must be circled

Recycled water mains

- All underground recycled water mains piping must be purple in colour or be wrapped in purple coloured plastic sleeve

[3] www.crcv.com.au/products/vera/vera.pdf
[4] www.pic.vic.gov.au/resources/documents/Recycled_Water_Plumbing_Guide.pdf

- All recycled water stand-pipes and fire hydrants must be purple in colour and be marked “recycled water”

Meter assemblies

- Recycled water meter assemblies must be purple in colour (Figure 2), fitted above ground in an accessible position as close as possible to the relevant property boundary and adjacent to the drinking water meter
- A dual check valve is required on the outlet of every drinking water meter assembly and must be visible, accessible and fitted in the horizontal section of the meter assembly



Figure 2 Recycled water meter assembly with purple to identify it contains recycled water

Inside the property

- All external tap outlets on the drinking water service shall be fitted with hose connection vacuum breakers
- All hose taps must have removable handles to prevent unauthorised use
- “DO NOT DRINK” signs must be displayed above all external recycled water outlets
- All pipe work inside a property must be approved for use with recycled water
- All buried pipe must have identification tape installed on top of the recycled water pipe running longitudinally and fastened to the pipe at 3 metre intervals
- The warning tape must be at least 75 mm wide and state “Warning: Recycled or Recycled Water – Do not drink” continually along its length and coloured in accordance with clause 9.5.4 AS/NZS 3500.1:2003 (AS/NZS 2003)

- All other installation requirements of AS/NZS 3500.1:2003 (AS/NZS 2003) Section 3 and 5 installation of cold water services also apply



Figure 3 Example of warning tape above buried pipe that reticulates recycled water. Tape meets Australian standard being a minimum of 75 mm wide and stating "Recycled water" and "Do not drink"

3.1.6 Knowledge gaps and future issues

A review of the current guidelines and handbooks available to the viticultural sector for use of recycled water and management of any associated risk indicate that there were limited specific guidance for the viticultural industry and use of recycled water in Australia. This represents a significant knowledge gap that may slow adoption of recycled water use in the viticultural sector as potential users find it difficult to find information about their specific industry and use of recycled water.

3.2 Reuse schemes

3.2.1 Recycled water use in Australia

Growing urbanisation, rising population numbers and climate change are increasingly placing demands on global freshwater resources (Toze 2008). Australia produces approximately 1800 GL of effluent per year (Table 4) and recycled around 5 to 20% varying between states.

Australia now has more than 600 different recycled water schemes operating. Approximately 240 of these schemes use recycled water in the urban environment (e.g. golf courses and recreational parks), 80 are related to industry (e.g. washing and cooling) and 270 are agriculturally based (e.g. horticulture, forestry, pasture, flowers, viticulture and cane). Many of these recycled water schemes have now been operating for more than 20 years with no impacts on human health or the environment.

Table 4 Annual water reuse from water utility STPs in Australia, 1996-9, 2001-2 and 2005-6

Region	1996-9			2001-2			2005-6		
	Effluent, GL/yr	Reuse, GL/yr	%	Effluent GL/yr	Reuse GL/yr	%	Effluent GL/yr	Reuse GL/yr	%
QLD	328[2]	38[2]	11.6[2]	339	38	11.2	360	47.5	13.2
NSW	548[1]	40.1[1]	7.3[1]	694	61.5	8.9	679[5]	47.6[5]	7.0[5]
ACT	31[2]	0.25[2]	0.8[2]	30	1.7	5.6	31	2.1	6.7
VIC	367	16.9	4.6	448	30.1	6.7	439	81	18.4
TAS	43	1	2.3	65	6.2	4.5[4]	68	3.6	5.3
SA	91[2]	9[2]	9.9[2]	101	15.2	15.1	96	18.9	19.6
WA	109	5.5	6.1	123[3]	12.0[3]	9.7[3]	139	16	11.5
NT	21[2]	1[2]	4.8[2]	21	1.1	5.2	16	2.0	12.3
Aust.	1538	112.9	7.3	1824	166.5	9.1	1828*	218*	12.0*

[1]1996 [2]1998 [3] Minor correction since original publication [4]Corrected for 5% approved, not operational [5]2004-5
*assuming NSW 2004-5 data for 2005-6

Source: Radcliffe 2007

Uses of recycled water (Wetherall *et al.* 2007) include:

Industrial

- Internal recycling within the wastewater treatment plant (WWTP)
- Refineries
- Construction/washing
- Power generation

Urban

- Dual reticulation
- Golf courses
- Open space/recreational irrigation

Agricultural

- Horticulture
- Trees/woodlots
- Pasture (dairy and non-dairy)
- Lucerne
- Cotton
- Flowers
- Nurseries
- Vegetables
- Viticulture
- Turf farms
- Canefields
- Cropping

Environmental

- Wetlands
- Environmental flow

Other

- Unknown uses/not specified

See also Table 8

Despite the potential economic and environmental benefits of the uses discussed above, the use of recycled water to supplement drinking water supplies is sometimes excluded from

water supply options analyses based on the perception of community concerns (Radcliffe 2007). However, the current Australian urban water shortages along with the development of the Australian Guidelines for Water Recycling, have resulted in a number of communities considering options for indirect potable reuse (IPR) (Radcliffe 2007; NRMMC and EPHC 2008). Communities considering IPR in 2007 included Toowoomba, Goulbourn, South East Queensland and Canberra (Radcliffe 2007).

The demand for recycled water has grown so fast that the pressure for horticulture to use recycled water has strengthened (Hamilton *et al.* 2005) from 2005 to 2008. However, other demands and uses for recycled water have begun to take priority in some cities with the focus turning to:

- indirect potable reuse (IPR)
- potable replacement (e.g. industry using recycled water rather than drinking water)

The use of recycled water for the irrigation of vineyards is a practice gaining increasing acceptance (Table 5). In 2007 there was a 14.8% increase in the area of vines irrigated with recycled water over a three year period. Recycled water is widely becoming recognised as a secure and sustainable water resource (Boland *et al.* 2006; Radcliffe 2007).

Many of these options use recycled water all year round rather than seasonally like grape production. Much of the STP water recycled to date has been recycled using the easy and cost effective schemes (Boland *et al.* 2006). In many states the STP effluent water that can be recycled conveniently and cost effectively has been recycled. For example, in rural WA nearly 80 -100% of effluent water is recycled and some water authorities in Victoria (e.g. Western Water) have achieved over 80% recycling. There are still some opportunities for securing recycled water in rural Australia. However, with the current water shortage these opportunities are rare. Much of the 88% of STP water not recycled requires storage during the demand for irrigation or is trapped by urban sprawl around STPs making it difficult and costly to install infrastructure to deliver the recycled water to the horticultural sector (Boland *et al.* 2006).

Table 5 Area of grapevines irrigated with recycled water

State	2003-2004		2006-2007	
	Area (ha)	Sites	Area (ha)	Sites
New South Wales	117.1	9	39	6
Victoria	419.7	21	659.3	30
Queensland	196	2	No Data*	
South Australia	1885.7	75	2341.8	80
Western Australia	76	2	74.2	1
Tasmania	11.8	6	3.5	6
Northern Territory**	0	0	0	0
Australian Capital Territory	83.1	1	83.1	1
Total	**2789.4**	**116**	**3200.9**	**124**

* there were no recycled water statistics for Queensland in 06-07

** there were no recycled water statistics for Northern Territory

Source: ABS www.abs.gov.au

3.2.2 Recycled water use around the world

Recycling of treated wastewaters in amenity horticulture has been practiced around the world for more than 50 years. Any recycled water scheme developed now is by no means a

'world first'. Recycled water is currently being used in many countries (e.g. United States, Israel and Australia) for irrigating a range of production and amenity horticulture applications (Asano *et al.* 2007). There are also increasing demands for use of recycled water in industry and for environmental flows, both with a focus of freeing up water for drinking purposes (i. e. potable replacement).

The growing trends in reclamation and reuse of water around the world are primarily driven by water scarcity, water pollution control measures and where there are strict controls on effluent leaving wastewater treatment plants (Asano *et al.* 2007). Most of the significant developments in recycled water have occurred in arid regions of the world. Portugal, Spain, Southern France, Italy Cyprus and Greece have been the initiators. While Israel, Tunisia, Jordan, United Arab Emirates and Kuwait have well advanced agricultural irrigation programs using recycled water (Asano *et al.* 2007). The demand and use has recently been very high in several US state as water resources have become limited with climate change and population growth.

Publicly available information from these countries on the volumes of recycled water used or areas irrigated of viticulture are limited. However, it would reasonable to expect that most countries would have portion of the agricultural use as viticultural production.

California is now considered a leader in the world of recycling of water at a large scale; driven by the lack of water and increasing populations in this state of the USA. Currently, California's agricultural, industrial, and urban sectors use a total of about 530,000 acre-ft (653,746 ML) of recycled municipal wastewater per year. About 46% is used to irrigate agricultural crops (Tanji *et al.* 2007). About 21% is used for landscape irrigation and about 14% for groundwater recharge. The rest (19%) goes to various uses, such as cooling water for oil refineries and power plants and flushing toilets and urinals, as well as to environmental enhancements, such as supplying water for wetlands and ponds, including reflecting ponds.

Many of these countries have had the need to recycled water much greater than Australian and therefore recycle greater proportion of their effluents. However, within the last decade Australia has become one of the most active countries in promoting water reuse (Asano *et al.* 2007).

3.2.3 Knowledge gaps and future issues

As of June 2006 only 12 % of water from sewage effluent was recycled in Australia, with South Australia leading the way in water reuse. This indicates there was still significant opportunity for the viticultural sector to secure this recycled water. However, spatial and storage challenges (Section 7.3) make much of the water difficult to access for the viticultural industry. An assessment of potential opportunities for the viticultural sector to secure recycled water is recommended.

3.3 Opportunities for viticulture to access recycled water

3.3.1 Cases considered

Recycled water has the potential to provide a secure supply of water for Australian viticulture. This section of the report considers four hypothetical cases where viticulture could access recycled water.

- Case 1 – Dry season effluent flow (usually November to April) currently **unallocated** recycled water supplied to existing viticulture regions (i.e. minimal storage required) – relatively low cost;
- Case 2– Annual effluent flow (allocated and unallocated) could be available to supply existing viticulture regions (i.e. winter flow of effluent is stored for use during the irrigation season – large storage required and effluent already allocated would need to be purchase from users – medium to high cost due to storage requirements);
- Case 3 – Viticulture relocates to available unallocated supplies of recycled water or new viticulture areas are developed if climatic conditions are deemed suitable – high cost due to relocation; and
- Case 4 - Viticulture relocates and utilises water that is currently allocated to other end uses – high cost due to relocation.

These scenarios (Table 6) represent different opportunities for the viticulture industry with different timescales and costs. Case 1 represents the most viable use of recycled water in the near future and is analysed in most detail. Case 4 represents the most difficult case, where the viticulture industry relocates/develops and secures recycled water from existing end use in addition to what is currently unallocated.

It should be noted that estimates in the report are essentially a broad screening process to identify possible opportunities for the viticulture industry. These estimates require further detailed on-site investigation specific to any - wine growing area relative to the Sewage Treatment Plant (STP) as part of any detailed business case.

Table 6 Summary of the four cases assessed for possibility of recycled water use in existing or newly developed wine regions.

Case	Proximity to existing viticulture	Unallocated dry season effluent captured only	Total effluent flow captured	Storage requirement	Comment
1	STP within 200 km of Viticulture area	y		Low	Relatively easy to develop and potential lower cost due to lower storage requirements
2			y	High	High cost than Case 1 as storage requirement to capture winter flow. Also involves reallocation of recycled water to viticulture from another use. This may involve cost and other difficulties.
3	STP outside a 200 km radius of STPS	y		Low	As per Case 1 above but required new feasibility of developing viticulture in the are to be assessed
4			y	High	As per Case 2 above but required new feasibility of developing viticulture in the are to be assessed

3.3.2 Estimation of sewage treatment plants location, effluent produced and water recycled

Data identified for estimating sewage treatment plant (STP) recycled water was completed in great detail in 2004 using data from 2000 to 2003 (Radcliffe 2004) which was partially updated in 2007 (Radcliffe 2007). For this report Radcliffe's data and easily obtainable data relating to the major reuse schemes commissioned in Australia over the 2003 to 2008 period (summarised in Table 8) was used. Additional data to Radcliffe was obtained primarily through contacts at water authorities and stories included in ReWater[5]. It has been assumed that total influent flow to STPs have not changed considerably since 2002 as population increases and increased projected flows have been offset by decreased influent flows due to water restrictions and greywater use (this varies from state to state).

In order to assess the opportunity to match supply of recycled water from STPs with demand from viticulture, the location and known volumes of recycled water were given latitude and longitude coordinates[6] by identification of the suburb/town where they were located (Appendix Table 47).

3.3.3 Estimation of wine growing areas and volumes irrigated

Wine areas were supplied by GWRDC and were given latitude and longitude coordinates[7] by identification of the suburb/town where they were located (Appendix Table 48).

3.3.4 Estimating distance between STP and wine region

Using the latitude and longitude identified in Section 3.3.2 and 3.3.3 above the Great Circle Distance Formula was used[8] to estimate the closest distance between STP and the closest wine district. This formula required use of spherical geometry and a high level of floating point mathematical accuracy - about 15 digits of accuracy (sometimes called "double-precision"). In addition, the trig math functions used in this formula required conversion of the latitude and longitude values from decimal degrees to radians. To convert latitude or longitude from decimal degrees to radians, the latitude and longitude values in the database was divided by 180/pi, or approximately 57.29577951. The radius of the Earth was assumed to be 6,378.8 km or 3,963.0 miles.

Great Circle Distance Formula using decimal degrees:

3963.0 * arccos[sin(lat1/57.2958) * sin(lat2/57.2958) + cos(lat1/57.2958) * cos(lat2/57.2958) * cos(lon2/57.2958 -lon1/57.2958)]

From a matrix of STP and Wine district coordinates distances were calculated. Although this calculation is relatively accurate, the general allocation of coordinates to suburbs introduces an error which allows indicative comparison to be made only.

The location of the STP and viticulture are based on co-ordinates near the town centre. This is a necessary simplification based on the current data but introduces an error of at least several kilometres. If any of the sites look attractive to explore as a supply of water for viticulture, an initial task would be to precisely locate the wastewater treatment plant and the viticulture areas, and re-calculate the specific distances between the two. The approximations need to be confirmed and tested. The specific features of the proposed pipe track would also need to be noted as these could significantly impact on the cost. For

[5] www.recycledwater.com.au/rewater
[6] www.maps.google.com.au
[7] www.maps.google.com.au
[8] www.meridianworlddata.com/Distance-calculation.asp

example, are there roads, rivers or other land marks to cross? This level of detail has not been included in the screening methodology which aims to identify opportunities and relative cost.

The selected sewage treatment plants (STPs) water plants have been identified as near (< 200km) a viticulture region (Table 47). For example, there are two STPs in Queensland (Stanthorpe and Kingaroy) near viticulture areas identified. All the recycled water plants in South Australia are listed as the viticulture regions are more widespread opening additional possibilities of connections between the supply and demand.

It must be noted that this screen methodology does not account for the geography between the source of the recycled water and the site of the viticulture. For example, there is sea in the direct line between Cowes and the wine growing regions of the Mornington Peninsula, hence it is impractical to supply recycled water between the two points. The Glenelg STP is closest to the Currency Creek Vine growing area; however the pipe would need to be laid through many suburbs of Adelaide, and would be difficult and costly.

There are also other opportunities for the supply of recycled water that are not fully captured by this approach. For example, there is 50 km of effluent pipe from Melbourne Water's ETP to the ocean outfall (this is fairly unique in Australia). This pipe passes relatively closely to the Mornington Peninsula's vine growing region, yet the proximity to the available source of recycled water is identified as 33.6 km (Table 47) in the distance matrix model. However, the accessibility of recycled water may be much closer given the outfall pipe probably travels within 5 km of the Red Hill Wine district. Similarly the Western Corridor Recycled Water project in Queensland, may open up new possibilities as the viticulture industry may be able to "piggy back" on emerging infrastructure to reduce the up front capital and operational expenditure (CAPEX or OPEX).

3.3.5 Details of cost estimates for piping recycled water.

The approximate cost (capital and operating expenditure) for pumping recycled water between the wastewater treatment plant and the specific viticulture region as a function of distance and volume transferred per year. These are indicative costs only. The actual cost is strongly dependent on the landscape and terrain that the pipe is layed.

3.3.5.1 Cost estimation for irrigation pipe

These cost figures are approximate only (Table 7) using estimates from projects undertaken or costed across Australia recently (pers. comm. Lucas Energy, Tyco). It should be noted that this is for indicative purposes only. There is no attempt to take account of the pipe wall thickness, or any specifics of the pipe track difficulties.

In order to account for the additional capital cost of pumps and project management, design and approvals, the following assumptions are made –

Pump stations are 20% of the installed value of pipe. Project management, design and approvals are 20% of the installed value of pipe. There could be significant variation in these costs give the local terrain and conditions, however, at the general overview level of this report it was not possible to consider all these variables.

In order to assess the pumping cost of recycled water, it is assumed that the cost of power is $0.12/kWhr and pumping cost per ML is $ 0.55 per metre of head loss. Based on the Hazen-Williams equation for pressure drop for plastic pipe, the head-loss is approximately 15 m per kilometre distance.

Table 7 Indicative costs for pipe installation and operation

Distance water piped (km)	Total volumes delivered through pipe (ML/annum)				
	100	500	1000	5000	10000
	Net Present Cost estimate for delivery of water ($/ML)				
5	119	86	75	51	50
25	593	431	374	253	250
50	1,186	861	748	506	501
100	2,373	1,722	1,495	1,011	1,001

Note: Capex and Opex are incorporated into cost and assume 5% depreciation over a 25 year period. 20% pumping and 20% design costs have also been incorporated into the estimate of $/ML. No allowance is made for other operations and maintenance costs, other than power. Nor is any other allowance made for the replacement of pumps and other mechanical and electrical equipment which typically has a life of 15 years.

This results in an approximate cost of $ 8.25 per ML per kilometre. However this does not account for elevation difference between the points of supply and demand, and opportunities for off-peak power.

3.3.5.2 Estimation of recycled water available for viticulture

There are already significant demands on recycled water. The following assumptions are made to determine the potential volumes of recycled water available for viticulture.

- The flow of recycled water is constant over the entire year.
- Existing uses of recycled water are during the irrigation season (Nov-Apr). (This is not the case for industrial use of recycled water, however, is generally a valid assumption for agricultural irrigation).
- The potential volume of water for viticulture is the volume of water free during the irrigation season (Nov-April). The presence of storage could enable some additional volume of recycled water, however, this is excluded from the initial analysis (Case 1 and 3).
- It is also possible that viticulture might represent a higher value use of recycled water, so currently utilised recycled water could be reallocated to viticulture in the future (Case 2 and 4). However as a conservative initial assumption it was assumed that allocated water was not available (Case 1 and Case 3).

3.3.6 Current use of recycled water in viticulture

Some areas already use recycled water for viticulture (Table 8). For example, South Australia is leading the way in the use of recycled water for grape production. In comparison, NSW has a high volume of recycled water yet none of this is used for irrigation within viticulture. These areas have not been included in the Case 1 and 3 (Table 6) as recycled water has been allocated. Current prices of recycled water across Australia vary from $100 to $1100 per ML depending on use and circumstances (Section 7).

3.3.7 Validation against current schemes

Six STP sites in South Australia and Victoria were manually evaluated against wine district to validate the method of assesses proximity of STP to vine growing area.

In South Australian STPs (Figure 4) checked were:

1. STP – Victor Harbour,
   Closest wine district - Currency Creek (17.6 km away)
2. STP – Milang,
   Closest wine district – Langhorne Creek (14 km away)
3. STP – Strathalbyn,
   Closest wine district - Langhorne Creek (13.5 km away)

Note no STP was reported for Goolwa or Port Elliot, indicating a septic tank area or their sewage is piped to Victor Harbour.

In Victorian STPs checked (Figure 5) were:

- STP – Rosebud,
  Closest wine district – Red Hill (10.3 km)
- STP – Cowes
  Closest wine district – Red Hill (20.4 km) – (note: over water!)
- STP –Mornington
  Closest wine district – Red Hill (16.5 km)

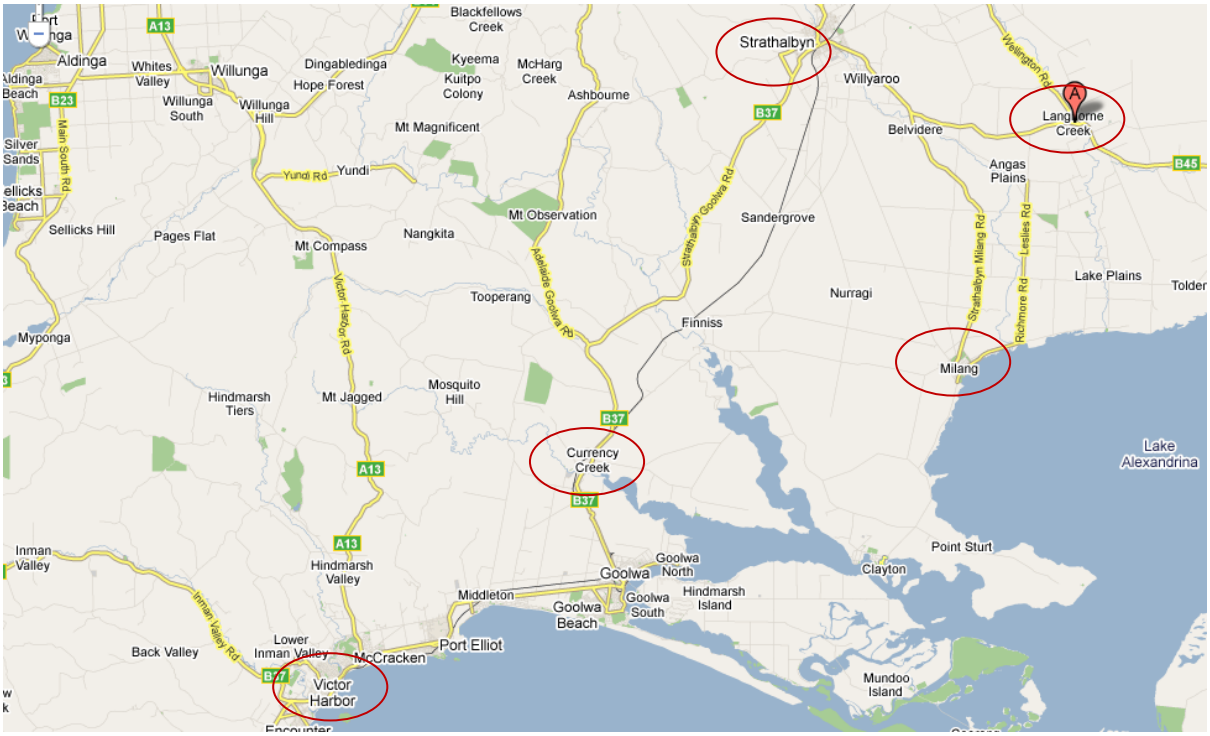


Figure 4 **Map of several South Australian Wine districts and townships with sewage treatment plants (Source www.maps.googles.com.au)**

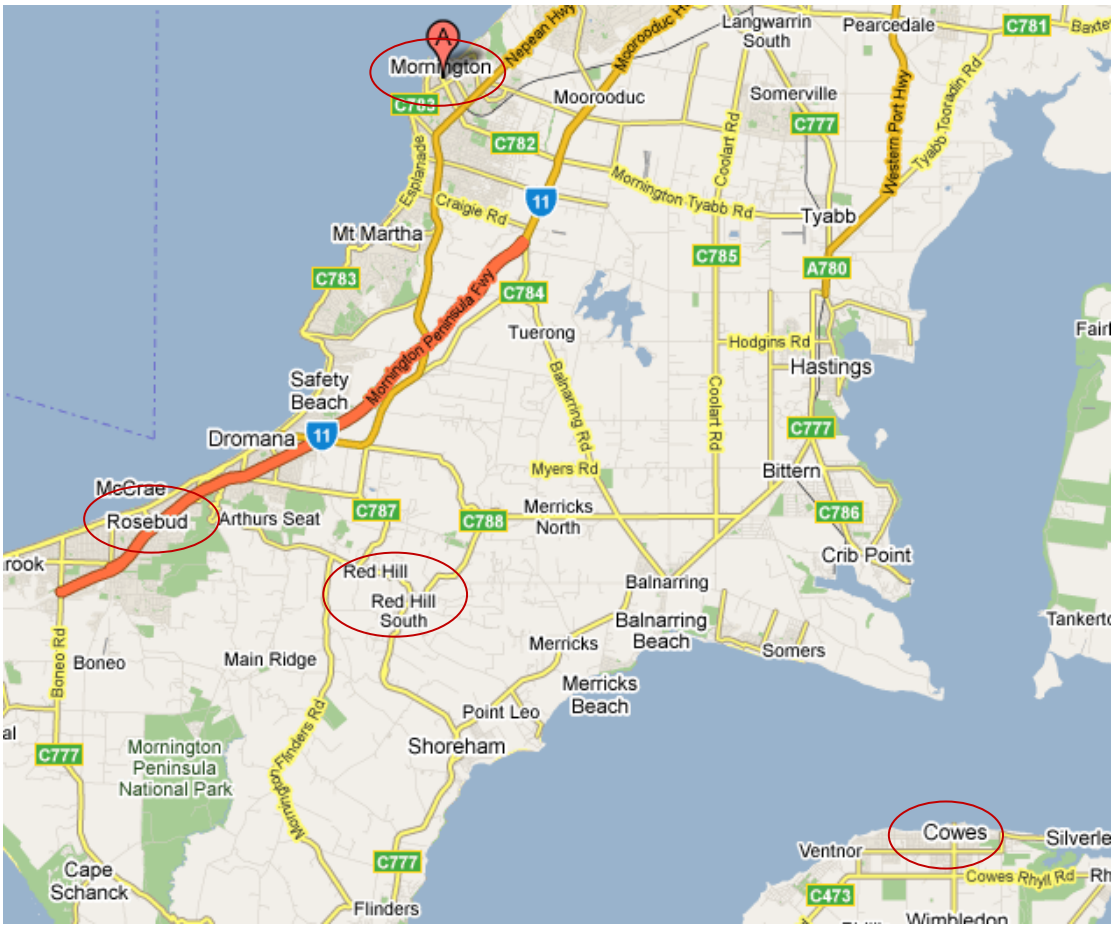


Figure 5 **Map of a Victoria Wine districts and townships with sewage treatment plants (Source www.maps.googles.com.au)**

Table 8 Estimates of volumes of water recycled and the number of schemes using effluent water for uses identified

State	STP	Industry general	Industry power gen	Industry washing	Industry dust	Golf Course	Recreational	Third Pipe	Agriculture indirect	Farm General	Horticulture	Trees	Pasture (non dairy)	Pasture Dairy	Lucerne	Cotton	Flowers	Orchard	Nursery	Vegetables	Viticulture	Hydroponics	Turf farm	Canefields	Cropping	Wetlands	Environmental water	Annual Effluent Flow	Effluent Reused
	Industrial					Amenity			Agriculture																	Environment		ML	ML
Estimate of the volumes of water recycled from sewage effluent in each state involving the uses above																													
NSW	11,369	6,166	1,542	4,499	378	5,834	3,833	1,046	1,431	729	50	4,085	6,202	2,473	983	1,396	0	15	0	0	0	3	0	0	0	960	0	607,153	53,085
Vic	47,442	0	0	1,837	0	2,257	2,200	0	0	4,420	110	11,791	12,532	1,331	0	0	597	0	3,318	0	1,198	0	597	0	3,156	0	16	384,177	92,106
Qld	1,843	4,001	137	0	587	4,868	2,914	0	1,120	579	140	425	953	337	640	0	0	0	155	0	0	0	581	2,329	0	0	825	180,850	22,433
SA	1,165	0	0	0	0	349	6,588	1,828	0	1,602	0	51	41	0	22	0	0	0	0	14,624	6,534	0	0	0	0	485	380	87,060	33,667
WA	0	1,434	0	0	60	1,674	3,664	0	0	0	96	1,645	933	0	0	0	0	0	0	0	0	0	0	0	0	0	194	13,611	9,699
Tas	238	0	0	0	0	526	278	0	0	4,314	0	0	0	400	0	0	0	0	0	0	0	0	0	0	0	0	0	12,940	5,755
ACT	0	0	0	0	0	900	0	0	0	0	0	0	0	0	0	0	0	0	0	0	900	0	0	0	0	0	0	30,000	1,800
NT	0	0	0	0	0	212	845	0	0	0	0	365	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14,071	1,466
total	62,056	11,600	1,679	6,336	1,025	16,618	20,321	2,874	2,551	11,644	396	18,362	20,704	4,541	1,644	1,396	597	15	3,473	14,624	8,632	3	1,178	2,329	3,156	1,445	1,415	1,329,862	220,010
Estimate of the number of scheme in each state involving uses above																												Total Count	
NSW	30	1	3	4	1	52	33	2	2	3	1	17	29	4	4	3	0	2	0	0	0	1	0	0	0	1	0	193	
Vic	6	0	0	1	0	16	7	0	0	6	1	25	62	8	0	0	1	0	4	0	4	0	1	0	6	0	1	149	
Qld	17	2	2	0	7	40	22	0	1	9	1	5	3	3	3	0	0	0	1	0	0	0	4	8	0	0	1	129	
SA	1	0	0	0	0	3	4	1	0	3	0	2	2	0	1	0	0	0	0	1	4	0	0	0	0	1	1	24	
WA	0	4	0	0	1	8	29	0	0	0	1	7	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	53	
Tas	1	0	0	0	0	5	2	0	0	21	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	31	
ACT	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	
NT	0	0	0	0	0	1	4	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	
total	55	7	5	5	9	126	101	3	3	42	4	58	99	17	8	3	1	2	5	1	9	1	5	8	6	2	4	589	

Source: Radcliffe 2004 and modified through personal communication during this project

3.3.8 Comparison of the accessibility of viticulture to recycled water - Case 1 to 4

3.3.8.1 Case 1 and 2 – Access of established wine regions to recycled water from STPs

Based on the quantity of water available, and the approximate distance between the recycled water source and the site of viticulture, it was possible to estimate the cost of water $/ML and the amount of water supplied as a percentage of the irrigation needs. For Case 1 and 2, (Table 6), estimates of costs for delivery of recycled water were compared with distance of delivery and indicated that cost become excessive (> $1000/ML) at greater the 50 km (Figure 6). Therefore all subsequent analysis for Case 1 and 2 were included on site where the STP and wine regions were < 50 km apart. As discussed above (Section 3.3.4) these distances are complicated by the spatial variability within suburbs and wine districts. As such they could vary ± 20-40% depending on specific circumstances and should be considered as indicative only.

