Grape and Wine
Research and
Development Corporation

Standardised protocol winery production waste management

FINAL REPORT to
GRAPE AND WINE RESEARCH & DEVELOPMENT CORPORATION

Project Number: **CRS 95/2**

Principal Investigator: **Dr J Chapman**

Research Organisation: **SARDI**
(formerly CRC Soil & Land Mgmt)

Date: **1999**

Cleaner Industries Demonstration Scheme Project

Standardised Protocol for Management of Winery Production Waste

CRS 95/2

GWRDC FINAL REPORT

Dr Jeanette Chapman

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Waste not,

Want not,

Its YOUR choice.

Winery Wastewater Management

Clockwise from top right:

-malodour
-soil solution extractors and, tensiometers and gypsum blocks connected to a data logger
-constructed wetland
-ready for harvest
-Cellar Management Tour (teaching)
-panorama of Barossa Valley

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Standardised Protocol for Management of Winery Wastewater

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Summary

Product Development

Two major industry publications were produced:

"Cleaner Production for the Wine Industry", a 32 page handbook that outlines procedures for conducting a wastewater audit, and identifying technical and non-technical strategies for minimising water waste, product loss, and salt. The handbook was an outcome of a consultancy.

"Winery Wastewater: Production, Impacts and Management", Winetitles, early 2001. The book produced on request by the wine industry was an opportunity to share information gained over 10 years work on winery wastewater management. Chapters include origins of water waste, chemical loading, variation, impacts on soil, water, grapevines and tree plantations, management systems, predictive models, monitoring, and Cameo Winery a hypothetical company choosing a waste management system. A small section on solid waste management is also included.

Research

The current trend in discharge of winery wastewater by irrigation is a direct response to social pressure in minimising malodours, and avoidance of costly pretreatment systems. Many wineries irrigate treelots that yield no economic return. A greater number of wineries are beginning to discharge their wastewater to vineyards in response to production, or use the wastewater to irrigate vineyards based on normal irrigation practices. These two management approaches have considerably different potential environmental impacts and effects on yield and quality of the winegrapes.

The research component "Use of Winery Wastewater on Vineyards" aimed to quantify the impacts of the 'use' and 'discharge' of winery wastewater on winegrapes on yield and quality, and on soil and water quality.

Besides management approach, the size of the winery and site history were important determinants of impacts of wastewater irrigation at each experimental site.

Discharge of wastewater to winegrapes

As with most wineries the small to medium operation had no historic records on wastewater production and characteristics. Annual wastewater production was estimated at 3700 kL with about 75% generated during the 6-10 week vintage beginning in February, i.e., outside the major growing period of the vineyard. The remaining volume was discharged sporadically throughout the remainder of the year.

The field site contained Shiraz on Schwartzmann rootstock that had been managed as a dryland vineyard.

The field experiment compared discharge of winery wastewater with a similar volume of mainswater. A second non-irrigated control was included to assess the impact of irrigation.

In the 1997/98 season only 3 applications occurred prior to harvest; the soils were also irrigated manually to enable soil moisture sensors to be installed, which also effected results. Vine yield was significantly higher for the irrigated treatments than non-irrigated control. Juice quality was unaffected by the treatments.

A model was used to estimate leaching patterns. Potentially excessive drainage from the discharge site was predicted depending on actual volumes of wastewater

generated. Pulses of salts and nutrients would be associated with the downward passage of water. Soil solution extracted at 1.2 m indicated effective removal of organic carbon from the wastewater treated soil (<30 mg/L). Salinity of soil solution extracted from wastewater treatments was about double that of mainswater treatments, but <50% of estimated wastewater concentrations due to dilution by rainfall. Soil solution extracted at 0.3m was highly sodic for both wastewater and mains water treatments. Sodicity of soil solution extracted at 1.2m fell for both treatments but remained moderately-highly sodic for wastewater treatments compared with non-sodic levels for mains water treatments.

Unfortunately the collaborating company sold the site during 1998, which resulted in closure of the winery. Thus the full potential for yielding useful data that could separate effects of water from nutrients and salt was therefore not realised.

Use of wastewater for irrigation of winegrapes

The large winery annually produces about 50 ML wastewater. Vineyards surrounding the winery are essentially the last ones harvested during vintage. Thus a substantial proportion of wastewater is generated during the growing season, i.e., non-vintage wastewater from December to January and vintage wastewater from February to May.

Groundwater used for past irrigation of the Cabernet Sauvignon vineyard was more saline than the wastewater, and had impacted on soil chemical composition.

The collaborating company wanted to compare standard 4 L/h drip system with microjet spray. The latter system, through a combination of greater horizontal distribution of water and lower water use efficiency, allows a higher volume of wastewater to be discharged. Thus irrigation of winery wastewater by the two systems was compared, using groundwater as a control.

Predicted improvements in, chloride, soil salinity and levels of inorganic salts occurred in the wastewater treatments compared with groundwater treatments. However only wastewater irrigation using the drip emitters was sustainable, the remaining treatments led to continual increased salinity in the subsoil clay. Application of a leaching fraction was recommended.

Juice and wine quality from grapes harvested from wastewater treatments showed significant improvement in chloride. However, juice and wine from vines irrigated with wastewater contained significantly higher concentrations of sodium. This effect appeared associated with the higher relative concentration of sodium to those of calcium and magnesium in the wastewater, known as sodicity, which can vary considerably with extent of caustic washing of equipment. Solution concentrations of sodium and were lower in the wastewater especially during non-vintage than in the groundwater. The groundwater, however, contained higher concentrations of calcium and magnesium resulting in lower sodicity. Soil sodicity did not significantly vary between treatments.

By contrast to salts, nutrient levels in the soil were rarely affected by either water type or irrigation method.

