Improving Water Use Efficiency of Vineyards in the Great Western Region by using Effluent Water and Soil Amelioration Practices



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Title Page

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Abstract

Rapid growth of the Australian wine industry in recent years has resulted in a number of challenges, including expansion of wine grape production onto less desirable soil types, and issues of limited water supplies. Expansion of production in the Great Western region of Victoria has been made possible through the supply of recycled water to meet irrigation demands. The impacts of using recycled water for vineyard irrigation was investigated to determine whether there were any impacts to soil properties and vineyard sustainability. Results indicate that soil electrical conductivity and exchangeable sodium percentage have increased as a result of irrigation with recycled water, indicating the need to development management strategies to ensure the long term sustainability of this practice.

Executive Summary

The viticultural industry is becoming an increasingly significant part of the Australian agricultural sector. The success of the industry has been built on the production of high quality premium fruit and wines. Expansion of the industry in the last decade has been rapid, however its heavy reliance on irrigation means that further expansion and ability to produce high quality produce in many regions is limited by the availability of water. This problem is not confined to the viticultural industry, with ever increasing pressures on water resources worldwide.

Among the challenges facing the viticultural industry is the need to balance environmental sustainability with economic viability, and in doing so, promote a 'clean and green' image to the international market. In order to achieve production of quality product, and ensure both economic and environmental sustainability, the wine industry must develop innovative strategies for more effective, environmentally sound, and cost efficient water use.

In the Great Western region of Victoria, expansion limitations associated with a lack of available water resources were overcome with the development of a scheme whereby treated municipal wastewater is supplied to vineyards for irrigation. The Ararat/Great Western Recycled Water scheme has resulted in significant expansion in wine production in the region.

The use of recycled water for irrigation provides a number of benefits. Among them are the reduced demands on potable supplies, and the opportunity for expansion of irrigated agriculture, including viticulture. Recycled waters however, contain constituents which have the potential to cause deleterious effects to both production and the environment. These include the development of soil salinity and sodicity, productivity impacts associated with nutritional deficiency and/or toxicity, and off site contaminant transport to natural waters.

This study was developed to investigate the sustainability of using recycled water for irrigating vineyards in the Great Western wine growing region. Particular emphasis was placed on the impacts of recycled water on soil properties, such as the development of salinity, sodicity, and structural degradation problems. Previous studies have recognised the soils in the Great Western region as having poor chemical fertility, being marginally sodic, and prone to hydraulic deficiencies such as poor infiltration, intermittent waterlogging, and poor subsoil drainage. The soils have inherently poor physical and chemical properties compared to many other viticultural regions in Australia, and potentially may respond differently to the application of effluent water.

The fate of contaminants was also considered, as were the impacts of water quality on the productivity of the vines. The project also considers the applicability/role of soil amendments in improving soil structural properties and counteracting potential deleterious effects of recycled water irrigation.

Field studies were conducted to identify: changes in soil properties; the fate of contaminants; and impacts to vine productivity resulting from irrigation with recycled water. Laboratory soil core experiments were conducted to complement the field studies by simulating existing irrigation management scenarios, allowing a highly detailed study of the spatial and temporal responses of the soils to recycled water application. A number of soil amendments were also trialled in the field, including gypsum and green waste, for their ability to improve the properties of the often poorly structured soils of the region. These studies form the basis of the research conducted by P. Kane (ARC Linkage program).

The results of the field studies indicate that recycled water has caused an elevation in electrical conductivity and exchangeable sodium percentage in vineyard topsoils, and to a lesser extent in the subsoils. The natural tendency of the subsoils to disperse spontaneously has been improved generally by irrigation practices, however those irrigated with recycled water at Hyde Park Vineyard and Montara Winery still show a tendency towards dispersing spontaneously.

The results to this stage indicate that the sustainable use of recycled water on these soils will require diligence with regards to irrigation and soil management practices. A detailed study of the spatial and temporal aspects of solute interactions and transport, is still in progress, and will also provide a greater understanding of the processes occurring in irrigated soils. This will allow predictions to be made regarding the long term sustainability of recycled water application on these soils, as well as recommendations for irrigation and soil management to ensure sustainability is achievable. Future reports from this study will also elucidate the efficacy of various soil amelioration strategies at improving soil properties as well as counteracting the impacts of recycled water.

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List of Terms and Abbreviations

EC	electrical conductivity
ESP	exchangeable sodium percentage of soil
LTV	long term trigger value: the maximum concentration of contaminant tolerated in irrigation water assuming 100 years of irrigation
PAW	plant available water
RAW	readily available water
Recycled Water	in the context of this research it refers to the recycling of treated municipal effluent
SAR	sodium absorption ratio of irrigation water
STV	short term trigger value: the maximum concentration of contaminant tolerated in irrigation water assuming 20 years of irrigation
Wastewater	liquid byproduct/waste from municipal and/or industrial processes

Background

The viticultural industry is a significant part of the Australian agricultural sector, with gross earnings of over $4 billion in 2002 (ABS, 2002). Expansion of the industry has been rapid in the last decade, with total wine grape production increasing from 870 kT during the 1995-96 season, to 1895 kT in 2003-04 (Gordon, 2005). Expansion of the wine grape growing in Australia presents both opportunities and challenges to the viticultural industry. Among the challenges are limited water supplies, the rising costs of irrigation water (the wine grape industry relies on irrigation for approximately 86% of its output (Thomas, 1999)), and the need to balance environmental sustainability with economic viability. For instance, the key environmental issues identified for/by the viticultural industry through the Ecovine Project (2002) include:

- the impacts to environmental flows through extractions and farm dams,
- management and sustainable harvest of groundwater resources,
- water quality issues such as loadings of nutrients, chemicals, and salts in discharges from farms to surface waters and groundwaters,
- soil management and health,
- waste reduction and disposal, and
- water use efficiency (Anon, 2002).

In order to achieve production of quality product, provide for further expansion, and ensure economic sustainability, the wine industry must develop innovative strategies for more effective, environmentally sound, and cost efficient water use.

The substitution of fresh water with recycled water is an increasingly accepted practice, and stems from the realisation that wastewater must not be viewed as a liability, but rather, a valuable resource (Gleick, 2000). Given that irrigated agriculture accounts for some 85 percent of all water consumption worldwide (Shiklomanov, 1998), and some 67% in Australia in 2001 (ABS, 2006), agricultural use of recycled water has the potential to liberate significant quantities of water. For instance, between 1996-97 and 2000-01 alone water recycling within the agricultural industry increased from 38,118 ML to 423,264 ML (ABS, 2006).

The benefits of substituting recycled water for potable or other fresh water include reduced demand on natural water resources, making them available to other users and the environment, and less waste discharged to surface waters, reducing the inputs of nutrients and other contaminants which contribute to water pollution and algal blooms. The potential for production in otherwise water limited regions also provides the agricultural sector with opportunities for expansion. As wastewaters typically contain nutrients and essential elements for plant growth, recycled water can reduce the input of chemical fertilizers and hence presents a potential financial saving. With Australia's dry and variable climate, recycled water can provide reliability of supply which can assist in the production of high quality produce.

Irrigation with recycled water can, however, result in deleterious impacts to the environment and primary production caused by salts, nutrients, organic

substances, trace elements and heavy metals. These impacts arise where constituents either accumulate in the soil, posing a threat of toxicity to soil biota and plants, or leach from the soil potentially harming groundwater and surface water resources (EPA, 1991).

Recycled water is often of medium salinity rating (EC of 0.6-1.7 dS/m) (Feigin, *et al*, 1991). The accumulation of salts within the soil profile can result in the development of saline/sodic soils which can impede plant growth, reduce soil physical fertility and result in land degradation. The predominant impact of elevated soil salts is an increase in the osmotic pressure of the soil water solution which makes water extraction by plant roots exceedingly difficult. This can result in water stress and reduced productivity (Sumner *et al*, 1998). Specific ion toxicity can also occur if uptake of ions such as sodium and chloride exceeds plant requirements. Elevated concentrations of sodium and chloride in vine leaves as a result of saline irrigation have been reported (Stevens and Walker, 2002). Salinity stress in grapevines has been shown to cause reduced photosynthetic rate, reduced root and shoot vigour, leaf burn, and decreased yields (Stevens *et al*, 1999; Stevens & Walker, 2002) Whilst grapevines are considered to be moderately sensitive to salinity (McCarthy *et al*, 1992; ANZECC, 2000; Rogiers & Creece, 2005), the response of grapevines to saline irrigation can vary considerably depending on the variety and rootstock. For example rootstocks including Ramsey and 1103 Paulsen have been shown to be reasonably salt tolerant (Rogiers & Creece, 2005).

For any irrigation system to be sustainable, application of water in excess of plant requirements is necessary to leach the salts from the root zone and hence prevent the development of soil salinity. The amount of water applied in excess of plant requirements is referred to as the leaching fraction (LF). The dilemma this creates however, is that leaching can lead to the contamination of groundwater by the leached salts, as well as the other constituents of the wastewater (Smith, *et* al,1996; Dillon, *et al*,1996). Among these other constituents are nutrients such as nitrogen and phosphorus. Whilst both are vital for plant health and productivity, applications in excess of requirements can result in transport to groundwater and surface water resources through leaching (Lawrie, 1996; Dillon *et* al, 1996; Gallegos *et* al, 1999; Hatch *et* al, 2002), or undesirable effects to plants as a result of excessive uptake (Robinson, 1992). Nitrate is very soluble and is not easily fixed to soil clay minerals, and hence if not taken up by plants, is readily leached in drainage (Hatch *et* al, 2002) Leaching of nitrate to groundwater as a result of effluent irrigation has been reported extensively in the literature, including reports from Mexico (Gallegos *et* al, 1999), South Australia (Dillon *et* al, 1996), and New South Wales (Dillon *et* al, 1996; Lawrie, 1996). Elevated nitrogen uptake by grapevines has been associated with excessive vigour, which is linked to reduced bud fertility, reduced fruit set (Robinson, 1992), and shading which can result in immature or ‘green’ characters in wine (Small, 2003).

Phosphorus is more readily fixed within soils, and hence its transfer from soils is usually associated with plant uptake or soil transport processes such as erosion (ANZECC/ARMCANZ, 2000). However, subsurface pathways such as preferential flow have gained significant attention in recent times (Turner &

Haygarth, 2000). The phosphate retention capacity of soil has also been implicated as a factor in phosphorus leaching in New Zealand soils irrigated with effluent (Magesan, *et al*, 1999).

Recycled water typically contains a high proportion of sodium relative to other cations. This is reported as the sodium absorption ratio (SAR), with recycled waters having SAR's in the range of 4.5 to 8.0 (Feigin, *et al*, 1991). Irrigation with waters of high SAR can lead to the development of, or exacerbation of existing soil sodicity. Soil sodicity can be characterised chemically as a soil with a high proportion of sodium on the cation exchange sites in the soil, and is characterised by the exchangeable sodium percentage (ESP). In Australia, a soil with an ESP of 6 or greater can be classified as sodic (Isbell *et al*, 1997). Soils can also be classified as sodic according to behaviour, such as soils with poor structural stability which are prone swelling and dispersion, poor hydraulic and infiltration properties, compaction and waterlogging. Sodic soils are well represented in Australia (340 million hectares) (FAO, 1988), with a significant proportion of vineyards in South Australia, New South Wales, and Victoria established in regions with sodic subsoils (Northcote, 1988). Sodic soils are difficult to manage. Productivity on sodic soils is constrained by factors such as: poor plant establishment; water stress associated with poor water infiltration into the rootzone, as well as periods of waterlogging; reduced rooting depth; nutritional constraints including both deficiencies and toxicities (Ford, *et al*, 1993); and increased surface runoff and erosion (Sumner, *et al*, 1998).

The Great Western wine region, located in western Victoria, was established during the gold rush era of the 1850's. Water resources in the region are confined to surface storage dams only, as groundwater and surface water resources are limited and saline (Coombe and Dry, 1988). Expansion of plantings in the region has therefore been limited historically by a lack of available water resources. In 1999, the Grampians Water Authority completed a 17 kilometre pipeline from the Ararat Wastewater Treatment Plant, to deliver at least 600 megalitres of recycled water a year to vineyards in the Great Western region (NRE, 2002). The water is treated to a secondary standard, and is classified as Class C effluent according to the EPA (2003), making it suitable for urban (non-potable) and industrial uses where human contact is controlled, and agricultural uses such as crops which are cooked or processed, and grazing/fodder for livestock. The Ararat/Great Western Recycled Water Scheme provided Grampians Water Authority with an alternative option for the disposal of wastewater, while at the same time providing vineyards in the Great Western region with the opportunity to expand existing plantings.

Since the construction of the pipeline, an additional 300 hectares of vines have been planted in the Great Western region, adding to the 174 hectares of vines present in 1994. Irrigation began in the 1999/2000 season. It is evident that a substantial financial investment has been made in the region as a result of this new water supply scheme. The cost of the scheme was estimated at $4.1 million (Courtney, 2000). Establishment of additional plantings also comprised a significant investment with an estimated cost (1995) of $25 000

to $30 000 per hectare (Davidson, 1992). In return an additional $40 million in wine sales was forecast (Courtney, 2000).

With the wine industry in many parts of Australia looking closely at water management issues such as *in situ* recycling, and alternative water sources, the Ararat/Great Western Recycled Water Scheme has generated considerable interest. In particular, the applicability and sustainability of such practices is of great interest to an industry facing increasingly stringent regulations regarding water resource management and environmental credibility. Little is known, however, of the potential long term consequences of the use of recycled water on the soils of the region, and the health and productivity of the vines. The success of the Ararat/Great Western Recycled Water scheme will be reliant on identification and appropriate management of the potential risks associated with irrigating with recycled water.

Project Aims and Performance Targets

This project was developed to investigate the potential long term impacts of using recycled water for irrigation of Great Western vineyards. Particular emphasis was placed on the structural integrity and chemical properties of vineyard soils, as the soil is not only the first point of contact, but a vital foundation on which vine health and productivity relies.