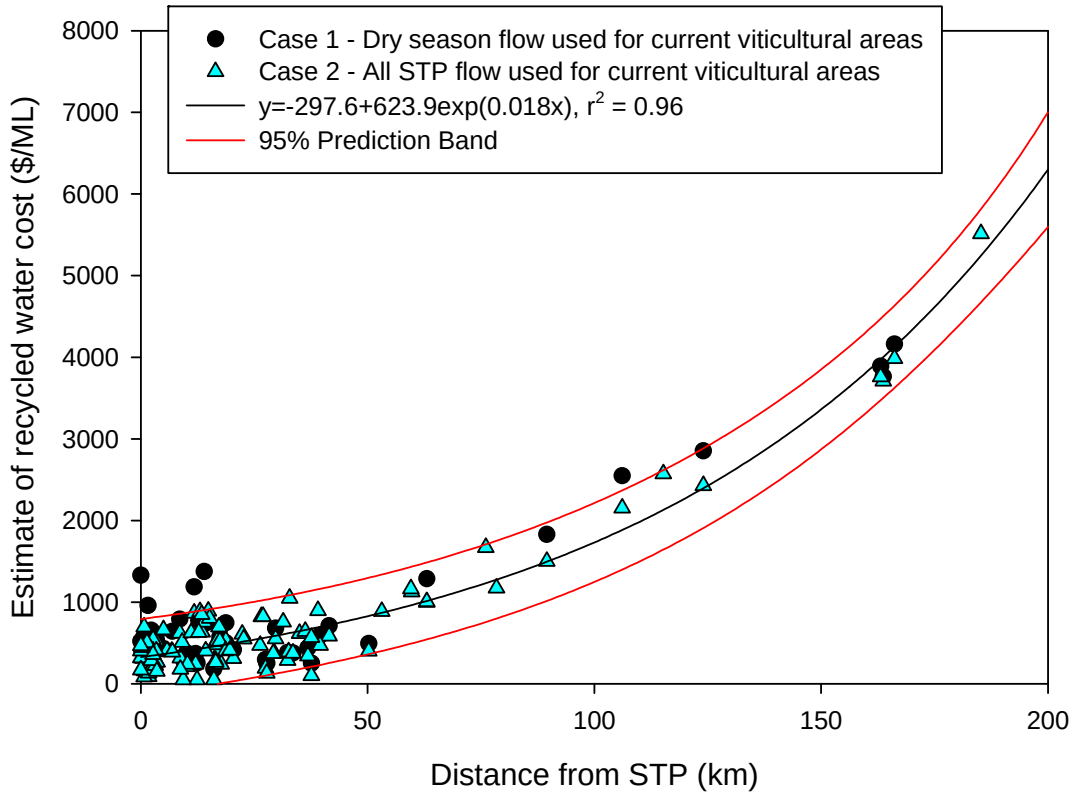


Figure 6 **Indicative distance from Sewage Treatment Plant (STP) compared with cost for delivery of water to existing wine regions**

Total areas of vines in each state were compared with the potential area that could be irrigated with available recycled water on to existing vine growing areas (Figure 7) using maximum irrigation rates supplied by GWRDC as stipulated in Table 9.

Figure 7 highlights only a small proportion of viticultural areas could be irrigated with recycled water due to location to a STP. In most existing viticultural regions, the majority of plantings are not within 50km of a STP.

For Case 1, only 4.6% of total vine area (excluding TAS) could be irrigated with recycled water relatively easily. Tasmania shows the greatest potential for the use of recycled water due to locality within 50km of STPs. The use of annual effluent flow incorporating winter storage of recycled water (Case 2) allows the potential to increase the area vines to be irrigated (Table 9).

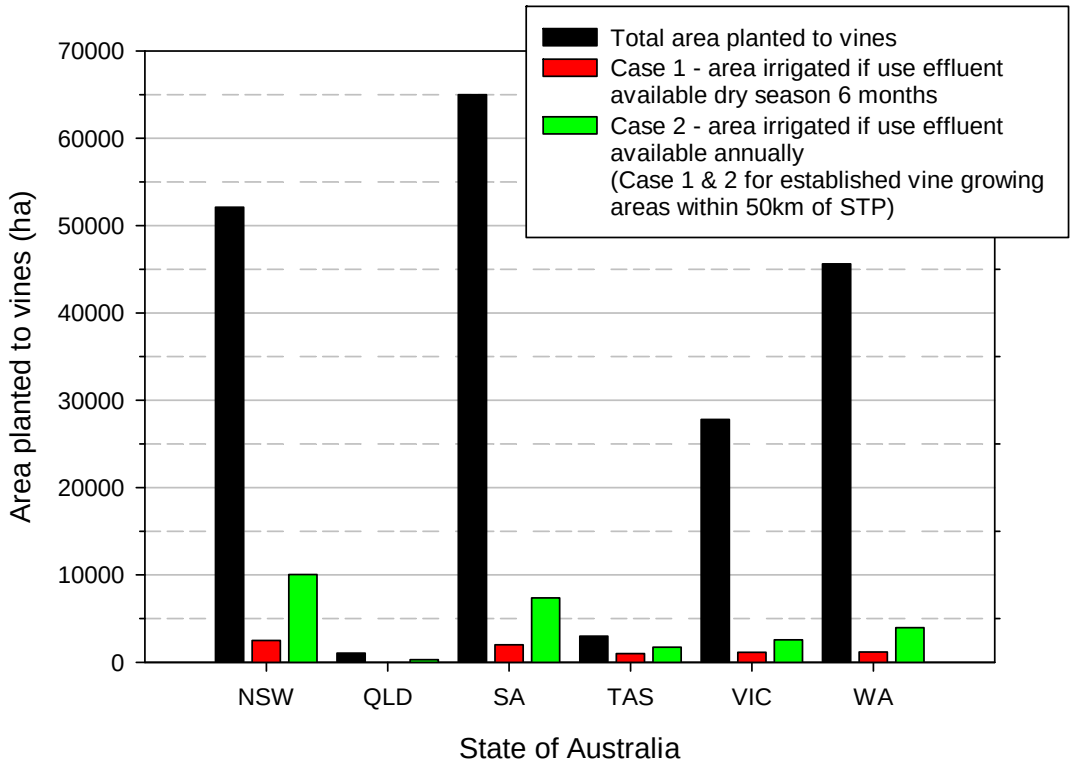


Figure 7 **Comparison of total area of vines planted in each state of Australia compared with possible increase in area of vines assuming Case 1 or 2 – considers established wine growing areas within 50km of sewage treatment plant (STP). Assumes high irrigation requirement quoted for specific wine growing area.**

Table 9 Summary of total vines area irrigated compared to areas irrigated with recycled water (Established wine regions only)

State	Total vines (ha)		Area of vines Within 200 km radius of STP (ha)	Percent of total calculated area of vines	Case 1		Case 2		Number of STP with in		
	AWBC [A]	Calculated[B]			Area supplied (ha)	Portion of total vines grown (%)	Area supplied (ha)	Portion of total vines grown (%)	< 10 km	10-20 km	20-50 km
NSW	43574	40,749	7,850	19%	2,498	6%	10,041	23%	9	8	12
QLD	3176	1,050	1,050	100%	71	2%	300	9%	2	0	1
SA	73155	73,300	29,400	40%	2,636	4%	11,831	16%	5	8	45
TAS	1507	1,000	1,000	100%	1,000	66%	1,733	115%	1	1	0
VIC	37472	34,098	33,500	98%	1,131	3%	2,574	7%	0	8	12
WA	13431	12,250	10,100	82%	1,181	9%	3,967	30%	5	10	22

[A]Area of vines from AWBC website[9]- Winefacts – Australian Wine Sector, State by State – 2008. [B]Calculated from assumptions in report.

A key conclusion from Figure 7 and Table 9 is that the demand for irrigation water for viticulture is significant and that all recycled water in close proximity (Case 1 and Case 2) can only meet a small proportion of this total demand. This still may represent a significant area of vines and subsequently reduce reliance on mains and aquifer water used in these areas. There is already a significant demand on recycled water that is located in the proximity of viticulture. It is unclear how much of this existing share could be captured by viticulture in the near future, because negotiations maybe in place.

It should be noted that irrigation rates vary considerably across Australia and specific regions (summarised in Table 10, details in Appendix Table 48). , with an irrigation rate of 2.5ML/ha the median upper estimate across viticultural regions. In some instances, a rate of 7.6 ML/ha have been applied (e.g. Mildura uses a maximum of 8.5 ML/ha - Table 48). Where possible, specific irrigation rates for regions have been used for Case 1 and 2 calculations. For Case 3 and 4 (Where flows from all STPs are considered with no link to currently established wine regions), an irrigation rate of 2.5 ML/ha/year was assumed (Table 10) as most likely to represent the upper limit of average irrigation rates used across industry at this point in time.

Table 10 Statistical comparison of irrigation rates across Australian wine regions

Measure for irrigation rates in all viticultural areas across Australia	Irrigation rate (ML/ha)		
	Percentile		
	5th	50th or median	95th
Highest irrigation rate quoted for a specific wine growing region	1.0	2.5	7.6
Lowest irrigation rates quoted for a specific wine growing area	0.0	0.5	3.7
Combined (Highest and lowest)	0.0	1.0	4.2

Source: GWRDC; Table 48 (Appendix 10.3)

[9] www.awbc.com.au/winefacts/data/free.asp?subcatid=94

3.3.8.2 Specific cases worthy of further examination

Ultimately it is only specific regions that can make the business case for securing recycled water at a given cost. The benefits of the security of supply need to be offset against the additional cost of water. However it is useful to identify some of the relatively achievable opportunities to enable the viticulture industry to explore their merit in more detail.

The analysis of some of the easier low cost options (Case 1 and 2) have been summarised below (Table 11). There are a number of opportunities for some vine growing regions to access and use recycled water to irrigate vines (Table 11). In many cases the dry season water (when water is required for irrigation over summer – Case 1) has already been partially or fully allocated and the demand met is low relative to the water requirement from a wine region. However, there still appear to be some opportunities warranting further investigation. For example, the STP at Bolivar in SA still has some summer flow available (Table 47 – 4570 ML) and a large portion of winter flow (approximately 22,500 M). This observation highlights the fact that much of the easy to access and use recycled water has already been allocated and used. However, there are opportunities to increase the amount of demand met in winter flows could be easily stored, in these cases large storages will be required.

Table 11 Summary of indicative opportunities for use of recycled water with established wine regions.

Sewage treatment plant data				Closest Wine District											
										Case 1			Case 2		
STP Data Region	Town/ suburb	Total WW avail. ML/yr	Dry Season WW not taken ML/irr season	Closest Wine district	Township	STP to WD (est.) km	Area Vines Ha	Min Vol Req ML	Max Vol Req ML	Cost Est.[A] $/ML	Demand met	Area (ha)	Cost Est. [A] $/ML	Demand met	Area (ha)
New South Wales															
Young Shire	Young	700	280	Hilltops	YOUNG, NSW 2594	0.5	700	350	1400	446	20%	140	312	50%	350
Orange City	Orange	3900	0	Orange	Orange, NSW	0.8	1500	750	1500	NA	0%	0	85	260%	1,500
Cessnock	Cessnock	1570	15.7	Hunter	Cessnock, NSW 2325	1.6	4000	0	8000	960	0%	8	203	20%	785
Queensland															
Kingaroy	Kingaroy	550	126.5	South Burnett	Kingaroy, QLD 4610	0.6	450	225	1350	571	9%	42	347	41%	183
Stanthorpe	Stanthorpe	350	87.5	Granite Belt	Stanthorpe QLD 4380	1.9	600	300	1800	632	5%	29	413	19%	117
South Australia															
SA Country	Mount Barker	660	171.6	Adelaide Hills	Mt Barker, SA 5251	0.0	3800	1900	7600	522	2%	86	321	9%	330
SA Country	Hahndorf	380	0	Adelaide Hills	Mt Barker, SA 5251	5.8	3800	1900	7600	NA	0%	0	405	5%	190
SA Country	Aldinga	200	0	McLaren Vale	McLaren Vale, SA 5171	9.1	6050	3025	15125	NA	0%	0	508	1%	80
Metropolitan	Christies Beach	10700	856	McLaren Vale	McLaren Vale, SA 5171	9.4	6050	3025	15125	296	6%	342	50	71%	4,280
Adelaide	Bolivar	45700	4570	Adelaide Plains	Virginia , SA 5120	12.4	500	250	1250	253	366%	500	50	3656%	500
Tasmania															
Hobart	Selfs Point	4750	1900	Tasmania	Hobart, Tas. 7000	2.5	1000	0	1500	209	127%	1,000	209	317%	1,000
Victoria															
North East Water	Rutherglen	372	3.72	Rutherglen	Rutherglen, VIC 3685	0.0	1000	750	3500	1328	0%	1	403	11%	106
Lower Murray Water	Robinvale	190	0	Robinvale	Robinvale, VIC 3549	1.4	900	4050	7650	NA	0%	0	506	2%	22
Coliban Water	Bendigo	7410	963.3	Bendigo	Bendigo, VIC 3554	1.7	900	900	2700	268	36%	321	132	274%	900
Grampians Water	Ararat	850	76.5	Grampians	Ararat, VIC 3377	2.3	550	275	1375	656	6%	31	286	62%	340
Glenelg Water	Hamilton	1020	0	Henty	Hamilton, VIC 3300	2.7	150	75	375	NA	0%	0	403	272%	150
Western Australia															
Great Southern	Albany 2	2010	0	Great Southern	Albany, WA 6331	0.0	3150	1575	7875	NA	0%	0	170	26%	804
South West	Manjimup	280	0	Manjimup	Manjimup, WA 6258	0.2	300	300	900	NA	0%	0	446	31%	93

[A]to meet current Viticultural requirements (Max. vol), WW = Wastewater, est. = estimated, avail.= available. NA = no available water. Source: Table 47. WD = Wine district. STP region identified through latitude and longitude coordinates

3.3.8.3 Case 3 and 4 – Access to recycled water from all sewage treatment plants

For Case 3 and 4 a much larger portion of recycled water is available, as all effluent produced is considered (i.e. current location of wine regions is not considered). In contrast to Case 1 and 2, there is sufficient recycled water to irrigate more than the areas currently growing vines (Figure 8). Both Case 3 and 4 require relocation and high costs to acquire recycled water. Although these cases highlight the large volumes of water that could be accessed (Table 12), it should be noted that much of this volume (i.e. large cities) is difficult and costly to access due to the requirement of extracting it through cities to areas were it could be use for irrigation (Boland *et al.* 2006).

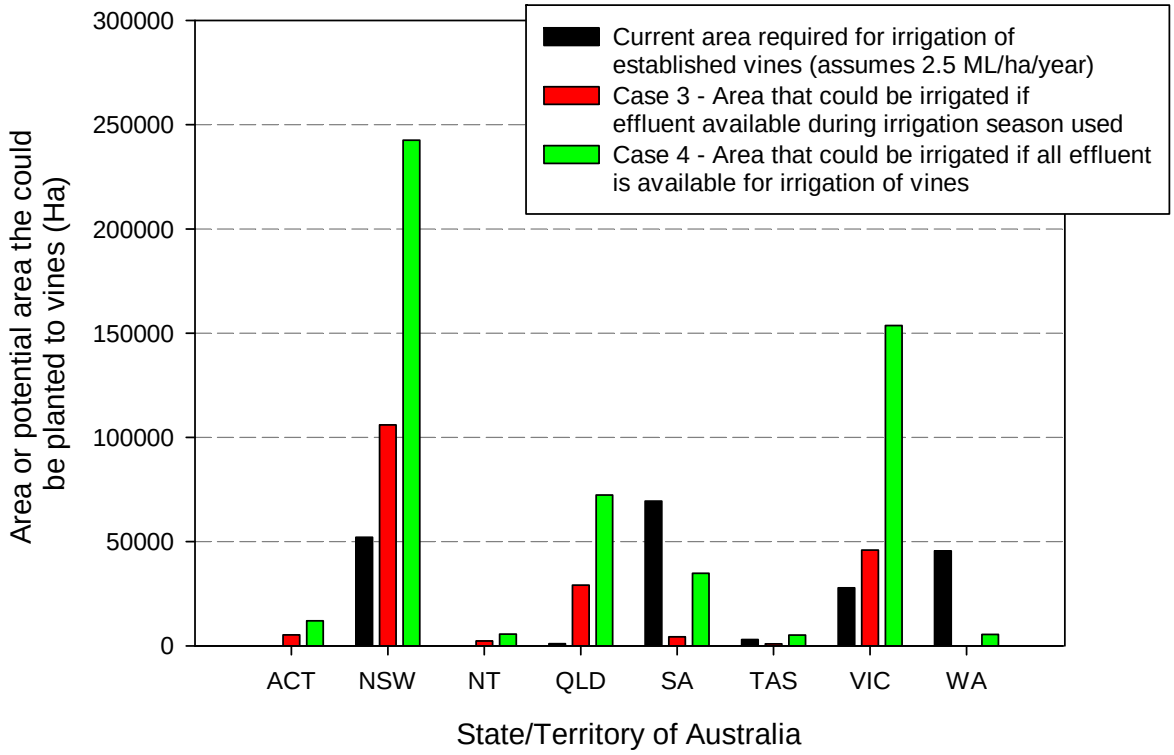


Figure 8 **Comparison of total areas of current wine regions with possible areas of vines irrigated if effluent (reclaimed water) is available during the irrigation season (i.e. Case 3 & not already allocated) and total volumes of effluent are available annually (i.e. Case 4). All calculations assume an irrigation rate of 2.5 ML/ha/year.**

Table 12 Comparison of possible irrigation requirements for wine regions, assuming an irrigation rate and total sewage treatment plant (STP) effluent flows from all STPS – no consideration for location of established wine regions compared to established vines.

State	Hectares of Vines	Assumed ML/ha used[A]			Case 4- Total STP annual Flow(ML)	Allocated Over irrigation season(ML)	Case 3-STP flow unallocated during irrigation season(ML)
		1	2.5	7.6			
		Total ML/required per state					
ACT	NA				30,000	1,800	13,200
NSW	43574	43,574	108,935	331,162	606,353	52,285	264,981
NT	NA				14,071	1,466	5,758
QLD	3176	3,176	7,940	24,138	180,850	22,433	72,923
SA	73155	73,155	182,888	555,978	87,060	33,667	10,811
TAS	1507	1,507	3,768	11,453	12,940	5,755	2,496
VIC	37472	37,472	93,680	284,787	384,177	92,106	114,927
WA	13431	13,431	33,578	102,076	13,611	9,699	685

[A]Assumed irrigation rates where determined as described in Section3.3.8.1 - Table 10.

3.3.9 Conclusions and recommendations for future action

The methodology developed provides viticulture industry with a useful tool to explore the opportunities for the supply of recycled water. Some of the key conclusions are:

- Much of the available recycled water located near viticulture regions is already allocated. It is unclear how difficult it will be for viticulture to negotiate this supply from existing users.
- There are some opportunities for existing regions identified in this report that could warrant use of recycled water for irrigation. In these cases, it would be useful for the GWRDC to test the merit of these opportunities with the specific vineyards. What is the acceptable cost premium for a secure supply of water?
- The available large volumes of recycled water are located within Australia's major cities. This represents a significant future opportunity for viticulture to access these water sources, however, the cost of infrastructure would be high. Additionally, there is significant cost and project complexity if the viticulture industry relocates in closer proximity to these sources (Case 3 and Case 4).
- There will be emerging opportunities as the network of large scale recycled water pipelines expands across Australia. For example, the Western Corridor in SE Queensland, and plans to expand recycled water use out the Eastern Treatment Plant in Melbourne may open up new opportunities for viticulture. Whereby large scale infrastructure is developed by water authorities, and the viticulture industry can purchase water on a volume basis.
- The cost of recycled water from these current and future large scaled recycled water schemes will be a strong function of the quality of water supplied. Ideally to fully capture the benefits of such scheme, the water quality must not significantly exceed the requirements of viticulture. If recycled water is treated to a very high level, such as Indirect Potable Reuse standard there will be an unnecessary cost premium paid for by viticulture, and more competition for the water.

Recommendations

- GWRDC consult with specific vineyards to gauge whether the industry views the indicative opportunities in the report worthy of future investigation.
- GWRDC should maintain a watching brief on new recycled water infrastructure from major cities that may reduce the pipeline distance to existing viticulture regions, or may open up new viticulture regions.

4 MANAGEMENT OF RISKS POSED BY RECYCLED WATER

In most cases, environmental (including agronomic) and health risks can be managed through the level of wastewater treatment or by the carefully managed use of recycled water. However, in some cases the recycled water may not be of suitable quality for an intended use and therefore should not be used. Some of the major risks associated with recycled water in the viticultural sector are outlined below and are discussed in detail in later sections.

4.1 Human health risks

Microbial pathogens in wastewater from sewage effluent are the major concern for human health when recycling water. The major groups of pathogens are:

- Bacteria (e.g. Escherichia coli, Salmonella spp, Campylobacter)
- Viruses (e.g. Enteroviruses, Rotavirus, Hepatitis A)
- Protozoa (e.g. Giardia Lamblia, Cryptosporidium parvum)
- Helminths (e.g. *Taenia* spp (Tapeworm), *Ancylostoma* spp (Hookworm))

Bacteria can cause illness such as gastroenteritis, dysentery, cholera, respiratory illness and skin/eye/ear infections in humans. Viruses can cause illnesses such as gastroenteritis, respiratory illness, nervous disorders and infectious hepatitis. Protozoa can cause illnesses such as gastroenteritis, amoebic meningitis and amoebic dysentery. Helminths are intestinal nematodes such as *Taenia* which causes tapeworm in humans, cysticercosis in cattle and pigs, and ascaris that causes roundworms in humans

Not all infections make you sick. To become infected by a pathogen you must be exposed to a sufficient number of pathogens for an infection to occur. If recycled water is fit for the intended purpose, any possible exposure will be prevented or very low and infection very unlikely.

Recycled water uses in the viticultural sector that require particular attention for health risk assessment include:

- Irrigation of readily accessible public areas with potential for direct exposure to recycled water (e.g. cellar door sales with public access to vines);
- Irrigation of vines used for wine or sultana production;
- Cross connections with drinking water supplies;
- Storage of recycled water on-farm; and
- Where workers may either come into direct contact with recycled water or ingest aerosols in their normal working environment.

Another risk to human health is on-site workers who come into direct contact with recycled water containing high numbers of blue-green algae, which may lead to skin and eye irritations or gastric upsets. This risk is higher with recycled water than many other sources of water as recycled water often contains high nitrogen and phosphorus levels which feed the algae (Section 6.5).

4.2 Environmental/Horticultural Risk

Some of the common environmental/horticultural risks (NRMMC and EPHC 2006) from recycled water include:

- **Nitrogen**
  a major nutrient required by plants. However, excess nitrogen can cause excessive growth, which can lead to extra maintenance or affect turf wear tolerance. It can also cause eutrophication (excessive nutrient levels) in land and aquatic ecosystems.
- **Phosphorus**
  a major nutrient required by plants and is usually of benefit. However, it can be toxic to some native plant species. Can lead to eutrophication of water bodies on and off site.
- **Potassium**
  a major nutrient required by plants. Excess can lead to decreased quality of berries/wines.
- **Salinity**
  a chronic problem that needs to be managed in many urban irrigation systems if using recycled water. Salinity can stress plants and impact on the aesthetics of the garden or landscape. Salinity can also degrade soils and impact on freshwater plants and invertebrates in natural ecosystems if discharged directly with little dilution.
- **Sodium/Chloride**
  can be toxic to plants if sprayed directly on leaves and if it accumulates in soils from ongoing irrigation.
- **Sodicity**
  can cause soil dispersion and swelling, reducing water infiltration on heavier textured soils leading to excessive runoff or water-logging.
- **Algae**
  blooms from the high levels of nitrogen and phosphorus found in recycled water.
- **Boron**
  can cause plant toxicity in some sensitive plant species in some soils if it accumulates from ongoing irrigation.
- **Hydraulic loading**
  excess can result in excess groundwater recharge, water logging and secondary salinity.
- **Chemicals of concern**
  there are several chemicals that have recently been identified in the scientific literature that may pose risks to the environment or human health. In many cases there are no guidelines at present to determine the risk associated with these chemicals and research is still identifying the level of risk and what, if any, control measures are required.

- **Plant pathogens**
  research on human pathogens has been extensive. However, little data is available on plant pathogens found in recycled water.

4.3 Financial risks associated with supply of recycled water

There are a number of economic constraints that require careful evaluation to determine the financial feasibility of collecting and treating water for distribution to the viticultural sector. The cost of water is a function of water treatment, length and size of pipe infrastructure and storage requirements.

4.4 Public image and acceptance of recycled water use

Any product grown with recycled water and for sale to consumers must be accepted by consumers. The use of water recycled from STP effluent to grow grapes may have a positive or negative impact on consumers' acceptance of these products. Many food production industries have already overcome these issues. However, it has not been specifically addressed for the viticultural sector.

4.5 Summary

The risks outlined above are discussed in more detail in the following chapters in the context of the viticultural industry. Gaps in the knowledge and potential future issues are identified through the literature and industry knowledge, where specific viticultural data or examples could not be located other commodities are used.

5 HUMAN HEALTH RISKS WHEN USING RECYCLED WATER IN VITICULTURE

5.1 Hazard to human health

The major risks posed by recycled water to human health are pathogens (NRMMC and EPHC 2006). Chemicals are generally not considered a human health risk directly due to the low exposure if not ingested (Section 5.4.3). The four main types of pathogens and common examples of these types found in recycled water are shown in Table 13. These groups of pathogenic species are relatively long lived in the natural environment compared with pathogens as a whole. They do not have fixed maximum lifetimes. The population will 'die' over a given and measurable period (Khan and Roser 2007). Extensive data has shown that WWTPs and biosolids production methods are very effective and also reduce the levels of pathogens (EC 2001; Epstein 2002).

There are two types of control measures (NRMMC and EPHC 2006) used to minimise the risk potentially posed by these pathogens:

- exclusion (source control or treatment/removal); and
- restrictions on end-use (how the water is used)

All control measures ultimately lower the exposure (concentration x duration) to acceptable levels of low risk.

The concentration of pathogens in sewage effluent has been well documented across the world (NRMMC and EPHC 2006). The AGWR use this information to set a level of removal of pathogens required to ensure that exposure will not lead to an unacceptable level of infection from the use of recycled water. To do this from a human health and pathogens point of view, log removal of pathogens can be implemented as a control measure either by:

- log removal using exclusion control (e.g. removal via the treatment process); or
- 'equivalent log removal' (e.g. end-use restrictions on irrigation practice or access restrictions).

The methods for minimising any risk associated with pathogens present in recycled water are discussed below in terms of occupational health and safety (OHS).

The effectiveness of WWTPs to treat water to levels where it is fit for the purpose of irrigation of food crops is now well established from the perspective of managing human health (NRMMC and EPHC 2006; Sheikh *et al.* 1999). However, little seems to be known of the efficiencies of STPs to remove plant pathogens (discussed below in Section 6.10).

The log removal of human pathogens for sewage water needs to be equivalent of 4.4/6.1/5.0 for Cryptosporidium/Rotavirus/Campylobacter (Table 14).