Vine yields were consistently 15% higher for the wastewater treatments. Yield increases were associated with variable effects on quality. In 1996/97 berries from wastewater treatments remained similar in size to berries from the groundwater treatments, but produced wine of superior quality. By contrast, wastewater irrigation resulted in larger berries in 1998/99 and consequential loss in quality, which is the more regular occurrence according to general vineyard records. Historically the Cabernet Sauvignon grapes from the vineyards are used in a medium to low price point blend sold domestically, hence loss of fruit quality is normally accepted, particularly since the extra volume of fruit keep profits 'revenue neutral'. Fruit quality could be improved by calculating the nutrient value of the wastewater and restricting use normal vineyard requirements.

Conclusion

Use of winery wastewater as an irrigant of winegrapes has greatest economic potential and environmental benefits for large wineries and locations with no or saline groundwater. Smaller wineries do not produce sufficient quantity during the growing season to justify use on vineyards. Use of vineyards for disposal of winery wastewater potentially results in greater environmental risk. Use of tree plantations with discharge vineyards would provide better environmental protection, but the trees usually require additional irrigation during dry months to maintain active growth. In both situations continual monitoring of wastewater parameters and impacts on the discharge environment is essential to adjust and improve management strategies that begin with waste minimisation within the winery.

The apparent effect of sodicity of irrigation water on juice and wine quality requires further investigation by others. Many current experiments on effects of salinity keep sodicity constant. Others have not controlled nor monitored sodicity, creating a potential for misinterpretation of results.

1.0 Background

In 1992 GWRDC funded the project "Land Disposal of Winery and Distillery Wastewaters". Yalumba Wines and Southcorp Wines Pty Ltd provided collaborative support. The project quantified the removal of soluble organic carbon from the wastewaters by the processes of adsorption and microbial metabolism in soil. The laboratory-based research demonstrated that a high (>95%) removal of the SOC from winery wastewater was potentially achievable, whereas distillery wastewater required pretreatment to reduce the organic loading prior to irrigation (Chapman 1995a-c).

In 1995 the Environment Protection Act (SA) was proclaimed (Environment protection legislation now exists in all States). Wineries in South Australia that crushed more than 500 tonnes must be licensed for which a waste management plan is required. The plan is based on two key principles outlined by the National Effluent Management Guidelines for Wineries and Distilleries ARMCANZ/ANZECC (1995):

- Waste minimisation,
- Effective recycling and reuse.

1.1 Objectives

To provide industry-specific information on:

1. Non-technical and technical strategies for reducing water waste and pollution load based on Cleaner Production principles,
2. Suitability of winery wastewater for irrigation of winegrapes

2.0 Structure

2.1 Projects

Two projects were conducted, an outline is provided in Figure 2.1.

1. Cleaner Industries Demonstration Scheme Project.
2. Standardised Protocol for Management of Winery Production Waste.

Each project will be reported on separately.

2.2 Technical Support

A two-tiered steering and technical committee structure was used to manage the projects. The objective of the steering was to champion the importance of environmental issues affecting winery waste management within the national industry. The role of the technical committee was to ensure national relevance of information derived from the projects. Membership for both committees came from the grape and wine industry, state government, advisory, research institutes.

This project structure proved very successful. Interest in the technical committee was especially high, as it became an initial point of contact and peer review for new information on waste management.

NATIONAL WATER QUALITY MANAGEMENT STRATEGY
NATIONAL MANAGEMENT GUIDELINES FOR WINERIES AND DISTILLERIES

PROMOTES

CLEANER PRODUCTION
Cleaner Industries Demonstration Scheme Project
SAWBIA, CRC S&LM, INDUSTRY

PRODUCT
"Cleaner Production for the Wine Industry"
(32pp; available from SAWBIA)

OUTCOMES
- Model audit of wastewater
- Strategies for minimising
- Strategies for minimising pollution load
- Demonstration of economic benefits

IMPACTS
- The Australian wine industry is becoming more water wise
- From: 3-5 kL/tonne grapes crushed
- To: 1-3 kL/tonne
- Reduction of pollution load was more difficult to achieve due to:
  -State EPA's using volume as the basis of licensing wineries
  -lack of benchmarks

EDUCATION
Cleaner Production is now included in the curriculum of many winemaking courses offered at TAFE and tertiary level.

WINERY WASTEWATER IRRIGATION
Standardised Protocol for Management of Winery Wastewater
GWRDC, CRC S&LM, INDUSTRY

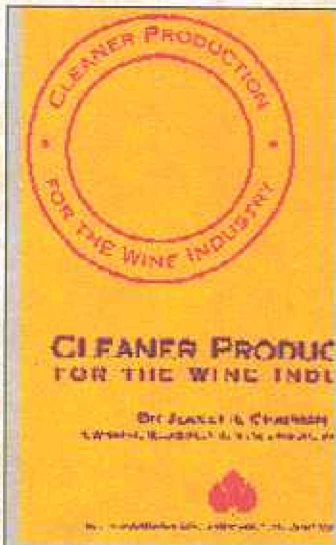
PRODUCT
Winery Wastewater:
-Production,
-Impacts,
-Management,
(100pp; Publisher to be announced)

OUTCOMES
- Better understanding of effects of cleaning and processing operations on production of key wastewater components
- Better understanding of potential environmental impacts and suggested benchmarks
- Better understanding of management principles and practices

POTENTIAL IMPACTS
- Greater Industry appreciation of the sociological and environmental impacts of wine manufacture, rather than economic worth.
- Encourage open debate on the above point.

EDUCATION
It is envisaged that this book will become a major text.

Figure 1.1 Outcomes, impacts and educational outreach of the Cleaner Production and Winery Wastewater Irrigation projects.