The specific aims of this project were developed during a meeting with key researchers in the fields of viticulture, wastewater irrigation, and salinity, where long term research priorities, directions and synergies were discussed (Allinson, 2002).

The broad aim of this project was to investigate the impact of soil management and recycled water irrigation on sub soil conditions of irrigated vineyards in the Great Western wine growing region. Specifically, the project aimed to:

a) assess the impact of recycled water on the sustainability of soil resources (specifically focussing on sodicity and salinity);
b) determine the impact of water use efficiency on grape production using row management and amelioration strategies to improve sub soil conditions, and;
c) identify potential interactions between use of poor quality water and row management on sustainability of soil resources in vineyards

The project aim was to be met through the following objectives:

a) to assess the impact of effluent water on subsoil chemical and physical properties beneath grapevines in the Great Western region;
b) to determine the effectiveness of various soil management strategies on improving subsoil conditions and water use efficiency of wine grape production;

c) to test the applicability of current mathematical models in predicting water and chemical transport and solute accumulation in soils under commercial scale field conditions; and
d) to analyse these results in consultation with GWRDC studies in South Australia to identify clear regional differences/challenges/ issues in the potential use of effluent water for viticulture.

The outcomes of this project are of both local and national industry relevance, as they will provide:

1. improved knowledge of the impacts of recycled water on the soil environment of vineyards,
2. identification of key soil management strategies required under recycled water irrigation scenarios, and
3. assist in the development of new protocols for risk assessment, through the development of novel decision support tools for predicting impacts and risks.

The project performance targets detailed three specific components to the study, namely field studies, laboratory studies, and mathematical modelling. This project has been undertaken by two postgraduate research students, Karen Hermon, funded by GWRDC, and Peta Maher-Kane, funded by the ARC Linkage scheme. Specific aims were developed for each student program, but with an emphasis on providing a synergistic approach to elucidating the environmental impacts and industry sustainability issues involved in the use of recycled water. The results of the GWRDC funded components of the research program are described in this report. The ARC Linkage component of the research is on-going, as is the mathematical modelling, which is part of an ongoing collaboration with researchers from Wageningen University, The Netherlands. These components of the research will be finalised at the end of the year and published in international journals.

Methods

The project addressed its first objective, namely *to assess the impact of effluent water on subsoil chemical and physical properties beneath grapevines in the Great Western region*, in four vineyards in the Great Western region of western Victoria. The four vineyards rely wholly or partially on recycled water for irrigation of vines. The vineyards chosen for the study represent a range of differing soils types, management practices, and irrigation histories representative of the region.

Experimental Design

A fenceline experimental design was employed involving comparisons between three treatments:

1. recycled water irrigation (dominant application),
2. fresh water irrigation (where practiced), and
3. pasture/control (pasture adjacent to vineyard plantings, no irrigation).

Eleven sites across the four vineyards were chosen for the study (Table 1). Because the vineyards in this study were already under established irrigation management practices, the location of sites (the datum points) was dictated by those management practices. The pasture areas adjacent to vines were incorporated to provide a baseline for the study, allowing background soil properties to be determined. Coupled with comparisons between recycled water and freshwater irrigation treatments, the study aimed to identify the impacts of vineyard establishment and irrigation, the impacts of water quality, and the potential rate of change.

Table 1: Experimental design and datum points for field based studies.

Datum point	Vineyard	Block name	Soil type	Treatments investigated		
				Recycled	Fresh	Pasture
1	Hyde Park	Sweeney's	Yellow Duplex	ü	ü	ü
2	" "	Lynd's	" "	ü	û	ü
3	" "	Daly's	" "	ü	û	ü
4	" "	Dalberti's	Red Duplex	ü	û	ü
5	Seppelts	Arrawatta-Bay 5&6	Red Duplex	ü	ü	ü
6	" "	Arrawatta-Bay 5	Red Duplex	ü	û	ü
7	" "	Arrawatta-Bay 7	Red Duplex	ü	û	ü
8	" "	St Peters	Yellow Duplex	û	ü	ü
9	Westgate	Riesling	Red Duplex	ü	ü	ü
10	" "	" "	Red Duplex	ü	û	ü
11	Montara	Riesling block	Red/Yellow Duplex	ü	û	ü

Note: Recycled = recycled water irrigation, **Fresh =** freshwater irrigation, **Pasture =** adjacent pasture, no irrigation

Site Descriptions

The topography of the area is described as moderately undulating, whilst the soils consist predominantly of hard, mottled yellow duplex soils on the flats (Dy 3.41, Dy 3.42) and hard red duplex soils on the slopes (Dr 2.21, Dr 2.22). Soils are acidic to neutral, have inherently poor physical properties and poor chemical fertility. The climate of the region is continental, with slightly winter dominated rainfall (average annual rainfall = 591 mm), moderate evaporation, radiation, and relative humidity, and spring frosts (Beeston, 2002).

Hyde Park Great Western Vineyard (datum points 1-4)

Datum points 1 to 4 were located in Hyde Park vineyard, which was planted in 1998 with predominantly Shiraz hybrids (clones 1127, PT23, and 1654, all on own rootstock), and Cabernet sauvignon (Clones LC10, LC14) (Cass and Dowley, 1999).

Drip irrigation is employed in this vineyard, delivering 1-1.5ML/ha/yr. The majority of the vineyard is irrigated with recycled water, however, a small portion of Sweeney's Block has been irrigated with fresh water since planting as a result of its proximity to a small natural watercourse (Hart, *pers. comm.*). This requirement originates from EPA guidelines regarding the use of reclaimed water (EPA 2002), and forms part of the required Environment Improvement Plan prepared by vineyard management.

The soils in Sweeney's, Daly's, and Lynd's Blocks are described (Cass and Dowley 1999) as Duplex Yellowish Brown Clays, comprising a sandy loam topsoil over a hard, mottled clay. Cass and Dowley suggested that the topsoils are structurally poor, and the tendency of the topsoil to slake indicates poor resilience to traffic and a tendency to seal. The abrupt topsoil/subsoil interface presents a barrier to both root penetration and drainage, resulting in a periodically perched water table, further evidenced by the presence of mottles in the clay subsoil. The Effective Root Depth (ERD) is low (380mm). The subsoils exhibit few pores or cracks, possibly as a result of its tendency to disperse. The soils are acidic (pH_{CaCl2}<5), marginally sodic to sodic (SAR of • 6), with a low (1-2) to very low (<1) Ca:Mg ratio, low phosphorus content, and potentially low potassium content. In terms of water storage characteristics, total available water content is low (65-70 mm PAW), suggesting that vines would struggle to obtain sufficient water without development of extensive root systems.

The soils of Dalberti's Block are described by Cass and Dowley (1999) as a complex of Gradational Reddish Brown Clays and Duplex Reddish Brown Clays, with outcrops of sedimentary siltstone and basaltic rock. On the hills and ridges, the red gradational soils are relatively shallow (400-700mm), becoming deeper on the midslopes (although the subsoils are not as well structured), giving way to Duplex Reddish Brown Clays on the lower portions of the block. The duplex clays are unstable, poorly structured, with bleached subsurface layers indicating a perched water table. Effective Root Depth was calculated to be adequate (about 790 mm) (Cass and Dowley, 1999).

<u>Seppelts Great Western Vineyard (datum points 5-8)</u>

St Peters block (datum point 8) was planted with Shiraz vines approximately 80 years ago, and is drip irrigated with dam water. The dominant soils are Stawell Sandy Loams and Stawell Sandy Clay Loams (Badawy, 1982). These soils are yellow duplex, with near neutral pH, a bleached A2 horizon, and a mottled, medium to heavy clay subsoil.

Vines in datum points 5 and 6 are Shiraz 1654, own rooted, whist those in datum point 7 are Shiraz St Peters/R110. Vines were planted in 1998, and are irrigated with recycled water with the exception of Bay 6.1 (datum point 6), which is irrigated with dam water when available. Recycled water was applied to this bay in the 2002/3 season due to drought conditions. A reconnaissance soil survey conducted in 1996 identified the soils as being Class 2 in terms of land suitability classification, with the following limitations: low pH and associated nutrient deficiency problems; reduced infiltration of the surface

layer; localised ponding and run-off; and subsurface water accumulation and lateral flows. Vertically tilted parent material (siltstone) combined with a friable and well structured subsoil is considered indicative of good aeration and permeability. Rootzone readily available water (RAW) in the vicinity of the chosen bays (5,6, & 7) was found to range from 47mm to 58mm (IMT 1996) which is within an optimum range (Cass and Dowley, 1999).

Westgate Vineyard (datum points 9 – 10)

Westgate Vineyard comprises some 13 hectares of vines. 8 hectares of Riesling vines were planted in 1969, with a further 5 hectares of Shiraz vines planted in the late 1990's as a result of the Ararat/Great Western Wastewater Reuse Scheme. Irrigation at that time switched to recycled water by drip irrigation, while a small section of the vineyard remained under fresh water irrigation, delivered via sprinkler. Datum points 9 and 10 are located in the block containing Riesling, allowing comparison of recycled irrigation, fresh water irrigation, and pasture (control) treatments.

Soils at Westgate were surveyed in 1980 (Badawy 1982), and are very complex in their distribution. The reader is directed towards this text for complete descriptions. In summary, the soils comprise red gradational soil in the highest parts of the property, while the lower areas, which constitute much of the vineyard, are red duplex soils, with yellow duplex soils occurring in depressions and gullies.

Montara Winery (datum point 11)

Montara Winery, located in Ararat, has been irrigated with recycled water from the Ararat Wastewater Treatment Plant since 1972 (Coutts, 2004). The block chosen for this study (datum point 11) is planted with 28 year old Riesling vines, which have been irrigated with recycled water via drip irrigation since planting.

The soil type in the chosen block at Montara Winery is a complex of red duplex and yellow duplex, becoming yellow duplex in the depressions. The soils comprise a sandy clay loam topsoil over a mottled medium to heavy clay subsoil (Badawy, 1982).

Irrigation Water Monitoring

Both the fresh water and recycled water were sampled monthly during the 2003-2004 irrigation season. Sample collection and analysis protocols, including collection, sample container type, preservation requirements, and maximum holding periods, followed EPA recommendations (EPA, 2000).

Waters termed 'fresh' in this study comprised dam water at both Hyde Park Vineyard and Seppelts Great Western Vineyard, and groundwater extracted from a disused gold mine shaft at Westgate Vineyard. No fresh water collection was required at Montara Winery due their complete reliance on recycled water.

Recycled water quality information was provided by the water authority (GWMWA) for the license point at the final lagoon of the Ararat Wastewater Treatment Plant (AWWTP). This data was considered satisfactory for studies at Montara Winery as water is drawn directly from the final lagoon for irrigation. Recycled water was collected individually at Seppelts, Westgate, and Hyde Park where water is stored in tanks, a reservoir, and taken from the pipeline respectively. Samples were collected on five occasions between October 2003 and April 2004. Comparisons were made between the quality of these water sources and that of the final lagoon to identify whether water quality changed between the treatment plant and the point of irrigation.

Physical and chemical analysis of irrigation waters was conducted by the Water Quality Laboratory at Deakin University, Warrnambool (Accredited Laboratory No. 2457) using standard (APHA, 1992) or NATA accredited laboratory methods (Table 2).

Table 2: Methods employed for analysis of irrigation water quality.

Parameter	Reporting units	Method of analysis: APHA (1992) unless specified as WQL method
pH		4500-H+ B. Electrometric Method
Electrical Conductivity (ECw)	µS/cm	2510 B. Laboratory Method
Total Alkalinity	g/m^3	2320 B. Titration Method
Suspended Solids	g/m^3	2540 B. Total Suspended Solids
Sodium (Na^+)	g/m^3	3500-Na D (spectrophotometric method)
Potassium (K^+)	g/m^3	3500-K D (spectrophotometric method)
Magnesium (Mg^{2+})	g/m^3	3500-Mg B (spectrophotometric method)
Calcium (Ca^{2+})	g/m^3	3500-Ca D (spectrophotometric method)
Chloride (Cl^-)	g/m^3	4500-Cl-C Mercurimetric Method
Sulphate (SO_4^{2-})	g/m^3	4500-SO_4^{2-} E.Turbidometric
Total Phosphorus	g/m^3	4500 –P B/E or WQL-07 (flow injection analysis - FIA)
Soluble Reactive Phosphorus (SRP)	g/m^3	WQL-06 (flow injection analysis - FIA)
Total Nitrogen	g/m^3	4500-N_{total} B Total Nitrogen or WQL-05 (flow injection analysis - FIA)
Total Kjeldahl Nitrogen (TKN)	g/m^3	4500-TKN B/E
Oxidised Nitrogen	g/m^3	WQL-04 (flow injection analysis - FIA)
Dissolved Organic Carbon (DOC)	g/m^3	WQL-08 (photocatalytic oxidation/conductimetric determination)

Soil analysis

Intact soil cores measuring 100cm long by 4.6cm diameter were collected from the recycled and fresh irrigation treatments using a Geoprobe Model 54LT with a GH42 hammer system. Samples from adjacent pasture were collected using a trailer-mounted soil sampling rig. Procedures for the collection, transport, and post-analysis disposal of all soil samples were

subject to the conditions of the National Protocol developed to prevent the spread of grapevine phylloxera (NVHSC, 2000).

In May 2003 49 cores were collected, and each core was divided into increments of 0-10cm, 10-20cm, 20-40cm, 40-60cm, 60-80cm, and 80-100cm. Soil characteristics were recorded for each core, as outlined in Table 3.

Table 3: Soil characteristics, descriptors and units used to describe soil cores.