Table 13 Examples of principle pathogens found in sewage water and potentially in sewage sludge

Pathogen type	Examples	Illness
Bacteria	*Salmonella*	Gastroenteritis, reactive arthritis, salmonelloisis (food poisoning), typhoid
	Campylobacter	Gastroenteritis, Guillain–Barré syndrome
	Pathogenic Escherichia coli	Gastroenteritis, haemolytic uraemic syndrome
	Shigella	Dysentery
	Yersinia	Gastroenteritis, septicaemia
	Vibrio cholerae	Cholera
	Atypical Mycobacteria	Respiratory illness (hypersensitivity pneumonitis)
	Legionella spp	Respiratory illness (pneumonia, Pontiac fever)
	Staphylococcus aureus	Skin, eye, ear infections, septicaemia
	Pseudomonas aeruginosa	Skin, eye, ear infections
	Helicobacter pylori (?)	Peptic ulcers
	Escherichia coli O157:H7 and [STEC]	Shiga toxin
Viruses	Enterovirus	Gastroenteritis, respiratory illness, nervous disorders, myocarditis
	Adenovirus	Gastroenteritis, respiratory illness, eye infections
	Rotavirus	Gastroenteritis
	Norovirus	Gastroenteritis
	Hepatitis A	Infectious hepatitis
	Calicivirus	Gastroenteritis, with severe diarrhoea
	Astrovirus	Gastroenteritis
	Coronavirus	Gastroenteritis
	Reovirus	Respiratory infections, gastroenteritis
	Norwalk and Norwalk-like viruses	Epidemic gastroenteritis with severe diarrhoea
	Poliovirus	Poliomyelitis
	Hepatitus E, Hep TT	Hepatitis
	Echovirus	
	Coxsackievirus	Meningitis, hepatitis, fever
Protozoa	*Cryptosporidium*	Gastroenteritis
	Giardia	Gastroenteritis
	Naegleria fowleri	Amoebic meningitis
	Entamoeba histolytica	Amoebic dysentery
	Balanta (Balantidium) coli	Diarrhoea ,dysentery
	Toxoplasma gondii	Toxoplamosis
Helminths (parasitic worms)	*Taenia saginata*	Tapeworm (beef)
	Taenia solium	Tapeworm (pigs)
	Ascaris lumbricoides	Roundworm (humans)
	Ascaris suum	Large roundworm (pigs)
	Trichuris trichiura	Whipworm (humans)
	Necator americanus	Hookworm (mammals - e.g. dogs, cats, human)
	Hymenolepis nana	Tapeworm (humans)
	Toxocara canis	Fever, muscle ache, abdominal discomfort

Sources of references (Ref): 1 NRMMC and EPHC 2006, 2 US EPA 2003, 3 Godfree and Farrell 2005, 4 Gerba 2005, 5 WEAO 2001

Table 14 Log reductions for priority uses of recycled water from treated sewage

Activity	Route of exposure	Exposure (litres) × freq (per year)	Log reduction		
			Crypto-sporidium	Rotavirus	*Campylo-bacter*
Commercial food crops (i.e. grapes for eating or making wine)	Ingestion – Lettuce – Other produce	0.005 × 70 0.001 × 140			
	Total	0.49	4.8	6.1	5.0
Dual reticulation					
Garden irrigation	Ingestion of sprays Ingestion – Low – High	0.0001 × 90 0.001 × 90 0.1 × 1			
	Total	0.2	4.4	5.8	4.6
Garden food crops	Ingestion – Lettuce – Other produce	0.005 × 7 0.001 × 50			
	Total	0.09	4.0	5.3	4.2
Internal uses					
Toilet flushing	Ingestion of sprays	0.00001 × 1100	3.1	4.5	3.3
Washing machine	Ingestion of sprays	0.00001 × 100	2.1	3.5	2.3
Cross-connections	Ingestion	1 × 0.365	4.7	6.1	4.8
Total internal use (no garden use)		0.38	4.7	6.1	4.8
Total residential use (garden + internal)		0.67	4.9	6.3	5.1
Municipal irrigation	Ingestion of sprays	0.001 × 50	3.7	5.2	4.0
Dual reticulation plus municipal irrigation	Ingestion of water and sprays	0.72	5.0	6.4	5.1
Fire fighting	Ingestion of water and sprays	0.02 × 50	5.1	6.5	5.3

Log reduction calculations: *Cryptosporidium* = Log (number of organisms in sewage × exposure (L) × frequency ÷ 1.6×10^{-2}); Rotavirus = Log (number of organisms in sewage × exposure (L) × frequency ÷ 2.5×10^{-3}); *Campylobacte*r = Log (number of organisms in sewage × exposure (L) × frequency ÷ 3.8×10^{-2}) Source: NRMMC and EPHC 2006

5.2 Occupation health and safety (OHS)

5.2.1 OHS Guidelines

Any recycled water scheme should comply with the Occupational Health and Safety Act[10]. This act is designed to provide a broad framework for improving standards of workplace health and safety to reduce work-related injury and illness. The Act aims to:

[10] e.g. www.worksafe.vic.gov.au/wps/wcm/resources/file/ebcd02435d8383b/ohssummaryvwa.pdf

- Secure the health, safety and welfare of employees and other people at work
- Protect the public from the health and safety risks of business activities
- Eliminate workplace risks at the source
- Involve employers, employees and the organisations that represent them in the formulation and implementation of health, safety and welfare standards.

5.2.2 Good OHS practice

A large variety and concentration of pathogenic (disease causing) organisms can be present in wastewater (Table 13). The concentration and types of pathogens removed are dependent on the level of treatment during the production of recycled water (Figure 1), the higher the level of treatment the lower the number of pathogens.

Occupational exposures associated with the use of recycled water can be managed by minimising ingestion and exposure to aerosols (fine air bourne water droplets).

5.2.3 General good practice

Persons engaged in any operation involving recycled water should:

- Avoid consumption of recycled water (Class A to D are not considered fit for drinking) and unnecessary exposure to sprays and aerosols
- Wash hands with soap and clean water before eating, drinking or smoking, and at the end of each working day
- Cover any wounds, open cuts or broken skin
- Use appropriate protective clothing and equipment if required.

In many cases, the irrigation system used will also govern the risk of exposure and should be considered when planning and operating a reuse scheme (Table 15).

Table 15 Risk of occupational exposure to recycled water relative to the irrigation system

	Risk level		
Exposure	Drip	Sprinkler	Furrow
Ingestion risk	Low	Medium	Medium
Contact risk	Low	High	High
Aerosol risk	Low	High	Low

Source: Stevens *et al.* 2006 p 120

5.2.4 Precautions to protect health of workers

All employees and contractors should be advised of limitations placed on the use of recycled water and the precautions that need to be taken to protect their health:

- For lower class water (less than A), hepatitis A immunisation (a faecal-borne disease) may be recommended, although the risk even to workers at sewage treatment plants is considered low (Brugha *et al.* 1998; Glas *et al.* 2001). Hepatitis B is a blood-borne disease and as such is

unlikely to be a risk, so vaccination is not usually necessary (CDCDP 1993). If you require further advice contact the Department of Human Services, Melbourne.

- All external tap outlets on the drinking water service should be fitted with hose connection vacuum breakers to prevent backflow and possible contamination of potable water supply.

5.2.5 Signage and pipe labelling

Signage is an important part of risk management. All recycled water external tap outlets must have a prohibition sign complying with AS1319 (AS 1994). All entrances to sites using recycled water must have adequate signage informing of the use of recycled water.

Most recycled water guidelines state that warning signs with both a pictorial sign and words indicating that recycled water is being used should be placed in strategic positions. Content should be consistent with the examples provided (Figure 9).

Two-tone colouring should be used with black picture and text and red symbols. The number of signs and size of wording should be determined on the basis of the visual distance from the observer (for example, 100 mm wide sign at a distance of 3 m, AS1319 - AS 1994).

There is also specific signage and pipe labelling required for plumbing fittings (see Appendix 3.1.5, p 17). If hoses are connected to recycled water outlets they should also be purple in colour to identify them as containing recycled.



Figure 9 Warning signs indicating not to drink the water and informing the public that recycled water is used on the property

5.2.6 Training and auditing

5.2.6.1 Pre-commissioning

Pre-commissioning audits must be performed to prevent any cross connections with the potable drinking water supply. All plumbing work must be carried out by a licensed plumber.

5.2.6.2 Induction of new staff

All new staff should be inducted into the work space and given a guided tour of the premises, which identifies all recycled water outlets, applications, best practices when using recycled water, and the importance of maintaining best practice.

5.2.6.3 Ongoing training

Updated training should be provided yearly to ensure all staff are made aware of any changes made to individual recycled water systems and/or changes to the guidelines and regulations covering recycled water use in amenity horticulture.

5.3 Public health

Most existing recycled water guidelines and regulations specify a range of preventive measures that reduce risk by lowering exposure to recycled water (NRMMC and EPHC 2006). These control measures can include:

- restricting uses of recycled water (types of crops grown)
- controlling methods of application (irrigation methods)
- setting withholding periods between application of recycled water and use of irrigated areas or harvesting of produce
- controlling public access during application or use of recycled water
- using signage, labelling and communication to minimise accidental exposure.

The methods of these control measures are discussed below.

5.3.1 Restrictions on-site

5.3.1.1 Buffers

Adequate buffers (e.g. between 25 to 30 m; NRMMC and EPHC 2006, p 97) should be installed and maintained between the storage area and the boundary of the property.

The AGWR (NRMMC and EPHC 2006) indicate that buffer zones of 25 to 30 m offer a reduction in exposure to pathogens by 1 log (Table 16). Irrigation methods and removal of recycled water with contact of the harvestable portion and restrictions on access can also provide reduction in exposure to pathogens (2 to 6 log; Table 16). In total for food crops, log removal of 4.4/6.1/5.0 for *Cryptosporidium*/Rotavirus/ *Campylobacter* is required (Table 14).

Table 16 Exposure reductions provided by on-site preventive measures

Control measure	Reduction in exposure to pathogens
Cooking or processing of produce (e.g. cereal, wine grapes)	5–6 log
Removal of skins from produce before consumption	2 log
Drip irrigation of crops	2 log
Drip irrigation of crops with limited or no ground contact (e.g. tomatoes, capsicums)	3 log
Drip irrigation of raised crops with no ground contact (e.g. apples, apricots, grapes)	5 log
Subsurface irrigation of above ground crops	4 log
Withholding periods — produce (decay rate)	0.5 log/day[a]
Withholding periods for irrigation of parks/sports grounds (1–4 hours)	1 log
Spray drift control (microsprinklers, anemometer systems, inward-throwing sprinklers, etc)	1 log
Drip irrigation of plants/shrubs	4 log
Subsurface irrigation of plants/shrubs or grassed areas	5–6 logs
No public access during irrigation	2 log
No public access during irrigation and limited contact after (non-grassed areas) (e.g. food crop irrigation)	3 log
Buffer zones (25–30 m)	1 log

a Based on virus inactivation. Enteric bacteria are probably inactivated at a similar rate. Protozoa will be inactivated if withholding periods involve desiccation.

Source (NRMMC and EPHC 2006)

5.3.1.2 Access

No public access should be allowed to recycled storage sites. Signs indicating this should be present on entrances to storage sites. Locked gates and impenetrable fences should be installed around storage sites.

5.3.1.3 Run-off

Run-off to waterways and neighbouring sites must be prevented through good irrigation scheduling and monitoring.

5.3.1.4 Odours

Odour can be minimised by managing flow into storage sites, aeration and volumes of water stored for long periods; with the aim being to prevent the water going stagnant.

Flushing irrigation equipment with fresh water following irrigation can stop the odour associated with stagnant recycled water in irrigation pipes.

5.3.1.5 Colour

Piping must be installed as per the state guidelines or plumbing industry guidelines.

5.3.1.6 Algae

The high levels of nitrogen and phosphorus in recycled water can lead to algae blooms in water storage sites exposed to the sun. If an algal bloom is toxic, direct contact with humans should be avoided (Section 6.5). All algal blooms should be treated as toxic until species have been identified and are considered safe.

5.3.2 Restricted public access to irrigation site

If lower class water is used (B, C or D) restricted public access to the irrigation site might be a crucial component of minimising health risks. Restrictions could include:

- Withholding periods - no access after irrigation, until dry (1–4 hours)
- Buffers - suggested buffer distances from the edge of the wetted area to surface waters for the use of Class C recycled water in Victoria are summarised in Table 17.

Table 17 Suggested buffer distances for Class C water use in Victoria

Irrigation Type	Buffer distance (m)
Flood/high pressure spray	100
Low pressure spray	50
Trickle or subsurface irrigation	30

Source: EPA Victoria 2003b

It may be appropriate to reduce these buffer distances (Table 17) if Class A or B recycled water is used. The following buffer distances (boundary of the irrigation area to the nearest sensitive development areas such as residential areas, public parks, schools and shops) are suggested for spray irrigation applications:

- Class A recycled water quality – no buffer distances are prescribed due to the high microbiological water quality. However, irrigation should ensure no spray drift or water movement off-site to avoid nuisance and environmental impacts to waterways.
- Class B recycled water quality – at least 50 metres from the edge of the wetted area to the nearest sensitive development.
- Class C and D recycled water quality – at least 100 metres from the edge of the wetted area to the nearest sensitive development.

These buffer distances may need to be increased if high pressure spraying is conducted. The buffer distances may be reduced if suggested best practice measures are implemented to reduce spray drift. These measures may include one or a number of the following, dependent upon the sensitivities of the area:

- Tree screens
- Anemometer switching systems
- Restricted times of watering
- Irrigation systems that prevent the generation of fine mist, such as low rise sprinklers, small throw or micro sprinklers, and part circle sprinklers.

Other measures may be approved if you can demonstrate that they significantly reduce the risk to public health and amenity associated with spray drift.

5.3.3 Irrigation methods and maintenance

5.3.3.1 Irrigation times

Irrigation at night or the use of a time buffer (no access after irrigation, until dry (1–4 hours)) between the end of irrigating and public access may be required depending on the Class of the recycled water. Buffer requirements are outlined in many state and national guidelines for lower classes of recycled water (i.e. Class B,C,D).

5.3.3.2 Irrigation systems

The method of irrigation should be considered as one tool to minimise human exposure to recycled water, while meeting irrigation requirements. For water not fit for direct human exposure, drip irrigation can lower the health risks, compared with sprinkler irrigation, as there is very little risk of human exposure. However, the irrigation systems selected should consider all site conditions and irrigation requirements. In Australia, greater than 75% of vineyard plantings are irrigated with drip irrigation systems (Rawnsley 2008).

Other options could include spray drift control through low-throw sprinklers (180° inward throw), buffer zones of 10 – 15 metres, vegetation screening, drip irrigation near boundaries (surface or subsurface) or automatic switches stopping irrigation if wind speeds exceed trigger levels (NRMMC and EPHC 2006).

5.3.4 Odour control

If odour is a concern, human exposure to odours can be minimised on-site by:

- Flushing irrigation lines/pipes with a non-recycled water source after each irrigation
- Irrigating at night when public are generally indoors
- Install and maintain adequate buffers between the irrigation area and the boundary of the property to help diffuse and dilute odours.

Odour may not pose any health risk but can lead to negative perceptions regarding recycled water; - if it smells bad it must be bad.

5.4 Consumer health

5.4.1 Pathogens

The major control measures for managing risk posed by pathogens in recycled water to consumers, from the use of recycled water to irrigate grapes are:

- Treatment to a level fit for the purpose
- Restrictions on irrigation systems used
- Processing required after harvesting (a kill step).

Recycled water can also be used in the viticultural operation for washing down equipment or storage containers, if treated to the appropriate level. As a general rule, anything that is involved with food

processing or manufacturing must use potable water. Therefore, if the recycled water has not been treated to fit for drinking it should not be used in the processing or manufacturing.

Recycled water can be treated to a level where it is fit for washing field equipment, but not fit for drinking. In these cases, if recycled water not fit for drinking is being used then appropriate OHS protocols should be implemented (Section 5.2.1) to minimising exposure to workers and the general public visiting the farming operation.

Several research groups have completed research to indicate the safety of food (including wine) production with recycled water (Kelly and Stevens 2002; Sheikh *et al.* 1999; Smith 1985; Mendoza-Espinosa *et al.* 2008). This research is supportive of the AGWR (NRMMC and EPHC 2006) and confirms the water recycled from STPs can be treated to a level where there is no detectable contamination of human pathogens. In fact, some research indicated that other sources of water or the place of sale can potentially increase the indicators of contamination (Kelly and Stevens 2002).

5.4.2 Pathogens in the environment

By minimising exposure of principal pathogens of concern that can be found in sewage effluent, pathogen risks are minimised to acceptable levels for the specific use of the recycled water. These organisms and other pathogens can cause infection or disease if humans and animals are exposed to sufficient levels of the organisms or pathogens. The levels, called infectious doses, vary for each pathogen and each host.

One concern is the potential effect of some human pathogens on animals. Enteric viruses can cross species lines, and animal life, particularly warm blooded animals, can be affected if they are exposed to some of the pathogens found in sewage sludge. Domestic animals are usually protected by high levels of treatment or site restrictions which limit grazing (limiting ingestion of soil or plant material until pathogen levels have decreased to acceptable levels).

The soil environment is generally hostile to pathogens through light (intensity and duration) desiccation, temperature and pH. Soil organic matter and clay content affect pathogen retention in soils, with most pathogens generally retained in the top 15 cm of the soil. There is comprehensive data that indicate that bacteria and viruses do not survive in soils for extensive periods (Epstein 2002).

When recycled water is applied to the surface of soils or plants, survival of pathogens is limited due to exposure to sunlight, ultraviolet light and desiccation (Epstein 2002; Table 18).

Table 18 Survival times (days) of pathogen in soil and plants

	Soil		Plants	
Pathogen	**Absolute maximum**	**Common maximum**	**Absolute maximum**	**Common maximum**
Bacteria	365	60	180	30
Virus	180	90	60	30
Protozoa	10	2	5	2
Helminths worms	2500	730	150	30

Source WEAO 2001

These survival times (Table 18) are influenced by the difference in environmental compartments (Table 19). The soil and plant surface provide a harsh environment for persistence of pathogens. Oron (2001) also highlighted the harsh environment of the soil can lead to decreases in pathogens present in recycled water when irrigating vines with surface and subsurface drip (Oron *et al.* 2001).

It is important to note the large differences between the soil environment, compared with the aquatic (water) environment, and the effect the receiving environment has on the specific hazards (Overcash *et al.* 2005). These extremes are highlighted in Table 19; with the plant likely to be similar to the aquatic environment regarding microbial populations.

Table 19 Contrast in aquatic and terrestrial environments

Parameter	Aquatic environment	Terrestrial environment
Organic carbon content	4 mg C/L	40 000 mg C/kg soil
Microbial populations	$1x10^7$ cells /L, with eutrophication effects if population dramatically increases	$1x10^{12}$ cells /L, little effect if population dramatically increases
Residence time	1 to 20 d	Years to decades
Significant pathways	- Microbial decomposition - Abiotic reactions - Photolysis - Small to moderate sorption - Moderate to low oxygen transfer to the liquid phase	- Microbial decomposition - Abiotic reactions - Phytoremediation - Substantial sorption - Highly buffered - High oxygen transfer to the soil gas phase

Adapted from Overcash *et al.* 2005

5.4.3 Chemical risks to human health

From a human health perspective, chemicals in recycled water are not usually considered a significant risk unless the recycled water is to be treated to a level fit for the purpose of drinking (NRMMC and EPHC 2006; 2008). However, there may be additional implications from a contamination of product perspective (See Section 6.9).

5.5 Knowledge gaps and future issues

The extensive research and on-the-ground experience into management of human pathogens in water recycled from STP effluent discussed above indicated that the appropriate exclusion or restriction measures can manage the health risks posed by pathogens to the viticultural sector. Therefore, no knowledge gaps have been identified. It is important for all users of recycled water in the viticultural sector to understand, adopt and practice using recycled water in ways that comply with the appropriate guidance and recommendations.

6 ENVIRONMENTAL RISKS WHEN USING RECYCLED WATER IN VITICULTURE

6.1 General

The environmental (including agronomic) risks from using recycled water are usually chemically based. If the water is treated to protect human health, any pathogen present in the water will have limited impact on the environment (NRMMC and EPHC 2006). This is reasonable for human pathogens, however, little is known of plant pathogens in sewage and reductions of these in the STP (Section 6.10).

A number of studies have indicated that the use of recycled water has increased beneficial microbial activity and increased cycling and/or availability of nutrients to plants (Meli *et al.* 2002; Rawnsley 2008). Meli *et al.* (2002) showed an increase in quantity of easily available nutrients, with an improvement of the metabolic efficiency of soil microflora coupled with a more marked activity of total hydrolase and phosphatases. Rawnsley (2008) found that the use of recycled water improved microbial activity and may improve nutrient transformation in the soil.

Root stock can also have an impact on nutrient uptake (N, P, K and B) and balance when irrigating with recycled water (Angelakis *et al.* 2006; Csikasz-Krizsics and Diofasi 2007). These observations suggest that recycled water may be beneficial for microbial populations in soils.

Some commonly measured hazards in sewage water are listed below (Table 20) as indications of concentrations that can be found in water recycled from STPs in Australia. On review of the literature, it was found that several of the key hazards identified in national guidelines were relative to the viticultural sector. These are discussed in detail in the following sections.

Additional information for potassium (K) was source as K concentrations were not included in the AGWR (NRMMC and EPHC 2006). These data highlight the high variability of K in some recycled water (Table 21).

6.2 Nutrients

There are three nutritional elements that are of particular interest with respect to the irrigation of grapevines with recycled water:

- Nitrogen (N);
- Phosphorus (P); and
- Potassium (K).

A range of other micro and macro nutrients are found in recycled water (Table 20). However, these are generally not found in concentration where excesses will lead to impacts on plants or the environment (other than other hazard discussed in review).

Grapevine nutritional requirements need to be met by integrating N, P and K applied in the recycled water with the vineyards fertiliser program to ensure vines and fruit quality remains well within

acceptable limits of growth and quality. These three major nutrients are discussed in this section from a grapevine production and quality perspective.

Table 20 Chemical constituents of sewage that could be used as a source of recycled water

Hazard	Symbol	Units	From reported median			
			Average	n	Minimum	Maximum
Total nitrogen	Ntot	mg/L	15.2	40	2.8	39.0
Ammonium	NH4	mg/L	8.4	11	0.1	34.0
Total phosphorus	Ptot	mg/L	5.9	40	0.0	12.0
pH		pH	7.9	31	6.2	9.8
Total dissolved salts	TDS	mg/L	675	25	145	1224
Electrical conductivity	EC	dS/m	1.3	15	0.2	2.9
Sodium adsorption ratio	SAR	$(mmolc/L)^{0.5}$	6	15	3	12.2
Sodium	Na	mg/L	181	12	62.0	312.0
Calcium	Ca	mg/L	35	13	10	74.0
Magnesium	Mg	mg/L	19	13	6	40.0
Potassium[A]	K	mg/L	50	2	22	62
Chloride	Cl	mg/L	135	10	9.3	340.0
Aluminium	Al	µg/L	227	10	11.0	665.0
Arsenic	As	µg/L	1.9	7	0.0	4.0
Barium	Ba	µg/L	9.7	5	1.0	37.5
Boron	B	µg/L	289	9	90	480
Cadmium	Cd	µg/L	0.3	8	0.1	0.5
Chromium	Cr	µg/L	9.4	9	1.0	21.0
Cobalt	Co	µg/L	0.7	5	0.4	1.3
Copper	Cu	µg/L	23.5	15	2.0	91.0
Cyanide	CN	µg/L	<1.0	4		
Iron	Fe	µg/L	722	11	30	4725
Lead	Pb	µg/L	5.4	10	1.0	20
Manganese	Mn	µg/L	35.2	7	19.0	69
Mercury	Hg	µg/L	0.1	6	0.1	0.2
Molybdenum	Mo	µg/L	9.8	5	1.0	21
Nickel	Ni	µg/L	7.0	14	2.0	20
Silver	Ag	µg/L	2.6	2	0.1	5.0
Zinc	Zn	µg/L	48	16	4.9	110
Selected organics						
Anionic surfactants		µg/L	200	2	200	200
Phenol		µg/L	4.6	2	0.5	7

n = number of sites sampled for a particular parameter
Note: Possible recycled water sources surveyed from 40 sewage treatment plants across Australia
[A]Potassium data is from water recycled from the Bolivar STP, SA for the year 2000 and Paranychianakis *et al.* 2006. Potassium is not generally reported.
Source: Adapted from NRMMC and EPHC 2006

Table 21 Potassium concentrations (mg/L) in recycled water from a variety of sources

Location	Min.	Median	Average	Max.	Count	Reference
Australia						
Bolivar 2003/04	36	44	43	49	12	SA Water
Eastern Irrigation Scheme	15	22		54	10	www.topag.com.au
NSW	5.6	22		29.4	5	Confidential
Vic.		95			1	Confidential
Averages Australia	**19**	**46**	**43**	**44**		

International						
San Diego, USA		14				WRF 2007
San Diego, USA		17				WRF 2007
Los Angeles, USA		17				WRF 2007
Monterey, USA		15				WRF 2007
Greece	22		31	37		Paranychianakis *et al.* 2006
Averages international	**22**	**16**	**31**	**37**		

It should be noted that N and P are also potentially hazards off-site in aquatic environments where they can cause eutrophication of water ways or contamination of ground water (ANZECC and ARMCANZ 2000b; NRMMC and EPHC 2006). However, if nutrients are not supplied in excess and good environmental management systems are used then N and P movement off-site can be managed and several documents have already providing this information so it is not necessary to discuss further in this review (ANZECC and ARMCANZ 2000b; Nind and Taylor 2002 (Reviewed 2007); NRMMC and EPHC 2006).

6.2.1 Nitrogen

The importance of interactions between water and nitrogen (N) in crop production has been well studied (Pier and Doerge 1995) and are not unique to irrigation with recycled water. When irrigating with recycled water, matching water and N supply can be complicated as growers lose some control over the timing of fertiliser application (Baier and Fryer 1973) because of the N in recycled water (Table 20 and Table 22). If periods of peak crop water demand do not match peak N demand then N supply may be in excess of crop requirements. This may cause produce quality or yield decline, depending on the crop being grown or environmental problems off-site (Unkovich *et al.* 2004). These problems are complicated and need to be addressed on a site by site basis, as nitrogen is probably the most variable component of recycled water (Westcot and Ayers 1984; Asano *et al.* 2007; NRMMC and EPHC 2006).

Table 22 Nutrients applied in irrigated recycled water

Irrigation Applied		Nitrogen			Phosphorus			Potassium			
		Min.	Mean	Max.	Min.	Mean.	Max.	Min.	Mean	Max.	Recycled water
(ML/ha)	mm	2.8	15.2	39	0	5.9	12	22	50	62	mg/L
1.0	100	2.8	15	39	0	5.9	12	22	50	62	Nutrient applied in kg/ha
1.5	150	4.2	23	58	0	8.9	18	33	75	93	
2.0	200	5.6	30	78	0	11.8	24	44	100	124	
2.5	250	7.0	38	97	0	14.8	30	55	125	155	
3.0	300	8.4	46	117	0	17.7	36	66	150	186	
3.5	350	9.8	53	136	0	20.7	42	77	175	217	
4.0	400	11.2	61	156	0	23.6	48	88	200	248	
4.5	450	12.6	68	175	0	26.6	54	99	225	279	
5.0	500	14.0	76	195	0	29.5	60	110	250	310	

By comparing nutrients applied with recycled water at various irrigation rates (Table 22) with nutrient removed (Table 23 and Table 24) an indication of nutrient balance is possible. Note that nutrient removed varies considerable on the type, location and how the grapes have been grown (Appendix

10). For example, excess N is applied relative to removal in harvest depending on the irrigation rate and nitrogen concentration of the recycled water (Table 25).

Depending on the recycled water quality (Table 22), there is potential for oversupply of nitrogen when irrigating vineyards with recycled water. For example, when irrigating with low N concentration of 2.8 mg/L then the nitrogen applied only exceeds the nitrogen removed for crop yields of 5 t/ha when the irrigation rate exceeds 3 ML/ha (orange cells). In reality application rates that exceed nutrient removal by between 0 and say 30% would not be considered excessive due to normal losses due to leaching, immobilisation and volatilisation.

Considering further nitrogen losses from storage, volatilisation and denitrification, typically losses of 20 - 25% can be lost during storage and irrigation (Asano *et al.* 2007). There are other losses as discussed above, considering the loss of nitrogen through leaching, to maintaining soil properties and sustainable leaching fractions of 15% typically need to be required. Assuming that leaching of nitrogen is equivalent to the leaching fraction and considering storage and leaching losses then approximately 36% of nitrogen could be lost. This would have a significant impact on the nitrogen balance between the recycled water and vines (Table 26).

Table 23 Nutrient removal per ha of grapes harvested

Origin	Crop Yield	Fruit Moisture	Mean Nutrient Removal (kg/t FW)						Source
	t/ha fw	%	N	P	K	S	Ca	Mg	
Aust	20		1.6	0.55	2.25				1
Aust*		81	1.12	0.19	1.94		0.18		2
Aust*		79	1.60		1.80		0.10	0.09	3
Vic	25-35		1.02	0.26	3.10	0.11	0.46	0.14	4
WA	20		1.90	0.4					5
		Average	1.4	0.4	2.3	0.1	0.2	0.1	

Source
1. J. Glendinning (pers. comm.)
2. Thomas and Corden (1977) EP=95%
3. Wills (1987) EP=98%
4. B.P. Holzapfel & M.T. Treeby (pers. comm) Shiraz grapes
5. McPharlin (pers. comm)

Table 24 Nutrient removal per harvest depending on total yield

Yield (t/ha fw)	N	P	K	S	Ca	Mg
	Nutrient removed kg/ha					
5	7.2	1.8	11.4	0.6	1.2	0.6
10	14.5	3.5	22.7	1.1	2.5	1.2
15	21.7	5.3	34.1	1.7	3.7	1.7
20	29.0	7.0	45.5	2.2	4.9	2.3
25	36.2	8.8	56.8	2.8	6.2	2.9
30	43.4	10.5	68.2	3.3	7.4	3.5
35	50.7	12.3	79.5	3.9	8.6	4.0

Source: Nutrient removal information from Incitec Pivot by Doug Reuter (Note: does not consider nutrients removed in pruning).

Table 25 **Highlights imbalances in nitrogen removal for different irrigation rates, concentration of nitrogen in recycled water and crop removal rates.**

				Yield per hectare						
				5 t	10 t	15 t	20 t	25 t	30 t	35 t
				Nitrogen removed kg/ha						
Irrigation	Nutrient applied (kg/ha)			7.2	14.5	21.7	29.0	36.2	43.4	50.7
ML/ha	Min	Mean	Max	N applied > N removed (Excess N)						
1	2.8	15.2	39.0							
1.5	4.2	22.8	58.5							
2	5.6	30.4	78.0							
2.5	7.0	38.0	97.5							
3	8.4	45.6	117.0							
3.5	9.8	53.2	136.5							
4	11.2	60.8	156.0							
4.5	12.6	68.4	175.5							
5	14.0	76.0	195.0							

Maximum nutrient applied with recycled water is less than nutrient removed for a certain yield (insufficient)
Maximum nutrient likely to be applied with recycled water exceeds nutrient removed for a certain yield
Mean nutrient likely to be applied with recycled water exceeds nutrient removed for a certain yield
Minimum nutrient likely to be applied with recycled water exceeds nutrient removed for a certain yield

Table 26 **Imbalances in nitrogen removal for different irrigation rates, concentration of nitrogen in recycled water and crop removal rates (64% nitrogen use efficiency).**

				Yield per hectare						
				5 t	10 t	15 t	20 t	25 t	30 t	35 t
				Nitrogen removed kg/ha						
Irrigation	Nutrient applied (kg/ha)[A]			7.2	14.5	21.7	29.0	36.2	43.4	50.7
ML/ha	Min	Mean	Max	N applied > N removed (Excess N)						
1	1.8	9.7	25.0							
1.5	2.7	14.6	37.4							
2	3.6	19.5	49.9							
2.5	4.5	24.3	62.4							
3	5.4	29.2	74.9							
3.5	6.3	34.0	87.4							
4	7.2	38.9	99.8							
4.5	8.1	43.8	112.3							
5	9.0	48.6	124.8							

Maximum nutrient applied with recycled water is less than nutrient removed for a certain yeild (insufficient)
Maximum nutrient likely to be applied with recycled water exceeds nutrient removed for a certain yeild
Mean nutrient likely to be applied with recycled water exceeds nutrient removed for a certain yeild
Minimum nutrient likely to be applied with recycled water exceeds nutrient removed for a certain yeild

[A] 64% of nutrient applied in Table 25.