3.0

CLEANER PRODUCTION FOR THE WINE INDUSTRY

Clockwise from top left

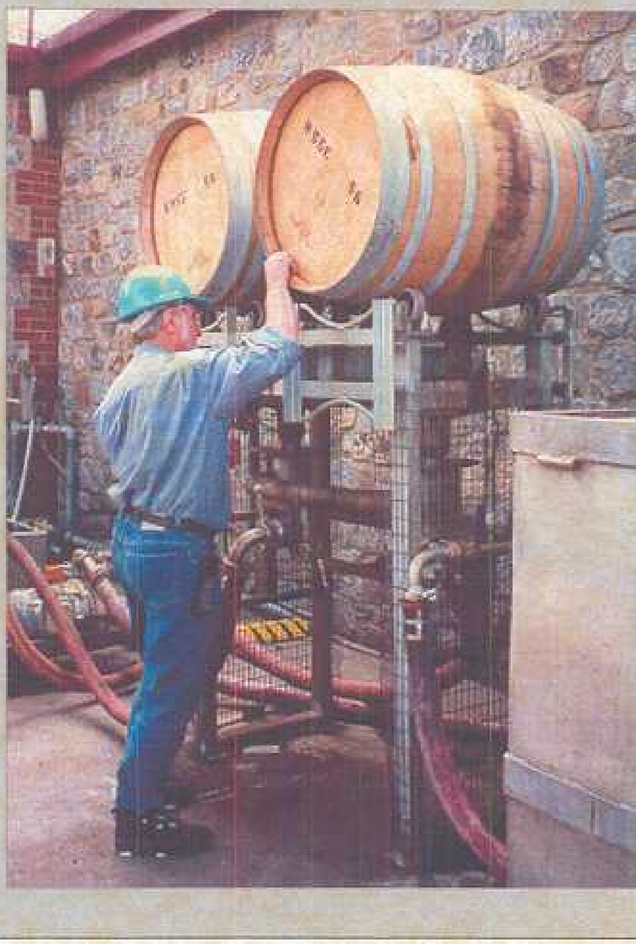
-Cleaner Production handbook

-Field demonstration of barrel washing (back saving method)

-End of pipe

-Field demonstration of lees separation into a duel drain system

-Field demonstration of lime dosing for pH adjustment



3.0 Cleaner Industries Demonstration Scheme Project

3.1 Introduction

Cleaner Production is the process of developing economic strategies for minimising volume and pollution load of waste based on the following hierarchy:

Figure 3.1 Cleaner Production -hierarchy of strategies.

Usually about 80% of developed strategies are cost-neutral or cost-beneficial within 12 months of implementation. These savings can then pay for implementing more expensive strategies that often require process modification as part of a 5-year plan.

3.1.1 Funding

The South Australian Wine and Brandy Industry Association (SAWBIA) was awarded a $15 000 grant[1] by a Commonwealth Government funded Cleaner Production program, administered by State Environment Protection Authorities or equivalent. The project was offered to the Cooperative Research Center for Soil and Land Management, with Dr Chapman as the consultant.

3.2 Objectives

1. Define a model wastewater audit process for wineries.
2. Identify technical and non-technical strategies for minimising water waste and pollution focussing on organic loading, salinity and sodicity. Solutions to encompass better housekeeping, process control and modification, education and training, and management.
3. Demonstrate the economic benefits of identified strategies at two agreed sites –Orlando Wyndham, Rowland Flat, and d'Arenberg Wines, McLaren Vale.

3.3 Outcomes

1. Production of the "Cleaner Production for the Wine Industry" handbook, 32pp, published by SAWBIA, November 1996.

[1] The application was prepared jointly with Dr Chapman, as the applicant had to be an industry body, rather than a research body.

- Development of greater industry awareness and adoption of Cleaner Production strategies as a result of networking initiating with a 2-day workshop and field demonstration November 1996.
- Inclusion of winery wastewater management in the curriculum of the Bachelor of Agricultural Science (Oenology), University of Adelaide (1996 onwards, pictured on front cover).
- Members of the technical committee that assisted with the preparation of the handbook are now part of a larger **Environment Committee of SAWBIA**.

3.4 Impacts

1. The Australian wine industry is gradually becoming more water wise –from generating 3 to 10 kilolitres (kL) of wastewater per tonne (t) of winegrapes processed by a crushing-bottling winery to 1-5 kL/t.
2. The Australian wine industry is struggling to become more pollutant wise.

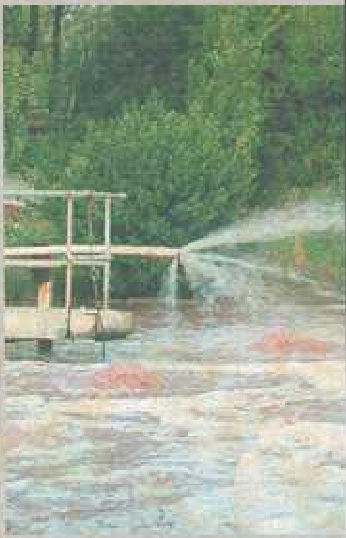
Possible reasons for these trends include:

- State Environmental Protection Authorities placing greatest (or sole) emphasis on wastewater volume for licensing winery operations and imposing monitoring requirements.
- Communities no longer tolerate malodours; response of wineries has been towards adopting minimal storage prior to discharge by irrigation; large volumes of wastewater produced during wetter months is recognised as a major limitation to successful management, and hence been specifically targeted for reduction.
- Lack of benchmarks for acceptable pollution loading of winery wastewater.

The last point is especially important as quality benchmarks, if only informal rather than part of license agreements, enables site managers to:

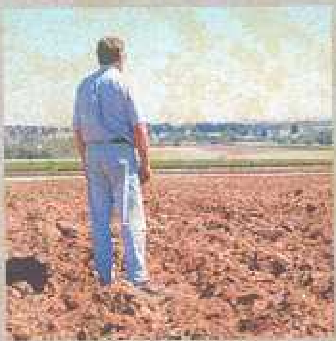
- choose pre-treatment systems that best meet quality targets,
- interpret data from site monitoring programs to ensure management meets the spirit of license agreements (or codes of practice).

Establishing informal quality benchmarks, therefore, became a major objective of the Winery Wastewater Management Handbook.