Characteristic	**Descriptors and units**
Landscape Position	crest, slope (upper, mid, lower), flat, depression[1] also aspect and slope %[1]
Horizon types	A1, A2, B1, B2 Upper and lower depth: of each horizon in mm[1]
Layer Change - distinctness	Sharp: ,5mm, Abrupt: 5-20mm, Clear: 20-50mm, Gradual: 50-100mm, Diffuse: >100mm: [1,2]
Mottles:	% estimate by eye [1], colour [2,3]
Soil Colour	Munsell colour chart [3]
Gravel	% estimate of volume [1]
Structure: Shape	platy: flat, columnar: tall, blocky: square, even faces, polyhedral: faces flat but uneven, lenticular: elliptical, granular: spherical [1,2]
Structure: Hardness/Plasticity	force req'd to break soil fragment: Loose: nil, Weak: small force req'd, Firm: moderate force req'd, Strong: breaks under foot [from1]

1. Cass and Dowley 1999, 2. McDonald, *et al,* 1998, 3. Munsell, 1975

An additional 130 soil cores were collected in 2004 and divided into the same depth increments as the previous samples. Soils from 2003 and 2004 were air dried (<40°C) for at least 7 days before crushing and sieving to <2mm. Physical and chemical analyses were then conducted according to methods detailed in Table 4. Only the 0-10cm and 40-60cm increments were analysed to provide an indication of topsoil and upper subsoil properties. The remaining samples were not analysed due to time restraints.

To determine whether there were any statistical differences in soil physical and chemical properties between the three treatments, a Mann-Whitney U-test was performed in SPSS for Windows (version 11.5.2.1). The Mann-Whitney U-test compares the median values of two sets of data. This test was chosen as the data was found to be not normally distributed, and hence did not meet the assumptions of typical parametric analyses.

Table 4: Soil physical and chemical analyses performed.

Parameter	Units for reporting	Method & Reference
pH 1:5 water		4A1 Rayment & Higginson (1992)
pH 1:5 $CaCl_2$		4B2 Rayment & Higginson (1992)
$EC_{1:5}$ (1:5 soil:water)	dS/m	3A1 Rayment & Higginson (1992)
Exchangeable bases	mequiv./100g	15A1 NH_4Cl at pH 7.0 Rayment & Higginson (1992)
Water soluble ions*	mequiv./100g	Ion Chromatography
ESP	%	15N1 Rayment & Higginson (1992)
Bulk Density	g/cm^3	Core Method 13-2 Blake & Hartge (1986)
Spontaneous Dispersion	%	modification of Spontaneous Dispersion Rengasamy *et al* (1984)
Mechanical Dispersion	%	Mechanical Dispersion Rengasamy *et al* (1984)
Total Organic Carbon	%	6B1 – Heanes Wet Oxidation Rayment & Higginson (1992)

* Sample extracts have been prepared and frozen, analysis not completed.

Vine Productivity Monitoring

Vine productivity data for treatments 1 and 2 was collected *in situ*, comprising bunch counts in 2002-03 and 2003-04. The number of bunches per panel was determined for 14 panels per treatment (a panel is defined as the area between two treated pine posts). The panels were selected randomly using random number generation. The number of vines per panel was reported in each case, although in all but one case there were three vines per panel.

Bunch weights were measured at Hyde Park (datum point 1) and Seppelts (datum point 5) in March 2004. 25 bunches were picked at random from each of 10 panels (also chosen at random) from each treatment and weighed on site).

Results/Discussion

Water Quality

There was little change in water quality between water from the final lagoon of the treatment plant and irrigation water as it was applied at the Seppelts site and Westgate. Complete summaries of water quality data collected are provided in Appendix 5a, but Figure 1 illustrates the average values observed for pH, EC and SAR across the four sites. These observations suggest that water quality data collected at the treatment plant and disseminated to the growers was indicative of actual values on site for Seppelts, Westgate, and Montara, and so for these sites the discussion of results for recycled water quality will be grouped together. Hyde Park Vineyard water quality was somewhat different, with pH, EC and SAR of the recycled water higher on site than in the final lagoon, although the water quality monitoring also suggests

that the recycled and dam water are of similar quality with regards to the majority of parameters (Table 6).

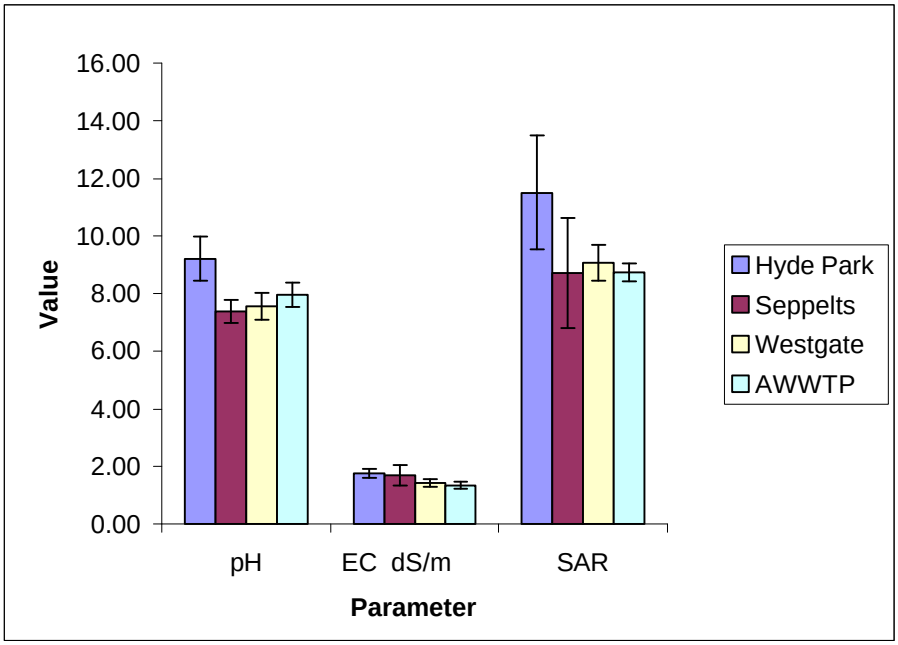


Figure 1: Comparison of selected recycled water quality parameters across all sites.

The results of the water quality monitoring can be compared with guideline values and recommendations for wastewater irrigation, set out by the EPA (1991), the National Water Quality Management Strategy (ANZECC/ARMCANZ, 2000) for irrigation, and McCarthy *et al* (1992) for grapevine irrigation (Table 5). The relationship between the EC and SAR of irrigation water with reference to the likely impacts on soil dispersion, soil structural integrity, and degradation is shown in Figure 2

Hyde Park Vineyard: The pH of the recycled water at Hyde Park was slightly higher than recommended by the EPA (1991) (Table 6), which might contribute to symptoms of toxicity and deficiency in grapevines, and contribute to dripper blockages. Both the recycled water and fresh water at Hyde Park were of medium salinity rating, and hence ought to only be recommended for moderately tolerant crops (ANZECC/ARMCANZ, 2000). Whilst grapevines are considered to be moderately sensitive to salinity, the response of grapevines to saline irrigation can vary considerably. Likewise, the chloride concentrations in the recycled and fresh water were high enough to pose a toxicity risk to vines, although again this is also dependent on variety and rootstock (McCarthy *et al*, 1992; Rogiers & Creece, 2005). When the EC is considered in conjunction with SAR, both recycled and fresh water sources pose a risk of soil structural degradation, though this is dependent on soil properties and rainfall patterns (ANZECC/ARMCANZ, 2000). Given that the soils in this vineyard have already been identified as being prone to dispersion and structural deterioration, this finding is of significant concern. Whilst there are no trigger values defined for the alkalinity of irrigation water (ANZECC/ ARMCANZ, 2000) elevated levels of alkalinity (in the form of carbonate and bicarbonate) can cause the precipitation of calcium and magnesium ions as

insoluble carbonates. The formation of these precipitates can result in an elevated SAR in the irrigation water, which in turn can result in an increased soil ESP. Nitrogen levels are within recommended levels, however phosphorus concentrations in both water sources exceed long term trigger values (LTV) for irrigation which indicates a risk of bioclogging of irrigation equipment (ANZECC/ARMCANZ, 2000).

The fresh water at Hyde Park Vineyard was actually of poorer overall quality than the recycled water, with greater variability in water quality across the season. The highly variable results are predominantly the result of ongoing drought throughout the region and seasonal deterioration in water quality associated with evaporation. Variability in nitrogen and phosphorus levels related to a sample which was taken from the dam after a heavy rain event which saw soil, associated elements and organic materials flushed into the dam in overland flow. Total nitrogen and phosphorus concentrations of 16 g/m^3 were recorded, in association with a higher than normal level of suspended solids. The quality of fresh water at this site is an example of the highly variable and sometimes poor quality of the various sources of irrigation waters collectively termed 'fresh', as discussed by Unkovich, *et al,* (2006).

Table 5: Guidelines and recommendations for selected water quality parameters with regards to irrigation.

Parameter	**Guidelines and Comments**
pH	6.5 - 8.4 to prevent toxicity and deficiency symptoms in plants [1], <7.0 to prevent clogging of drippers [1]
EC	Classified into salinity classes - recommended uses, management requirements and risks identified for each class [1]. Salinity threshold for [3].
SAR	Risk of soil permeability loss dependent on both EC and SAR of irrigation water [1,2].
Chloride	Concentrations > 142mg/L can pose toxicity risk to grape vines [3]. <350mg/L to reduce risk of increased Cd uptake by plants [2]
Total Nitrogen	LTV is 5.0mg/L to minimise effects to crop yields and quality [2]. STV is 25-125mg/L to protect natural waters [2]. Recommended that application rate matches crop requirements, and irrigation reduced or ceased in winter to prevent leaching [1]
Total Phosphorus	LTV is 0.05mg/L to minimise bioclogging of irrigation equipment [2]. STV is 0.8-12mg/L to protect natural waters [2]. Application should not exceed crop requirements [1].
BOD	<50mg/L acceptable for this form of irrigation [1]
Suspended Solids	<50mg/L acceptable for this form of irrigation [1]

References: 1: EPA (1991), 2: ANZECC (2000), 3: McCarthy *et al* (1992)
LTV is the long term trigger value, the maximum concentration of contaminant tolerated in the irrigation water assuming 100 years of irrigation
STV is the short term trigger value, the maximum concentration of contaminant tolerated in the irrigation water assuming 20 years of irrigation

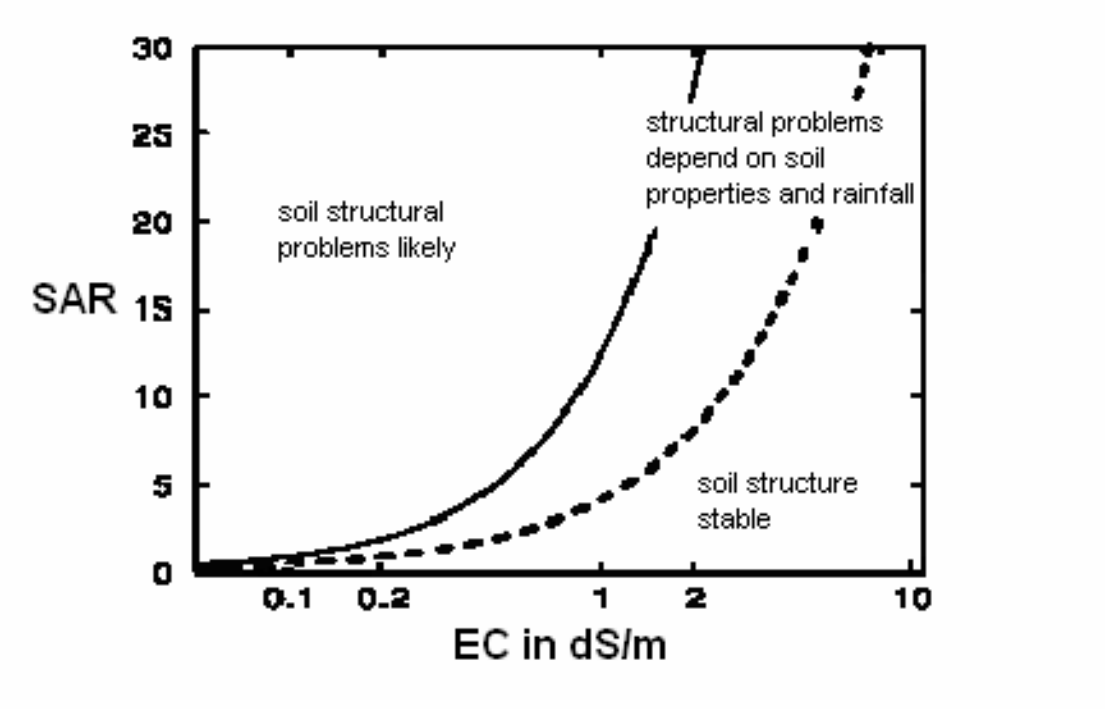


Figure 2: Relationship between EC and SAR of irrigation water with regards to soil structural integrity. (adapted from ANZECC/ARMCANZ, 2000).

Table 6: Quality of recycled and fresh water at Hyde Park Vineyard during the 2003/04 season.

		Recycled (n=5)		Fresh (n=5)	
Parameter	**Units**	**Mean**	**Std Devn**	**Mean**	**Std Devn**
pH		9.20	0.76	8.41	0.53
EC	uS/cm	1756	160	2504	1062
SS	g/m^3	20	21	47	37
Cl-	g/m^3	398	43	592	269
SO42-	g/m^3	76	10	56	21
Total Alkalinity	g/m^3	298	16	506	235
Na+	g/m^3	304	40	432	224
K+	g/m^3	34	3	20	8
Ca2+	g/m^3	14	5	34	9
Mg2+	g/m^3	24	2	45	24
Oxid. N	g/m^3	1.3	1.9	2.8	6.2
Total N	g/m^3	3.8	2.3	4.7	6.3
Total P	g/m^3	7.5	2.0	3.3	7.1
SRP	g/m^3	6.0	2.9	3.0	6.7
SAR		11.5	2.0	11.1	3.4

Seppelts, Westgate, and Montara: As mentioned previously, the recycled water quality was essentially the same as that at the treatment plant (Tables 7-9). The EC of the recycled water was of medium classification, however the EC in combination with the SAR indicates that there is as a risk of soil

structural problems (ANZECC/ARMCANZ, 2000; Figure 2). Chloride concentrations were high enough to pose a toxicity risk to vines. Nitrogen concentrations exceed long term trigger values (LTV) which has potential implications for drops in yields and quality (ANZECC/ARMCANZ, 2000). Phosphorus concentrations exceed both long term and short term trigger values, and therefore have the potential to cause bioclogging of irrigation equipment, and for transport to groundwater and surface water resources (ANZECC/ARMCANZ, 2000).