Some impacts from excess nitrogen application that could be relevant to viticulture include:

- N, P and K can reduce fruit firmness (Sams 1999)

- Yield reduction following excessive N application (Baier and Fryer 1973)
- The date of maturation of crops may change (but not yield), or fruit size can decrease (e.g. peaches) (Unkovich *et al.* 2004)
- Excessive vegetative growth, reduced yield, delayed maturity and impairment of juice quality (Paranychianakis *et al.* 2006).

Grape varieties respond differently to excess N. For example, Malbec is very sensitive and Pinot Noir one of the least sensitive. The principal problem for grapevines is caused by pre-flower bud shatter when tissue nitrate-N reaches 1%. Problems may persist for more than one year if cane wood quality declines and impacts on next year's growth and yield. Grapes can also accumulate phytotoxic levels of NO_3^- (Unkovich *et al.* 2004). The nitrogen balance is very dependent on irrigation rates and recycled water N concentration. For example, in many cases discussed above excess N would be applied if the average N concentration and 20t/ha fw grape production (Table 25) is assumed. However, others have questioned if sufficient N is applied (McCarthy 2007).

Where N applied in the irrigation water exceeds the demand of annual crops, perennial crops can be grown as a management tool as these may have higher capacity for N uptake (Pettygrove *et al.* 1985).

The above provides an example of the affects from over-fertilisation with N, whether recycled water or any water source that contains 'elevated' concentrations of nitrogen. In studies with vines that were trickle irrigated with recycled water or well water (Neilsen *et al.* 1989a), yields of recycled water irrigated vines were higher than well watered irrigated vines, despite application of >34 g N/vine/yr for vines irrigated with well water. Neilsen et al. 1989a concluded that the additional P and K applied in the recycled water contributed to the increased yield. Although this obviously reflects poor crop nutrition rather than beneficial effects of the recycled water *per se*, it does serve to illustrate the economic value of the contributions to crop production afforded by recycled water. These authors found similar results to parallel studies on apples (Neilsen *et al.* 1989b) and cherries (Neilsen *et al.* 1989c).

The important point from the findings above is understanding grapevine nitrogen requirements. These requirements need to be met by integrating nitrogen and potential other nutrients applied in the recycled water with the vineyards fertiliser program to ensure vines and fruit quality remain well within acceptable limits of growth and quality.

6.2.2 Phosphorus

Phosphorus (P) is an important element in Australian agriculture due to the age of Australian soils, which are generally highly leached and hence low in plant available phosphorus, highlighted in Figure 10. Chvyl and Maier (2006a) highlight that in soils with low P levels, less than 25-30 mg/kg Cowell P, that a banded P (SSP) application of between 0.5 to 1.0 t/ha is recommended. These application rates supply 44 - 88 kg/ha of elemental P based on SSP phosphorus concentration of 8.8% (Incitec Pivot). The application of phosphorus fertilisers, is therefore essential for productive vineyards.

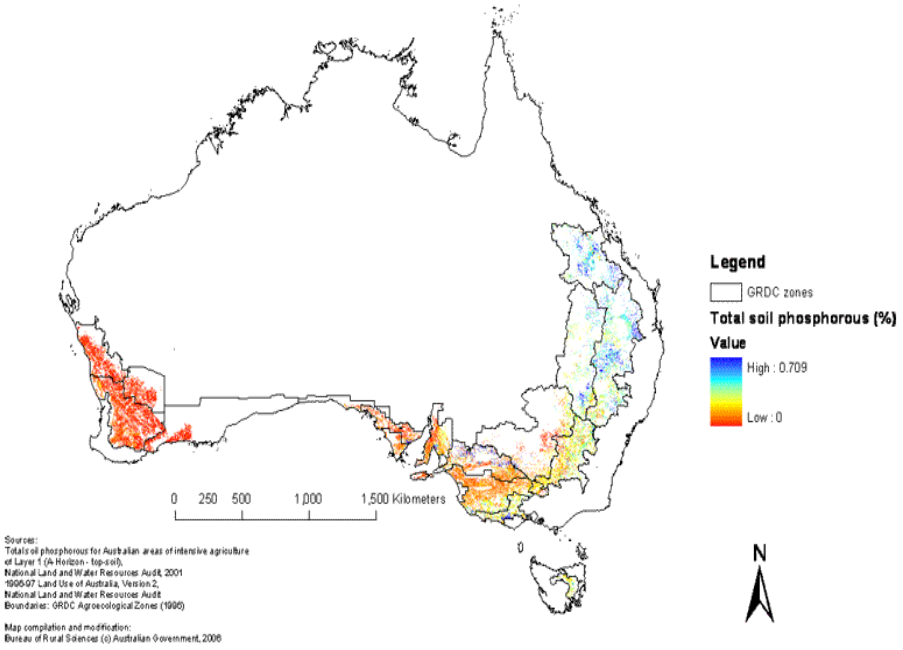


Figure 10 Total soil phosphorous (%) in land under cropping in the Grains Research Development Corporation (GRDC) zones

Phosphorus deficiency in vines can have significant effect on crops before visible symptoms can be observed (Hidden hunger). Phosphate deficiency can significantly reduce berry size and weight, delay in fruit maturity, reduce bunches per vine and bunch weight (Singh 2006).

The phosphorus removal per ha for a range of wine grape crop yields can range from 1.8 – 12.3 kg per hectare for crop yields of 5 – 30 t/ha respectively (Table 24). Similar to nitrogen, recycled irrigation water can apply significantly more phosphorus than is required (Table 27).

Phosphorus is the most chemically reactive nutrient element and readily reacts with chemical groupings on the surfaces of soil particles. This makes P a relatively inaccessible, unavailable and immobile nutrient element. It also means that the P concentration in the soil solution is very low. The extent of these reactions depends on the P sorption, or P buffering capacity (PBC) of the soil. Australian soils have a wide range of PBC values, and this soil property has important implications for management from a productivity and environmental viewpoint.

Plant roots have to grow into the soil matrix, reducing the P concentration in the soil solution in the immediate vicinity of the root surface. This results in the depletion and the subsequent diffusion of P from the soil surfaces into that solution volume. Increased phosphorus efficiency has been demonstrated by Sakadevan *et al.* (2000) in pasture and increased leaf P concentration in vines (Paranychianakis *et al.* 2006). The authors even suggest that fertiliser P could be eliminated under recycled water irrigation.

Phosphorus availability in soil is controlled by mineralisation, immobilisation and fixation processes where mineral P is converted into organic forms and visa versa Figure 11. Sakadevan *et al.* (2002) showed that there was an increase in dry matter production and P removal in pasture under recycled water irrigation and less P leaching than with SSP application.

It is unlikely that over-fertilisation with P will occur from irrigation of recycled water, since most of the P will be immobilised in the soil and not be readily available to plants (Ryden and Pratt 1980).

Table 27 Imbalances in phosphorus removal for different irrigation rates, concentration of phosphorus in recycled water and crop removal rates.

				Yield per hectare						
				5 t	10 t	15 t	20 t	25 t	30 t	35 t
				Phosphorus removed kg/ha						
Irrigation ML/ha	Nutrient applied (kg/ha)			1.8	3.5	5.3	7.0	8.8	10.5	12.3
	Min	Mean	Max	P applied > P removed (Excess N)						
1	0.0	5.9	12.0							
1.5	0.0	8.9	18.0							
2	0.0	11.8	24.0							
2.5	0.0	14.8	30.0							
3	0.0	17.7	36.0							
3.5	0.0	20.7	42.0							
4	0.0	23.6	48.0							
4.5	0.0	26.6	54.0							
5	0.0	29.5	60.0							

Maximum nutrient applied with recycled water is less than nutrient removed for a certain yield (insufficient)

Maximum nutrient likely to be applied with recycled water exceeds nutrient removed for a certain yield

Mean nutrient likely to be applied with recycled water exceeds nutrient removed for a certain yield

Minimum nutrient likely to be applied with recycled water exceeds nutrient removed for a certain yield



Figure 11 Reactions of soil phosphorus showing the processes of mineralisation and immobilisation

6.2.3 Potassium

Potassium (K) is a nutrient required in relatively large quantities in plants. Potassium is required for a number of functions in vines including: enzymes essential for photosynthesis, respiration, starch and protein production and osmotic pressure and cell turgor (Singh 2006). Potassium is one of the most abundant elements in soils, present as a structural component in clay lattices and as a cation on the exchange complex.

Most Australian soils naturally contain adequate levels of potassium, but potassium deficiencies have been reported in many regions of Australia. These are most commonly in the southern coastal regions of Victoria and South Australia, the southwest of Western Australia, throughout most of Tasmania, and in the eastern regions of New South Wales and Queensland.

Concerns with heavy applications of potassium and its effect on grape juice and hence on red wine quality, high juice pH, reduced colour and flavour have been identified (Chvyl and Maier 2006b;

Mpelasoka *et al.* 2003). However, high levels of potassium are specified, and potassium fertiliser should only be applied where tissue analysis indicates marginal or significant deficiencies for potassium. Singh (2006) supports that high potassium reduces wine pH and quality and others have linked soil chemistry with wine grape quality (Mackenzie and Christy 2005).

Singh (2006) highlights nutrient interactions in the presence of increased K application, elements including calcium (Ca), magnesium (Mg), and nitrogen (N). Moderate K concentrations can also increase Ca uptake, suggesting that K determines the interaction between K and Ca (Singh 2006).

Recycled water contains significant concentrations of potassium (Table 20). Note these concentrations are from two recycled water sites (23 samples across the year from one and an average from another), as K in recycled water is not often reported. Additional data sourced from Australian and International recycled water schemes, indicated that the K concentration in Australian recycled water is highly variable and requires further investigation (Table 21) to confirm the extent of this variability.

Winery wastewater is also known for its high potassium (Chapman 1999). Table 28 indicates the potential for significant potassium imbalance between the potassium applied and the potassium removed by grape harvest (i.e. minimum to mean concentration of K in recycled water apply excess K for most irrigation rates). This K imbalance could lead to a decline in grape and wine quality over time. However, as K is not generally considered to be an environmental pollutant the level of research into the effect of over supply has been less than for elements like N and P.

The observations above indicate that potassium supplied with recycled water and the effects on grape/wine quality are a gap in current knowledge for the viticultural sector. The identification of critical petiole nutrient concentrations needs to be understood and any changes in grape/wine quality from insufficient or excess K quantified.

Table 28 Imbalances in potassium removal for different irrigation rates, concentrations of potassium in recycled water and crop removal rates.

				Yield per hectare						
				5 t	10 t	15 t	20 t	25 t	30 t	35 t
				Phosphorus removed kg/ha						
Irrigation	Nutrient applied (kg/ha)			11.4	22.7	34.1	45.5	56.8	68.2	79.5
ML/ha	Min	Mean	Max	K applied > K removed (Excess N)						
1	22	50	62							
1.5	33	75	93							
2	44	100	124							
2.5	55	125	155							
3	66	150	186							
3.5	77	175	217							
4	88	200	248							
4.5	99	225	279							
5	110	250	310							

Maximum nutrient applied with recycled water is less than nutrient removed for a certain yield (insufficient)

Maximum nutrient likely to be applied with recycled water exceeds nutrient removed for a certain yield

Mean nutrient likely to be applied with recycled water exceeds nutrient removed for a certain yield

Minimum nutrient likely to be applied with recycled water exceeds nutrient removed for a certain yield

Excess potassium build up in soils can also contribute to soil sodicity (Section 6.4.2), leading to soil structural decline (Bond and Smith 2006).

6.2.4 Knowledge gaps and future issues

In general recycled water can provide an excellent nutrient source for food crop production that can reduce fertiliser costs, provided that careful attention is paid to nutrient budgeting. There is *no* evidence to suggest that recycled water irrigated crops, managed appropriately, produce berry or wine of lower quality than crops irrigated with other waters (Unkovich *et al.* 2004;Mendoza-Espinosa *et al.* 2008;Paranychianakis *et al.* 2006). In fact the world's best Shiraz in 2008[11] was grown with recycled water, indicating the contrary (Section 7.6).

However, knowledge for management of nitrogen and phosphorus are more advanced than potassium and potassium may pose the greatest risk to grape/wine quality. Potassium concentration in recycled water is often not reported (Table 20; NRMMC and EPHC 2006) and difficult to find (Table 21). Future research should first establish that the K ranges in recycled water across Australia and identify locations where K in recycled water poses risks to viticulture.

If significant potassium concentrations of recycled water are found across Australia, then potassium supplied with recycled water and the effects on grape/wine quality are relevant gaps in current knowledge. The identification of critical petiole nutrient concentrations needs to be understood and any changes in grape/wine quality from insufficient or excess K quantified. If identifiable, areas where recycled water with high K concentration has irrigated vines should also be investigated.

Environmental risks associated with N and P from recycled water should be manageable through best practice fertiliser management, incorporated nutrients applied with recycled water into any fertilisation program. Environmental improvement programs required for the use of recycled water should ensure excessive nutrients are not applied during irrigation of vines.

6.3 Salinity

Salinity is potentially the greatest impediment to plant growth in Australia. Soil and water salinity can be measured as total dissolved salts (TDS; unit = mg/L) or electrical conductivity (EC; unit dS/m or multiply by 1000 for µS/cm). Salinity tolerance of plant species and variety vary considerably. Some salt tolerant plants can tolerate water or soil salinity greater than an electrical conductivity of 16 dS/m, while salt sensitive plants can only tolerate 0.65 dS/m (Table 29). Grapevine can tolerate 0.8 to 8 dS/m depending on rootstock, variety, application method and soil type (NRMMC and EPHC 2006). They would therefore be considered moderately sensitive to tolerant.

Table 29 Irrigation water salinity ratings

ECi (dS/m)	TDS (mg/L)	Plant salt tolerance groupings	Water salinity rating
<0.65	<415	Sensitive plants	Very low
0.65 – 1.3	415 – 830	Moderately sensitive plants	Low
1.3 – 2.9	830 – 1,860	Moderately tolerant plants	Medium
2.9 – 5.2	1,860 – 4,160	Tolerant plants	High
5.2 – 8.1	4,160 – 6,480	Very tolerant plants	Very high
>8.1	> 6,480	Generally too saline	Extreme

Source: ANZECC and ARMCANZ 2000b
ECi = electrical conductivity of the irrigation water; TDS = total dissolved salts

[11] www.syrah-du-monde.com/pages/20_result/index.en.html

Some soils can be quite saline (ECe (soil saturation paste extract salinity) up to 19 dS/m) due to a combination of naturally occurring conditions and the accumulation of salt. High salinity means that plants will not grow as well and have an undesired appearance. Soil salinity can change over time due to the salinity of irrigation water, irrigation practices and agronomic mismanagement (e.g. excessive use of saline fertilisers or manures). Soil testing should therefore be undertaken regularly and irrigation practices altered accordingly.

The interaction between irrigation water and soil salinity needs to be managed to ensure the ongoing sustainability of any irrigation scheme, as recycled water is usually more saline (Table 20) than the source water for a particular region (i.e. salts are added through the sewage system). Plant sensitivity to salinity should be factored into the site's soils and recycled water quality that it will be irrigated with (Table 29).

Salinity can negatively affect plants in four ways:

1. Reduced ability to extract water from saline soil (Section 6.3.1);
2. Indirect effects of salts on nutrient uptake and balance (Section 6.3.2);
3. Direct toxicity of individual salts on plants (Section 6.4); and
4. Negative impacts on soil structure through effects of sodicity (Section 6.4.2).

In practice, these effects are often hard to distinguish from other causes because of variations in response according to plant species, cultivars and root stocks, plant growth stage, types and ratios of salts, duration of exposure and environmental conditions.

The assessment of salinity on soils and vine growth has been studied extensively around the world (Grant *et al.* 2004; Jayawardane *et al.* 2001; Paranychianakis and Angelakis 2008; QDNR 1997; Rhoades *et al.* 1999; Rhoades *et al.* 1992;Cass *et al.* 1995; Fitzpatrick *et al.* 1992; Garcia and Charbaji 1993; Hermon *et al.* 2004a; Maher *et al.* 2004a; Paranychianakis *et al.* 2004; Paranychianakis and Angelakis 2008; Stevens 1993; Stevens and Walker 2002; Walker *et al.* 2002).

This section discusses salinity specifically (1 and 2 above); direct effects of sodium and chloride (3 and 4 above) are discussed separately in Sections 6.4.

6.3.1 Ability to extract water

Plants vary considerably in their susceptibility to the osmotic and toxicity effects from salinity (NRMMC and EPHC 2006). As soils dry out, the salinity of the remaining soil water tends to increase, and so the effects become more severe. Plants affected by salinity have a reduced growth rate and show signs of water stress (e.g. wilting). Leaves may suffer burning along the margins due to the combined effects of salinity, chloride and sodium toxicity (Section 6.4). Perennial plants (e.g. grapevines) tend to be more sensitive than annuals, possibly because they accumulate salts over a much longer period of time than do short-lived annual plants.

6.3.2 Nutrient uptake and balance

There is some data indicating that K can replace Na in the function of some plants, with detrimental impacts (Marschner 1995). There seems to be little data on the nutrient imbalance from excess salinity, suggesting this is not a major contributor to grapevine stress.

6.3.3 Management of salinity

6.3.3.1 Reduce salt input

It is difficult to avoid adding salt to soils through irrigation as all water contains some salts. However, using irrigation water with low salinity will add less salt (Table 30). Salinity of irrigation water can also be decreased by mixing ("shandying") with water of lower salinity if available. Some salts are essential for plant growth; problems usually arise when they are present far in excess of requirements.

Table 30 Relationship between salinity of irrigation water, application rate and the salt applied per hectare

Irrigation water salinity		Irrigation rate				
EC (dS/m)	TDS (mg/L)	2ML/ha 200 mm	4ML/ha 400mm	6ML/ha 600mm	8ML/ha 800mm	10ML/ha 1000mm
		Salt (t/ha)				
0.65	415	0.8	1.7	2.5	3.3	4.2
1.3	830	1.7	3.3	5.0	6.6	8.3
2.9	1,860	3.7	7.4	11.2	14.9	18.6
5.2	4,160	8.3	16.6	25.0	33.3	41.6
8.1	6,480	13.0	25.9	38.9	51.8	64.8

Note for irrigation rate mm also = L/m^2

Irrigators should also avoid over-irrigation as this may lead to rising water tables. Water tables near 2 m of the surface are likely to cause surface salinisation. The more water applied the more salt applied (Table 30). So the more efficiently the water is used by the plants the less salts applied to the soil. For example, subsurface drip irrigation can minimise water losses through evaporation and deliver water to plant directly, but water applied through sprinkler irrigation can increase losses through evaporation during application (i.e. effective irrigation), leaving the salt behind.

Landscape managers also need to be aware of the salt content of soil amendments. Soluble fertilisers, animal manure and amendments like gypsum and lime contain a high concentration of salts and should only be used in recommended quantities and applied at appropriate times.

6.3.3.2 Leaching salt from the root zone

Salt from any irrigation water accumulates in soil when the water evaporates from the soil and/or is used by plants, leaving behind the salts not required by the plant. This accumulation of salt leads to degradation of soil and also has direct salinity effects on plants. Plants use some salts, but these are usually relatively small amounts compared with salt applied through irrigation with recycled water.

To manage the accumulation of salts in the root zone of plants, a quantity of water called the leaching requirement (LR) is required. The leaching requirement is applied in the form of excess irrigation water, greater than plant requirements; the excess rates of water leaching salts below the root zone of the plant. Irrigation rates above plant and evaporation requirements (evapotranspiration) washes accumulated salts downward. However, frequent light irrigations that just meet evapotranspiration rates are likely to leave salts concentrated in the root zone.

Work with grapevines and saline waters (Stevens *et al.* 1999; Stevens and Walker 2002) has shown that irrigation with non-saline water (rainfall) for 2 months usually returned soil ECe back to the pre-saline irrigation value. Irrigation with fresh or blended water prior to planting is also a useful option since it provides the seedlings, which are more sensitive to salt (Maas 1987), with a less saline

environment during establishment. This would also reduce the requirement for leaching during subsequent crop growth (George *et al.* 1985). Balancing fresh and saline or recycled water irrigation may be a valuable tool for maintaining soil quality under irrigated crops, but this should be practiced with caution as this can lead to increased soil dispersion, especially at the soil surface (causing crusting), as increases in water salinity can decrease soil dispersion (Section 6.3.4).

Recent research has indicated that relatively low salinity (Table 29) was not a concern with recycled water (TDS 807 mg/L) used to irrigated vines (Rawnsley 2008).

6.3.3.3 Method of irrigation

There are several methods of irrigation available in horticultural applications; drip (surface or subsurface), set sprinkler (impact, spray, micro spray), hand held sprinklers or sprays, and in some cases furrow. The majority of vines are irrigated with drip irrigation (75% - Rawnsley 2008) and under canopy microspray.

Drip irrigation allows the use of irrigation water with higher salinity, as evaporation losses (and therefore resulting salt concentrations in the soil) are minimsed. Drip irrigation can also reduce the effects of salinity by:

- Keeping the soil around the plant roots continuously moist;
- Providing steady leaching of salt to the edge of the wetted zone around the plant; and
- Not applying water to plant foliage.

Drip irrigation might apply less salts with less water. However, salt concentration can build up on the outer wetting front of the drip area and should be managed as required (e.g. application of leaching fractions or irrigation during rainfall to help flush the soils from the rootzone).

Sprinkler irrigated plants can suffer extra damage through uptake of salts through the leaves; especially if marginally saline water. Under these circumstances, evaporation should be minimised to reduce accumulation of salt on the leaves by watering at night, early in the morning or late in the evening. Sprinkling should also be avoided under hot and/or windy conditions. Slow revolution impact sprinklers also allow drying periods, with salt accumulation on the leaves, and they should be avoided when using irrigation water with salinity higher than ideal. Table 31 shows general comparisons between the sustainability of different irrigation methods and salinity levels.

Table 31 Water salinity and recycled water irrigation system suitability

	Total dissolved	Suitability[A]		
Salinity	Salts (mg/L)	Drip	Sprinkler	Furrow
Low	<830	High	High	Medium
Moderate	830–1860	High	Medium[B]	Medium
High	>1860	Medium	Low	Low

[A]assuming soils have reasonable drainage, if drainage is very poor, then drip should be used; [B]leaf burn becomes a problem. Source: modified from Christen *et al.* 2006, p120. Note: Clogging of drip irrigation can be a problem if recycled water has excessive concentrations of some components.

6.3.4 Interaction of salinity with sodicity

Saline irrigation water can have a stabilising effect on soil structure. This effect is called the electrolyte effect. Sodic or dispersive soils are likely to be less dispersive when irrigated with saline

water than with rain water. If the sodium adsorption ratio (SAR) of irrigation water is high relative to its EC, soils containing clay are likely to exhibit structural instability (Figure 12).

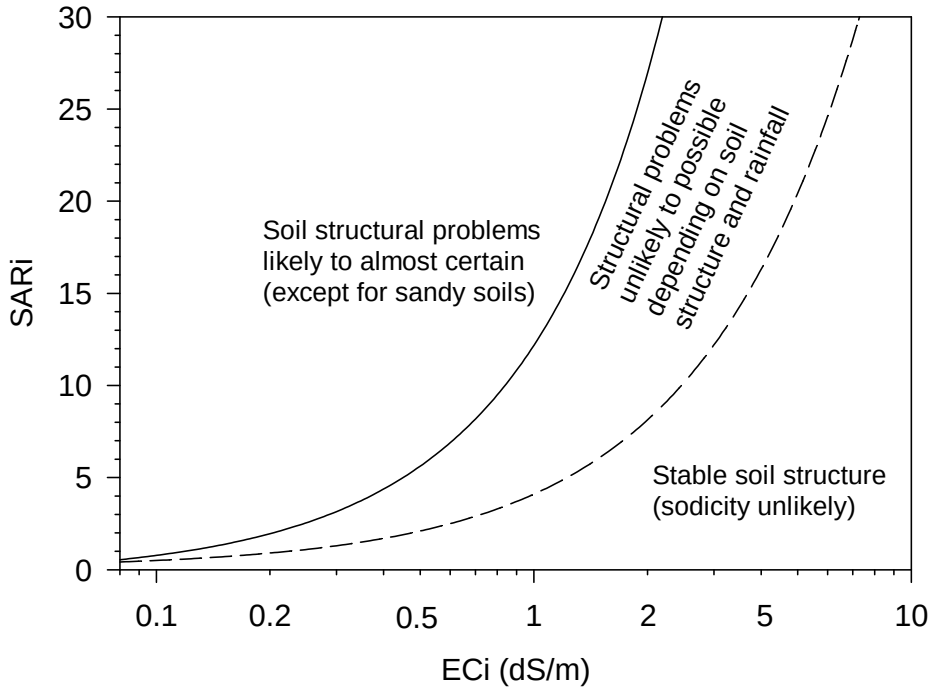


Figure 12 Relationship between sodium adsorption ratio (SARi) or irrigation water and electrical conductivity (ECi) of irrigation water and likelihood of soil structure breakdown (modified from ANZECC and ARMCANZ 2000b)

One of the main concerns with salinity and SAR of irrigation water are their effects on structural stability and hence the hydraulic properties of soil. Good hydraulic properties need to be maintained to enable the appropriate leaching requirement to move salts below the root zone. Good soil structure also aids root development, improving plant health and drought resistances.

Some research in the wine industry has shown winery wastewater (very different in physico-chem properties to water recycled from sewage) has negatively impacted on soil hydraulic property due to sodicity and organic load (Chapman 1999; Kumar and Kookana 2006). In these cases, irrigation water quality would not have been considered fit for irrigation purposes if assessed by the AGWR (NRMMC and EPHC 2006). These observations highlight the limitation to out-farming systems both from an agronomic and environmental perspective. It also highlights that robust guidelines and management strategies are well known and if not complied with detrimental impact can occur.

The effects of soil salinity have been studied extensively across the world for a range of irrigation water sources and quality. Recycled water has no major differences to these water sources regarding salinity, other than it may be more saline than the source water used in the sewage system (which could be lower or higher than irrigation water salinity). Therefore, the extensive research already undertaken is relevant to the viticultural sector and in many cases has been undertaken on vines and the impact of salinity in viticulture.

The findings and management tools developed over decades should be useful in assessing and managing salinity of recycled water in the viticultural industry.

However, the viticultural industry should also be aware of the potential impact of future increases in the salinities of recycled water and the impact this will have on recycled water being fit for the purpose of irrigating vines. Water restrictions are decreasing flows into STPs and increasing salinity due to less dilution by greywater or more water efficient appliances. These salinity increases are being counteracted by tradewaste controls and blocking of salty groundwater ingress into sewers in some sewage systems. If salinity of recycled water increases to unacceptable levels for irrigation of specific grapevines, then further water treatment may be required. These observations highlight the importance of having an agreed salinity threshold for supply of recycled water to the viticultural sector.

An increase in recycled water salinity combined with decreases in rainfall across Australia will increase the challenge of managing root zone salinity in grapevine products. However, if appropriate volumes of recycled water can be applied considering a leaching requirement, the rootzone salinity should be manageable (Ayers and Westcot 1985; FAO Accessed 2005; Rhoades *et al.* 1999; Rhoades *et al.* 1992). If a leaching requirement cannot be applied, the often higher salinity of recycled water may lead to an increase of rootzone salinity. In this case, irrigation methods to manage this salinity may need to be improved or modified to ensure suitable grape production or survival until sufficient water is available to leach salts through the soil. Methods to manage this scenario in the viticultural sector represent a knowledge gap. However, this knowledge gap may be addressed through current research projects (McCarthy 2007; [12] ;Biswas *et al.* 2008; Murray *et al.* 2008).

6.3.5 Knowledge gaps and future issues

Environmental impacts other than plant growth from saline recycled water on and off-site should also be recognised. Excessive leaching can lead to salination of groundwater or surface water nearby and can lead to raised groundwater levels, with obvious environmental and agronomic impacts (e.g. secondary salinity). The future challenges and knowledge gap for grape production will be to manage water of high salinities (with limited water) while minimising environmental impacts. If this is not possible, water treatment will be required which comes at a cost and requires disposal of the waste stream from this process (Section 7.2.1.1)

No other future research is recommended for salinity related to recycled water. However, a scientifically sound management handbook, based on current salinity management would provide grape growers with a useful management tool for development and management of vineyards using recycled water.

6.4 Sodium and chloride

6.4.1 Sodium and chloride toxicity

Sodium is not an essential element; it is a “beneficial mineral nutrient” and is actually beneficial in some plants under certain conditions. Most plant species are natrophobic (“sodium hating”) and have mechanisms to exclude sodium from uptake by the roots. In woody perennial plants, like olives and grapes, the selection of root stock that limits the uptake of sodium forms part of an effective sodium management strategy.

[12] http://npsi.gov.au/national-program-sustainable-irrigation/projects/root-zone-water-salinity-and-nutrient-management-un

Sodium can also be absorbed through the leaves from sprinkled irrigation water. Hence, plants that can exclude sodium at the roots may still suffer damage from leaf-absorption of sodium. Chloride is an essential plant micro-nutrient, all plants need a small amount of chloride in order to function and grow. Chloride is usually readily available to plants, is found in soil and water, and is easily absorbed by roots and leaves. However, high concentrations can lead to chloride toxicity and can also reduce production through imbalances with other nutrients.