4.0

Standardised Protocol for Management of Winery Production Waste



Clockwise from top left:
-aeration lagoon
-young healthy vines irrigated with winery wastewater
-effluent from vintage operations with red wine
-Dr Alfred Cass (CRC Soils supervisor) at the Orlando Wyndham field site
- flooding from subsoil runoff after excessive irrigation

4.0 Standardised Protocol for Management of Winery Production Waste.

4.1 Aims

1. Quantify the effects of winery wastewater irrigation of winegrapes on:
   - Soil and water quality
   - Grape and wine quality.
2. Prepare a handbook on winery wastewater irrigation management.

The technical committee recommended that the handbook should be generic, rather than based solely on the outcomes of the research. This proved to be a major task. A separate report on the handbook therefore follows.

4.2 Handbook

"Winery Wastewater: -production -impacts -management"

4.2.1 Introduction

The Australian wine industry enjoys a 'clean and green' marketing image. Originally this image focussed on the core activities of growing winegrapes and making high quality wine in an environment relatively free of pollutants unlike that found in the Northern Hemisphere. More recently demonstrating a proactive approach to minimising environmental impacts of these core activities and maximising the resource potential of the liquid and solid wastes generated from the production process have become equally important.

4.1.2 Sections

The handbook has 4 sections:

1. Production and characteristics
2. Impacts
3. Management
4. "Cameo Winery"

Wastewater generated by processing and cleaning operations is the predominant waste issue. The first step of waste management is developing an understanding of the origins of water waste and major chemical components generated by manufacture of wine. Section A of this handbook remedies a lack of published information on this topic.

Winery wastewater is most commonly irrigated onto land. Irrigation management requires an understanding of how different waste components may potentially affect soil and groundwater environments, and crop growth and productivity, whether plantations or winegrapes. Impacts of winery wastewater irrigation are outlined in Section B.

Each winery has its unique wastewater composition, and combination of local site, environmental and community issues, that will require different approaches to management. Several examples of wastewater management are therefore given in Section C. Motivation, whether must do, should do or choose to, can impart a bias towards attitudes that in turn may influence priority allocation of waste management and successful adoption of strategies. The role of all levels of management in developing a mission statement for waste management is discussed. Two other key tools of waste management –budgets and monitoring are also outlined.

The potential use of information in this handbook is demonstrated for 'Cameo Winery' in Section D.

Each Section consists of several Modules – 14 in total. Approximately 100 pages, the handbook will be a substantial publication.

4.1.3 Progress

A panel of industry, government and advisory persons that have a wide technical background is currently reviewing a draft copy of the handbook. Their role is to assess that the content of each module meets up-front objectives, identify definitions for inclusion in a glossary, and make recommendations for improving current text or inclusion of additional topics (within reason).

Drafting of 3 of the modules on management and Cameo Winery is waiting the reporting to the South Australia Department of Industry and Trade of a tender on Winery Wastewater Management in Environmentally Sensitive Areas due February 2000. Some of the information from the tender, e.g., costings of pretreatment options, will be useful to include in the handbook.

The second draft of each module has been forwarded on request to David Hall and Tim James of GWRDC for reviewing.

The handbook will be published in 2000.

4.1.4 Anticipated Outcomes

The handbook should provide:

- Greater industry understanding on how processing and cleaning operations contribute to winery wastewater composition and variability
- Make more informed decisions on reuse options focussing on irrigation
- Develop benchmarks for wastewater volume and composition that allow greater focussing and potential adoption of Cleaner Production strategies
- Greater appreciation of the importance of monitoring and interpretation of data
- Stimulate industry commitment to better environmentally sustainable waste management practices

4.2 Winery Wastewater Irrigation

4.2.1 Background to establishment of field experiments

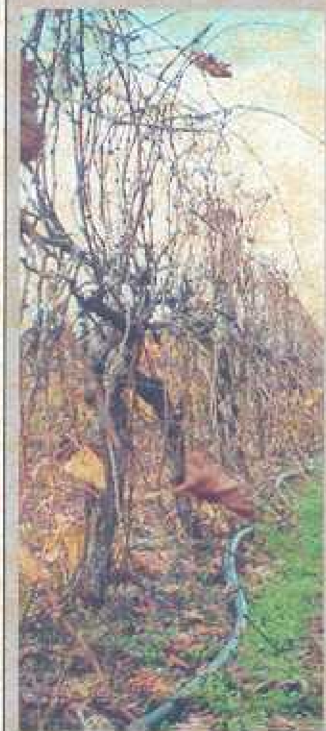
Two field experiments were originally proposed for an existing vineyard at Yalumba Wines, Angaston South Australia, and a newly planted vineyard at Orlando Wyndham, Jacobs Creek South Australia. Both companies agreed to install the irrigation system as part of their 'in-kind' contribution –a very expensive task, and thus were closely involved with establishing the experimental objectives and approval of the statistical design. Yalumba Wines required 12 months to budget and install the mains, sub-mains and irrigation lines with the field site commissioned for the 1996/97 season. Due to an unforeseen management decision to concentrate bottling at the Rowland Flat Winery, Orlando Wyndham had to withdraw from the project late in the year 1 consultation phase as irrigation blocks required for the control water treatment could no longer be released.

In lieu of the loss of Orlando Wyndham, GWRDC ex board member Tony Devitt recommended that a site could be established in West Australia and negotiated with Evans and Tate Ltd to establish an experiment at the Gnangara winery, upper Swan Valley. Due to the extra costs of operating an interstate field site, additional funding was provided in 1996/97 to allow planning and commissioning of the irrigation system by vintage 1998.