Fresh water used for irrigation of Arrawatta (datum points 5-7) and St Peters blocks (datum point 8) at Seppelts is supplied by rain fed dams located adjacent to or near to the blocks. The water from these dams is considerably fresher than the recycled water with regards to EC and SAR (Figure 3a), and the average concentrations of the major ions chloride, sulphate, sodium potassium and calcium. Although the EC and SAR of the fresh water resources are lower than the recycled water, when considered in combination, the water used to irrigate St. Peters block still presents a definite risk of soil structural deterioration, whilst that used for Arrawatta Block presents only a moderate risk. The biggest factor is the low EC which can contribute to the dissolution of salts such as calcium from the soil complex (McCarthy *et al*, 1992). Phosphorus concentrations in the fresh water may contribute to bioclogging of irrigation systems, but poses minimal environmental threat (ANZECC/ARMCANZ, 2000).

Table 7: Quality of recycled and fresh water at Seppelts Great Western Vineyard during the 2003/04 season.

		Recycled Water (n=5)		Fresh Water (Arrawatta) (n=5)		Fresh Water (St Peters) (n=5)	
Parameter	**Units**	**mean**	**std dev**	**mean**	**std dev**	**mean**	**std dev**
pH		7.39	0.40	8.11	0.62	8.25	0.45
EC	uS/cm	1684	348	704	516	136	23
SS	g/m^3	17	13	19	15	18	6
Cl-	g/m^3	364	106	136	109	13	5
SO42-	g/m^3	69	22	53	30	10	9
Total Alkalinity	g/m^3	345	99	127	61	79	19
Na+	g/m^3	270	35	104	83	32	33
K+	g/m^3	35	13	20	9	8.5	0.7
Ca2+	g/m^3	27	3	14.6	6.6	4.6	1.4
Mg2+	g/m^3	33	25	23	27	4.7	1.0
Oxid. N	g/m^3	3.2	3.4	1.9	4.1	0.2	0.3
Total N	g/m^3	6.3	4.3	3.6	5.3	2.7	2.3
Total P	g/m^3	12.2	6.9	3.4	6.8	4.8	10.2
SRP	g/m^3	12	7	3.2	6.9	0.0	0.0
SAR		8.7	1.9	4.0	3.1	2.3	2.2

Fresh water at Westgate Vineyard was of low to medium salinity, making it slightly more suitable for sensitive crops than the other waters. This water had a significantly lower SAR (Figure 3b) which, when considered in conjunction with the EC, indicates a minimal threat to soil structural properties (ANZECC/ARMCANZ, 2000). Chloride concentrations are potentially high

enough to result in toxicity symptoms in grapevines. Phosphorus concentrations indicate a risk of bioclogging of irrigation equipment, but pose minimal environmental threat (ANZECC/ARMCANZ, 2000).

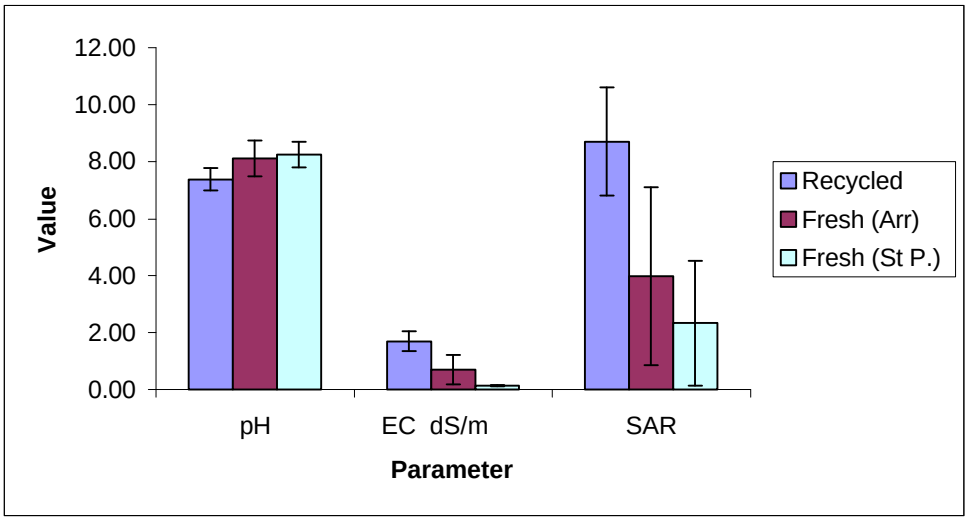
Table 8: Quality of recycled and fresh water at Westgate Vineyard during the 2003/04 season.

		Recycled n=5		Fresh n=5	
Parameter	**Units**	**Mean**	**Std Devn**	**Mean**	**Std Devn**
pH		7.56	0.47	7.82	0.13
EC	uS/cm	1412	135	1195	137
SS	g/m^3	12	5.4	1.5	0.4
Cl-	g/m^3	276	27	300	44
SO42-	g/m^3	68	17	32	3
Total Alkalinity	g/m^3	252	42	168	19
Na+	g/m^3	232	20	163	19
K+	g/m^3	35	2	5.9	0.6
Ca2+	g/m^3	24	3	15	2
Mg2+	g/m^3	15	2	36	3
Oxid. N	g/m^3	5.2	3.7	0.02	0.02
Total N	g/m^3	7.4	4.5	1.1	0.22
Total P	g/m^3	15	2.9	0.30	0.47
SRP	g/m^3	14	2.9	0.02	0.005
SAR		9.1	0.6	5.2	0.5

Table 9: Quality of recycled water at Montara Winery during the 2003/04 season (data from license point at final lagoon, Ararat Wastewater Treatment Plant, supplied by Grampians Wimmera Mallee Water Authority).

		Recycled n=5	
Parameter	**Units**	**Mean**	**Std Devn**
pH		8.0	0.4
EC	uS/cm	1337	122
SS	g/m^3	13	9.4
Na^+	g/m^3	203	5.8
Ca^{2+}	g/m^3	19	1.5
Mg^{2+}	g/m^3	13	1
Oxid. N	g/m^3	7.3	3.4
Total N	g/m^3	15.6	6.4
Total P	g/m^3	14	3.5
SAR	g/m^3	8.7	0.31

a)



b)

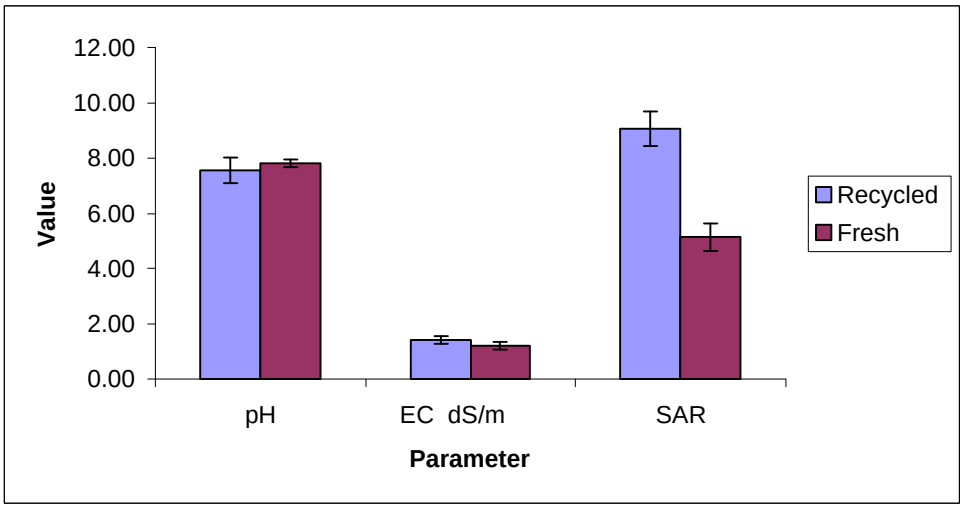


Figure 3: Comparison between pH, EC, and SAR of recycled and fresh water at a) Seppelts, and b) Westgate Vineyard

In conclusion, water quality monitoring indicates that there is a significant threat to soil structural integrity from the use of recycled water. Elevated sodium levels, coupled with a medium salinity rating, can result in soil structural deterioration. The chloride concentrations are also high enough to pose a threat to the health and productivity of the grape vines. Also of concern are the concentrations of nitrogen and phosphorus in the recycled water. Whilst they will no doubt contribute to grapevine nutrition, excessive application over the long term could result in yield reductions. Long term application could also result in the contamination of groundwater and surface water resources.

Soil Analysis

Summary results for a number of key soil chemical properties are provided in Appendix 5b. Comparisons between soil properties under the three treatments using the Mann-Whitney U-test indicated a number of soil property changes than can be attributed to the application of recycled water. Appendix 5c details

the results of the statistical analysis on the 2004 data set. Boxplots were chosen to present the results as they allow comparison of the median values for each treatment as well as the degree and nature of spread of the data.

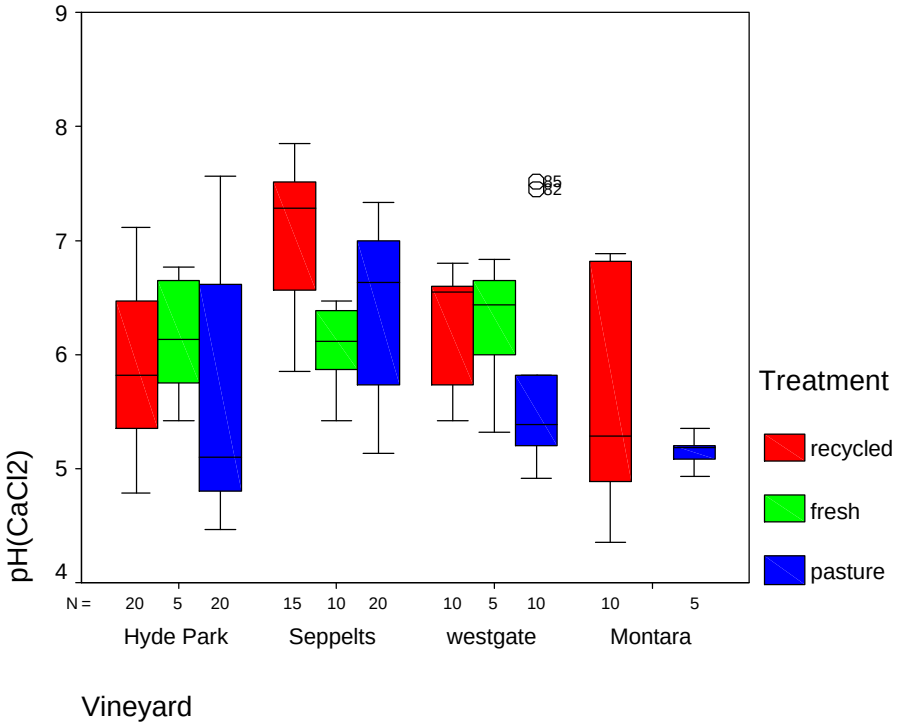
Soil pH

The pH of the soil environment affects the availability of minerals, including vital plant nutrients. If the pH is too high or too low, these constituents may either become unavailable leading to deficiency symptoms, or become increasingly available leading to toxicity problems (Robinson, 1992).

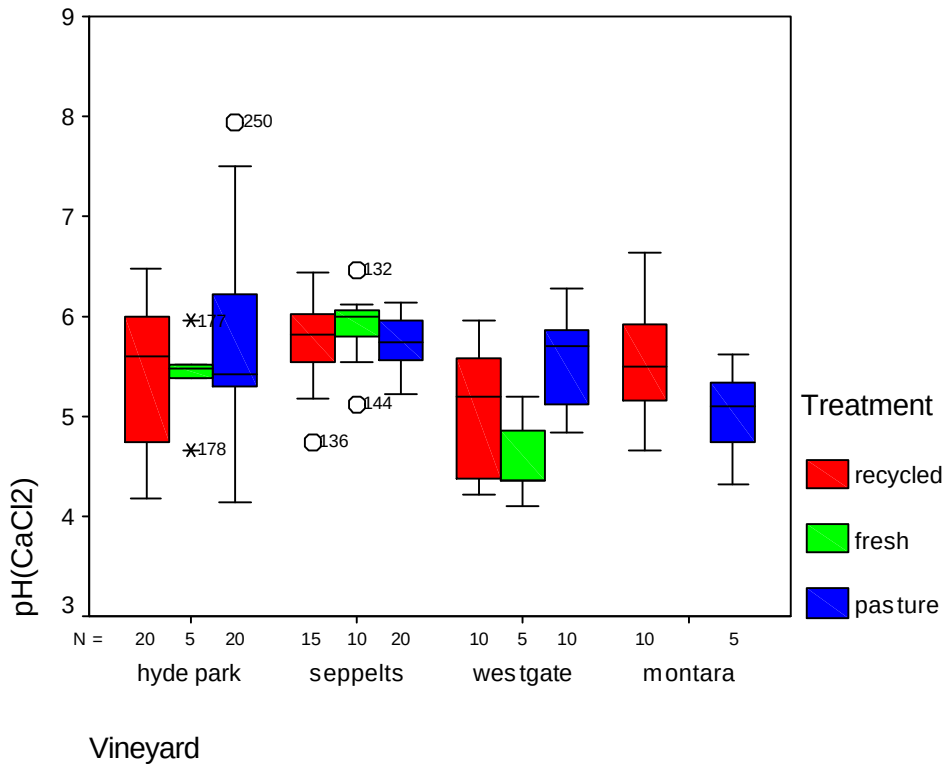
Soil pH results are presented as $pH_{(1:5\ CaCl2)}$ (Figures 4a and 4b) because this is more representative of field conditions, and often gives less variability in results than $pH_{(1:5water)}$ due to seasonal fluctuations and fertilizer inputs (White, 1969).