Like sodium, high chloride can be damaging to plants through soil uptake and through direct application to leaves as irrigation water. Visible symptoms include leaf burn at the tip of older leaves which progresses back into the leaf blade, premature senescence (seasonal wilting of leaves and flowers), bronzing and defoliation. Most non-woody species are not specifically sensitive to sodium and chloride toxicity, with the exception of many leguminous species (nitrogen fixing species including pasture plants like clovers and medics) and some cultivars of beans and soybeans. Woody plants (e.g. grapes - Table 32) are generally more susceptible to chloride toxicity, depending on species, cultivar and rootstock.

Table 32 Approximate chloride and sodium concentration (mg/L) that can cause foliar injury in plants from saline sprinkling water. Degree of injury is affected by site specific environmental and agricultural conditions.

Chloride			
Sensitive <175	Moderately sensitive 175–350	Moderately tolerant 350–700	Tolerant >700
Sodium			
Sensitive <115	Moderately sensitive 115–230	Moderately tolerant 230–460	Tolerant >460
Almond	Pepper	Barley	Cauliflower
Apricot	Potato	Maize	Cotton
Citrus	Tomato	Cucumber	Sugar Beet
Plum		Lucerne	Sunflower
Grape		Safflower	
		Sesame	
		Sorghum	

Source: ANZECC and ARMCANZ 2000b

Grapevines are similar to citrus with respect to the impact of rootstock on salinity tolerance (or most likely sodium and chloride toxicity) of scions, and thus changing the rootstock can eliminate leaf burn and maintain grape yields (Walker *et al.* 2002). Cass *et al.* (1995) highlighted that most vines in Australia would be suffering substantial yield penalties due to salinity of normal irrigation waters and soils if not grafted onto salt tolerant rootstocks. Table 33 demonstrates the control of Cl^- uptake and Na^+/K^+ balance as a function of grapevine rootstock.

Table 33 Chloride (Cl^-), Na^+ and K^+ content of grapevine petioles and laminae of scions of grapes on "own roots" or grafted onto salt tolerant rootstocks (Atwell *et al.* 1999)

	Ion content (%DM)		
Petioles	Cl-	Na+	K+
Own roots	1.64	0.57	0.74
Rootstock 1	0.29	0.07	3.08
Rootstock 2	0.15	0.09	3.83
Laminae			
Own roots	0.248	0.113	0.69
Rootstock 1	0.039	0.038	0.72
Rootstock 2	0.028	0.036	0.76

Vines that are sprinkler irrigated may be more sensitive to Na^+ and Cl^- than vines not sprinkler irrigated since the salts are readily absorbed by the leaves without the benefit of the salt excluding rootstocks. In this case, Francois and Clark (1979) found that the presence of counter-ions (Ca^{++} or $SO_4^{=}$) did not reduce Na^+ or Cl^- absorption. It has been shown that high sodium, chloride and potassium may reduce (McCarthy and Downton 1981) or increase (Walker *et al.* 2002) wine quality, and that this can be managed to some extent by choice of rootstock (Cass *et al.* 1995; Walker *et al.* 2002).

However, the European Economic Community requires wines to have <1g/L NaCl. In order to maintain wine quality and export markets it is important that the levels of these ions in grapes and wines be kept down (Lee 1990). Thus, for wine grape production from saline irrigation waters, efforts need to be focussed on reducing ion concentrations in the fruit, especially Cl^-, through careful selection of rootstocks and irrigation management (timing and leaching fraction, Stevens *et al.* 1999; Stevens and Walker 2002). This is made difficult by further interactions with other soil properties such as salinity and waterlogging (Stevens and Walker 2002), and so very careful research and planning will be required if suitable grapes are to be produced from saline recycled water.

6.4.1.1 Knowledge gaps and future issues

Sodium and chloride toxicity in vines and a range of plants has been studied extensively. Rootstock selection offers an effective method of minimising sodium chloride uptake to the shoot and minimising toxic response by the plant. Both sodium and chloride are relatively easily leached through the soil and beyond the major root mass of vines which is usually in the 0-30 cm depth of soil. Both of these options offer reasonable management tools for managing sodium and chloride toxicity and no knowledge gapsin this area relating to recycled water use have been identified.

If concentration is above levels fit for the purpose of growing vines and cannot be managed appropriately then removal of sodium and chloride from recycled water during the treatment process may offer the most effective control measure.

A scientifically sound management handbook, based on the knowledge discussed above, for using recycled water with grapevines would provide grape growers with a useful management tool for development and management of vineyards using recycled water.

6.4.2 Sodicity

Recycled water can contain relatively large concentrations of sodium (180 mg/L -Table 20) compared to other cations like calcium (35 mg/L) and magnesium (19 mg/L) leading to a high sodium adsorption (SAR) ratio (Average SAR = 6 ranging from 3 – 12) . This can change the cations in the irrigated soil; potentially causing the soils to become sodic decreasing soil permeability and impeding movement of water through the soil. However, the affect is a combination of salinity and sodicity (Figure 12) and the soil type (Table 34). Sodium in recycled water comes from drinking water, industrial wastes, detergents, salt water incursions into sewer systems, and water softeners.

Table 34 Relationship between acceptable sodium adsorption ratio (SAR) of irrigation water and soil texture

	Acceptable irrigation water SAR	
Soil texture	Median	Range[A]
Sand, sandy loam	20	>20
Loam silty loam	10	8-20
Clay loam	8	5-13
Light clay	6	5-11
Medium to heavy clay	4	4-5

[A]related to charge of clay
Source modified from ANZECC and ARMCANZ 2000b, p 9.2.3
Note: subsoils should also be considered to ensure that deep leaching is possible if required.

Any impediment to the movement of a leaching requirement will impact on the removal of salt and hence cause it to accumulate. In time this salt can reduce plant health and production, increase the need for leaching (impacting on the environment) and further exacerbate problems associated with sodicity and salinity.

A soil is sodic when sodium constitutes a significant proportion of the total cations on the exchange complex (particularly in relation to calcium and magnesium). In sodic soil, there is sufficient sodium to interfere with the soils structural stability, often affecting plant growth.

Sodicity in soils can lead to a number of other problems including accumulation of salts, poor root penetrability and poor microbial health. Dispersion caused by sodicity can decrease water movement through soil, leading to accumulation of salts (e.g. Figure 13), and is therefore considered a significant barrier to sustainable irrigation practice.

Sodic soils containing clay disperse spontaneously into smaller particles when wet. The amount of dispersed clay is also affected by soil clay content, mineralogy, soil solution constituents (e.g. salinity), and organic matter content. Sodic soils tend to suffer from poor soil structure (NRMMC and EPHC 2006) with characteristics including:

- Hard setting soils
- Hardpans
- High soil strength when drying
- Surface crusting and
- Rain pooling on the surface.

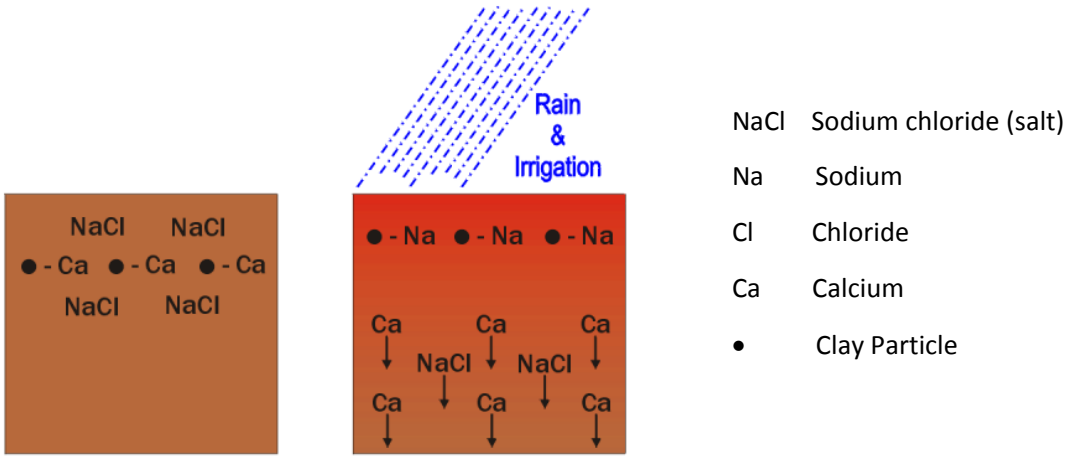


Figure 13 Saline soil being leached by rain (left) to form a sodic soil (right). Sodium salts, chloride and calcium are washed through the soil leaving sodium in the surface layers bound to clay particles. Source Kelly and Rengasamy 2006

These characteristics can cause problems with water infiltration, drainage, plant growth, cultivation and access of equipment. They can lead to significant management and sustainability problems for irrigated sites. Sodic soils are formed when sodium displaces other cations (e.g. calcium and magnesium) which are then leached from the profile of saline soils (Figure 13). The sodium remains behind, attached to clay particles and hence accumulates in the soil (Kelly and Rengasamy 2006).

Salinity and sodicity are separate issues (e.g. a soil can be sodic without being saline, or sodic and saline). Soil structure is the arrangement of soil aggregates (clumps) and pores (spaces filled with air and water) that make up the soil. Well-structured soils are easily broken up into small aggregates (1-20 mm diameter) that stay together when wetted. They also have an adequate mix of small and large pores to allow drainage, aeration and movement of roots through soil, while retaining water for plant use in small pores. Sufficient soil calcium and organic matter content can generally help to maintain or improve soil structure (Anderson *et al.* 2007).

Under conditions of high sodicity, clay soils may swell and individual clay particles disperse or separate from soil aggregates when wetted. Soil aggregates may collapse and the tiny clay particles can block soil pores. On drying, the soil becomes hard, dense and cloddy, with poor structure. There has been extensive research across the world in this area and Australia is one of the world leaders in assessment and management of soil sodicity (Rengasamy 1987; Rengasamy 2006; Rengasamy and Sumner 1998; Sumner *et al.* 1998) and several project/reviews completed with recycled water (Cass *et al.* 1995; Dowley 1995; Fitzpatrick *et al.* 1992; Hermon *et al.* 2004a; Maher *et al.* 2004a; Maher *et al.* 2004b; Stevens and Walker 2002).

There are several management strategies available with new technologies assisting ongoing management strategies (Hermon *et al.* 2004b; Rengasamy and Bourne 1998). However, this information has not been delivered in a user friendly document for managers and operators of vineyards.

6.4.2.1 Knowledge gaps and future issues

There is extensive knowledge on the impacts and management of sodic soils and management of sodic water sources. Many recycled water sources will be low risk as they have sodicity levels

considered below levels of concern. For sources which are above low risk trigger values, like any source appropriate management strategies exist that can be adopted for the viticultural sector. In some cases the recycled water will not be suitable for irrigation if sodicity is too high. Therefore, sodium removal or source control at or before the STP may be required to ensure the recycled water is fit for the intended purpose.

A scientifically sound management handbook, based on the knowledge discussed above, for using recycled water with grapevines would provide grape growers with a useful management tool for development and management of vineyards using recycled water.

6.5 Algae

Any water containing sufficient nutrients (N and P particularly – i.e. recycled water - Table 20) will potentially form algal blooms if other conditions are conducive (ie recycled water). Long periods of dry stable warm weather provide favourable conditions for algal growth.

Algal blooms are dense congregations of algae that can form over lakes, dams or streams. Factors that foster algal bloom formation and growth include:

- Temperature
- Light
- pH
- The availability of nutrients
- Lack of competition from other micro-organisms
- The absence of predators.

Algal blooms can cause major problems for the natural ecosystems including fish mortalities, and can interrupt water supply for towns and cities and limit recreational activities. These problems are mostly caused by blooms of cyanobacteria (commonly called 'blue-green' algae) which often produce toxins which are harmful to human and animal health. Species in Australia which are commonly found to be toxic are Microcystis and Anabaena.

Algae that flourish in secondary treatment lagoons and winter storages may pose a risk to the adequate treatment and distribution of recycled water during bloom events. Blue-green algae may also pose a risk to human and stock health through the production of toxins if the site is not appropriately managed. Generally, algae applied to pasture via recycled water will not affect stock health provided the appropriate withholding periods are implemented and stock are grazed on dry land. There is, however, a greater risk to stock health associated with drinking recycled water containing blue-green algae.

The toxins that can be produced are known to be resistant to degradation and could survive for several months on produce (Cooper *et al.* 1996). However, the contamination pathway at most risk is spray application of freshly eaten vegetables where the toxin is directly applied to the fruit. In the case of the wine industry, these risks are minimised by drip or microspray irrigation (unless recycled water is used in overhead spray irrigation and frost control) to prevent direct contact of the berry and recycled water. Plant uptake of toxins would be expected to be low as with most complex organic molecules.

With wine grapes there is also a processing step that would be expected to lead to degradation of any toxins with time. However, little information related to assessment of these risks and pathways could be located.

Algae blooms can also overload filtration systems, especially for drip irrigation. Therefore, any control measure should focus on prevention of blooms followed by robust filtration systems to hand blooms if required. Filtration would be expected to remove algae and the associated toxin (if present). However, filtration may not be sufficient for removal of toxins already released from the algae and present in the recycled water.

6.5.1 Control measures available

The best method for management of algae is to limit their growth by manipulating the factors discussed above that influence their growth. For example, restrict light, introduce predators or minimise storage time. Different algae may also live in different depths of the water storage. If this is the case, adjustment of water intake can minimise algae intake into the irrigation system. If a toxic bloom is identified it is very difficult to remove the toxins.

It is preferable to examine live samples for taxonomic identification of algae. If this is not possible storage of specimens can be preserved in a solution of 70% alcohol, 25% water and 5% glycerol. With storage, many features such as colour or the presence of flagella may be lost or changed making them more difficult to discern.

Control measures which help identification of algae blooms are also available. For example:

- Has your dam got a blue-green algae problem? (Thomas and Martinelli 1999)
- Minimising algae growth in farm dams. (Cummings 2002)
- www.dpi.vic.gov.au/dpi/nreninf.nsf/childdocs (then click on Landcare/waterquality). http://www.health.vic.gov.au/environment/water/bluegreenalgae.htm (CRC for WQT 2004)

6.5.2 Knowledge gaps and future issues that may arise

To-date there have been no reported impacts of algae toxins in recycled water dams impacting grape quality. Historical observations suggest that the likelihood of such an event is low. The method of irrigation (drip or micro spray under the vine) also restricts exposure and the likelihood of significant concentraton of toxins (if present) on berries reaching the wine making process. The wine making process also potentially offers a barrier of safety. However, little is known with respect to the effectiveness of this barrier.

Theoretically, the risk of algae toxin impacting on wine quality seems low, however, a thorough risk assessment should be undertaken to fill this knowledge gap and address any future issues that may arise, particularly with the potential increase in use of poor quality recycled water

6.6 Boron

Boron (B) is a micro-nutrient that is required by plants in small amounts (< 500 g/ha) but nevertheless B deficiency is a widespread problem across much of the world (Shorrocks 1997). Although B concentrations are not often reported, recycled water may have higher levels of B than other irrigation waters (Table 35).

Table 35 Boron concentration (mg/L) in recycled and other irrigation waters

Country	Recycled water	Ground (G), Well (W) or River (R) water	Source
Spain	1.0	0.16 (G)	(Reboll *et al.* 2000)
Chile		7.5 – 17.2(R)	(Ferreyra *et al.* 1997)
FL, USA	0.14	0.02 (W)	(Zekri and Koo 1994)
Canada	2.6	not measured	(Neilsen *et al.* 1989c)
CA, USA	0.6 – 1.3		(Asano *et al.* 1985)
Australia	0.29	0.16 (G)	(Kelly *et al.* 2001; Table 20)
Italy	1.91	0.64	(Meli *et al.* 2002)

Special care is needed in the management of boron because there is only a small concentration range in soils between plant deficiency and toxicity. Uptake and removal of boron by plants is usually less than input from soil minerals and irrigation water, depending on the irrigation water quality. As a result, the excess boron accumulates in the root zone if it is not leached down through soil.

The concentration of boron tolerated in irrigation and soil water by various agricultural plants without reduction in yield or vegetative growth (Table 36). These values provide a guide only, as the rate of uptake of boron by plants -and therefore their tolerance - depends on a range of other factors such as soil texture. Generally, higher uptake rates are seen in sandy soils and lower rates in clayey soils. Uptake rate is also much lower in a soil pH range of 7.5-9.5 and plants can tolerate higher soil boron levels in this range. The uptake of boron from the soil is inhibited by pH-values below 5 and above 7, respectively. Boron deficiency mainly occurs on poor, sandy, dry and calciferous soils. The appropriate choice of rootstock varieties makes it possible to influence the boron content of the vine (Csikasz-Krizsics and Diofasi 2007).

Typical symptoms of boron toxicity first appear in older leaves and include a yellowing and brown speckling pattern found between the veins and near the edge of the leaf, followed by the edges gradually turning brown and dying (necrotic tissue). Other symptoms include yellowing (chlorosis), tip burn, cupping of the leaves, reduced size, premature leaf drop and the development of a red, pink, purple or bluish band surrounding the edge of a chlorotic leaf (anthocyanins). Yield reductions are likely to occur before visible symptoms occur, so tissue analysis is an important tool to assess any potential for yield reduction resulting from boron toxicity.

Table 36 Maximum boron concentrations in irrigation or soil water tolerated by a variety of plants, without reduction in yields.

Tolerance	Boron in irrigation or soil water (mg/L)	Plant
Very intolerant	< 0.5	Blackberry, lemon, avocado, grapefruit
Intolerant	0.5-1.0	Peach, cherry, plum, grape, onion, garlic, sweet potato, sunflower, mung bean, sesame, lupin, strawberry, Jerusalem artichoke, kidney bean, lima bean, snap bean, peanut
Moderately intolerant	1.0-2.0	Broccoli, capsicum, pea, carrot, radish, potato, cucumber, lettuce, olive, pumpkin, radish
Moderately tolerant	2.0-4.0	Kentucky blue grass, Cabbage, turnip, corn, artichoke, mustard, sweet clover, squash, musk melon, cauliflower
Tolerant	4.0-6.0	Tomato, alfalfa, parsley, red beet, sugar-beet,
Very tolerant	6.0-15.0	Most grasses, asparagus, celery

Source ANZECC and ARMCANZ 2000b; Keren and Bingham 1985; Carrow and Duncan 1998.

Boron can be leached from soil by rainfall or irrigation leaching fractions. However, leaching of boron can be difficult because the rate of removal can be much slower for boron than for other salts, as boron can be attracted to or absorbed by soil particles. In some cases, leaching is unlikely to provide a permanent solution because more boron will be resupplied through breakdown of naturally occurring boron-containing minerals in the soil (Keren and Bingham 1985) and from further irrigation water additions.

Stevens *et al.* (2003b) studied B in irrigation waters and soil in a recycled water system in South Australia. Recycled water from the scheme had a higher concentration of boron (average of 0.36 mg/L) than local groundwater (0.15 - 0.17 mg/L) (Table 20; Kelly *et al.* 2001). Comparisons were made of the boron levels between three, differentially managed, soils in the region:

1. soil irrigated with groundwater;
2. soil irrigated with reclaimed water previously available from the Bolivar outfall channel (lower quality than the current Class A water); and
3. virgin, unirrigated soil.

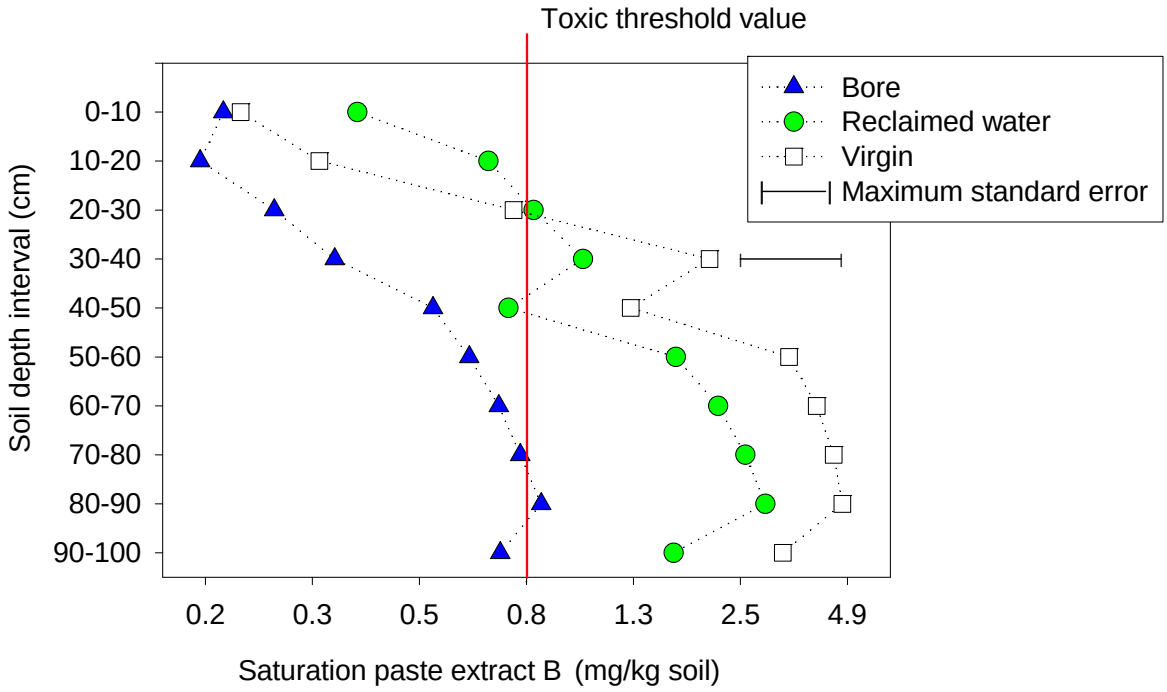


Figure 14 Change in soil boron concentration for soils irrigated with three types of water on the Northern Adelaide Plains. Note: Soil boron concentration is a log scale (Stevens *et al.* 2003b). The red line indicates toxic yield threshold above which yield reduction begins to occur for some plants (Table 36).

At the soil surface, recycled water irrigated soils had higher average boron concentrations than virgin and groundwater irrigated soils (Stevens *et al.* 2003b). Even though the average surface soil boron concentration increased with the use of recycled water, it remained below the toxic threshold value. Vines are known for the majority of the root mass being in the top 30 cm of soil (Rawnsley 2008). However, there were large variations in the data recorded for the soils, as was also reported by Ryan

et al. (1998). Growers need to verify their own soil boron concentrations. In the subsoil, irrigation with recycled water led to decreases in boron concentration compared with virgin soil while irrigation with local groundwater reduced the concentration of boron all the way through the soil profile (Figure 14). These decreases probably occurred as a result of leaching of boron down through the soil (Stevens *et al.* 2003b).

Because of the variation in tolerance between different crop varieties, one method of management is to grow more tolerant plant species or varieties in areas with high boron levels in irrigation water or soil (Or for vine boron tolerant root stock - Csikasz-Krizsics and Diofasi 2007). Table 36 shows the concentration of boron in irrigation and soil water tolerated by various agricultural crops without reduction in yield or vegetative growth (Grapes tolerate up to 0.5 to 1 mg/L boron in irrigation water - Table 36). These values provide a guide only, as the rate of uptake of boron by plants and therefore their tolerance will depend on other factors such as soil texture and pH.

It is reassuring that a variety of grapes have been gown on the Northern Adelaide Plains (South Australia) as part of the Virginia Recycled Water Scheme using recycled water for more than 25 years with no recorded impacts of boron concentration in recycled (Boron concentration 0.36 mg/L) on grapevines (Soil type 1, Table 1, Stevens *et al.* 2003b). With a possible range in Australia of 0.09-0.48 mg/L of boron in recycled water (Table 20), this data indicated that unless a very sensitive root stock or variety is grown and soils which are relatively high in available boron, then the risk from boron toxicity to grapevines is low, and the nutritional value most likely beneficial. Good practice and appropriate control measures to ensure recycled water, soils and plant concentrations of boron remain in the desired ranges are viable and should be practiced.

Recent research trials indicated that boron toxicity was not a concern with recycled water (0.23 mg/L B) used to irrigate vines (Rawnsley 2008).

6.6.1 Knowledge gaps and future issues that may arise

This study has identified sufficient knowledge of boron toxicity is available and control measures are available to ensure risks posed from boron in recycle d water to grapevines are managed. No crucial knowledge gaps or future issues were identified.

6.7 Chlorine disinfection residuals

Although related compounds, there are significant differences between the chlorine forms used in disinfection and chloride. Chlorine guidelines for protection of plants indicated less the 1- 5 mg/L is low risk for a range of plant (grapevines not specifically mentioned), while chloride guideliness indicate <175 mg/L is low risk (Table 32) for a range of plant species including grapevines (ANZECC and ARMCANZ 2000b). The potential toxicity to humans has been well studied (Anon 2002). However, data for the toxicity to plants (Phytotoxicity) is limited.

There are a number of products that may be added to wastewater to achieve chlorine disinfection. Three of the key products for water dosing are chlorine gas (Cl_2), Calcium hypochlorite ($CaCl_2O_2$) and sodium hypochlorite (NaOCl). The relatively strong oxidiser chlorine dioxide is also available and appears to be increasingly used.

The key chlorine dosing products react with water to produce hypochlorous acid (HOCl), which rapidly dissociates to form the hypochlorite ion according to the following reaction:

$$HOCl \leftrightarrow OCl^- + H^+$$

In addition to hypochlorous acid, the hypochlorite ion, and as dosed chlorine dioxide, chlorine may also be found in the monochloramine (NH_2Cl) and the dichloramine ($NHCl_2$) forms. In seawater, reaction with bromine results in formation of chloride ion and HOBr.

Knowledge of the dominant form of chlorine in a particular disinfection process is important as the different forms have different oxidising strengths and therefore biocidal efficiencies. The different forms also have a range of environmental fate characteristics. Hypochlorous acid (HOCl) is considered the most potent of the four main oxidising forms, while monochloramine is a less potent oxidant, but is more stable and less effected by chlorine demand chemicals (Pretorius and Pretorius, 1999). The dominant form of chlorine is dependent on the combination of parameters such as temperature, pH and ammonia concentrations. As pH increases, the proportion of hypochlorite ion tends to increase relative to hypochlorous acid, while increasing ammonia concentrations tends to increase monochloramine levels (EPA Victoria 2003a).

The term *free chlorine* refers to the sum of Cl_2, HOCl and OCl^-. The term total residual chlorine refers to the sum of free chlorine and combined chlorine eg monochloramine.

6.7.1 Water recycling guidelines and chlorine management

The majority of water recycling guidelines provide limited guidance on the impact of chlorine on plant and aquatic environments. However, EPA Victoria suggest a limit value for recycled water irrigation of 1 mg residual chlorine/L (EPA Victoria 2003a). Additional guidance on direct discharges to water ways is also included which lists chlorination as the least preferred method of disinfection and requires dechlorination to achieve a chlorine residual of < 0.1 mg/L prior to discharge.

Guidance on the risk levels for residual chlorine in water irrigated through overhead sprinklers (ie plant damage through foliar contact) has been specified by Asano *et al.* 2007. No restrictions on use are required where residual chlorine is less than 1 mg/L, 1 to 5 mg/L residual chlorine is considered to need slight to moderate restrictions on use, while greater than 5 mg/L is specified as requiring severe restrictions on use (Asano *et al.* 2007). The guideline does not specify the form of residual chlorine.

6.7.2 Assessing risks of chlorine phytotoxicity

Data on chlorine toxicity to plants is limited and varies between plant species (Date *et al.* 2005). The mechanisms of chlorine phytotoxicity were discussed by Price and Fox, (1984) and attributed to:

- direct oxidation of cellular organic matter;
- accumulation of phytotoxic sodium chlorate due to contamination of sodium hypochlorite solutions cells; or
- accumulation of sodium ions in a recirculating system leading to an altered sodium/potassium ratio in solution and symptoms of induced potassium deficiency. Plants such as carnations are considered particularly sensitive to this accumulation of sodium.

The most significant study underpinning the management of chlorine residuals in recycled water appears to be the work of Frink and Bugbee (1987 cited by Date *et al.* 2005). The authors concluded that irrigation water with a residual chlorine concentration < 1 mg/L should not adversely affect growth or appearance of most potted plants and vegetable seedlings grown in a peat/perlite/vermiculite medium. Sensitivity to the chlorine varied depending on the plant species, with plants having reduced weights and leaf chlorosis at:

- 2 mg/L chlorine - geranium and Begonia

- mg/L chlorine - pepper and tomatoes at 8 mg/L;
- 18 mg/L chlorine – lettuce;
- 37 mg/L chlorine - broccoli, marigold and petunia

Copes et al., (2002) examined the impact of chlorine dioxide sprayed five times at 3 day intervals on eight bedding plants and nine shrub species grown in pots. The experiment was performed in a greenhouse over a period of 23 days. Impacts at 5 and 20 mg/L ClO_2 were not found on any plants, however, damage was found on poppy after three sprays at 50 ppm, at 100 ppm on pansy after 3 sprays on azalea, mountain laurel and poppy after four sprays and a fern after 5 sprays. At 10000 mg/L all plants were impacted, including coleus, evolvulus, galium, English ivy, juniper, lilac, rhododendron and St Johns-wort after 1-2 sprays. Injury to leaves and flowers was considered to have occurred based on $\geq$ 4% of the surface area being affected. There was no flushing of salts from the leaves because watering was undertaken at the base of the plant, leading the authors to suggest that overhead watering may lessen the potential for damage.

The effect of chlorine dioxide on radish and lettuce seedlings was also examined in pot trials by Carrillo et al. (Carrillo *et al.* 1996). The authors considered these species to be relatively sensitive to chlorine toxicity. Seedlings received 1 to 5 applications of water containing chlorine dioxide directly to the soil, over time periods of 10 to 15 days. Experiments were conducted in sand and in agricultural soils and with sterile and non-sterile matrixes. In non sterile agricultural soil, five applications of chlorine dioxide was only associated with significantly reduced radish growth at a concentration of 26 mg active chlorine/L, no effect was found at 2.6 mg/L and lower concentrations. The reduction in weight was approximately 10%. In the sterile soil, the 2.6 mg/L but not a 1 mg/L solution was associated with growth reductions of approximately 10 to 15%.