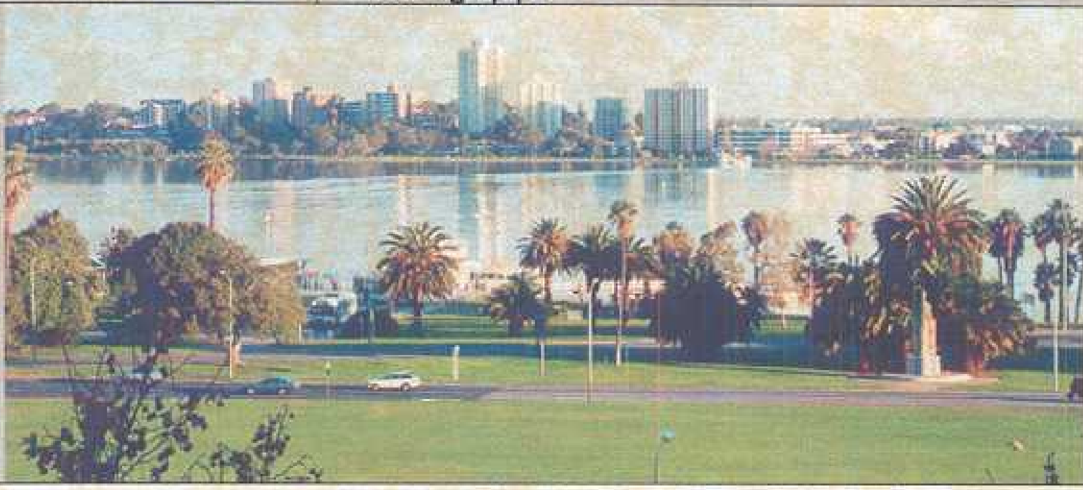
4.2.2 Objectives

1. Establish field experiments in two vineyards with contrasting systems of irrigation management.
2. Establish key questions on management and environmental impact, develop methods for assessment via a combination of direct field measurements and laboratory analysis. Hypotheses are given in the reports for Evans and Tate Ltd and Yalumba Wines.
3. Monitor each field site for a minimum of 2 seasons.
4. Make recommendations for irrigation management.

5.0
Evans & Tate Ltd
Swan Valley
WA



Clockwise from above left:
-Location of Swan River from the Henley Brook winery
-Coarse solids separation
-Swan River, 25 km downstream!
-Discharge pipe



5.0 Evans and Tate Ltd

5.1 Objective

This site examined the effect of discharge of winery wastewater, as dictated by production, by drip irrigation to grapevines on:

1. soil chemistry
2. juice quality.

5.1.1 Student Project

A 4th year student, Mr. Brad Smith under the supervision of Dr Judy Eastham[1] from the University of West Australia conducted the project "Investigation of the Groundwater Pollution Potential and Simulated Deep Drainage Loss associated with Winery Wastewater Disposal by Vineyard Irrigation". Objectives were to:

1. Investigate the effects of wastewater irrigation on solute concentration within the soil solution.
2. Simulate deep drainage loss and potential for pollution of groundwater for 2 scenarios of wastewater irrigation.

A transcript of the abstract[2] is located in Appendix V-I; additional comments are contained in the report.

5.2 Methodology

5.2.1 Site Location and History

The winery (Figure 5.1) and experimental site were located on older upper alluvial terraces of the northern end of the Swan Valley Region, West Australia (Australian Map Grid reference: 405500, 6481250).

The company began as a family operation on a 4 ha allotment. The Gnangara vineyard contained 'dryland' blocks of own rooted Chardonnay and Shiraz, and Shiraz on Schwarzmann rootstock, used for the experiment (Figure 5.2). Vines are spaced at 1.8m with 3.3m between rows. Grapes harvested from the vineyard were used in blends. In the absence of historic records of juice quality, analysis samples from vintage 1997 is given in (Table 5.1).

Figure 5.1
A panorama of the Evans and Tate Ltd site at Henley Brook, West Australia.
Photograph courtesy Mr. Brad Smith

[1] Dr Eastham was a colleague of the former Irrigated and Trees Subprogram of the Cooperative Research Center for Soil and Land Management.

[2] A copy of the thesis can be obtained, on request, from Dr Jeanette Chapman.

As with most wineries in Australia, Evans and Tate Ltd expanded rapidly during mid 1990's to a crush of 1700 tonnes in 1998. Due to a lack of available space, the company decided in 1998 to sell the Henley Brook site and move winery operations to Margaret River partly by vintage 1999 and completely by vintage 2000. Unfortunately the new owners decided that the picturesque site was an ideal restaurant development, and dismantled the winery prior to vintage 1999.

Thus only very limited information was obtained from in vintage 1998.

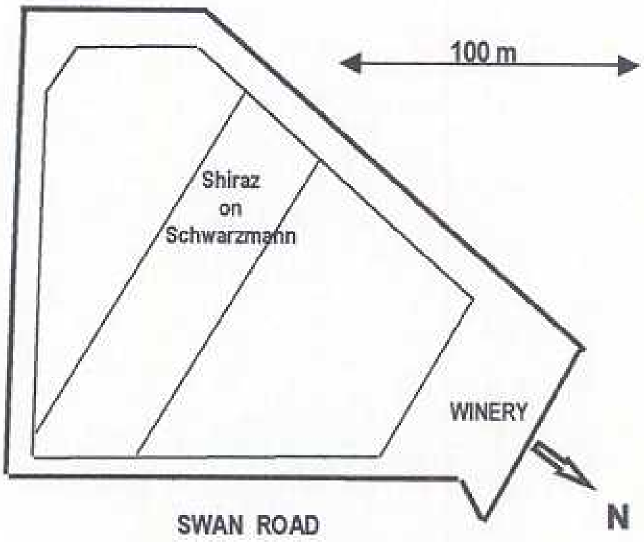


Figure 5.2 Site Plan of Evans and Tate Ltd Winery and Gnangara Vineyard, Henley Brook, West Australia.