The majority of samples tested in this study had median pH's in the slight to moderately acidic category (Figure 4), being in the lower end or below the desirable range for grapes (6.1 to 7.9) according to the EPA (1991). According to Robinson (1992), grapevines will grow over a pH range of 4.0 to 8.5, however 5.5 to 8.0 is identified as being more suitable. At the extremes of the range observed, many nutrients such as nitrogen, phosphorus are less readily available than at or near a neutral pH, whilst microelements such as manganese, boron, and aluminium may potentially become available in toxic quantities at low pH. (Robinson, 1992). On the other hand, an acidic soil can be favourable where structural degradation associated with soil sodicity is a concern. An acidic clay will potentially disperse less readily as hydrogen ions (H^+) and aluminium ions (Al^{3+}) available under acidic conditions are powerful coagulators (Leeper and Uren, 1993).

In general, pH was highly variable, and there were very few statistically significant results (Figure 4), suggesting that either variability was too high for there to be obvious treatment effects, or that few differences exist between treatments. For instance, no significant differences were observed between treatments at Hyde Park or Montara. At Seppelts, topsoil pH was significantly higher in the recycled treatment than in the pasture and fresh treatments ($p<0.05$ and $p<0.005$ respectively). Similar results were seen at Westgate, suggesting that recycled water irrigation has increased topsoil pH. Whilst there is a great deal of variability in the results, there is an indication that topsoil pH may be increasing as a result of recycled water application. An increase towards near neutral soil pH would generally improve nutrient availability, however, an increase towards alkaline conditions, although unlikely, could have significant impacts with regards to soil structural stability and nutritional balance.



a)



b)

Figure 4: a) pH of vineyard topsoils; b) pH of vineyard subsoils

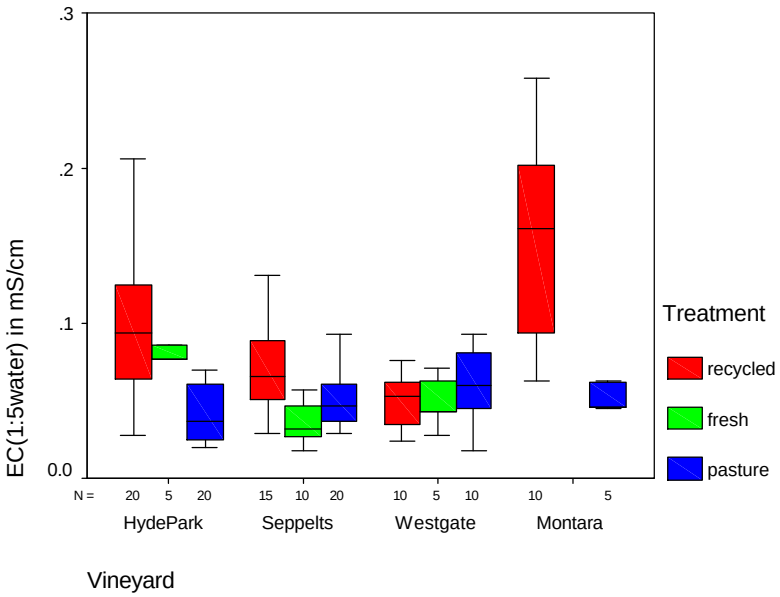
Soil Electrical Conductivity (EC)

At Hyde Park there were significant differences in topsoil (0-10cm) EC between recycled and pasture treatments ($p<0.001$), and between fresh and pasture treatments ($p<0.05$) indicating that vineyard irrigation has resulted in an elevated soil EC (Figure 5a). No statistically significant differences were detected between recycled and fresh treatments, however this was not surprising given that the two water types were similar with regards to EC (Table 6). The soils irrigated with freshwater are also downslope of those irrigated with recycled water, making them susceptible to subsurface lateral flow from soils irrigated with recycled water. No significant differences were observed between treatments for subsoils at Hyde Park (Figure 5b), suggesting that irrigation has not impacted on subsoil EC.

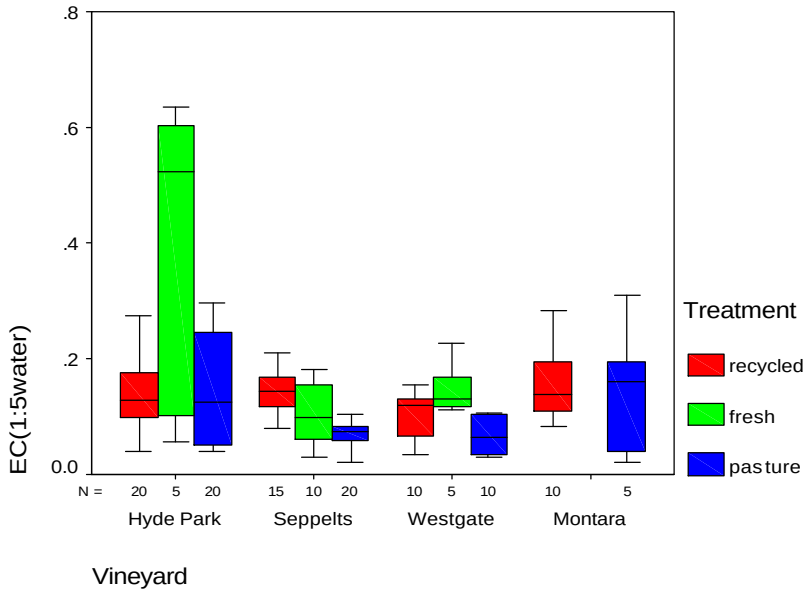
Within topsoils at Seppelts, there were significant differences between recycled and pasture treatments, and between fresh and pasture treatments ($p<0.05$; Figure 5a). These results reflect an increase in topsoil EC with recycled water irrigation, whilst irrigation with fresh water has resulted in a decreased EC in the topsoil. This was supported by comparison between fresh and recycled treatments ($p<0.005$). Within subsoils at Seppelts, a highly significant difference was detected between recycled and pasture treatments (Figure 5b), indicating that subsoil EC has also increased as a result of recycled water irrigation.

At Westgate vineyard there were no significant differences in topsoil EC between any of the treatments, indicating that irrigation or irrigation water quality has had no impact on topsoil EC (Figure 5a). Within the subsoils however, there were significant ($p<0.05$) differences between recycled and pasture treatments and between fresh and pasture treatments ($p<0.001$) (Figure 5b). The results indicate that irrigation has contributed to an increase in subsoil EC, but there is no significant difference between the fresh and recycled water treatments. Again this is not unexpected given the similar EC of both water sources (Table 8).

At Montara, a highly significant ($p<0.005$) difference was observed between the topsoil EC of recycled and pasture treatments indicating that recycled water irrigation has resulted in an increase in topsoil EC, however no significant difference was observed in the subsoils.



a)



b)

Figure 5: EC of vineyard a) topsoils and, b) subsoils collected in 2004.

The results of the analyses conducted indicate that irrigation with recycled water and waters of similar electrical conductivities (ie. dam water at Hyde Park, groundwater at Westgate) has caused topsoil electrical conductivity to increase. Little impact has been observed in vineyard subsoils, with the exception of those irrigated with fresh water at Westgate. Whilst the soils in this study are not considered saline, the salinisation of soils over the long term is highly undesirable. In particular, subsoil salinisation is of significant concern due the limited means by which it can be managed.

Soil Exchangeable Sodium Percentage (ESP)

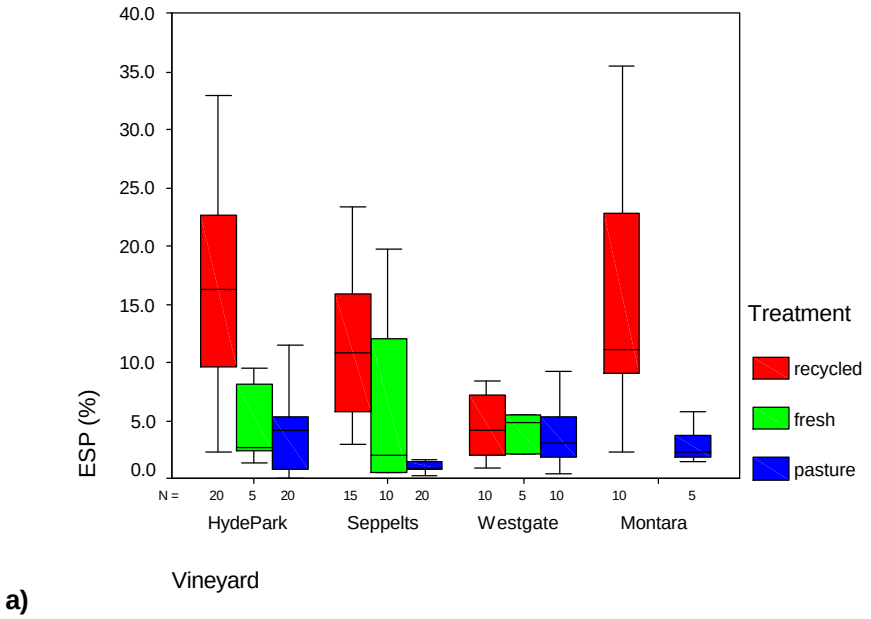
Soil ESP varied considerably, particularly within the recycled treatment (Figure 6). At Hyde Park, statistical analysis revealed that the ESP of topsoils in the recycled treatment was significantly greater than in the pasture treatment ($p<0.001$) and the fresh treatment ($p<0.005$). These results suggest that topsoil ESP has risen in association with the use of recycled water. In contrast, there was no significant difference between irrigation treatments in the subsoils.

Within topsoils at Seppelts the ESP of the recycled treatment was significantly greater than the pasture treatment ($p<0.001$), and the fresh treatment ($p<0.05$), indicating that recycled water has impacted negatively on topsoil ESP. Within the subsoils, ESP of the recycled treatment was significantly greater than in the pasture treatment ($p<0.05$) and the fresh treatment ($p<0.005$). These results indicate that recycled water has also impacted deleteriously on subsoil ESP.

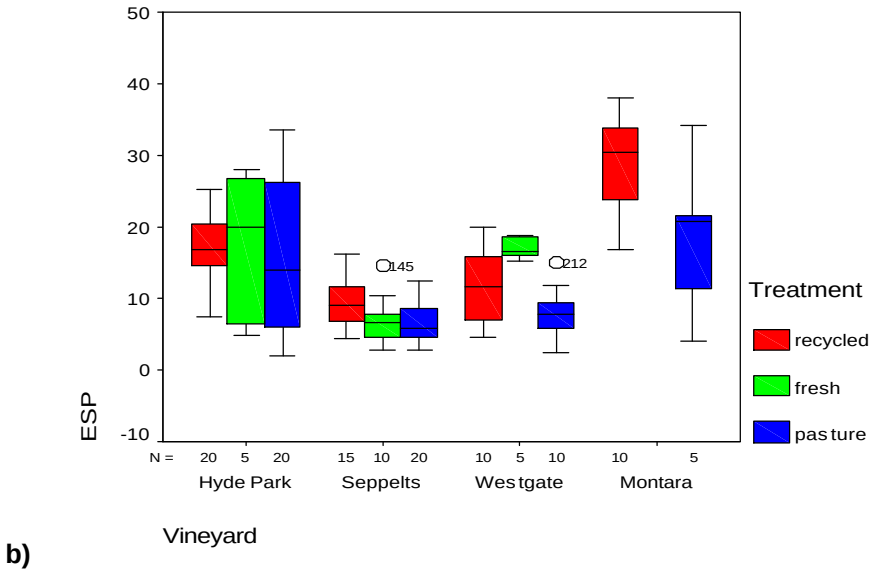
At Westgate vineyard, no significant differences in topsoil ESP were observed, but within the subsoil, the ESP of the fresh treatment was highly significantly greater ($p<0.005$) than that of the pasture, indicating that fresh water irrigation has had a greater impact on subsoil ESP than the recycled water. This is most likely a factor of irrigation management rather than water quality, as the SAR of the fresh water is less than that of the recycled water. It may also reflect how the water was applied, as fresh water is applied by sprinkler irrigation at less regular intervals than the drip irrigated recycled water. Smaller volumes of fresh water are also applied over the season, suggesting that leaching of sodium from the rootzone occurs less readily. Further evidence for this conclusion is provided by the observation that subsoil EC is significantly greater in the fresh treatment than in the pasture treatment.

At Montara, the ESP in the recycled treatment was significantly greater ($p<0.005$) than in the pasture treatment within topsoils, but not within subsoils ($p=0.129$), despite it appearing so in figure 6b. The results indicate that recycled water has impacted on surface soils, and to a lesser extent on subsoils.