In a sand matrix, impacts on radish were variable, with a reduction in growth noted at 2.6 mg/L but not at approximately 5 mg/L or at 1 mg/L. Lettuce growth was not effected by repeat applications within a sand matrix, even at concentrations of 5 mg/L. However, the toxicity index incorporating physical inspections (eg discoloration) did identify some apparent impacts in the inert sand matrix at concentrations above 1 mg/L.

In a study published by UWRAA (UWRAA 1990) wheat and pea seedlings were exposed to chloramine through solution culture, irrigation of soil and foliage spraying (in this experiment deionised water maintained soil moisture). The culture experiments involved 24 day exposure, soil irrigation occurred over five weeks with irrigation six times per week. The foliage applications involved 5 weeks of 3 times per day spraying (but the report only noted plants wet 3 hours per week). In the culture experiments, chloramine results in severe toxicity in the peas and wheat at 7.1 mg/l monochloramine. The pea had no toxicity at approximately 3 mg/l, while the wheat still had some toxicity at approximately 3 mg/l.

There have been limited studies directly comparing the phytotoxicity of the differing chlorine residual forms (such as free chlorine versus monochloramine). However, chloramine is considered a less potent oxidant and this would be expected to translate to chloramine being less phytotoxic than free chlorine. This assumption is supported by studies described in UWRAA (1990) involving a comparison of the effects on algae of free chlorine and chloramines. The results demonstrated a wide range of species sensitivities to the chlorine residuals, but that chloramine was consistently 1.5-3 times less phytotoxic than chlorine. However a more recent solution culture study reports the toxicity of chloramines to lettuce as 0.18 mg Cl/g root (0.5 mg Cl/L and 12 mg/L NH4 added to solution) (Date *et al.* 2005); suggesting it may be more toxic than chlorine.

To add to this contradictory data, Date et al. (Date *et al.* 1995) cited a report by Buxton (1938) that many plants grown in soil-based media would be killed by chlorine at concentrations typical of tap water. Kone et al (1931) was also cited as reporting that irrigation with water containing 5 mg/l residual chlorine caused very strong growth inhibition in seven species of potted plants. In their own study (Date *et al.* 1995) they concluded that reported impacts of chlorine within nutrient solutions was caused by chloramine rather than free chlorine.

The effect of chlorine residuals on crops (broccoli, cauliflower, lettuce and celery) was examined with and without dechlorination (Sheikh *et al.* 1990). The chlorine residuals applied varied from 1 to 10 mg/L with a median of 5 mg/L and was reported to have no observable effect on crops. The Virginia Recycled Water Scheme also includes disinfection to achieve free chlorine and a mean residual of approximately 1 mg/L and has not reported any impact on similar crops grown. Both these schemes have been operating now for several years with no recorded impacts on plants from chlorine.

It should also be noted the aquatic organisms have a much higher sensitivity to chlorine and if recycled water used for irrigation is stored on site in dams there may be detrimental impacts on aquatic life in the dam (ANZECC and ARMCANZ 2000a). The ANZECC guideline established a total residual chlorine trigger value of 3 μg/L as affording 95% protection for freshwater systems. This was also established as a low reliability trigger value for the marine environment. Chlorine in open storage dams has a relatively short half life, while chloramines could be reduced 2-4 fold by storage for 1 to 3 days (UWRAA 1990).

6.7.3 Knowledge gaps and future issues that may arise

The publications reviewed above suggest irrigation with chlorine residuals less than 1 mg/L poses a low risk to the limited number of plant species studied. Irrigation with chlorine residuals between 1-5 mg/L would also appear to pose a low risk of phytotoxicity. It seems that there is a significantly increased risks from chlorine in water based culture media compared to soil based irrigation (UWRAA 1990; Date *et al.* 1995).

Some risks from chlorine disinfection bioproducts could be posed to highly sensitive plants as the number of plants tested are limited. Grapevines are not specifically assessed in the data searched for this review regarding chlorine disinfection biproducts, representing a knowledge gap. Further research into the sensitivity to chlorine should be considered. Especially as some reuse schemes chlorinate to high levels or have loose controls on the variability of free chlorine. This is because the human health focus is usually to ensure chlorine levels are maintained above lower limits, but not below higher limits. Alternatively control measures to minimise chlorine residuals in recycled water used for irrigation of grapevines should be implemented at the treatment plant.

6.8 Heavy metals

Heavy metal and metalloid concentrations in recycled water are generally very low, although this depends on the sewage entering the WTP and the treatment processes. Simple loading calculations (volume applied multiplied by heavy metal concentration) allow the calculation of annual loading and potential for increases in concentration in soils, which may lead to toxicity in the long-term (ANZECC and ARMCANZ 2000c; Table 38). More detailed modelling should consider crop removal and possible leaching of heavy metals and metalloids through the soil profile. As Smith *et al.* (1996) point out, the long-term accumulation of metals in soils cannot be ignored, or it may eventually affect the sustainability of recycled water schemes.

Heavy metals are predominantly adsorbed to the solid phase (biosolids) of the wastewater treatment process (Bunel *et al.* 1995; Pettygrove *et al.* 1985). Concentrations for metal and metalloids in recycled water are generally within or below ANZECC long-term trigger values and are usually below ANZECC short-term trigger values (ANZECC and ARMCANZ 2000c; Smith *et al.* 1996; Stevens *et al.* 2000). Even though heavy metals are generally not found in high enough concentrations in recycled waters to be a direct threat to human health, they do have potentially harmful effects and should be monitored to ensure they are kept below toxic concentrations (Bahri 1998; Chang *et al.* 1996). Similarly, effects from long-term accumulation of heavy metals on plant growth should not be ignored as this could affect the long-term sustainability of a recycled water irrigation scheme (Smith *et al.* 1996; Stevens *et al.* 2003a).

Some research has found that some heavy metals required as micro nutrient can be supplied in sufficient amount to meet plant requirements but not exceed acceptable concentrations in fruit (Mendoza-Espinosa *et al.* 2008). It is important to consider soil baseline heavy metals have not be impacted by application of other soil ameliorant or pesticides. For example, these effects can be complicated for copper in grapevine production as the use of copper based pesticides may have elevated soil copper levels already (Delas *et al.* 1959; Moolenaar and Beltrami 1998). In this case small increase in soil copper may have significant impacts and the cumulative contaminant loadings (CCLs) specified (ANZECC and ARMCANZ 2000b) should be considered to manage this risk (See discussion below).

Metal and metalloid mobility and bioavailability in soil varies significantly with soil properties for similar total soil concentrations. Some metals pose little hazard to food chain contamination due to their strong phytotoxic effects (i.e. increasing metal concentrations cause mortality before transfer to the next trophic level has an opportunity to occur). This has been termed the “soil-plant barrier” and metals can fall into four groups based on their retention in soil and translocation within the plant (Table 37). Cadmium has been identified as the major heavy metal of concern in sewage as it is, relative to most other metals, more available to plants and is found at concentrations in harvestable portions of the crops that could be harmful to humans, but shows no toxic signs to the plant.

There are a number of guidelines for metals in soil and water. The National Environmental Protection Council (NEPC) in 2000 released the National Environmental Protection Measure (NEPM; NEPC 1999b), which included suggested health-based investigation levels (HBILs) for contaminants in soils. These were developed principally for urban or residential areas and are not appropriate for application to agricultural areas (unless these are being developed for residential use). A second series of investigation levels, Interim Urban Environmental Investigation Levels (EILs), were developed based on environmental thresholds, with plant phytotoxicity being used as the critical risk pathway. There are several shortcomings in using these EILs to assess contaminant risks in agricultural soils (McLaughlin *et al.* 2000), including lack of consideration of soil microbial risk pathways (i.e. risk of contaminants to soil health), poor inclusion of soil background concentrations and the drawbacks associated with using total contaminant concentrations to assess risk (i.e. a lack of appreciation of contaminant bioavailability).

Nevertheless, the NEPM EILs are forming the basis for agricultural soils. The last draft of the guidelines (February 2000) proposed Receiving Soil Contamination Ceiling Levels (RSCCLs) very similar to the NEPM EILs, except that Cd has a RSCCL of 1 mg/kg instead of 3 mg/kg in the NEPM EIL (Table 38); Note also that the NEPM specifies EILs for phosphorus of 2000 mg/kg, sulfur 600 mg/kg and sulfate 2000 mg/kg). Other states have defined similar soil limit values for sludge application to agricultural soils (McLaughlin *et al.* 2000).

The guidelines for fresh and marine water quality (ANZECC and ARMCANZ 2000c) define the Cumulative Contaminant Load Limit (CCL) as the maximum contaminant loading in soil defined in gravimetric units (kg/ha) and indicates the cumulative amount of contaminant added, above which site specific risk assessment is recommended if irrigation and contaminant addition is continued Table 38). The CCL was calculated based on background concentrations of contaminants in Australian agricultural soils. It allows the calculation of the additional contaminants that can be applied to the soil before additional testing may be required to determine if contaminant loadings applied through irrigation are an issue with respect to: existing Australian, New Zealand and international soil quality criteria and metal/metalloid guidelines; plant phytotoxicity; minimisation of toxic metal uptake into food crops (food quality); impact on farm infrastructure (e.g. bio-clogging of irrigation lines due to iron or manganese); off site impacts; impact on soil biota (ecotoxicity) (ANZECC and ARMCANZ 2000c). In many cases there was insufficient background soil information to calculate the CCL for metals and metalloids (Table 38), highlighting the lack of data for many metals and metalloids in Australian soils. These guideline values are based on total metal concentrations in soils, yet in many cases a measure of the bioavailable, or potentially bioavailable metal, could describe risk more appropriately. However, appropriate thresholds for inorganic contaminants in agricultural soils, which consider bioavailability, have not yet been derived in Australia (McLaughlin *et al.* 2000).

Where possible, if the trigger values and CCL specified in Table 38 are monitored and metal and metalloid loading rates calculated using recycled water concentrations and irrigation rates, metals and metalloid concentrations in soils should be easily managed. Prevention is much easier than remediation. There are a number of hyper-accumulator plants and chemical methods for removing metals and metalloids from contaminated soils (Brown *et al.* 1995). However, remediation is generally inefficient and costly.

Table 37 Metal and metalloid bioavailability grouping

Group	Metal	Soil adsorption	Phytotoxicity	Food chain risk
1	Ag, Cr, Sn, Ti, Y and Zr	Low solubility and strong retention in soil	Low	Little risk because they are not taken up to any extent by plants
2	As, Hg and Pb	Strongly sorbed by soil colloids	Plant roots may adsorb them but not translate to shoots or generally not phytotoxic except at very high concentrations	Pose minimal risks to the human food chain
3	B, Cu, Mn, Mo, Ni and Zn,	Less strongly sorbed by soil than group 1& 2.	Readily taken up by plants, and are phytotoxic at concentrations that pose little risk to human health.	Conceptually, the “soil-plant barrier” protects the food chain for these elements
4	Cd, Co, Mo and Se,	Least of all metals	Pose human or animal health risks at plant tissue concentrations which are not generally phytotoxic.	Bioaccumulation through the soil-plant-animal food chain.

Source (Chaney 1980)

Maximum levels of metal contaminant in foods (Table 39) have not been set for wine or alcholic drinks (FSANZ Access 2008). However, it is worth noting that arsenic, cadmium, mercury and lead are the main inorganic contaminants likely to be scrutinised in relation to food quality as maximum levels in foods have been defined by ANZFA (now FSANZ) (Table 39). Lead is rarely an issue in terms of crop uptake, as the metal is strongly sorbed by soil and if taken up by roots, is rarely translocated to edible plant parts. Where lead contamination has been identified, this is usually due to aerial contamination of the produce, either through dust contamination, or uptake of atmospheric lead derived from

automobile or industrial sources. Similarly, arsenic and mercury are strongly retained by soil and are generally not regarded as a high risk for food chain contamination via plant uptake. Cadmium is weakly bound to soils (relative to other heavy metals) and toxic to plants and relatively low concentrations. In nutrient solutions, cadmium has been shown to be toxic to a range of plants at levels ranging from 0.1 mg/L to 1 mg/L (Will and Suter 1994). However, human and animal health concerns are found at sub-phytotoxic levels (ANZECC and ARMCANZ 2000c) and therefore poses potentially the highest health risk for heavy metals in reclaimed water.

It is unlikely that either chromium or nickel pose great risks as these elements are often strongly adsorbed or precipitated in soils. For chromium, elemental speciation is critical in assessing risks, as the Cr(III) form is non toxic and precipitated in soil, while Cr(IV) is highly toxic and mobile. Lead is also strongly retained in soils and not readily taken up by plants or microorganisms.

Table 38 Soil Contaminant Investigation Levels and Loadings (mg/kg)

SUBSTANCES	Health				EILs[10]	Background	CCL
	A	D	E	F	Interim [5]	Ranges[6]	
METALS/METALLOIDS					Urban		
Arsenic(total)	100	400	200	500	20	1 to 50	20
Barium				300	300	100 - 300	
Beryllium	20	80	40	100			
Cadmium	20	80	40	100	3	1	2
Chromium(III)	12%	48%	24%	60%	400		
Chromium(IV)	100	400	200	500	1		
Chromium(Total)*[7]						5-1000	
Cobalt	100	400	200	500		1 to 40	
Copper	1000	4000	2000	5000	100	2-100	140
Lead	300	1200	600	1500	600	2-200	260
Manganese	1500	6000	3000	7500	500	850	
Methyl mercury		10	40	20			
Mercury (inorganic)		15	60	30	1	0.03	2
Nickel	600	2400	600	3000	60	5-500	85
Vanadium	50	20		500	50	20-500	
Zinc	7000	28000	14000	35000	200	10-300	300
					OTHER		
Boron	3000	12000	6000	15000			
Cyanides(Complexed)	500	2000	1000	2500			
Cyanides(free)	250	1000	500	1250			
Phosphorus					2000		
Sulfur					600		
Sulfate[9]					2000		

Source (NEPC 1999a & ANZECC and ARMCANZ 2000c). Blank cells indicated no data available.

[1]Human exposure settings based on land use have been established for Humand based Investigation Levels (HILs). These are:

A. 'Standard' residential with garden/accessible soil (home-grown produce contributing less than 10% of vegetable and fruit intake; no poultry): this category includes children's day-care centres, kindergartens, preschools and primary schools.

D. Residential with minimal opportunities for soil access: includes dwellings with fully and permanently paved yard space such as high-rise apartments and flats.

E. Parks, recreational open space and playing fields: includes secondary schools.

F. Commercial/Industrial: includes premises such as shops and offices as well as factories and industrial sites.

(For details on derivation of HILs for human exposure settings based on land use see Schedule B(7A).

[2] Site and contaminant specific: on site sampling is the preferred approach for estimating poultry and plant uptake. Exposure estimates may then be compared to the relevant ADIs, PTWIs and GDs.

[3] Site and contaminant specific: on site sampling is the preferred approach for estimating plant uptake. . Exposure estimates may then be compared to the relevant ADIs, PTWIs and GDs.

[4] These will be developed for regional areas by jurisdictions as required.

[5] Interim EILs for the urban setting are based on considerations of phytotoxicity, ANZECC B levels, and soil survey data from urban residential properties in four Australian capital cities.

[6] Background ranges, where HILs or EILs are set, are from data sets defined in NEPC (1999)

[7] Valence state not distinguished – expected as Cr (III).

[8] The carbon number is an 'equivalent carbon number' based on a method that standardises according to boiling point. It is a method used by some analytical laboratories to report carbon numbers for chemicals evaluated on a boiling point GC column.

[9] For protection of built structures.

[10]Ecological Investigation Levels (EILs)

Table 39 Maximum level of metal contaminant in food

Contaminant and food	Contaminant mg/kg as consumed
Arsenic (total)	
Cereals	1
Arsenic (inorganic)	
Crustacea	2
Fish	2
Molluscs	1
Seaweed (edible kelp)	1
Cadmium	
Chocolate and cocoa products	0.5
Kidney of cattle, sheep and pig	2.5
Leafy vegetables (as specified in Schedule 4 to Standard 1.4.2)	0.1
Liver of cattle, sheep and pig	1.25
Meat of cattle, sheep and pig (excluding offal)	0.05
Molluscs (excluding dredge/bluff oysters and queen scallops)	2
Peanuts	0.1
Rice	0.1
Root and tuber vegetables (as specified in Schedule 4 to Standard 1.4.2)	0.1
Wheat	0.1
Lead	
Brassicas	0.3
Cereals, Pulses and Legumes	0.2
Edible offal of cattle, sheep, pig and poultry	0.5
Fish	0.5
Fruit	0.1
Infant formulae	0.02
Meat of cattle, sheep, pig and poultry (excluding offal)	0.1
Molluscs	2
Vegetables (except brassicas)	0. 1
Mercury	
Crustacea mean level of	0.5*
Fish (as specified in Schedule 4 to Standard 1.4.2) and fish products, excluding gemfish, billfish (including marlin), southern bluefin tuna, barramundi, ling, orange roughy, rays and all species of shark	0.5*
Gemfish, billfish (including marlin), southern bluefin tuna, barramundi, ling, orange roughy, rays and all species of shark	1*
Fish for which insufficient samples	1
Molluscs	0.5*
Tin	
All canned foods	250

Source (ANZFA 2001).

* mean level of.

It has been known for some time that after addition of soluble metals to soil, availability of the metal decreases with time. Initially this decrease is associated with adsorption of metals to soil surfaces, but longer-term, slower "fixation" reactions appear to proceed, following adsorption, which continue to reduce metal bio- and phytoavailability. Metal adsorption needs to be distinguished from metal fixation – the former leads to a reversible binding of metal to the soil solid phase, while the latter leads to an irreversible (or less reversible) binding of metal to soil. The heavy metals added with reclaimed water are usually added slowly over time, which may allow slower fixation of these metal and plant availability may be lower in the long-term.

Some indirect effects of recycled water on plant cadmium concentrations should also be considered. Even though the concentration of cadmium in recycled water could be negligible and insignificant amounts of Cd would be added to the soil through irrigation with recycled water. Changes in soil salinity and chloride concentrations due to use of recyccled water has the potential to increase plant availability of Cd which is already in the soil (McLaughlin *et al.* 1994; ANZECC and ARMCANZ 2000c).

6.8.1 Knowledge gaps and future issues that may arise

In summary, heavy metals in recycled water are generally insignificant, however, they are potentially an issue if guideline values are exceeded and should be monitored. Loading rates of heavy metals in irrigation water can be easily calculated and potential issues identified with readily available guidelines.

The risk posed to the viticutlure from recyceld water containing heavy metals is relatively low. There is a comprehensive amount of data assisting our understanding of heavy metal's reaction in soil and plant availability. Combined with a comprehensive understanding of heavy metal concentrations that would be likely to be applied in recycled water and proven methods for their removal or management.

Consequently there seems to be little knowledge gaps or future issues related to the heavy metal concentration of recyeld water water an irrigation of grapevines.

6.9 Organic chemicals of concern

Approximately 63,000 chemicals are in common use worldwide; between 200 and 1,000 new synthetic chemicals enter the market each year (Desbrow *et al.* 1998). As a result there could potentially be thousands of chemicals in sewage effluent and the water reclaimed from it (Recycled water) (Anderson 2008). These compounds are usually found in common household chemicals, pharmaceuticals, personal care products, pesticides, herbicides, and there are innumerable industrial chemicals that find their way to wastewater collections systems through their production and use (Anderson 2008).

Non-prescription pharmaceuticals and personal care products (PCPPs) are produced and used by humans in quantities that exceed thousands of metric tons annually. The resulting concentrations of PCPPs in wastewater treatment plant effluents range from the nanogram per litre to the low microgram per litre range (CRC WQT 2007). Hormones produced by the human body, sometimes supplemented through pharmaceuticals, have also been identified in wastewater treatment plant effluents along with a whole host of compounds that are consumed by humans including pharmaceuticals, caffeine, food additives as well as their metabolites (Anderson 2008). Harrison (Harrison *et al.* 2006) also identified a range of organic chemicals found in sewage sludge and therefore potentially in water recycled from sewage effluent.

Organic chemicals can be categorised into 20 main compound classes (Table 40). A small fraction of these compounds have been recognised and regulated as pollutants. As a result, evaluating the impacts of many organic chemicals is a developing science because the majority have only recently been recognised as pollutants (e.g. fire retardants, fluorescent whitening agents, image contrast media, personal care products, pharmaceuticals, steroids, sterols and stanols) (Anderson 2008).

Because of the infancy of the measurement and assessment of human and environmental toxicity from many organic chemicals there are a number of research areas that could be developed to assist in managing potental risk posed by these chemicals (Anderson 2008). This includes:

- Detemining priority hazards to measure
- Development of standard methods for chemical analysis (Anderson 2008, p 90)
- Improvement of bioassays with enhanced sensitivities and greater selectivity for priority hazards.

Table 40 List of chemical categories of trace organic compound categories and their source in wastewater

Chemical category	Description (use and source in wastewater)
Aliphatics -short chained and chlorinated	Aliphatics (short chained and chlorinated) are used as building blocks (monomers and intermediates) in organic synthesis. These compounds are used to make a wide variety of products including plastics, coatings, adhesives, aerosols, fluorocarbons, paints & stripping products, pharmaceuticals, and cosmetics. Chlorinated solvents have properties that make them useful for degreasing fats, oils, waxes, and resins.
Anticorrosive	5-methyl-1H-benzotriazole is a commonly used antioxidant in antifreeze and deicers. Used in households and industry, this compound has been detected in effluents from municipal treatment plants. Likely sources include stormwater runoff and improper management and disposal.
Chlorobenzenes	Mono-, di-, and tri-chloro benzenes are primarily used as intermediates in the manufacture of organic chemicals, ploymers, dyes, herbicides, and pesticides. The primary source of chlorobenzenes in municipal wastewater is commercial production. According to EPA's Toxic Chemical Release Inventory, chlorobenzene releases to water totalled over 326,000 lbs between 1987 and 1993.
Complexing agent	This class includes compounds like nitrilotriacetic acid (NTA) and ethylenediaminetetraacetic acid (EDTA) which are widely used as chelating agents in commercial industry because of their ability to bind with metal ions and form metal organic complexes.
Disinfectant by-products	Disinfection by-products form in wastewater during reactions with chlorine.
Fire retardants (brominated diphenyl ethers(BDES), organophosphates, phenols	Brominated diphenyl esters (BDES) and organophosphates are added to thousands of consumer products because of their fire resistance properties. In 2001, 74.9 million tons were distributed for the manufacture of printed circuit boards used in electronic household equipment, and polyurethane foam padding used in carpets and textiles. BDES are ubiquitous and found in municipal wastewater presumably as a result of their manufacture and use.
Fluorescent whitening agents	Brominated diphenyl esters (BDES) and organophosphates are added to thousands of consumer products because of their fire resistance properties. In 2001, 74.9 million tons were distributed for the manufacture of printed circuit boards used in electronic household equipment, and polyurethane foam padding used in carpets and textiles. BDES are ubiquitous and found in municipal wastewater presumably as a result of their manufacture and use.
Fluorescent whitening agents	Fluorescent Whitening agents (FWA), also called optical brighteners, are used in a variety of commercial products. A large quantity is used in fabric detergents to restore whiteness during washing. Although these FWAs are partially bound to fabrics during the

Chemical category	Description (use and source in wastewater)
	washing process, a considerable fraction (5-80%) remains in the washing liquor and is discharged to the sewer.
Glycol ether	Propylene glycol ethers (PGEs) are comprised of mono-, di- and tri-PGEs and several of their acetate esters. The nature of applications that use PGEs suggests that there is a potential for both intentional and unintentional entry of the materials into the environment through manufacturing and as commercial products through their handling, use, transport and disposal.
Image contrast media	Hospitals and radiological practices use image contrast media for radiographic diagnostics. The compounds comprise the highest proportion of pharmaceuticals used in hospitals and their use exceeds thousands of tons per year. These compounds are discharged to the municipal wastewater after use.
Monocyclic hydrocarbons and heterocycles	Monocyclic hydrocarbons are found in nature and are produced commercially. This class is also referred to as aromatic hydrocarbons because of their characteristic strong, sweet odor. Benzene, toluene, and xylene (BTX) are used most widely as solvents, fuel additives, and ingredients in the manufacture of rubber, insecticide, synthetic chemicals, pharmaceuticals and explosives. This class also includes synthetic fragrances used as additives in perfumes, soaps, air fresheners, detergents, fabric softeners and household cleaning products. Many of these compounds are ultimately discharged to the municipal wastewater following their commercial and household use.
Nitrosamines	Nitrosamines form through reaction during chlorine disinfection of secondary wastewater effluent.
Organotins	Organotins are those compounds containing at least one bond between tin and carbon. They have been used in PVC stabilizers, biocides (antifouling paint formulations), catalysts, agrichemicals, and glass coatings. Organotins enter municipal wastewater primarily from production and commercial use.
Personal care products (PCP)	Personal care products used by humans number in the thousands and are used in large quantities (annual production exceeded 550,000 metric tons in the early 1990s in Germany alone). These chemicals include products such as cosmetics, hairsprays, soaps, detergents, insect repellents, sun-screen agents, skin ointments, and disinfectants. Personal care products enter municipal wastewater following human use.
Pesticides	Used for the control of disease vectors and agricultural pests, these compounds may be discharged to municipal wastewater from commercial production, consumer products, and nonpoint source stormwater runoff. Many compounds in this class are restricted or banned from use (e.g., DDT, aldrin, dieldrin) and evidence suggests that the level of chlorinated pesticides in sewage sludge is declining.
Pharmaceuticals	A wide-ranging class of compounds with approximately 3,000 different substances used in medicines such as pain killers, antibiotics, contraceptives, beta-blockers, lipid regulators, tranquilizers and impotence drugs. As a class pharmaceuticals have substantial variability in structure, function, behavior and activity. Pharmaceutics are released to municipal wastewater following human use.
Phthalate esters/plasticizers	Phthalates and ester/plasticizers are used extensively in commercial applications at a rate that exceeds millions of tons per year. Plasticizers can migrate from plastic to water during use and following disposal.
Polychlorinated biphenyls, polychlorinated naphthalenes, dioxins and furans (PCBS, PCNS, PCCDS and PCDFS)	Polychlorinated biphenyls (PCBs) comprise a class of 209 individual compounds. Historically the two main sources of PCBs were commercial production, commercial applications and formation/release from combustion processes for which PCBs were a bi-product (1.5 million tons produced). The manufacture, processing, use and distribution in commerce of PCBs is banned. PCBs are detected in municipal wastewater and evidence suggests that their levels are not decreasing. PCBs in wastewater are believed to originate from the atmosphere.
Polynuclear aromatic hydrocarbons (PAHs)	PAHs are a group of approximately 10,000 compounds. Most PAHs in the environment are from manufacturing air emissions, consumer products, roadway asphalt, incomplete burning of carbon-containing materials and naturally occurring fires. Many useful products such as mothballs, blacktop, and creosote wood preservatives contain PAHs.

Chemical category	Description (use and source in wastewater)
	They are also found at low concentrations in some special-purpose skin creams and anti-dandruff shampoos. Urban runoff is often attributed as the source of PAH observed in municipal wastewater.
Steroids, sterols & stanols	This class of compounds include hormones that are produced and excreted naturally by humans and animals as well as synthetic therapeutic hormones. These compounds typically enter municipal wastewater through human production/use.
Surfactant (alcoholethoxylate, phenols, nonyl phenols (NP), linear alkylbenzene sulfonates (LAS))	Surfactants are used in many practical applications and products, including detergents, fabric softeners, emulsifiers, paints, adhesives, and biocides. LAS is the most widely used surfactant in the world. Surfactants are discharged to municipal wastewater from the use of common household and personal care products.

Many organic chemicals found in sewage sludge are partially (30 -99%) removed in the sludge or degraded/voltilised during water treatment in the STP. The range of organic compounds known to exist in sludge is extensive and diverse (Langenkamp and Part 2001; Harrison *et al.* 2006). This level of removal will depend on the levels of treatment, retention time and treatment process[13].

However, some organic contaminant can remain in the recycled water. If the organic chemical is not removed during the treatment process and remains in signficant concentration in the recycled, consideration of plant uptake is an important pathway. Plant uptake of organic chemicals is influenced by physico-chemical features of the compounds, environmental conditions and plant characteristics (Ying 2006). An empirical relationship exists between plant uptake and the octanol-water partition coefficient (Kow value). Adsorption of organic compounds onto plant root surfaces increases with increasing Kow values. However, uptake by the root system and subsequent translocation within the plant is more efficient for organic compounds with log Kow values in the range of 1 to 2.5(Ying 2006).

Some organic chemicals have been identified as endocrine disrupting chemicals (EDC). These cases are usually in aquatic systems with direct exposure to effluent with limited treatment (not water recycled from it). Where endocrine disruption has been reported, it is usually where the organism has been exposed 24 hours a day to these chemicals in an aquatic system. That is, exposure is relatively high compared to the application of recycled water to soil (potential for further degradation and adsorption) and then a portion of this potentially taken up by the plant (if it can pass the root membranes). Plant can also adsorb some contaminant from the air or dust settling on the leaf, however, for irrigation of recycled water below the vine leaf canopy this pathway is unlikely (Ying 2006).

The likelihood of plant uptake is considered low for many organic chemicals. Historical data also support this as there is very little evidence for soil-crop transfer, despite the increasing intensity and extent of scientific investigation into the potential environmental consequences of organic contaminants applied to farmland in sewage sludge,. This observation suggests that the soil-plant root barrier is effective in preventing plant uptake for many plants. However, it should be noted that there seems to be limited data on this pathway specifically for grapevines.