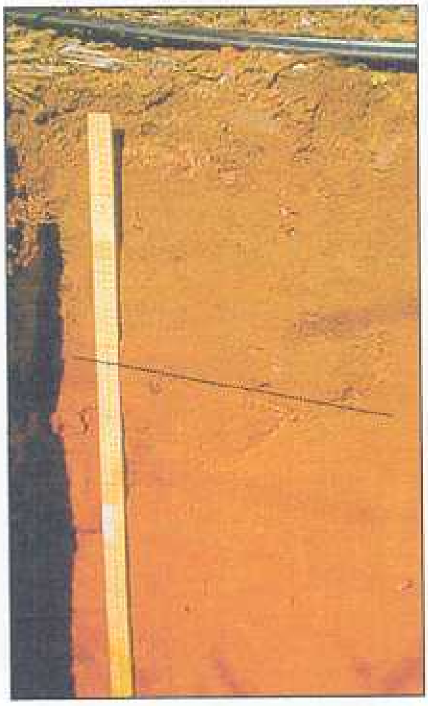
Table 5.1 Juice analyses of Shiraz on Schwarzmann sampled from the Evans and Tate Ltd Gnangara vineyard, vintage 1997.

Parameter	Mean	Stdev
Brix (%)	23.0	1.8
pH	3.88	0.13
Titratable Acidity (g/L)	3.57	0.38
Ammonium (mg/L)	63.4	10.0
Free Amino Nitrogen (mg/L)	276	43
Potassium (g/L)	2.13	0.43
Sodium (mg/L)	14.3	10.3
Chloride (mg/L)	8.9	5.9
Glucose (g/L)	116	11
Fructose (g/L)	114	11
Citric Acid (g/L)	0.24	0.07
Tartaric Acid (g/L)	7.21	0.33
Malic Acid (g/L)	1.31	0.31
No. Samples	18	

1. Analyses courtesy Mr. Bob Frayne, WADA.

5.2.2 Soil Type

The soil is typical of the Belhus sand series (Pym 1955) consisting of dark brown loamy sand grading to a reddish sandy clay loam with massive structure at 350 mm depth (Figure 5.3). Chemical characteristics of the soil prior to experimentation are shown in Table 5.2. A compacted zone occurred at 300-400mm depth due to trafficking.



A Horizon

350 mm

B Horizon

Figure 5.3 Belhus soil profile at Evans and Tate Ltd, Henley Brook.
Photograph courtesy Mr. B. Smith

Table 5.2 Soil characteristics of the Evans and Tate Ltd Gnangara vineyard.

Depth (m)	0-0.3	0.3-0.6	0.6-1	1-1.5
Sand, Silt, Clay (g/100g)	83, 8, 9	82, 6, 12	76, 8, 17	72, 6, 22
Total Organic Carbon (g/100g)	1.6	0.7	0.5	0.5
Total Kjeldahl Nitrogen (mg/kg)	850	190	120	100
Bicarbonate Extractable Phosphorus (mg/kg)	23	1	<1	<1
C:N:P (30:x:y)	30:1.5:0.4	30:0.9:0.1	30:0.5:0.1	30:0.6:0.1
pH	6.5	6.5	6.6	6.7
Electrical Conductivity 1:5 H_2O (dS/m)	0.015	0.005	0.003	0.003
Na 1:5 H_2O (mg/kg)	5	4	3	3
K 1:5 H_2O (mg/kg)	32	12	5	3
Ca 1:5 H_2O (mg/kg)	7	5	4	4
Mg 1:5 H_2O (mg/kg)	2	1	1	1
Cl 1:5 H_2O (mg/kg)	5	4	<1	<1
SAR	0.5	0.6	0.3	0.3

5.2.3 Wastewater Quality

As was the case with smaller wineries, there were no formal requirements to keep records on wastewater volume and pollution load. Evans and Tate Ltd estimated that due to the compact nature of the winery about 2-3 kL wastewater would be produced per tonne grapes crushed, and 75% of the annual volume generated during (6-10 weeks from February). Table 5.3 provides general wastewater characteristics based on these estimates.

Table 5.3. Estimated winery wastewater characteristics for Evans and Tate Ltd[1].

Parameter	Unit	Vintage	Non-Vintage
Volume	(kL)	3700	550
pH	pH	5.2	7.4
TDS	mg/L	1500	1000
Conductivity	dS/m	2-3.5	1.5-2.5
TOC	mg/L	2000	350
TKN	mg/L	40	10
Phosphorus as P	mg/L	10	3
C:N (30:1-2)	30:x	0.65	18.32
C:P (30:0.05)	30:Y	0.17	3.23
Calcium	mg/L	130	130
Magnesium	mg/L	15	15
Potassium	mg/L	220	100
Sodium	mg/L	350	320
SAR		10	9
Chloride	mg/L	425	426

1. Data based on analyses of wastewater generated by a similar size winery, and hence are approximate only.
2. SAR: Sodium Adsorption Ratio

5.2.4 Waste Management

In a scenario typical of many wineries in Australia waste management had little priority until proclamation of State Environmental Protection Acts, that required formal licensing of polluting industries.

Wastewater generated by the winery was spread directly on the vineyard through a soakage pipe that was periodically shifted, i.e. 'end-of-pipe' approach. This approach frequently led to flooding (Figure 5.4a) and associated problems including drowning of vines and salt scald (Figure 5.4b).

Based on external advice a storage/drip irrigation system was developed early 1997. Wastewater was pumped from an existing sump to a conical shaped base tank to allow easy removal of solids, with further settling time in two smaller tanks connected in series. A fourth tank containing rainwater was used for periodic dilution of the wastewater particularly after removal of lees and caustic washing of tanks and barrels. Irrigation water was passed through sand filters immediately prior to irrigation, with back-flushing waste from the filters returned to the treatment system. The wastewater was discharged by a 4L/h, drip system which could be moved between the grapevines and inter-row crop during vine dormancy.

Formal commissioning of the irrigation system was delayed until about 3 weeks before vintage 1998 by repeated appeals of the plans (which included expansion of the winery) by a neighbour to the local council[1]. Results from the 1997/98 season therefore, do not reflect a 'normal' irrigation season, in which sporadic irrigation would occur throughout the growing season.

Solid Waste was immediately disposed in the vineyard. This practice may be the reason for high levels of potassium in the topsoil (Table 5.2).