In general, the results indicate that irrigation with recycled water has resulted in an increase in topsoil ESP, and to a lesser extent in subsoil ESP. The exception to this observation occurred at Westgate vineyard, where it appears that recycled water has not impacted on soil ESP, whereas fresh water has caused an increase in subsoil ESP. It is speculated that this is a factor of irrigation type and volume. All topsoils irrigated with recycled water, and virtually all subsoils (regardless of treatment) in the study have an ESP>6, defining them as sodic (Isbell, 1996).



a)



b)

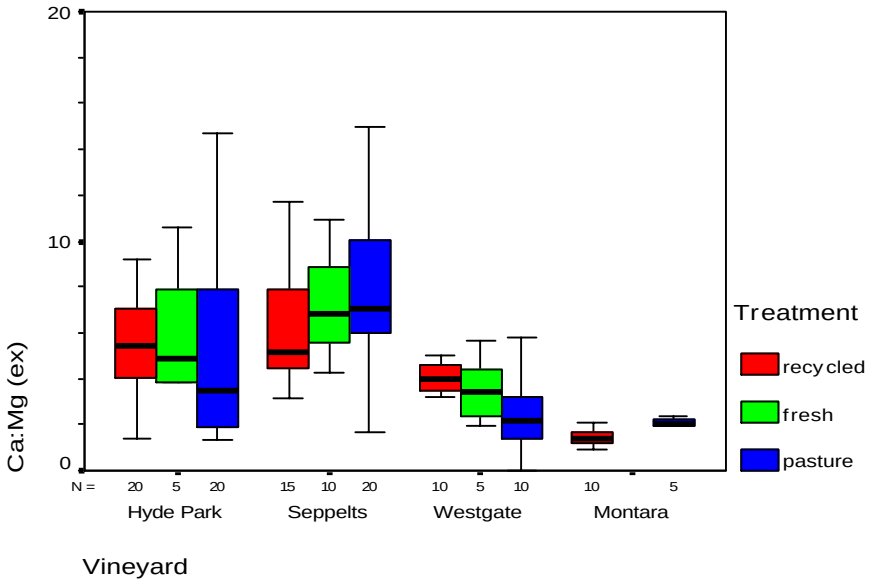
Figure 6: a) ESP of vineyard topsoils; b) ESP of vineyard subsoils

Calcium Magnesium ratio (Ca_{ex}:Mg_{ex})

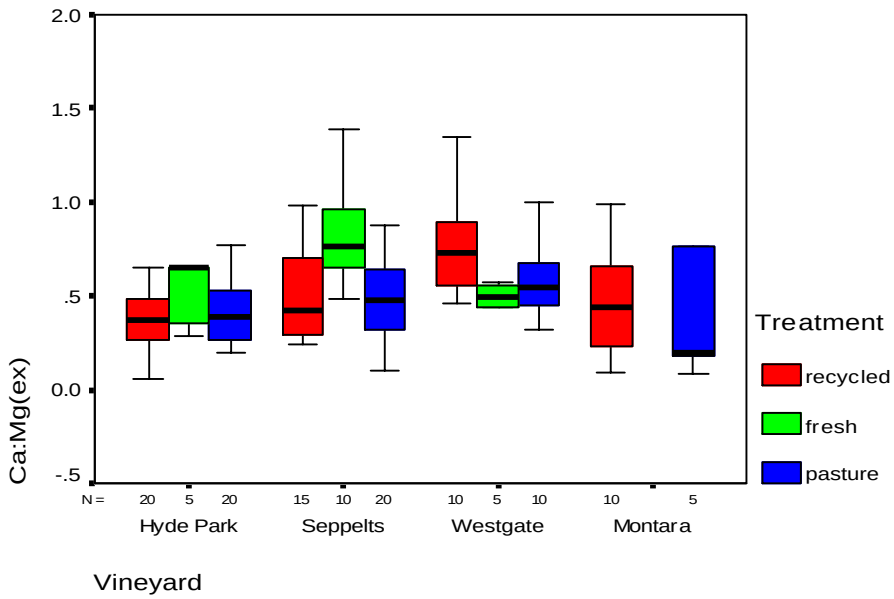
Previous research indicates that the subsoils of this region have a naturally low ratio of calcium to magnesium (Badawy, 1982a; Cass and Dowley, 1999). For example, work by Badawy (1982a) on soils from Montara indicated that subsoil Ca:Mg ranged between 0.3 and 0.7, which is supported by the results of this study (Figure 7). Topsoil Ca:Mg ranged between 1 and 22, with an average value of 5.4 ± 3.7, whilst the subsoil Ca:Mg was commonly less than 1 (average value of 0.55 ± 0.37). The ratio of calcium and magnesium in the soil can have important implications for the structural stability of the soil. For instance, magnesium can allow more sodium to adsorb to exchange sites than calcium, (Rahman & Rowell, 1979), and is reported to be less efficient in flocculating soil colloids than calcium (Rengasamy, 1983). Hence, where magnesium is present in the soil in greater proportions than calcium, soil ESP

can increase, resulting in potential for soil structural instability, which can be exacerbated by the lower flocculating efficiency of magnesium.

A suitable ratio of >1 has been recommended for red-brown earths (Rengasamy *et al*, 1986). Topsoils is this study have ratios well above that recommended for other soils (eg: Rengasamy *et al*, 1986), however the subsoils have a very low ratio, more commonly <1, which could contribute to soil structural instability under continuing application of the sodium rich recycled water.



a)



b)

Figure 7: Ca: Mg ratio of a) topsoils and b) subsoils

Another implication of low exchangeable calcium in soils is the threat of specific ion toxicity to grape vines. Calcium is thought to be capable of reducing the toxicity of other ions in the rootzone (Ayers & Wescot, 1985), and

hence there could also be impacts to grape vine health and productivity if not addressed. Cass and Dowley (1999) recommended that Ca:Mg be increased to above 2 (ideal range of 2 to 10) at Hyde Park Vineyard to provide for optimum vine performance. All subsoils in this study had Ca:Mg <2., indicating that vineyard soil management strategies, such as gypsum application at depth need to be considered.

Spontaneous dispersion

No topsoils (0-10cm) from the samples collected in 2004 exhibited evidence of spontaneous dispersion. Within the subsoils however, there was evidence of spontaneous dispersion in pasture soils from three of the four vineyards, and in soils irrigated with recycled water in two of the vineyards (Table 10). Subsoils under fresh water irrigation showed no evidence of spontaneous dispersion. The most dramatic evidence for spontaneous dispersion was recorded at Montara Winery where 100% of subsoils irrigated with recycled water and 80% of pasture subsoils exhibited slight spontaneous dispersion. Given that both irrigated and pasture soils exhibited this behaviour it is unlikely that it is the result of irrigation practices or water quality. At Hyde Park 25% of soils under recycled water and 35% of pasture soils showed evidence of spontaneous dispersion. A number of pasture soils at Seppelts (10%) and Westgate (30%) also exhibited spontaneous dispersion.

The results indicate that the soils in these vineyards are prone to dispersion naturally, which supports the literature available regarding these soils (Cass and Dowley, 1999). It would appear that irrigation has decreased the susceptibility of these soils to dispersion to some extent, with the exception of those irrigated with recycled water at Hyde Park and Montara.

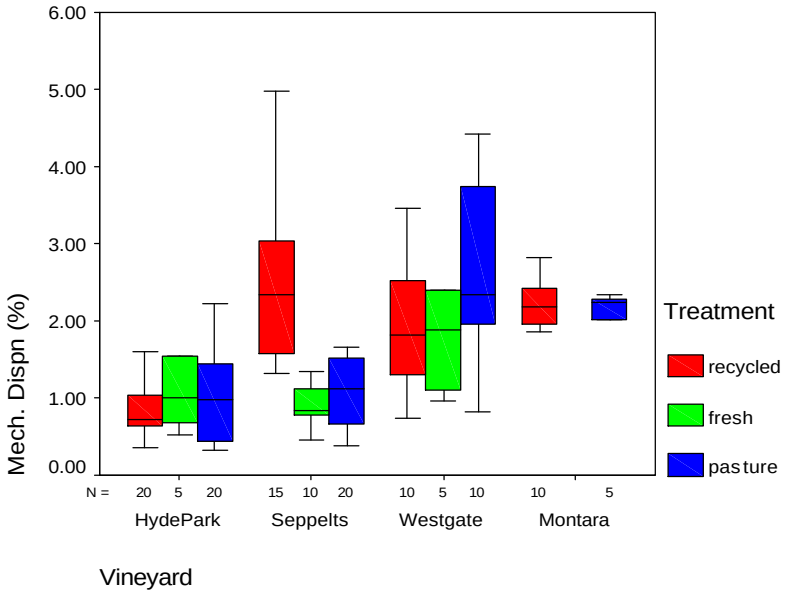
Table 10: Percentage of subsoils (40-60cm) sampled in 2004 to exhibit spontaneous dispersion.

Vineyard	Recycled	Fresh	Pasture
Hyde Park	25	0	35
Seppelts	0	0	10
Westgate	0	0	30
Montara	100	-	80

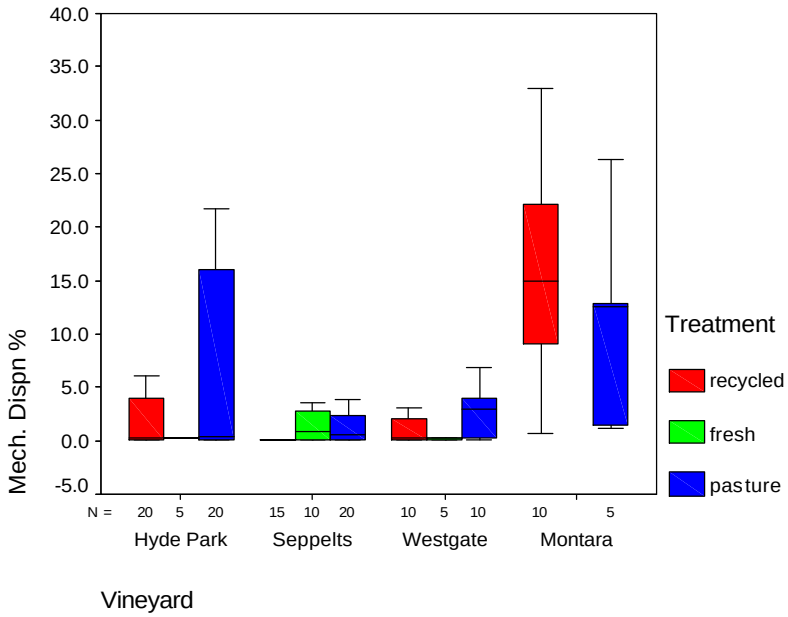
Mechanical dispersion

The potential for mechanical dispersion in vineyard soils was also measured (Figure 8), although it's relevance in a perennial system such as a vineyard is limited since activities such as cultivation are infrequent. The potential for topsoils to disperse under mechanical pressure was most pronounced at Montara Winery, where similar results were obtained for both soils receiving recycled water and those under pasture. Topsoils at Hyde Park and Seppelts exhibited significantly less mechanical dispersion than those from Montara. The exception was for soils irrigated with recycled water at Seppelts which

exhibited significantly greater potential for dispersion under mechanical force compared to those irrigated with fresh water or under pasture soils ($p<0.005$ and $p<0.001$ respectively). Subsoils from the recycled treatment at Seppelts, however, exhibited significantly less mechanical dispersion than those from the fresh and pasture treatments ($p<0.001$ and $p<0.005$ respectively).These results suggest that irrigation with recycled water has had a deleterious impact on the structural properties of topsoils, but a positive impact on subsoils at Seppelts. Mechanical dispersion in topsoils from all three treatments at Westgate vineyard was highly variable, but not significantly different. Within the subsoils however mechanical dispersion in the pasture treatment was significantly greater than in the fresh treatment ($p<0.05$), again suggesting a positive impact of recycled water irrigation.



a)



b)

Figure 8: Mechanical dispersion of a) topsoils and b) subsoils.

Analysis of the results has also included some preliminary exploration of the role of time with respect to changes in soil properties. Specifically, the number of years of irrigation, and the number of years of irrigation with recycled water have been investigated. Initial results indicate the length of time of irrigation or recycled water irrigation are not significant factors when considering the changes in soil properties observed in this study. In other words, there are no clear relationships between the length of time of irrigation and the changes in soil properties. These results, while still being investigated, indicate that other factors are more important in the management of recycled water irrigation of vineyards. These are likely to be both site specific to some extent as well as regional in their context.

These may include irrigation management issues such as the provision of a leaching fraction to prevent the build-up of sodium on the soil complex (as reflected in the increasing ESP) as well as the increase in soil electrical conductivity (EC).This would require careful management however, as the potential for a loss of structural integrity is increased as the soil water conductivity decreases. Within vineyard subsoils particularly, the inherently low proportion of calcium relative to magnesium (Ca:Mg) could also be an important factor contributing to the increased exchangeable sodium percentage observed. As mentioned previously, magnesium can allow more sodium to adsorb to exchange sites than calcium, (Rahman & Rowell, 1979).

Vine Productivity

The number of bunches per panel was generally higher in the effluent irrigated treatment than in the fresh irrigated treatment at Hyde Park vineyard in 2003 ($p<0.05$; Figure 9). Results for the effluent irrigated treatment were also much less variable than those for the fresh irrigation treatment, however, these results were confounded by differences in the volume and timing of water applied. There were no significant differences observed with treatment in 2004 (Figure 9 & 10), however the weight of individual bunches in the fresh water treatment at Hyde Park were significantly lower than those of the recycled treatment in 2004 (Figure 11), again reflecting the volume and timing of irrigation of the fresh irrigated vines. These results indicate that fresh irrigated vines at Hyde Park had a lower overall yield than those irrigated with recycled water during the study period. This is most likely due to a lack of fresh water available for irrigation of these vines.

At Seppelts, results over the study period indicate that there were no significant differences in the yield between the two treatments. This conclusion is based on bunch counts (Figure 10) and bunch weights (Figure 11). Similarly, no significant difference in bunch counts were reported at Westgate in 2004 (Figure 10).

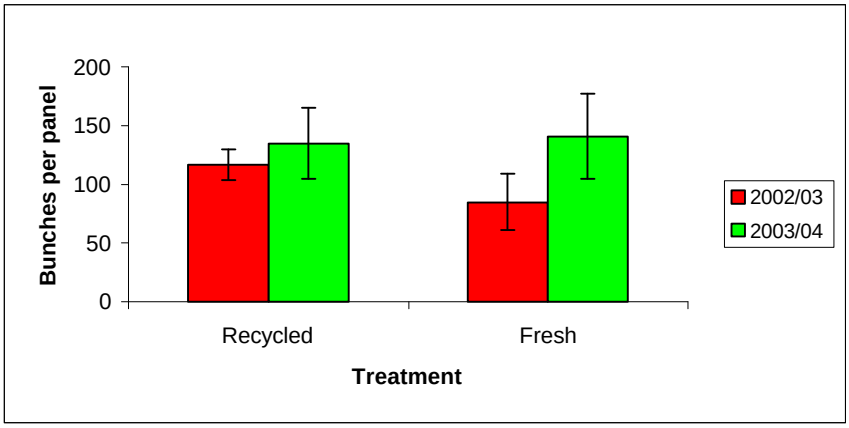


Figure 9: Bunches per panel for recycled and fresh irrigated vines at Hyde Park vineyard over two seasons.