Plant uptake is generally accepted as low because those compounds exhibiting some solubility and potential for plant uptake are also susceptible to rapid degradation processes in soil or are lost through volatilisation (a pathway to the plant also), whereas other more persistent compounds

[13] www.trentu.ca/academic/aminss/envmodel/models/STP211.html

usually have very low solubilities and are strongly adsorbed by the soil matrix in non-bioavailable forms.

Safety barrier for contaminants in the berry/wine are:

- Treatment process (STP)
- Soil degradation or adsorption
- Root membrane barrier
- Wine making process and storage time

The mulitbarriers identified above suggest the risk of organic contaminants potential found in recycled water reaching the grape berry or wine and causing food quality concerns is low. However, the build up of any organic chemical in the soil may not have any immediate impacts on this environment, but may have an impact on alternate uses for that land in the future. With recycled water treated to a high standard fit for fresh food production the concentration of organic chemical applied is generally very low. However, as grapes can be grown with water treated to a much lower level, a detailed risk assessment to quantify these risks should be undertaken. Some experimental work has been completed in Australia on winery wastewater (Kumar and Kookana 2006). However, there seems to be limited risk assessments of organic chemicals specifically relating to the viticultural sector for using recycled water.

6.9.1 Knowledge gaps and future issues

The data reviewed above indicated the risk to contamination of berries or wines from organic chemicals of concern is low, given the multibarriers. However, due to the range of chemicals potentially present in recycled water and the fact that recycled water with relatively low levels of treatment can be used to irrigate grapevine crops, a detailed environmental and human health risk assessment has been recognised as a knowledge gap. Such a risk assessment should focus specifically on pathways within the viticultural sector and identify any hazards that could pose a significant risk to soil contamination, soil microbes, aquatic systems, berry or wine quality and human health. The AGWR provide a framework for undertaking this type of risk assessment (NRMMC and EPHC 2006).

6.10 Plant pathogens

Plant pathogens detected from water resources (not water recycled from sewage effluent, but some effluents from other practices on farm or recycled within hydroponic systems) include 17 species of Phytophthora, 26 of Pythium, 27 genera of fungi, 8 species of bacteria, 10 viruses, and 13 species of plant parasitic nematodes (Hong and Moorman 2005). These observations highlight that plant pathogens can be transported in water. Plant pathogenic fungi occur most commonly in water sourced from the nursery and are most likely to cause disease in young grapevine (Stephens *et al.* 1999). In fact, there is substantial evidence demonstrating that contaminated irrigation water is a primary, if not the sole, source of inoculum for Phytophthora diseases of numerous nursery, fruit, and vegetable crops (Hong and Moorman 2005).

To-date limited data is available on the risk from plant pathogens in water recycled from treated sewage water (Cole *et al.* 1969; Mehl and Epstein 2008}. However, if water is recycled from other sources this may need to be managed (eg hydroponic systems - Cole *et al.* 1969; Potato washing - Mueller and Parusel 1998).

There is limited data relating plant pathogens in sewage influent or effluent from STPs (Cole *et al.* 1969). In theory, the loads of plant pathogens entering the sewer would be orders of magnitude lower than human pathogens (the highest loads to sewer is usually fecal). Therefore it would be reasonable to assume that if the required log reduction in pathogens for human safety is met by treatment then the concentration of plant pathogens would be fairly low (assuming similar removal rates to human pathogens – however, there is little information to confirm this assumption). It is also worth noting that a large portion of plant material usually ends up in bins and doesn't enter the sewer systems, and highly infected plant material usually doesn't make it to the market. These observations suggest that any plant pathogen in sewage water would be low in concentrations relative to human pathogens.

A complication to the assumption above is that grapes for wine production can be irrigated with water recycled from STPs with limited treatment. The protection from exposure to humans by human pathogens can be achieved by end use restrictions (eg. Drip irrigation or subsurface drip - Table 14 and Table 16), rather than treatment. More than 75% of the vineyard plantings in Australia are drip irrigated (Rawnsley 2008). However, this does not provide the protection required to minimise the exposure of plant pathogens to plants if they are present in the recycled water. The recycled water, with limited treatment, could be exposed directly to the vine. Therefore this is an area requiring further research to ensure the different qualities of recycled water use to irrigate vines does not become a vehicle for infection of grapevines with plant pathogens.

There has been some research to determine if use of recycled water increases susceptibility of vines to fungal diseases (Rawnsley 2008). This research indicates no difference in susceptibility between recycled water irrigated and traditional water irrigated vines. It also indicated that the recycled water improved microbial activity in the soil and nutrient availability (Rawnsley 2008).

Historical evidence from the Northern Adelaide Plains, SA indicates that vines irrigated for more than 25 years with Class D recycled water (Stevens *et al.* 2003b – personnel communication during this research) has no observed plant pathogen occurrence or impact on plant health or production. These observations suggest that the likelihood of the occurring is probably low, however, no literature supporting these observations could be found.

6.10.1 Knowledge gaps and future issues

There is limited data on presence of plant pathogens in sewage water and their removal though STP and the recycling process. The assumption has been that if recycled water is treated to a standard for irrigation of fresh foods then human pathogen will be removed (known) and plant pathogens will be also (unknown). However, water treated to a relatively low level can be used to irrigate vines through drip irrigation as berries are not contacted by the recycled water directly and/or there is a treatment step after harvesting.

Therefore recycled water with limited treatment can be exposed directly to plant vine roots and the level of plant pathogens in STP effluent is a knowledge gap.

7 FINANCIAL RISKS ASSOCIATED WITH SUPPLY OF RECYCLED WATER

In Australian irrigated agriculture there has been a history of relatively low water costs and high levels of inefficiency where arguably the economics of production is not inclusive of the "real cost of water". In a recent government report[14] some statistics listed were:

- Agriculture uses 14,000 GL annually
- 20% of water delivered to farms may be lost in on-farm distribution
- 60% of water is irrigated using high volume, inefficient gravity irrigation methods
- 10-15% of irrigation water is lost due to over irrigation

The cost and associated attitude towards irrigation of crops has been established largely on the premise that low cost high quality water has been freely available for production. This has seen the development of irrigated agriculture in Australia that has largely been developed using outdated technology with a low level of management.

The wine grape industry has been one sector of industry that has embraced newer and more efficient irrigation technologies. It could be argued that grape quality and deficit irrigation has been a significant driver for improved irrigation methodologies because as production has demanded greater irrigation control adoption of improved irrigation technology has been required to meet this demand[15].

7.1 Pricing of recycled water in Australia

A wide range of drivers, sometimes conflicting, have been taken into account in the costing and pricing of recycled water across Australia. The economics of water reuse has been discussed by others (Mooney and Stenekes 2008; Radcliffe 2007). The price for using recycled water is rapidly becoming similar to potable water sources (Table 41) in the urban context. There is also an increasing emphasis on the usage charge and reduced emphasis on the access charge (Radcliffe 2007). These changes will put pricing pressures on recycled water across all uses that have access to it.

However, there remains considerable variation in the charging policies of different suppliers. City West Water in Melbourne charges $0.8205/KL for recycled water, identical to the first tier of the three tier drinking water charge scale used by that supplier. SA Water at Mawson Lakes in Adelaide charges 75% of the second tier drinking water charge (currently $1.09) making the recycled water charge $0.82/KL, although its charge for the first 125KL/year (first tier) of drinking water is $0.47/KL, significantly lower than that for recycled water. Industrial users are paying a premium price of approximately $1.10/KL for recycled water from the Kwinana Water Reclamation Plant, the maximum price for drinking water charged to industrial users in Perth being $0.841/KL. It is evident that there needs to be further policy development in the determination of water prices, whether for drinking water or the various recycled water uses (Radcliffe 2007).

[14] www.environment.gov.au/water/agriculture/irrigation.html

[15] www.water.gov.au/WaterUse/Agriculturalwateruse/index.aspx?Menu=Level1_4_4

Table 41 Price path for recycled water provided by Sydney Water at Rouse Hill, 2006 - 2009

Water/Item	2006-07	2007-08	2008-09
Recycled water			
Usage ($/KL)	0.30	0.71	1.11
Access charge ($)	26.03	18.69	10.59
Drinking water			
Usage ($/KL) Tier 1	1.26	1.30	1.35
Tier 2	1.63	1.77	1.91
Access charge ($)	64.40	54.44	45.19

Source: Radcliffe 2007

If the costs of recycling water are compared to other sources of water the range in cost varies considerable between and within difference sources (Figure 15). This variation highlights the complexities of each specific systems and specific assumptions made on a case by case basis. Some specific cases are discussed in the following sections to highlight these complexities and knowledge gaps which may assist the viticultural sector assess the feasibility of developing reuse schemes given the limited resources of recycled water and the many demands for it (Section 3.2 and 3.3).

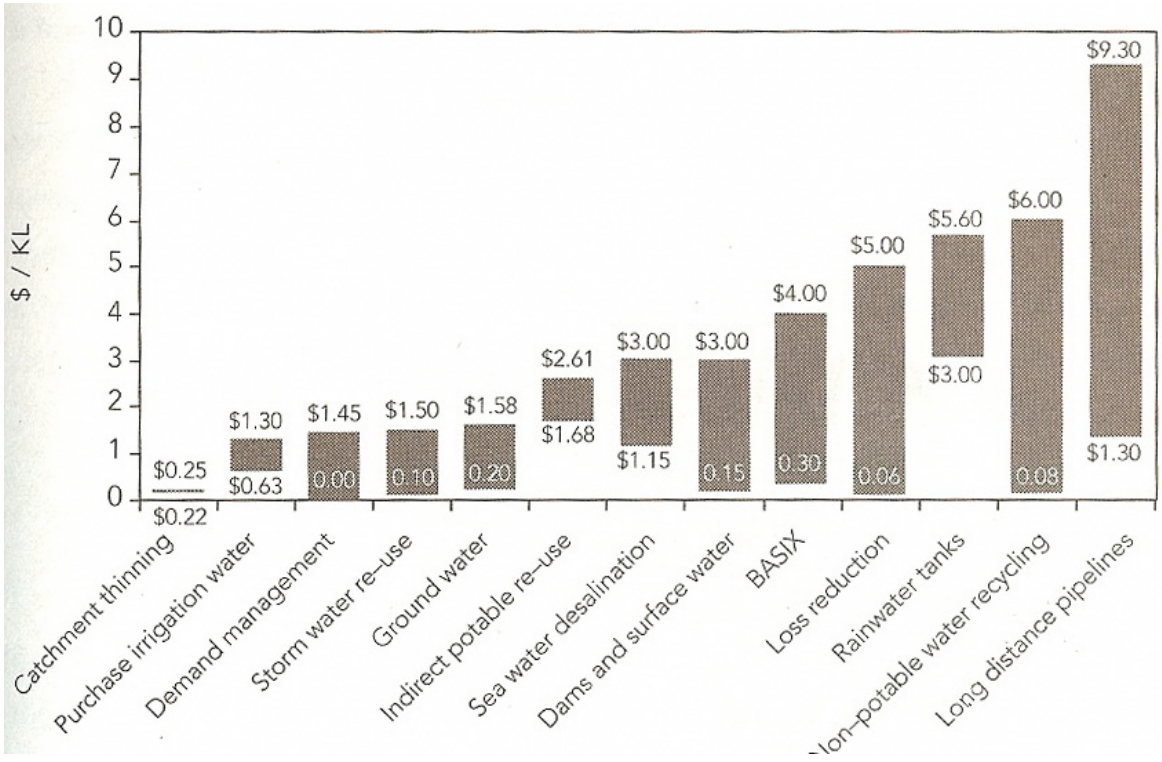


Figure 15 Direct cost of water supplies across Australia (Source Walquist 2008)

7.2 Infrastructure/treatment

Any discussion of the role that recycled water can play in the current and future needs of the viticultural sector must include a discussion into the relative cost of irrigation water. Treatment of STP effluent to produce recycled water for the irrigation of wine grapes or any other crop centres around the balance between the level of water treatment required to make the water fit for the intended use (Section 3.1) and the cost of water. As a general rule, the lower the level of water treatment, the lower the cost of treatment.

There are a variety of irrigation methods used in the wine grape industry, the two predominate methods include under canopy drip irrigation and spray irrigation. Water quality (health indicated by the respective guideline class) influences the type of irrigation method that can be used (Section 3.1). The use of drip irrigation with low/no aerosol production and no fruit contact allows the lower classes (less treatment) of recycled water to be used. This has the potential to keep the relative cost of recycled water low.

Table 42 highlights the similarities and differences in the recycled water schemes delivering water to three different vineyards. Of interest is that each of these schemes has not chosen high levels of treatment to improve water quality. By using under canopy drip irrigation they have been able to manage with Class C or B water, hence reducing the need for further high cost treatment. This feature of vineyard irrigation is usually attractive for Water Authorities as there has been little or no additional treatment while at the same time effectively managing their waste stream.

Table 42 Information on recycled water schemes where the predominate clients are vineyards

Irrigation Scheme	Water Quality	Volume p.a.	Typical Irrigation Volume	Capital Contribution	Cost/ML	Customer	Delivery System
Willunga Basin Water Company [A]	Class C South Australian Reclaimed Water Guidelines	4.5 GL	2.5ML/ha	$6600/ML	$680	105	Delivered under pressure to farm
Mt Barker Vine Irrigation Scheme[B]	Secondary treated water with chlorination (Class B)	60-70 ML	0.7-1ML/ha	User supplied all infrastructure	$40/ML	1	Supplied to an on-farm dam
Great Western Wine Growers Agreement [C]	Class C Victorian Recycled Water Guidelines	330 ML	0.8-2ML/ha	Nil	$100 – $150 rate varies as per agreement		Not available

[A] figures provided are for the 07-08 drought, there is also a potential $250/ML non usage
[A] *pers comm.* Glen Templeman, Willunga Basin Water Company
[B] *pers comm.* David Juers, Water Corporation & Max Mollam, Constellation Wines
[C] *pers comm*. Shane Philips, GWM Water

7.2.1.1 Cost of Salinity Management

Salinity is a problem effecting irrigated agriculture nationally. Water salinity can be a problem for plant water availability and crop nutrition through the osmotic effect and competition for uptake at the root – soil interface (Sections 6.2.2 and 6.3). Increasingly growers and water managers are looking at reverse osmosis (RO) as a way of improving water quality for irrigation purposes.

Table 43 highlights the capital cost and operational cost of RO in treating water to a salinity level of 500 mg/L (EC 0.32 dS/m). Reverse osmosis can add significantly to water treatment costs for growers. Also with any RO system there is a significant level of highly saline waste which can be difficult to dispose of.

Table 43 Estimate desalination treatment costs, target salinity 500 mg/L for a RO unit to treat 100 ML/annum (note: the costs include pre-treatment costs)

Salinity					
Feed (mg/L)	Feed dS/m	RO Capex ($/ML)	RO Opex ($/ML)	Waste Stream (%)	Waste Salinity (mg/L)
1000	1.48	1200	1100	24	5167
2000	2.96	1200	1100	24	10333
3000	4.44	1200	1100	24	15500
5000	17.4	1200	1100	24	25833
10000	14.8	1200	1350	30	43333
30000	44.06	2850	2900	55	84545

Based on 640 mg/L = 1 dS/m. Source: Peter Makris, Lucas Water

There could be an opportunity for the desalinisation of wastewater for the irrigation of vineyards. For example if a grower required 100 ML per annum and the inflow water salinity was 5000 mg/L or less the capital cost of the plant would be $120 000 with an annual operational cost of $110 000. Assuming a payback over 10 years at 10% interest the capital contribution repayment would be $19 032 p.a. The total RO cost to produce 100 ML of irrigation water at 500 mg/L including capital and operational costs will be approximately $130 000 or $1 300 per ML. This cost could potentially be a barrier to the use of reverse osmosis for polishing recycled water for irrigation purposes.

As a management strategy for controlling the salinity of recycled water for irrigation purposes it will be a cheaper model to, where possible, control salinity at the source (Source control).

7.3 Storage

A significant management issue with recycled water is that it is produced all year round and not closely linked with crop demand; often peak flows can occur in winter when crop demand is at its lowest. This is particularly true in the cooler temperate climates of southern Australia where the predominant production of wine grapes occur and for the seasonal nature of grape irrigation.

The cost of storage infrastructure (Table 44) can be a significant burden with respect to the cost of water. Storage can also allow evaporation (cause degradation of water quality by increasing salinity) and eutrophication (if exposed to sunlight with high levels of nitrogen and phosphorus) lead to the deterioration of water quality and requirement for additional treatment which comes at a cost of infrastructure and operation.

Table 44 Typical cost of irrigation water storage dams, liners and covers

Dam Volume	Dimensions (m)			Construction cost $	Liner cost $	Cover cost $	Total cost $
	Length	Width	Depth				
10 ML	54	54	8	13,000	41,000	41,000	95,000
100 ML	170	112	8	90,000	180,000	246,000	516,000
1 GL	436	300	10	560,000	1,100,000	1,550,000	3,210,000
10 GL	1380	850	10	1,686,000	8,900,000	14,000,000	24,586,000

Source: *Pers Comm*. Max Brady, Darling Downs Tarpaulin and Trevor Brooks, Brooks Earthmoving. Assume batter of 1:2.5 and 0.5 m freeboard for the 10 & 100ML dams and 1.0 m for the 1&10 GL dams. Costs vary from site to site depending local soil conditions.

Evaporative losses can be significant in some areas (especially in shallow dams) and can add significant cost to irrigation water. Some suggest that Australian farm dams and water storages could lose as much as 40% of their storage capacity (Considine 2007). Typical surface evaporation could be as high as two metres. Examining the dam depths in Table 44 of eight and ten metres then losses would be of the order of 25% and 20% respectively. However, it is important to note that dams rarely have vertical sides so the largest surface area is when the dam is full therefore losses could be greater.

Taking the 100 ML dam as an example (Table 44) with, dimensions of 170 x 112 metres with a surface area of 19,040 square metres assuming a 2 m evaporation loss (not considering rainfall additions), 38 ML of water would be lost. Using the Willunga Basin Water Company cost of water ($710/ML in the 2008-09 irrigation season, *pers. comm*. Glen Templeman) this water loss is the equivalent of $27,000. Assuming 4.0% inflation and 10% interest a cover cost of $246 000 pay back would occur in 16 years. Note that the Willunga Basin Water is supplied directly to growers under pressure and hence no dams are required. The water price for the Willunga Basin scheme was used as an example as it is the highest known price for recycled water used for irrigation of vines and hence would represent a best case scenario.

If a 100 ML dam is required (built, lined and covered) the total cost would be $516,000 (Table 44). Cost for 10 years at 10% per annum interest is $82 000 per annum. This reflects a per megalitre storage cost of $820 /ML/annum. If the capital recoupment period is increased to 20 years the cost per megalitre reduces to $600 /ML/annum. However, if a liner and cover are not required then the 10 year cost recoupment on a 100 ML dam would be $140 per ML/annum.

7.4 Reticulation

A significant barrier to the utilisation of recycled water for irrigation is the reticulation cost. Channels can be more cost effective than pipes, however, are seen as inefficient for the delivery and transfer of irrigation water due to losses (evaporation and seepage) and maintenance requirements. For example, Wimmera and Murray Goulbourn channel systems are being replaced by pipes.

Piping water over long distances has significant capital and operational costs (Table 45). The development of recycled water schemes in Australia has largely been limited to developments where there has been an irrigation district in reasonable proximity to the STP (Boland *et al.* 2006). Over the last decade several proposals to treat effluent wastewater from Brisbane and deliver to the Lockyer Valley and the Darling Downs which have failed partly on the grounds of water transfer costs.

Table 45 Cost of installed pipes typically used for reticulating water

Pipe size	Nominal pressure	$/m Installed	Flow rate L/s	Pump station require (km)
75 mm	Class 12	35	3	10
110 mm	Class 10	75	7	10
200 mm	Class 10	120	35	10
355 mm	Class 10	200	150	10
450 mm	Class 10	375	300	10
450 mm	Class 20 ductile	480	500	10

Source: Chris Farrell, GROMeng Pty Ltd. Specific site costs vary considerable soil and topography.

For example, a scheme of approximately 0.5 – 2.6 GL per annum a 355 mm pipeline will be required assuming that the water is delivered over a 200 day period. This would cost $200,000 per km. The cost per ML of water based on pipe infrastructure alone ranges from $400 (0.5 GL/annum) to $77 (2.6

GL/annum). These costs are calculated using 355 mm pipe and do not include pump station casts. If these costs are amortised over 10 years at 10% interest then the pipe cost per ML of water is $60 to $12 per annum respectively.

This type of information could be used to undertake a resource audit to identify the opportunities for the viticultural industry to utilise recycled water; identifying suitable sites where recycled water schemes could be developed to meet the needs at reasonable water costs.

7.4.1.1 Reticulation through existing infrastructure

As discussed above, the cost of providing infrastructure to reticulate recycled water adds a significant cost to the water (Section 7.4). One option to lower this cost is deliverance of recycled water through existing infrastructure. There are obvious health issues with respect to mixing water of any lower quality with drinking water. Therefore, any recycled water using a potable reticulation system will need to treat the water to a level fit for drinking. Treating STP effluent to this quality comes at a significant cost ($1680 to $2610/ML; Figure 15).

For example, a review of the literature has not revealed evidence of joint access for the delivery of non-potable recycled water and potable water through existing potable infrastructure. In South Australia irrigation water is delivered from the River Murray to Clare Valley and Barossa Valley grape growers. However, this water is from the same source (the River Murray) as the potable supply delivered through this infrastructure where the treatment and management of that water is carried out by SA Water.

Alternately, if the existing infrastructure reticulates irrigation water only (not fit for drinking) then it could be used to reticulate a similar quality (or often better) of recycled water. For example, the Werribee Irrigation District has been able to utilise their existing irrigation channel system for the delivery of recycled water to vegetable growers. In this instance the channels are scheduled for alternate flows of recycled water (Saturday to Thursday) and river irrigation water (Friday only). Since the commencement of the scheme in 2004 through to 2008 92% of WID growers are licensed to use recycled water, compared to approximately 40% in 2004 when the scheme commenced. This practice could be used in other irrigation districts where there is common infrastructure.

7.5 Knowledge gaps and future issues

There are a number of economic constraints that require careful evaluation to determine the financial feasibility of collecting and treating water for distribution to the viticultural sector.

The cost of water is a function of water treatment, length and size of pipe infrastructure and storage requirements. The parameters vary considerably between specific reuse schemes. However, as discussed above it would be valuable to undertake a resource audit for viticulture to identify where opportunities could potentially exist for development or use of recycled water. This is currently a gap in the available knowledge.

A recycled water development package could potentially be developed to help investors (growers or otherwise) assess the feasibility/risk of any potential opportunities of supplying recycled water to existing or new establishments of vines. There could be significant opportunity for private development with smaller regional STPs if not already recycling their water. If recycled water is already allocated there may also be opportunities to changes farming systems to viticulture (eg for new developments of vines).

7.6 Public image and acceptance of recycled water use

The risk of rejection of wine made from berries grown with recycled water due to poor public acceptance is low; especially given the historic use and growing public support for water recycling. However, the financial impact potential high.

The irrigator and public's image of recycled water has changed dramatically over the last decade. Recycled water has grown in a decade from the 'Yuck Factor' to 'Environmental Friendly' and the thing to do. This change has been pushed through prolonged drought and pulled by extensive communication, education and knowledge exchange over the last 20 years (e.g. www.recycledwater .com.au; Mooney and Stenekes 2008). Australia has gone from disposal operations into forestry with low risk and public exposure, to several recycled water schemes that recycle water for production of freshly eaten food crops (Boland *et al.* 2006; Hamilton *et al.* 2005; Kracman *et al.* 2001). In the late 90s public scrutiny and acceptance of recycled water for use in horticultural food production was high (Stevens *et al.* 2004; Symes and Nancarrow 2006).

Many of the guidelines and control measures used in development and operation of recycled water schemes across Australia have been shown to project human health, the environment and agronomic systems. Acceptance of recycled water for these purposes has now changed dramatically and the focus in many parts of the country has been turned toward indirect potable reuse of recycled water (NRMMC and EPHC 2008; Hurlimann 2008; Law 2006; Marks 2006; Rodriguez *et al.* 2007; Sheikh 2003; Toze 2008).

The wine industry may be slightly different to other food industries when it comes to the acceptance of recycled water use. However, recently the world's best Shiraz wine was awarded to Witchmount Estate for a wine grown with recycled water[16]. In fact, without recycled water this vineyard and winery would not exist (Tony Remano *pers comm*).

It is not widely known or promoted that this wine was grown with recycled water and the public acceptance of this practice for wine production has not been accessed directly (Marks *et al.* 2006; 2008; Nancarrow *et al.* 2008). However, similar values to other food crops grown with recycled water would be expected, given the known relationship between the distance of people from contact with produce grown with recycled water, or recycled water directly used, and acceptance (Marks *et al.* 2006). If this is the case, then the risk of consumer rejection of wines from berries grown with recycled water would be low. However, this has not been measured directly in the wine industry.

7.6.1 Knowledge gaps and future issues

The risk of rejection of wine made from berries grown with recycled water due to poor public acceptance is low; especially given the historic use and growing public support for water recycling. However, the financial impact is potentially high. To our knowledge this has not been directly measured in the viticultural sector, and is therefore a knowledge gap identified.

[16] www.syrah-du-monde.com/pages/20_result/index.en.html

8 CONCLUSIONS

The technology is available to produce clean water to whatever specifications are required to make it fit for the intended purpose from a human health and environmental perspective. However, as the level of treatment increases the embedded cost of the water increases. Costs of water are also linked to storage and reticulation requirements. Therefore, the lower the levels of treatment required, smaller distance required for reticulation and minimisation of storage will minimise the costs associated with recycling water.

While minimising treatment, storage and reticulation can minimise the actual cost of recycled water, the low quality water relies on restriction on-site to minimise human health and environmental risk. Therefore, control measures and use of recycled water requires good management practices to be maintained to avoid short and/or long-term impacts from the use of the recycled water. Given the number of recycled water irrigation schemes operating successfully in the world, it is clear that such systems can be made safe in terms of pathogenic organisms and (at least) short-term human health. The industry has thus moved successfully from theory into practise. As the industry expands, the following research areas might prove valuable:

Recommendations for future investment by GWRDC in research pertaining to use of recycled water in viticulture including those summarised in Table 1 in the Executive Summary.

This feasibility study has identified several areas where knowledge gap exists when using recycled water for irrigation in the viticultural sector. Before additional research is undertaken the potential for use of recycled water should be considered to determine the economic feasibility and opportunities for recycled water use across Australia.

The study also identified in many cases that sufficient research has been undertaken. However, the translation of the data into practical solutions for the use of recycled water in the viticultural sector specifically was not available. If opportunities are found to exist, a handbook (or the like) for using recycled water in the viticultural sector may benefit users or developers.

Where other information gaps were identified, the majority should be undertaken to ensure the long-term sustainable and beneficial use of recycled water is practiced in this industry without detrimental impacts on the environment or product quality. An order of priority and logical sequence for filling these gaps is also outlined in the Executive Summary.

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10 APPENDICES

10.1 Additional elemental analysis of grapes

Table 46 Elemental analysis of grapes

Sample location and grape type	Ca	Mg	Na	K	Cl	S	P	Zn	Cu	Fe	Mn	Dry Wt
	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	%
03 McLaren Vale Shiraz 1	0.11	0.05	0.01	0.91	0.05	0.05	0.11	1	6	10	6	34.3
06 McLaren Vale Shiraz SRHS	0.13	0.05	0.00	1.03	0.03	0.06	0.11	2	2	14	8	31.1
11 McLaren Vale Shiraz 4	0.12	0.05	0.01	1.02	0.08	0.06	0.12	1	8	18	9	36.0
05 Langhorne Shiraz	0.14	0.05	0.01	1.19	0.12	0.05	0.14	2	4	13	7	29.0
16 Langhorne Shiraz 2 1	0.12	0.05	0.00	1.17	0.06	0.05	0.13	2	3	11	8	25.1
07 Padthaway Shiraz	0.10	0.04	0.02	0.95	0.08	0.05	0.10	0	3	10	6	29.5
01 Padthaway Cab Sauv	0.09	0.05	0.00	1.04	0.06	0.06	0.12	0	3	16	6	29.9
04 Deakin Estate Cab Sauv	0.10	0.05	0.00	0.84	0.01	0.05	0.09	0	1	12	10	28.7
17 LCV Cab Sauv SRHS	0.11	0.04	0.00	0.72	0.03	0.05	0.09	0	10	8	6	25.5
09 Sthn Flinders Cab	0.15	0.06	0.00	1.48	0.04	0.08	0.14	2	3	24	13	28.4
12 LCV Merlot	0.09	0.04	0.01	0.74	0.02	0.04	0.10	0	8	9	5	29.3
02 Padthaway Semillon 2004	0.09	0.04	0.00	0.92	0.04	0.04	0.10	0	2	13	5	32.5
10 Padthaway Semillon	0.11	0.04	0.00	0.93	0.05	0.05	0.11	0	3	15	5	31.5
08 Clare Sauv blanc	0.10	0.05	0.00	1.38	0.02	0.06	0.13	1	7	15	8	24.2
13 Eden Valley Riesling 2	0.07	0.04	0.01	0.97	0.06	0.05	0.12	0	2	17	6	25.5
14 Eden Valley Riesling 1	0.08	0.04	0.00	0.81	0.05	0.04	0.12	0	2	15	5	24.5
Average	**0.11**	**0.05**	**0.00**	**1.01**	**0.05**	**0.05**	**0.11**	**0.7**	**4.2**	**13.8**	**7.1**	**29.1**

Source: Richard Merry pers.comm. (2008)

10.2 Australian Sewage Treatment Plants within 200 km of established Viticulture Areas

See table next page.