A.

B.

Figure 5.4 Problems associated with "end-of-pipe" wastewater management: A. flooding, B. salt scald.
Photographs courtesy B. Smith

5.2.4 Irrigation Management

The objective of irrigation management was to use the vineyard as a disposal site for the wastewater. Thus the volume of wastewater generated by the winery dictated time delays between applications. Times between successive applications to the experimental site were anticipated to range from <24h during peak vintage to >7 days to weeks during non-vintage.

An application time of 1h was used. Assuming that each 4L/h drip emitter wets a zone of soil with radius of 300mm each application is equivalent to about 14mm depth of water. Estimated volumes of soil water stored within the 0.3, 0.6 and 1.2 m layers corresponding to different soil water tensions are given in Table 5.4. Based on these estimates around 6, 4L applications will be required without loss of water to saturate the 0-30 cm layer.

[1] Disputes with neighbours/community are becoming more common and can be very protracted. The complainant in the Evans and Tate Ltd was an extreme aggressive example, who managed to get company personnel, government officials and even unsuspecting researchers offside. Wineries should approach neighbours during planning to avoid disputes.

Table 5.4 Estimated volume of stored within the 0-0.3m zone of soil water wetted by each drip emitter at different soil moisture tensions.

Soil Moisture[2] Tension (cm)	Estimated volume of stored water in soil layer (L)[1]		
	0.0.3	0.3-0.6	6.6-1.2
0	36.4	34.8	68.8
10	23.5	22.8	45.4
100	10.0	8.7	16.8

1. Assumes a straight edged circular zone of radius 0.3m was wetted.
2. Soil moisture retention curves courtesy Mr. B. Smith.

Hypothesis
Irrigation in response to wastewater production increases the risk of environmental impact, especially during times when climatic conditions exceed the wettest year in 10 used as the standard in design of wastewater irrigation systems.

5.2.4.1 Soil Moisture Monitoring

Soil moisture changes in response to irrigation was monitored in 3 of the 6 replicate treatments by combination of gypsum blocks (>100 kPa suction) and tensionmeters (<80 kPa suction). Installation occurred at a 45° angle to prevent preferential flow to the sensors which were placed at depths of 0.3, 0.6 and 1.2 m directly underneath a drip emitter (irrigated treatments) located mid-way between two vines 30 cm from the vine row (all treatments). The sensors were automatically read every 2 hours using loggers powered by solar panels (Figure 5.5). The loggers were connected to a communications box to enable downloading of information via the telephone.

Due to the extremely dry condition of the soil, 6 x 1h applications of wastewater (when available) and mainswater were used to wet the plots to assist installation of the sensors. Gypsum blocks were set in slurry of silica flour to ensure good contact with the surrounding soil.

Figure 5.5 The skills of Mr. William Besz, enabled automatic logging and downloading of loggers at the Evans and Tate Ltd field site possible from Adelaide.

5.2.5 Experimental Design

The objective of the experiment was to evaluate the impact of discharge of winery wastewater by surface drip on soil chemistry and juice quality. Mains water was used as the control water source. Since the vineyard had not been previously irrigated, a second non-irrigated control was also included.

A 3x3 Latin square design was chosen as it accounts for variation both along and between the rows of vines. Treatments are allocated only once within a given row or column of the square. By using 2 Latin squares side-by-side to increase the number of replicates to 6 (Figure 5.6), a 96% probability of detecting differences due to the treatments if they exist could be achieved. Twelve vines along 3 adjacent rows were used for each treatment. Measurements were confined to the middle 8 vines in the center row to remove edge effects.

5.2.6 Measurements –Soil

5.2.6.1 Sampling

To determine the potential depth of soil that may be chemically altered by discharge of the wastewater, 4 depths of sampling were used: 0-0.3, 0.3-0.6, 0.6-0.9, and 0.9-1.2m. Soil samples were taken adjacent to the drip line immediately after harvest (as quarantine restrictions applied at other times due to a snail pest).

5.2.6.2 Analyses

Analyses focussed on salts and nutrients that were most likely to impact soil fertility and quality of winegrapes, decided at a meeting of the 'Technical Committee' on site monitoring[1] following preparation of a discussion paper. Potential impacts on soil and winegrapes of wastewater components are described in the book Winery Wastewater: Characteristics, Impacts and Management. Soil parameters and methods of analyses used are summarised in Table 5.5

Table 5.5. Soil parameters and methods used.

Parameter	Method	Reference
Acidity/alkalinity	pH meter (1:5 soil:water)	Heanes (1981)
Salt	Electrical Conductivity	Rhoades (1982)
Organic Carbon	Dichromate digestion	Walkely and Black (1965)
Total Nitrogen	Kjeldahl digestion	Heanes (1981)
Ammonium	Spectroscopic	Heanes (1981)
Nitrate	Spectroscopic	Heanes (1981)
Plant Available Phosphorus	Bicarbonate extraction	Heanes (1981)
Plant Available Potassium	Bicarbonate extraction	Heanes (1981)
1:5 Na, K, Ca, Mg	Spectoscopic	Heanes (1981)
1:5 Chloride	Silver Nitrate Titration	Heanes (1981)
Texture	Hydrometer	Day (1965)

[1] The objective of the meeting was to determine monitoring requirements of the wastewater, discharge sites, groundwater and nearby rivers and creek, required under State Environmental Protection Agency Winery Wastewater Licence agreements.

5.2.7 Measurements –Vines

5.2.7.1 Sampling

Eight vines from the middle rows were harvested for yield. Juice was obtained from about 300 grapes picked according to P. Ireland (pers. comm) that accounts for variation within and between bunches harvested from both sides of the vines.

5.2.7.2 Analyses

Determination of juice quality was divided into 2 groups of parameters[1] (Table 5.6) where group 2 parameters would only be determined if statistical significance of parameters of group 1 occurred. The aim of this exercise was to minimise costs of analyses that had to be outsourced.