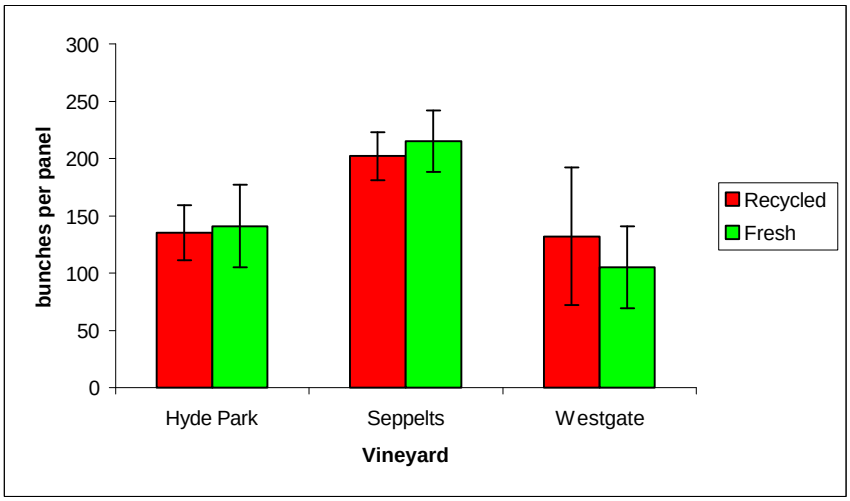


Figure 10: Bunches per panel for the 2003/04 season.

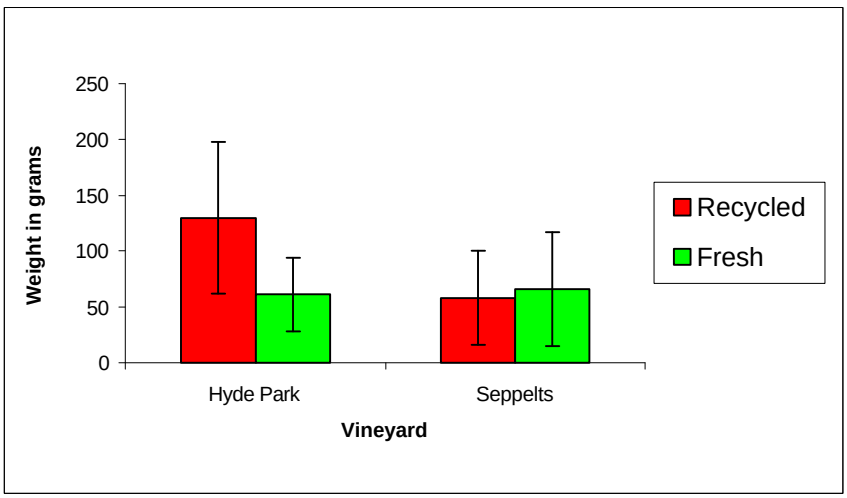


Figure 11: Average bunch weights for the 2003/2004 season.

Given the limited number of seasons used for data collection, further investigation of yields will be required to determine whether the observations are indicative of longer term trends in yield response.

Outcomes and Conclusions

The outcomes of this project include a clearer understanding of the impacts of using recycled water to irrigate Great Western Vineyards with respects to soil properties and sustainability.

The results of the field studies indicate that the application of recycled water in Great Western vineyards has impacted deleteriously on the properties of topsoils and to a lesser extent on subsoils. These impacts include an increase in soil electrical conductivity (EC) and soil exchangeable sodium percentage (ESP). These results concur with observations made by P. Maher-Kane (ARC Linkage program) whereby comparisons were made between the topsoils of the vine row and the cultivated pasture that comprises the inter-row area (Maher *et al,* 2005). In the knowledge that these soils have inherently poor physical structure and chemical fertility, these impacts will require consideration for future management.

The results of this study have highlighted the high degree of spatial variability often observed when studying soils. This variability is indicative of not only spatial distance across vineyard blocks, datum points, and vineyards, but also with distance from the dripper emitter in the vine row. Studies by Maher *et al* (2005) indicate that solute distribution in the vine row is not uniform with respect to distance from the dripper emitter. Hence it is likely that the random location of soil core sampling employed in this study incorporates this variability into the results. The variability of soil properties between datum points and between vineyards highlights the need to develop site specific management criteria, to be coupled with broader regional management strategies.

There is still much to be learnt about the response of these soils to recycled water. Nutrient fate is currently being investigated in the laboratory based studies conducted as part of this project. Results of these studies will be used to elucidate the fate and transport of nitrogen and phosphorus, among other solutes, under field conditions. Row management trials, conducted by P. Maher-Kane under the ARC Linkage program, will also provide valuable information about the effectiveness of various soil amendments at improving the sustainability of recycled water irrigation in Great Western vineyards.

The results of vine productivity monitoring indicated no impacts of water quality, however given time restraints, very little information was collected regarding the impacts to vine productivity, and certainly to vine health. Given that many of the vines in this study were planted in the late 1990’s, and are still establishing, measures of yield can be unreliable. Yield monitoring will become an increasingly useful tool for monitoring the impacts of recycled water irrigation as the vines establish and mature.

Recommendations

There have been few studies of the impact of recycled water on Victorian agricultural systems. This is particularly true of vineyards and also soils that are inherently poorly structured. There is much need to develop a strategic research plan to further understand the risks associated with chemicals in recycled water to viticultural systems, and to develop management systems to reduce the likelihood of adverse impacts.

The issue of low calcium in the subsoils is one that needs to be addressed in order to improve the inherent structural problems of these soils. Strategies to incorporate calcium at depth need to be considered to correct for this deficiency, and to ensure that the soils are better able to cope with the input of irrigation water characteristically high in sodium.

Whilst a number of soil chemical and physical properties were investigated in this study, there is still much to be learnt about the response of these and other soil types to recycled water irrigation. Further work in the Great Western region specifically, and on other Victorian soils is therefore recommended. The scope of research targeted during this project should certainly be continued to further our understanding of the complex interactions occurring in this agricultural system. For example, it is recommended that further research incorporate the determination of the threshold concentration of electrolytes (Quirk & Schofield, 1955) which refers to the minimum concentration of electrolytes required in the irrigation water to prevent dispersion of the soil. This is considered critical in the light of future irrigation management in Great Western vineyards. If this value can be determined it is possible for the water authority and growers to work collaboratively with the aim of achieving an optimal electrical conductivity in the recycled water, either through further treatment technologies or dilution of the final product. This will help to ensure that the electrical conductivity of the soil does not increase significantly, whilst at the same time, reduces the risk of structural deterioration associated with irrigation with waters of low electrolyte concentration.

Further to this work, the balance and relative proportions of ions in the recycled water should be considered, with particular emphasis given to reducing the sodium content of the water.

The phosphorus content of the recycled water exceeded both short and long term trigger values (Table 5), indicating a risk to both the efficiency of irrigation systems, and to the broader environment through contamination of groundwater and surface water resources. Hence as part of future studies, the phosphate sorption index of Great Western soils needs to be investigated to determine the capacity of these soils for adsorbing phosphorus. In conjunction with the results from the laboratory studies, this will allow predictions to be made regarding the long term threat to the quality of surface and groundwater resources. Treatment technologies to reduce the phosphorus concentrations in the recycled water also warrant consideration.

Production of a quality product is of paramount importance to the industry in general, and is an important factor in the acceptance of recycled water application in viticulture. Further research into the impacts of the use of recycled water on vine health and productivity is, therefore, recommended, as extensive coverage of this area was beyond the scope of this project. Petiole analysis is an effective means of determining the health and potential productivity of vines, providing an indication of the nutrient status of the vine, and hence identifies deficiency and toxicity problems being experienced by the vine. Grape and juice analysis should also be incorporated in future work to determine whether recycled water irrigation results in any changes to the composition and characteristics of the product, and their likely impact on the quality and taste of the wine. This is considered to be an essential component of future research in light of the industries desire to promote the production of premium wines using sustainable systems.

Appendix 1: Communications

Appendix 1a: Publications

Hermon, K. Maher, P., Ierodiaconou, D., Stagnitti, F., Allinson, G., Armstrong, R., LeBlanc, M., de Rooij, G., Bloem, E., and Hogervorst, F. (2004) Recycled effluent irrigation in vineyards: an Australian case study. 1. Issues and monitoring. In: Recent Research Developments in Crop Science. I. (Research Signpost. Kerala, India) *Attachment 2*

Maher, P., Hermon, K., Ierodiaconou, D., Stagnitti, F., Allinson, G., Armstrong, R., LeBlanc, M., de Rooij, G., Bloem, E., and Hogervorst, F. (2004) Recycled effluent irrigation in vineyards: an Australian case study. II. Management for sustainability. In: Recent Research Developments in Crop Science. I.(Research Signpost. Kerala, India) *Attachment 3*

Maher P, Hermon K, Allinson G, Stagnitti, F, Armstrong, R (2004) Monitoring and modelling the effects of recycled water and row management on vineyard soils. Australian and New Zealand Grapegrower and Winemaker Technical Issue 485a, 15-21. *Attachment 4*

Maher, PM, Hermon, KM, Allinson, G, Stagnitti, F, Armstrong, R (2005) Variability of soil chemistry under recycled municipal effluent irrigation: a Great Western vineyard case study. Water Resources Management III. Progress in Water Resources, Vol 11. M. de Conceicao Cunha & C.A. Brebbia (Eds) Wessex Institute of Technology, UK. *Attachment 5*

Hamilton, AJ, Versace, VL, Stagnitti, F, Li, P, Yin, W, Maher, P, Hermon K, Premier, R, and Ierodiaconou, D (2006) Wastewater reuse and the environment: reaping the benefits by minimising the impacts (to be published in WSEAS journal, 2006)

Appendix 1b: Conference presentations

Hermon K, Maher P, Allinson G, Stagnitti, F, Armstrong, R (2003) Improving water use efficiency of vineyards in the Great Western region by using effluent water and soil amelioration practices. In: NWGIC Industry Symposium. Charles Sturt University, Wagga Wagga, Australia. (Poster presentation)

Hermon K, Maher P, Allinson G, Stagnitti, F, Armstrong, R (2004) The use of recycled water in vineyards of the Great Western region. In: 12th Australian Wine Industry Technical Conference. Melbourne, Australia, 25-28 July, 2004. (Poster presentation)

Hermon K, Maher P, Allinson G, Stagnitti, F, Armstrong, R (2004) The impacts of recycled water on soil properties in vineyards in the Great Western region. In: Interact 2004, Gold Coast, Australia, 4-8 July, 2004. (Oral presentation)

Hermon K, Maher P, Allinson G, Stagnitti, F, Armstrong, R (2004) The impacts of recycled water on soil properties in vineyards in the Great Western region. In: Supersoil 2004. Sydney, Australia, 5-9 December, 2004. (Oral presentation).

Maher PM, Hermon KM, Allinson G, Stagnitti, F, Armstrong, R (2004) Management for sustainability of soil resources under drip irrigation recycled water. A Great Western Case Study. In:12th Australian Wine Industry Technical Conference. Melbourne, Australia, 25-28 July, 2004. (Poster presentation)

Maher,PM, Hermon, KM, Allinson, G, Stagnitti, F, Armstrong, R (2005) Variability of soil chemistry under recycled municipal effluent irrigation: a Great Western vineyard case study. Third International Conference on Water Resources Management. Algarve, Portugal, 11 - 13 April 2005. (oral presentation)

Hamilton, AJ, Versace, VL, Stagnitti, F, Li, P, Yin, W, Maher, P, Hermon K, Premier, R, and Ierodiaconou, D (2006) Wastewater reuse and the environment: reaping the benefits by minimising the impacts. In: The 2006 IASME/WSEAS International Conference on: Water Resources, Hydraulics & Hydrology. Chalkida, Evia Island, Greece May 11-13, 2006. (oral presentation)

Appendix 1c: Meetings/Workshops

Allinson, G (2002) Exploring water use in vineyards: issues and research questions arising from use of treated municipal effluent water. Waite Campus, University of Adelaide (sponsored by the GWRDC) *Attachment 1*

Meeting held at Hyde Park Great Western Vineyard (September 18, 2002) to discuss the outcomes of GWRDC workshop (see Allinson, 2002).

Wastewater User's Group meeting, Seppelts Great Western Vineyard (April, 2003), with growers and Grampians Water Authority representatives (Simon Coutts and Glenn McKinnon).

Meeting at Seppelts Great Western Vineyard (September, 2004) with Gioa Small (Southcorp), and Andrea Hart (Seppelts Great Western Vineyard) to present and discuss project progress and preliminary results.

Grampians Winemakers meeting (October 13, 2004) – dissemination of some results from both projects to the group.

Appendix 1d: Future Communications

Workshop to be held in Great Western mid 2006 to present results of research to representative growers, vineyard managers, winemakers, Southcorp, Grampians Wimmera Mallee Water Authority, DPI, GWRDC, and Deakin University.

PhD Thesis: ‘The Impacts of Recycled Water on Soil Properties in Vineyards in the Great Western Region’
Karen Hermon
Deakin University
to be submitted by late 2006

PhD Thesis: ‘Monitoring and Modelling the Effects of Recycled Water and Row Management on Vineyard Soils’
Peta Kane (nee Maher)
Deakin University
to be submitted by end 2006

Dissemination of results through the DPI Grapecheque News

Appendix 1e: Attachments

Please see CD included

1. Allinson (2000) – GWRDC sponsored workshop report
2. Hermon *et al.* (2004) – book chapter
3. Maher *et al.* (2004) – book chapter
4. Maher *et al.* (2005) – conference paper
5. Maher *et al.* (2005) – presentation to the board of Grampians Wimmera Mallee Water Authority

Appendix 2: Intellectual Property

All methods used in this research are in the public domain. No commercially valuable property has arisen from this research.