Table 47 Australian Sewage Treatment Plants within < 200km of established Viticulture Areas

STPS Region	Town/suburb	State	Total WW ML/yr	Dry Season WW avail. ML/yr	Viticulture Closest Wine district	Township	STP to WD (est.) km	Area Vines Ha	Min Vol Req ML	Max Vol Req ML	Case 1[A] $/ML CVR.	Demand met - Case1	Case 2[A] .. $/ML/ CVR.	Demand met - Case2	Number of STP in km < 10	10-20	20-50
Tweed Shire	Banora Point	NSW	2600	1196	Granite Belt	STANTHORPE QLD 4380	163.7	600	300	1800	3764	66%	3710	144%	0	0	0
Tweed Shire	Kingscliff	NSW	540	167.4	Granite Belt	STANTHORPE QLD 4380	166.2	600	300	1800	4160	9%	3983	30%	0	0	0
Young Shire	Young	NSW	700	280	Hilltops	YOUNG, NSW 2594	0.5	700	350	1400	446	20%	312	50%	1	0	0
Yass Shire	Yass	NSW	490	0	Hilltops	YOUNG, NSW 2594	78.4	700	350	1400		0%	1173	35%	0	0	0
Port Stephens	Karuah	NSW	75.9	0	Hunter	CESSNOCK, NSW 2325	59.7	4000	0	8000		0%	1126	1%	0	0	0
Cessnock	Branxton	NSW	459	160.65	Hunter	CESSNOCK, NSW 2325	17.4	4000	0	8000	572	2%	413	6%	0	1	0
Maitland	Morpeth	NSW	3720	1636.8	Hunter	CESSNOCK, NSW 2325	27.5	4000	0	8000	296	20%	191	47%	0	0	1
Maitland	Farley	NSW	1610	0	Hunter	CESSNOCK, NSW 2325	17.7	4000	0	8000		0%	240	20%	0	1	0
Port Stephens	Raymond Terrace	NSW	2110	1012.8	Hunter	CESSNOCK, NSW 2325	36.8	4000	0	8000	440	13%	342	26%	0	0	1
Cessnock	Kurri Kurri	NSW	1340	536	Hunter	CESSNOCK, NSW 2325	12.1	4000	0	8000	369	7%	243	17%	0	1	0
Cessnock	Cessnock	NSW	1570	15.7	Hunter	CESSNOCK, NSW 2325	1.6	4000	0	8000	960	0%	203	20%	1	0	0
Maitland	Shortland	NSW	2340	1146.6	Hunter	CESSNOCK, NSW 2325	32.4	4000	0	8000	382	14%	288	29%	0	0	1
Cessnock	Paxton	NSW	27	6.48	Hunter	CESSNOCK, NSW 2325	11.8	4000	0	8000	1188	0%	865	0%	0	1	0
Maitland	Edgeworth	NSW	6150	2337	Hunter	CESSNOCK, NSW 2325	27.8	4000	0	8000	252	?	131	?	0	0	1
Maitland	Dora Creek	NSW	1080	0	Hunter	CESSNOCK, NSW 2325	32.6	4000	0	8000		0%	392	14%	0	0	1
Mudgee Shire	Gulgong	NSW	150	0	Mudgee	MUDGEE, NSW 2850	22.4	3350	1675	6700		0%	609	2%	0	0	1
Mudgee Shire	Mudgee	NSW	1000	200	Mudgee	MUDGEE, NSW 2850	3.6	3350	1675	6700	499	3%	265	15%	1	0	0
Tenterfield Shire	Tenterfield	NSW	300	0	New England	TENTERFIELD, NSW 2372	2.9	150	0	150		0%	544	200%	1	0	1
Hastings	Port Macquarie	NSW	3800	1900	North Coast	PORT MACQUARIE, NSW 2444	1.7	0	0	0	177	0%	89	0%	1	0	0
Orange City	Orange	NSW	3900	0	Orange	Orange	0.8	1500	750	1500		0%	85	260%	1	0	0
Orange City	Spr.Hill/Lucknow	NSW	32	0	Orange	Orange	14.5	1500	750	1500		0%	841	2%	0	1	0
Murray Shire	Moama	NSW	400	0	Perricoota	MOAMA, NSW 2731	6.9	450	0	0		0%	399	0%	1	0	0
Corowa Shire	Corowa	NSW	720	0	Rutherglen	RUTHERGLEN, VIC 3685	8.7	1000	750	3500		0%	318	21%	1	0	2
Shoalhaven City	Bomaderry	NSW	1100	#N/A	Shoalhaven Coast	BERRY, NSW 2535	13.1	50	0	25		#N/A	885	4400%	0	1	1
Shoalhaven City	Nowra	NSW	2000	0	Shoalhaven Coast	BERRY, NSW 2535	14.9	50	0	25		0%	892	8000%	0	1	1
Gundagai Shire	Gundagai	NSW	220	59.4	South West Slopes	C/- PO NANGUS, NSW 2722	18.8	0		0	746	0%	529	0%	0	1	0

STPS Region	Town/suburb	State	Total WW ML/yr	Dry Season WW avail. ML/yr	Viticulture Closest Wine district	Township	STP to WD (est.) km	Area Vines Ha	Min Vol Req ML	Max Vol Req ML	Case 1[A] $/ML CVR.	Demand met - Case1	Case 2[A] .. $/ML/ CVR.	Demand met - Case2	Number of STP in km < 10	10-20	20-50
Wagga Wagga	Narrung St	NSW	4500	2160	South West Slopes	C/- PO NANGUS, NSW 2722	50.3	0		0	493	0%	400	0%	0	0	0
Tumut Shire	Tumut	NSW	500	220	South West Slopes	C/- PO NANGUS, NSW 2722	41.5	0		0	709	0%	587	0%	0	0	1
Armidale-Dumaresq	Armidale	NSW	2200	0	Southern New England	ARMIDALE, NSW 2350	0.8	0	0	0		0%	158	0%	1	0	0
Stanthorpe	Stanthorpe	QLD	350	87.5	Granite Belt	STANTHORPE QLD 4380	1.9	600	300	1800	632	5%	413	19%	1	0	1
Kingaroy	Kingaroy	QLD	550	126.5	South Burnett	KINGAROY, QLD 4610	0.6	450	225	1350	571	9%	347	41%	1	0	0
SA Country	Gumeracha	SA	50	0	Adelaide Hills	Mt BARKER, SA 5251	26.6	3800	1900	7600		0%	823	1%	0	0	5
SA Country	Bird-in-Hand (Winery)	SA	280	#N/A	Adelaide Hills	Mt BARKER, SA 5251	16.3	3800	1900	7600		#N/A	481	4%	0	1	6
SA Country	Hahndorf	SA	380	0	Adelaide Hills	Mt BARKER, SA 5251	5.8	3800	1900	7600		0%	405	5%	1	1	4
SA Country	Mount Barker	SA	660	171.6	Adelaide Hills	Mt BARKER, SA 5251	0.0	3800	1900	7600	522	2%	321	9%	1	0	4
Adelaide	Bolivar	SA	45700	4570	Adelaide Plains	VIRGINIA , SA 5120	12.4	500	250	1250	**253**	366%	50	3656%	0	1	4
SA Country	Angaston	SA	100	38	Barossa	TANUNDA SA 5352	8.6	10000	5000	25000	791	0%	619	0%	1	0	2
Metropolitan	Glenelg	SA	20800	4576	Currency Creek	CLARENDON, SA 5157	17.6	900	450	2250	106	203%	196	924%	0	1	4
SA Country	Mannum	SA	90	0	EDEN VALLEY	EDEN VALLEY, SA 5235	31.4	1750	875	4375		0%	757	2%	0	0	2
SA Country	Murray Bridge	SA	970	0	Langhorne Creek	LANGHORNE CREEK, SA 5255	29.4	6050	3025	15125		0%	381	6%	0	0	2
SA Country	Strathalbyn	SA	100	0	Langhorne Crk	LANGHORNE CREEK, SA 5255	13.5	6050	3025	15125		0%	634	1%	0	1	4
SA Country	Milang	SA	50	3.5	Langhorne Crk		14.0	6050	3025	15125	1373	0%	756	0%	0	1	4
SA Country	Victor Harbor	SA	990	415.8	Currency Creek	Currency Creek, SA	17.6	900	450	2250	428	18%	305	44%	0	1	3
Metropolitan	Christies Beach	SA	10700	856	McLaren Vale	McLAREN VALE, SA 5171	9.4	6050	3025	15125	296	6%	50	71%	1	1	2
SA Country	Aldinga	SA	200	0	McLaren Vale	McLAREN VALE, SA 5171	9.1	6050	3025	15125		0%	508	1%	1	1	2
SA Country	Myponga	SA	40	0	Southern Fleurieu	MT COMPASS, SA 5210	15.2	350	175	875		0%	802	5%	0	1	2
SA Country	Port Augusta W	SA	230	0	Southern Flinders	PORT GERMEIN, SA 5495	63.1	150	75	375		0%	999	61%	0	0	0
SA Country	Renmark	SA	220	41.8	Southern Flinders	PORT GERMEIN, SA 5495	63.1	150	75	375	1287	11%	1006	59%	0	0	0
West Tamar	Riverside	TAS	1020	408	Tasmania	147 Davey St, Hobart, Tasmania 7000	163.1	1000	0	1500	3890	27%	3761	68%	0	0	0
Brighton	Bridgewater	TAS	1100	0	Tasmania		16.5	1000	0	1500		0%	286	73%	0	1	0

STPS Region	Town/suburb	State	Total WW ML/yr	Dry Season WW avail. ML/yr	Viticulture Closest Wine district	Township	STP to WD (est.) km	Area Vines Ha	Min Vol Req ML	Max Vol Req ML	Case 1[A] $/ML	CVR.	Demand met - Case1	Case 2[A] .. $/ML/	CVR.	Demand met - Case2	Number of STP in km < 10	10-20	20-50
Hobart	Selfs Point	TAS	4750	1900	Tasmania		2.5	1000	0	1500	**209**		127%	209		317%	1	0	0
Clarence	Rosny	TAS	2800	0	Tasmania	147 Davey St, Hobart, Tasmania 7000	2.5	1000	0	1500			0%	209		187%	1	0	0
North East Water	Bright	VIC	300	132	Alpine Valleys	MYRTLEFORD, VIC 3737	29.7	850	0	1275	680		10%	552		24%	0	0	1
Central Highlands Water	Ballarat	VIC	8000	2400	Ballarat and District	Creswick, VIC 3363	16.1	0	0	0	181		0%	50		0%	0	1	0
North East Water	Beechworth	VIC	510	107.1	Beechworth	BEECHWORTH, VIC 3747	3.4	100	0	150	600		71%	545		340%	1	1	4
Coliban Water	Bendigo	VIC	7410	963.3	Bendigo	BENDIGO MAIL CENTRE, VIC 3554	1.7	900	900	2700	268		36%	132		274%	1	0	1
Barwon Water	Black Rock	VIC	19900	8756	Geelong	GEELONG WEST, VIC 3218	3.2	450	225	1350	**224**		649%	224		1474%	1	0	0
Gippsland Water	Drouin	VIC	430	86	Gippsland	WARRAGUL, VIC 3820	7.0	200	0	300	641		29%	388		143%	1	0	0
Goulburn Valley Water	Nagambie	VIC	170	0	Goulbourn Valley	NAGAMBIE, VIC 3608	3.4	1500	750	3750			0%	525		5%	1	0	2
Grampians Water	Stawell	VIC	440	0	Grampians	ARARAT, VIC 3377	26.3	550	275	1375			0%	470		32%	0	0	1
Grampians Water	Ararat	VIC	850	76.5	Grampians	ARARAT, VIC 3377	2.3	550	275	1375	656		6%	286		62%	1	0	0
Coliban Water	Heathcote	VIC	150	0	Heathcote	HEATHCOTE, VIC 3523	2.7	1300	650	3250			0%	544		5%	1	0	3
Glenelg Water	Hamilton	VIC	1020	0	Henty	HAMILTON, VIC 3300	2.7	150	75	375			0%	403		272%	1	0	0
North East Water	Wangaratta	VIC	2050	492	King Valley	OXLEY, VIC 3678	10.1	650	325	1625	376		30%	211		126%	0	3	3
Coliban Water	Keyneton	VIC	510	163.2	Macedon Ranges	KYNETON, VIC 3444	3.4	150	75	375	531		44%	404		136%	1	0	2
Western Water	Woodend	VIC	210	0	Macedon Ranges	KYNETON, VIC 3444	16.8	150	75	375			0%	527		56%	0	1	1
Melbourne Water	ETP – Carrum	VIC	140000	60200	Mornington Peninsula	RED HILL SOUTH, VIC 3937	33.6	650	325	1300	376		4631%	376		10769%	0	0	1
South East Water	Mornington	VIC	4800	0	Mornington Peninsula	RED HILL SOUTH, VIC 3937	16.5	650	325	1300			0%	263		369%	0	1	0
South East Water	Rosebud	VIC	3040	0	Mornington Peninsula	RED HILL SOUTH, VIC 3937	10.3	650	325	1300			0%	241		234%	0	1	0
Westernport Water	Cowes	VIC	1060	498	Mornington Peninsula	RED HILL SOUTH, VIC 3937	20.4	650	325	1300	416		38%	310		82%	0	0	1
Lower Murray Water	Mildura	VIC	2270	0	Murray Valley	MILDURA, VIC 3502	3.5	23300	104850	198050			0%	156		1%	1	0	0
Lower Murray Water	Red Cliffs	VIC	220	0	Murray Valley	MILDURA, VIC 3502	17.4	23300	104850	198050			0%	523		0%	0	1	0
Coliban Water	Echuca	VIC	2000	0	Perricoota	MOAMA, NSW 2731	8.7	450	0	0			0%	180		0%	1	0	0

STPS Region	Town/suburb	State	Total WW ML/yr	Dry Season WW avail. ML/yr	Viticulture Closest Wine district	Township	STP to WD (est.) km	Area Vines Ha	Min Vol Req ML	Max Vol Req ML	Case 1[A] $/ML CVR.	Demand met - Case1	Case 2[A] .. $/ML/ CVR.	Demand met - Case2	Number of STP in km < 10	10-20	20-50
Coliban Water	Rochester	VIC	260	0	Perricoota	MOAMA, NSW 2731	35.0	450	0	0		0%	618	0%	0	0	1
Grampians Water	St Arnaud	VIC	180	0	Pyrenees	AVOCA, VIC 3467	53.2	750	375	1500		0%	886	12%	0	0	0
Lower Murray Water	Robinvale	VIC	190	0	Robinvale	ROBINVALE, VIC 3549	1.4	900	4050	7650		0%	506	2%	1	0	0
North East Water	Rutherglen	VIC	372	3.72	Rutherglen	RUTHERGLEN, VIC 3685	0.0	1000	750	3500	1328	0%	403	11%	1	0	4
Yarra Valley Water	Craigieburn	VIC	820	262	Sunbury	SUNBURY, VIC 3429	18.7	200	100	500	502	52%	406	164%	0	1	0
Western Water	Romsey	VIC	220	0	Sunbury	SUNBURY, VIC 3429	22.7	200	100	500		0%	551	44%	0	0	2
Western Water	Riddell's Creek	VIC	99	0	Sunbury	SUNBURY, VIC 3429	11.1	200	100	500		0%	627	20%	0	1	1
Western Water	Gisborne	VIC	450	54	Sunbury	SUNBURY, VIC 3429	14.3	200	100	500	743	11%	402	90%	0	1	1
Western Water	Sunbury	VIC	2850	0	Sunbury	SUNBURY, VIC 3429	2.7	200	100	500		0%	361	570%	1	0	1
Western Water	Melton	VIC	2950	0	Sunbury	SUNBURY, VIC 3429	19.7	200	100	500		0%	411	590%	0	1	0
Western Water	Parwan South	VIC	1030	0	Sunbury	SUNBURY, VIC 3429	29.2	200	100	500		0%	371	206%	0	0	2
Goulburn Valley Water	Bonnie Doon	VIC	100	44	Upper Goulburn	MERTON, VIC 3715	12.8	200	100	500	775	9%	631	20%	0	1	1
Great Southern	Narrogin	WA	370	30	Blackwood Valley	Boyup Brook, WA 6244	124.0	350	350	1050	2853	3%	2429	35%	0	0	0
Great Southern	Wagin	WA	70	10	Blackwood Valley	Boyup Brook, WA 6244	106.2	350	350	1050	2549	1%	2153	7%	0	0	0
South West	Bridgetown	WA	50	0	Blackwood Valley	Boyup Brook, WA 6244	27.0	350	350	1050		0%	826	5%	0	0	2
Great Southern	Katanning	WA	280	39	Frankland River	Frankland River, WA 6396	89.5	?			1829	#VALUE!	1500	#VALUE!	0	0	0
Great Southern	Kojonup	WA	60	0	Frankland River	Frankland River, WA 6396	59.6	?				#VALUE!	1165	#VALUE!	0	0	0
South West	Harvey	WA	240	0	Geographe	BUNBURY, WA 6231	36.3	900	450	2250		0%	642	11%	0	0	1
South West	Dardanup	WA	30	0	Geographe	BUNBURY, WA 6231	13.4	900	450	2250		0%	850	1%	0	1	0
South West	Donnybrook	WA	20	0	Geographe	BUNBURY, WA 6231	32.8	900	450	2250		0%	1050	1%	0	0	1
Great Southern	Albany 2	WA	2010	0	Great Southern	ALBANY, WA 6331	0.0	3150	1575	7875		0%	170	26%	1	0	1
South West	Manjimup	WA	280	0	Manjimup	MANJIMUP, WA 6258	0.2	300	300	900		0%	446	31%	1	0	1
South West	Dunsborough	WA	430	0	Margaret River	MARGARET RIVER, WA 6285	37.6	5350	5350	16050		0%	568	3%	0	0	1
South West	Margaret River	WA	240	0	Margaret River	MARGARET RIVER, WA 6285	0.0	5350	5350	16050		0%	469	1%	1	0	0
Great Southern	Lake Grace	WA	13	0	Mount Barker	MOUNT BARKER, WA	185.2	IS					5515		0	0	0

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Great Southern	Mt Barker	WA	60	0	Mount Barker	6324	0.8	IS						698			1	0	1
South West	Halls Head	WA	720	324	Peel	MANDURAH DC, WA 6210	5.0	50	13	75	427		432%	662		960%	1	0	0
South West	Pinjarra	WA	250	0	Peel		17.2	50	13	75			0%	698		333%	0	1	0
Great Southern	Boddington	WA	20	0	Peel	MANDURAH DC, WA 6210	76.0	50	13	75			0%	1669		27%	0	0	0
South West	Waroona	WA	60	0	Peel		39.1	50	13	75			0%	898		80%	0	0	1
Great Southern	Pingelly	WA	30	0	Perth Hills	KALAMUNDA, WA 6926	115.2	350	175	1050			0%	2573		3%	0	0	0

LEGEND

KEY

	Color	Rating	$/ML	Demand met
A		Good	0-300	>50%
		Possible	301-600	
		Unlikely	>600	<50%

CVR = Current Viticultural Requirement

10.3Vine growing data across Australia

Table 48 Summary of data from vine growing areas currently in Australia

WineRegion	Central Town	State	Area under vine	Approx ML/ha High	Approx ML/ha Low	Durration of Irrigation Season	Total Volume of Water (Max)	Total Volume of Water (Min)	MIN DEMAND	MAX DEMAND	LON 1	LAT 1
Cowra	COWRA, NSW 2794	NSW	2050	2	0.5	Dec - Apr	4100	1025	4100	1025	148.694458	-33.832779
Hilltops	YOUNG, NSW 2594	NSW	700	2	0.5	Dec - Apr	1400	350	1400	350	148.301697	-34.316218
Hunter	CESSNOCK, NSW 2325	NSW	4000	2	0	Nov - Apr	8000	0	8000	0	151.353836	-32.81671
Mudgee	MUDGEE, NSW 2850	NSW	3350	2	0.5	Dec - Apr	6700	1675	6700	1675	149.586411	-32.558389
New England	TENTERFIELD, NSW 2372	NSW	150	1	0	Dec - Mar	150	0	150	0	152.021255	-29.015346
North Coast	PORT MACQUARIE, NSW 2444	NSW	na	na	na	na	na	na	na	na	152.908401	-31.417823
Orange	Orange	NSW	1500	1	0.5	Dec - Mar	1500	750	1500	750	149.100008	-33.27644
Perricoota	MOAMA, NSW 2731	NSW	450	na	na	na	na	na	na	na	144.755859	-36.050209
Riverina	GRIFFITH, NSW 2680	NSW	18150	8	4	Aug - Apr	145200	72600	145200	72600	146.043663	-34.275943
Shoalhaven Coast	BERRY, NSW 2535	NSW	50	0.5	0	Jan-Mar	25	0	25	0	150.696716	-34.763051
South West Slopes	C/- PO NANGUS, NSW 2722	NSW	na	na	na	na	na	na	na	na	147.906189	-35.030559
Southern Highlands	MITTAGONG, NSW 2575	NSW	150	1	0	Dec - Mar	150	0	150	0	150.450897	-34.442026
Southern New England	ARMIDALE, NSW 2350	NSW	na	1	0	Dec - Mar	na	na	na	na	151.669092	-30.505854
TUMBARUMBA	TUMBARUMBA, NSW 2653	NSW	200	1.25	0.25	Dec - Mar	250	50	250	50	148.017426	-35.728677
Alpine Valleys	MYRTLEFORD, VIC 3737	VIC	850	1.5	0	Nov - Apr	1275	0	1275	0	146.727219	-36.536674
Ballarat and District	Creswick, VIC 3363	VIC	na	1.5	0.5	Dec-Apr	na	na	na	na	143.893776	-37.419799
Beechworth	BEECHWORTH, VIC 3747	VIC	100	1.5	0	Dec - Apr	150	0	150	0	146.691513	-36.329509
Bendigo	BENDIGO MAIL CENTRE, VIC 3554	VIC	900	3	1	Oct - Apr	2700	900	2700	900	144.280357	-36.743011
Geelong	GEELONG WEST, VIC 3218	VIC	450	3	0.5	Oct - Apr	1350	225	1350	225	144.347992	-38.135367
Glenrowan	GLENROWAN, VIC 3675	VIC	200	2.5	0.5	Oct - Apr	500	100	500	100	146.222534	-36.451665
Goulbourn Valley	NAGAMBIE, VIC 3608	VIC	1500	2.5	0.5	Oct - Apr	3750	750	3750	750	145.154114	-36.75484
Grampians	ARARAT, VIC 3377	VIC	550	2.5	0.5	Oct - Apr	1375	275	1375	275	142.928009	-37.260392
Heathcote	HEATHCOTE, VIC 3523	VIC	1300	2.5	0.5	Oct - Apr	3250	650	3250	650	144.709167	-36.897744
Henty	HAMILTON, VIC 3300	VIC	150	2.5	0.5	Oct - Apr	375	75	375	75	142.020264	-37.719133
King Valley	OXLEY, VIC 3678	VIC	650	2.5	0.5	Oct - Apr	1625	325	1625	325	146.382866	-36.431503

WineRegion	Central Town	State	Area under vine	Approx ML/ha High	Approx ML/ha Low	Durration of Irrigation Season	Total Volume of Water (Max)	Total Volume of Water (Min)	MIN DEMAND	MAX DEMAND	LON 1	LAT 1
Macedon Ranges	KYNETON, VIC 3444	VIC	150	2.5	0.5	Oct - Apr	375	75	375	75	144.453049	-37.217753
Mornington Peninsula	RED HILL SOUTH, VIC 3937	VIC	650	2	0.5	Nov - Mar	1300	325	1300	325	145.023136	-38.367368
Murray Valley	MILDURA, VIC 3502	VIC/NSW	23300	8.5	4.5	Aug - Apr	198050	104850	198050	104850	142.165833	-34.152727
North East Victoria	GLENROWAN, VIC 3675	VIC	250	2.5	0.5	Oct - Apr	625	125	625	125	146.222534	-36.451665
Pyrenees	AVOCA, VIC 3467	VIC	750	2	0.5	Oct - Apr	1500	375	1500	375	143.473892	-37.059561
Robinvale	ROBINVALE, VIC 3549	VIC	900	8.5	4.5	Aug - Apr	7650	4050	7650	4050	142.772141	-34.577822
Strathbogie Ranges	Euroa, Vic 3666	VIC	550	2.5	0.5	Oct - Apr	1375	275	1375	275	145.571594	-36.73173
Sunbury	SUNBURY, VIC 3429	VIC	200	2.5	0.5	Oct - Apr	500	100	500	100	144.73114	-37.552743
Swan Hill	SWAN HILL, VIC 3585	VIC/NSW	7000	6.5	3	Aug - Apr	45500	21000	45500	21000	143.56041	-35.305039
Upper Goulburn	MERTON, VIC 3715	VIC	200	2.5	0.5	Oct - Apr	500	100	500	100	145.727034	-36.983358
Rutherglen	RUTHERGLEN, VIC 3685	VIC	1000	3.5	0.75	Sep - Apr	3500	750	3500	750	146.459255	-36.053523
Gippsland	WARRAGUL, VIC 3820	VIC	200	1.5	0	Dec - Mar	300	0	300	0	145.93086	-38.163058
Yarra Valley	HEALESVILLE, VIC 3777	VIC	2600	2.5	0.5	Nov - Apr	6500	1300	6500	1300	145.516191	-37.654335
Adelaide Hills	Mt BARKER, SA 5251	SA	3800	2	0.5	Nov - Apr	7600	1900	7600	1900	138.858186	-35.063953
Adelaide Plains	VIRGINIA , SA 5120	SA	500	2.5	0.5	Nov - Apr	1250	250	1250	250	138.560514	-34.666958
Barossa	TANUNDA SA 5352	SA	10000	2.5	0.5	Nov - Apr	25000	5000	25000	5000	138.958941	-34.524838
Clare	CLARE, SA 5453	SA	4650	3	0.5	Nov - Apr	13950	2325	13950	2325	138.611927	-33.83351
COONAWARRA	COONAWARRA, SA 5263	SA	6200	2.75	0.75	Nov - Mar	17050	4650	17050	4650	140.83904	-37.292099
Currency Creek	VICTOR HARBOUR, SA	SA	900	2.5	0.5	Oct - Apr	2250	450	2250	450	138.629351	-35.109535
EDEN VALLEY	EDEN VALLEY, SA 5235	SA	1750	2.5	0.5	Nov - Apr	4375	875	4375	875	139.132254	-34.666447
Kangaroo Island	PENNESHAW, SA 5222	SA	100	2.5	0.5	Nov - Apr	250	50	250	50	137.936751	-35.718051
Langhorne Creek	LANGHORNE Ck, SA 5255	SA	6050	2.5	0.5	Oct - Apr	15125	3025	15125	3025	139.033881	-35.295539
Limestone Coast	COONAWARRA, SA 5263	SA	450	2.75	0.75	Nov - Mar	1237.5	337.5	1237.5	337.5	140.839233	-37.261485
McLaren Vale	McLAREN VALE, SA 5171	SA	6050	2.5	0.5	Oct - Apr	15125	3025	15125	3025	138.542404	-35.202147
Mount Benson	KINGSTON, SA 5275	SA	300	2.5	0.5	Nov - Mar	750	150	750	150	139.851837	-36.790591
Padthaway	PADTHAWAY, SA 5271	SA	4900	2.75	0.75	Nov - Mar	13475	3675	13475	3675	140.494537	-36.58576
Riverland	BERRI, SA 5343	SA	21350	8.5	4	Aug - Apr	181475	85400	181475	85400	140.600624	-34.273106
Southern Fleurieu	MT COMPASS, SA 5210	SA	350	2.5	0.5	Oct - Apr	875	175	875	175	138.621712	-35.35109
Southern Flinders	PORT GERMEIN, SA 5495	SA	150	2.5	0.5	Oct - Apr	375	75	375	75	138.000255	-33.019747
Wrattonbully	NARACOORTE, SA 5271	SA	2000	2.75	0.75	Nov - Mar	5500	1500	5500	1500	140.741419	-36.956116

WineRegion	Central Town	State	Area under vine	Approx ML/ha High	Approx ML/ha Low	Durration of Irrigation Season	Total Volume of Water (Max)	Total Volume of Water (Min)	MIN DEMAND	MAX DEMAND	LON 1	LAT 1
Blackwood Valley	Boyup Brook, WA 6244	WA	350	3	1	Oct - Mar	1050	350	1050	350	116.388431	-33.83335
Frankland River	Frankland River, WA 6396	WA	na	2.5	0.5	Oct - Mar	na	na	na	na	117.008085	-34.353286
Geographe	BUNBURY, WA 6231	WA	900	2.5	0.5	Nov - Mar	2250	450	2250	450	115.636994	-33.327005
Great Southern	ALBANY, WA 6331	WA	3150	2.5	0.5	Oct - Mar	7875	1575	7875	1575	117.883548	-35.023873
Manjimup	MANJIMUP, WA 6258	WA	300	3	1	Oct - Mar	900	300	900	300	116.144757	-34.243222
Margaret River	MARGARET RIVER, WA 6285	WA	5350	3	1	Oct - Mar	16050	5350	16050	5350	115.073826	-33.950818
Mount Barker	MOUNT BARKER, WA 6324	WA	na	2.5	0.5	Oct - Mar	na	na	na	na	117.661815	-34.626499
Peel	MANDURAH DC, WA 6210	WA	50	1.5	0.25	Nov - Mar	75	12.5	75	12.5	115.732555	-32.532559
Pemberton	PEMBERTON, WA 6260	WA	700	2	0.5	Nov - Mar	1400	350	1400	350	116.034894	-34.444415
Perth Hills	KALAMUNDA, WA 6926	WA	350	3	0.5	Oct - Mar	1050	175	1050	175	116.056738	-31.97196
Swan Valley	MIDLAND, WA 6936	WA	1100	3	0.5	Oct - Mar	3300	550	3300	550	116.008029	-31.886103
Granite Belt	STANTHORPE QLD 4380	QLD	600	3	0.5	Jul -Jan	1800	300	1800	300	151.935768	-28.638773
South Burnett	KINGAROY, QLD 4610	QLD	450	3	0.5	Jul -Jan	1350	225	1350	225	151.836548	-26.531408
Tasmania	147 Davey St, Hobart, Tasmania 7000	TAS	1000	1.5	0	Dec - Apr	1500	0	1500	0	147.330265	-42.868667

Source: GWRDC (Troy Fisher). Longitude and latitudes determined using www.maps.google.com.au