Appendix 3: References

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Appendix 5: Raw Data

Appendix 5a: Water Quality

Table A1: Hyde Park Vineyard - Comparison of recycled and fresh water quality - 2003/04

		Recycled Water (n=5)					Fresh Water (n=5)				
Parameter	**Units**	**Mean**	**Std Devn**	**Median**	**Min**	**Max**	**Mean**	**Std Devn**	**Median**	**Min**	**Max**
pH		9.20	0.76	9.44	7.87	9.81	8.41	0.53	8.50	7.60	9.06
EC	uS/cm	1756	160	1800	1500	1920	2504	1062	2640	1400	3850
SS	g/m3	20	21	12	0.8	55	47	37	34	18	100
Cl^-	g/m3	398	43	390	340	450	592	269	620	290	900
SO_4^{2-}	g/m3	76	10	80	60	85	56	21	44	42	90
Total Alkalinity	g/m3	298	16	300	270	310	506	235	600	195	740
Na^+	g/m3	304	40	310	260	360	432	224	440	210	770
K^+	g/m3	34	3	32	32	38	20	8	18	10	32
Ca^{2+}	g/m3	14	5	13	8.4	22	34	9	40	24	42
Mg^{2+}	g/m3	24	2	24	22	28	45	24	46	15	75
Oxid. N	g/m3	1.3	1.9	0.33	0.01	4.6	2.8	6.2	0.04	0.01	14
Total N	g/m3	3.8	2.3	2.5	2.2	7.4	4.7	6.3	1.9	1.7	16
Total P	g/m3	7.5	2.0	7.5	5.1	9.8	3.3	7.1	0.08	0.06	16
SRP	g/m3	6.0	2.9	6.8	1.2	8.2	3.0	6.7	0.01	0.01	15
Ca	meq/L	0.7	0.3	0.65	0.42	1.1	1.7	0.4	2.0	1.2	2.1
Mg	meq/L	2.00	0.20	2.00	1.83	2.33	3.73	2.00	3.83	1.25	6.25
Na	meq/L	13.22	1.76	13.48	11.3	15.65	18.78	9.72	19.13	9.13	33.48
SAR		11.5	2.0	12.2	8.6	13.6	11.1	3.4	11.2	8.1	16.4

Table A2: Seppelts Vineyard - Comparison of recycled and fresh water quality - 2003/04

		Recycled Water (n=5)					Fresh Water - Arrawatta Block (n=5)					Fresh Water - St Peters Block (n=5)				
Parameter	**Units**	**mean**	**std dev**	**median**	**min**	**max**	**mean**	**std dev**	**median**	**min**	**max**	**mean**	**std dev**	**median**	**min**	**max**
pH		7.39	0.40	7.69	7.44	8.42	8.11	0.62	7.97	7.70	9.20	8.25	0.45	8.22	7.68	8.94
EC	uS/cm	1684	348	1580	1460	2300	704	516	760	160	1460	136	23	140	100	160
SS	g/m3	17	13	16	0.1	35	19	15	12	11	45	18	6	17	11	24
Cl^-	g/m3	364	106	330	290	550	136	109	170	15	280	13	5	14	5.2	17
SO_4^{2-}	g/m3	69	22	75	31	85	53	30	70	5.9	75	10	9	11	0.2	24
Total Alkalinity	g/m3	345	99	325	230	500	127	61	115	65	230	79	19	85	48	95
Na^+	g/m3	270	35	250	250	330	104	83	120	14	220	32	33	18	12	90
K^+	g/m3	35	13	36	14	48	20	9	18	12	36	8.5	0.7	8.5	7.8	9.5
Ca^{2+}	g/m3	27	3	28	24	32	14.6	6.6	18.0	6.4	20	4.6	1.4	5.4	2.4	5.8
Mg^{2+}	g/m3	33	25	19	15	75	23	27	14	7.3	70	4.7	1.0	4.6	3.4	6.2
Oxid. N	g/m3	3.2	3.4	2.8	0.01	8.7	1.9	4.1	0.05	0.01	9.3	0.2	0.3	0.01	0.01	0.78
Total N	g/m3	6.3	4.3	4.7	1.6	13	3.6	5.3	1.3	1.1	13	2.7	2.3	1.7	1.5	6.8
Total P	g/m3	12.2	6.9	14.5	0.06	17.5	3.4	6.8	0.37	0.11	15.5	4.8	10.2	0.21	0.17	23
SRP	g/m3	12	7	15	0.01	17	3.2	6.9	0.08	0.05	15.5	0.0	0.0	0.04	0.02	0.1
Ca	meq/L	1.4	0.2	1.4	1.2	1.6	0.7	0.3	0.90	0.32	1.0	0.2	0.1	0.27	0.12	0.29
Mg	meq/L	2.78	2.11	1.58	1.25	6.25	1.9	2.2	1.17	0.61	5.83	0.4	0.1	0.38	0.28	0.52
Na	meq/L	11.74	1.51	10.87	14.35	10.87	4.5	3.6	5.22	0.61	9.57	1.4	1.4	0.78	0.52	3.91
SAR		8.7	1.9	9.1	5.6	10.6	4.0	3.1	2.8	0.9	8.7	2.3	2.2	1.3	1.1	6.2

Table A3: Westgate Vineyard - Comparison of recycled and fresh water quality - 2003/04

		Recycled Water (n=5)					Fresh Water (n=4)				
Parameter	**Units**	**Mean**	**Std Devn**	**Median**	**Min**	**Max**	**Mean**	**Std Devn**	**Median**	**Min**	**Max**
pH		7.56	0.47	7.51	6.91	8.21	7.82	0.13	7.80	7.70	7.97
EC	uS/cm	1412	135	1460	1180	1520	1195	137	1190	1040	1360
SS	g/m3	12	5.4	14	2.9	17	1.5	0.4	1.4	1.2	2
Cl^-	g/m3	276	27	280	240	310	300	44	300	250	350
SO_4^{2-}	g/m3	68	17	75	46	85	32	3	31	30	37
Total Alkalinity	g/m3	252	42	240	210	310	168	19	160	155	195
Na^+	g/m3	232	20	240	210	250	163	19	155	150	190
K^+	g/m3	35	2	36	32	38	5.9	0.6	6.0	5.2	6.5
Ca^{2+}	g/m3	24	3	24	20	28	15	2	16	12	17
Mg^{2+}	g/m3	15	2	15	12	18	36	3	37	32	38
Oxid. N	g/m3	5.2	3.7	3.2	1.6	9.5	0.02	0.02	0.02	0.01	0.05
Total N	g/m3	7.4	4.5	5.3	2.6	14	1.1	0.22	1.10	0.81	1.3
Total P	g/m3	15	2.9	15	11	19	0.30	0.47	0.08	0.03	1.0
SRP	g/m3	14	2.9	15	9.7	17	0.02	0.005	0.02	0.01	0.02
Ca	meq/L	1.2	0.16	1.2	1	1.4	0.76	0.11	0.80	0.6	0.85
Mg	meq/L	1.28	0.19	1.25	1	1.5	3.00	0.24	3.08	2.67	3.17
Na	meq/L	10.1	0.9	10.4	9.13	10.87	7.07	0.82	6.74	6.52	8.26
SAR		9.1	0.6	9.2	8.2	9.7	5.2	0.5	5.0	4.7	5.9

Table A4: Ararat WWTP - Recycled water quality - 1998-2006

Parameter	Units	Mean	Std Dev	Median	Min	Max
pH		7.8	0.3	7.7	7.1	8.6
EC	uS/cm	1282	148	1260	920	1720
SS	g/m^3	10	11	6	1	60
Na^+	g/m^3	178	28	170	140	220
Ca^{2+}	g/m^3	17	2	18	13	21
Mg^{2+}	g/m^3	11	2.2	11	8.1	16
Oxid. N	g/m^3	8.9	5.0	9.4	0.47	19
Total N	g/m^3	16	4.8	16	7.1	25
Total P	g/m^3	15	3.1	15	8.8	26
SAR		7.9	1.4	8.15	4.4	9.2

Appendix 5b: Summary results for some key soil chemical properties determined on soils collected in 2004.

Vineyard	Profile location *	Treatment		$EC_{1:5water}$ mS/m	ESP %	$pH_{(CaCl2)}$	Mechanical dispersion %
Hyde Park	Topsoil	Recycled	Mean (n=20)	0.104	16.4	5.90	0.94
			Std. Deviation	0.063	8.5	0.71	0.59
		Fresh	Mean (n=5)	0.075	4.8	6.14	2.85
			Std. Deviation	0.030	3.7	0.57	4.30
		Pasture	Mean (n=20)	0.061	6.3	5.58	1.03
			Std. Deviation	0.095	11.2	1.06	0.57
	Subsoil	Recycled	Mean (n=20)	0.140	17.0	5.43	3.29
			Std. Deviation	0.062	4.7	0.69	5.25
		Fresh	Mean (n=5)	0.380	17.2	5.41	0.28
			Std. Deviation	0.280	11.1	0.47	0.16
		Pasture	Mean (n=20)	0.261	16.5	5.72	9.90
			Std. Deviation	0.380	10.6	1.02	16.30
Seppelts	Topsoil	Recycled	Mean (n=15)	0.077	11.0	7.03	2.79
			Std. Deviation	0.045	6.5	0.67	1.85
		Fresh	Mean (n=5)	0.036	5.8	6.07	0.89
			Std. Deviation	0.013	6.9	0.33	0.28
		Pasture	Mean (n=20)	0.052	1.4	6.39	1.40
			Std. Deviation	0.019	1.3	0.73	1.01
	Subsoil	Recycled	Mean (n=15)	0.140	9.6	5.77	0.10
			Std. Deviation	0.370	3.3	0.44	0.80
		Fresh	Mean (n=5)	0.103	6.9	5.91	1.42
			Std. Deviation	0.520	3.5	0.36	1.45
		Pasture	Mean (n=20)	0.079	6.6	5.73	1.60
			Std. Deviation	0.034	2.8	0.03	2.27
Westgate	Topsoil	Recycled	Mean (n=15)	0.054	4.4	6.26	1.92
			Std. Deviation	0.025	2.8	0.50	0.85
		Fresh	Mean (n=5)	0.050	6.8	6.25	2.28
			Std. Deviation	0.017	7.1	0.61	1.64
		Pasture	Mean (n=20)	0.080	3.8	5.75	3.11
			Std. Deviation	0.078	2.9	0.95	2.25
	Subsoil	Recycled	Mean (n=15)	0.101	12.0	5.09	1.31
			Std. Deviation	0.040	5.5	0.68	2.18
		Fresh	Mean (n=5)	0.151	17.1	4.58	0.28
			Std. Deviation	0.047	1.6	0.44	0.22
		Pasture	Mean (n=20)	0.067	7.9	5.61	2.61
			Std. Deviation	0.030	3.8	0.51	2.26
Montara	Topsoil	Recycled	Mean (n=15)	0.157	16.0	5.54	2.14
			Std. Deviation	0.065	10.5	0.96	0.52
		Pasture	Mean (n=20)	0.052	3.0	5.15	2.03
			Std. Deviation	0.009	1.7	0.15	0.46
	Subsoil	Recycled	Mean (n=15)	0.167	29.1	5.54	17.08
			Std. Deviation	0.085	7.0	0.62	13.74
		Pasture	Mean (n=20)	0.145	18.5	5.03	10.85
			Std. Deviation	0.118	11.4	0.51	10.36

* Profile locations: topsoil = 0-10cm depth increment, subsoil = 40-60cm depth increment

Appendix 5c: Results of statistical analysis of soil data

Mann-Whitney Test - exact significance - 2-tailed (SPSS for Windows 11.5.2.1)

		Topsoils (0-10cm)						Subsoils (40-60cm)					
		pH ($CaCl_2$)	EC	ESP	Ca:Mg	TOC	Mech. Disp	pH ($CaCl_2$)	EC	ESP	Ca:Mg	TOC	Mech. Disp
Hyde Park	recycled vs pasture	0.155	**0.000*** **	**0.000*** **	0.208	0.686	0.579	0.659	0.784	0.82	0.713	0.686	0.324
	fresh vs pasture	0.153	**0.022***	0.818	0.401	1.000	0.53	0.857	0.243	0.818	0.163	0.800	0.563
	recycled vs fresh	0.477	0.417	**0.006** **	0.818	1.000	0.361	0.629	0.277	0.818	0.132	0.800	0.987
Seppelts	recycled vs pasture	**0.014***	**0.043***	**0.000*** **	0.211	0.143	**0.001** **	0.499	**0.000*** **	**0.008***	0.98	0.857	**0.000*** **
	fresh vs pasture	0.152	**0.027***	0.146	0.94	0.267	0.165	0.158	0.235	0.983	**0.002** **	0.533	0.854
	recycled vs fresh	**0.001** **	**0.002** **	**0.041***	0.331	0.8	**0.000*** **	**0.420**	0.88	**0.053** **	**0.01***	0.400	**0.001** **
Westgate	recycled vs pasture	**0.050***	0.1447	0.739	**0.016***	1.000	0.165	0.123	**0.043***	0.123	0.224	1.000	0.128
	fresh vs pasture	0.218	0.356	0.513	0.206	0.667	0.513	**0.008***	**0.001** **	**0.001** **	0.296	1.000	**0.052***
	recycled vs fresh	0.977	1.000	0.768	0.679	0.667	0.859	0.165	0.217	0.099	**0.025***	0.667	0.924
Montara	recycled vs pasture	0.573	**0.001** **	**0.005** **	**0.018***	0.667	0.768	0.165	0.953	0.129	0.768	0.667	0.768

Note: *** p < 0.05 significant, ** p < 0.005 highly significant, and *** p < 0.001 very highly significant**

Appendix 6: Budget Reconciliation

See Attachment 6 for signed pdf version of Form B