Table 5.6 Juice analyses conducted for the Evans and Tate Ltd site.

Parameter	Units	Method[1]
Group 1		
Brix	%	Hydrometer
pH		Meter
Titratable Acidity (pH 8.2)	g/L	Titration
Sodium	(mg/L)	Flame Photometer Spectroscopy
Potassium	(g/L)	As above
Chloride	(mg/L)	Titration with silver nitrate
Group 2		
Ammonium	(mg/L)	Enzymatic
Organic Acids and Sugars	(mg/L)	High Performance Liquid Chromatography
Colour Density		Spectral

1. Methods courtesy Mr. B. Frayne, Viticultural Laboratory Services, West Australia Department of Agriculture

[1] Parameters were selected by members of the West Australia Technical Committee assisting management of the Evans and Tate Ltd site.

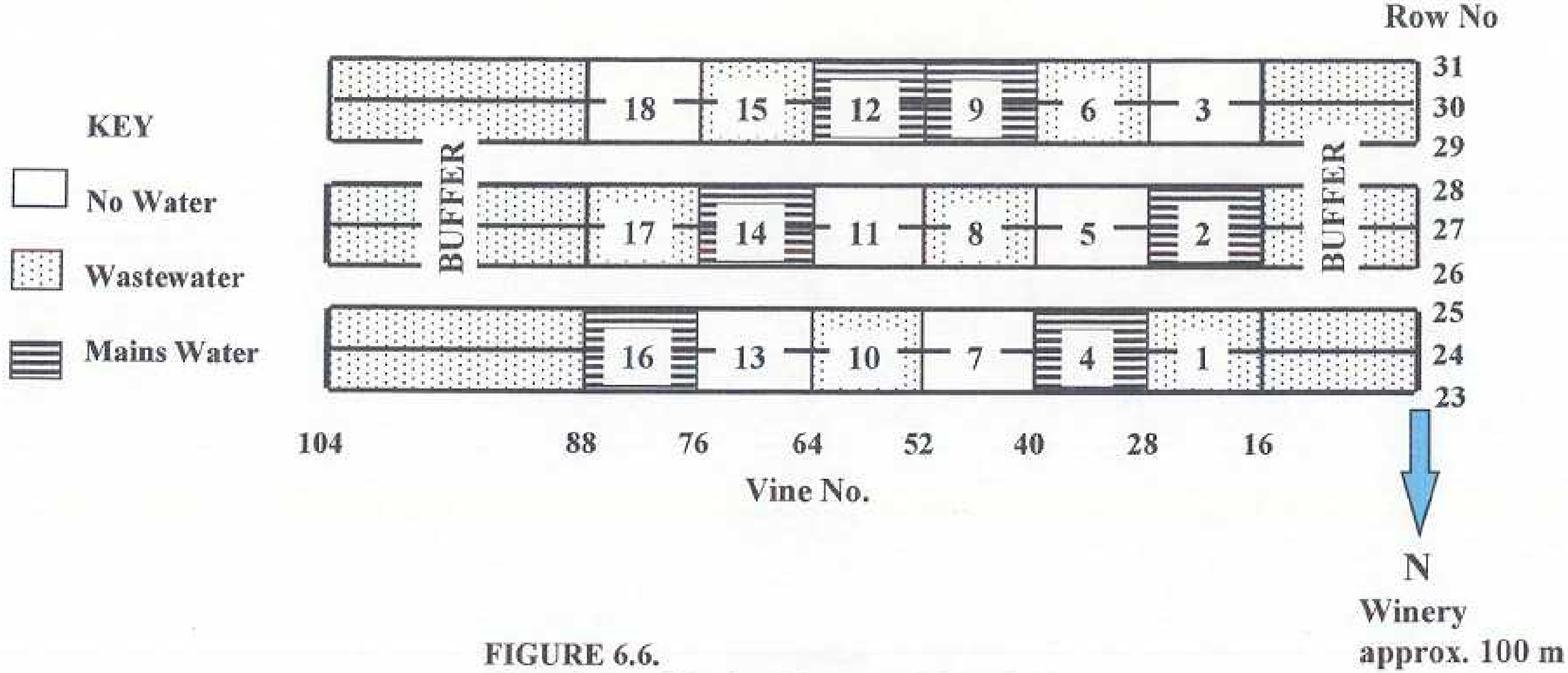


FIGURE 6.6.
Experimental Design, Evans and Tate Ltd
Gnangara vineyard, Henley Park WA.

5.3 Results

5.3.1 Irrigation volume

Irrigation can be divided into 2 phases: Phase 1 associated with installation of soil moisture monitoring equipment as outlined in Section 5.2.4.1 and, Phase 2 in response to winery wastewater produced through pre-vintage cleaning operations. Figure 5.7 shows the effects of the phases on soil moisture responses monitored by gypsum blocks –tensiometers continually failed due to leaking in of air and thus did not yield any usable data.

Phase 1 –No Water Treatments: Between 2-4 weeks for the 0.3 m layer to 3-6 weeks for the 0.6 and 1.2 m layers were required for the gypsum blocks to 'recover' i.e., reach a suction of >200 kPa from the effects of being wetted for installation. Thus longer drying times were assumed to be due to the presence of soil stored water. The example in Figure 5.7 A shows the effect of an 'end-of-pipe' flood in an adjacent area. This mishap clearly resulted in lateral flow of water at the 1.2m depth. Grapevines from this plot yielded 25% higher than the average for the non watered treatment. Significant rainfall did not occur until March 10.

Phase 1 –Mains Water and Wastewater Treatments: Soil Suction remained at <200 kPa for significantly longer periods –3 to 6 weeks for the 0.3m layer, and 4 to 9 weeks for the 0.6 and 1.2m layers.

Phase 2 –Mains Water and Wastewater Treatments: Three applications occurred pre-harvest (17th February 1998), that are clearly evident in Figure 5.7 B. The small volume of application 4L from the drip emitter, at each occasion meant that the 0.3m layer only became wetted to suction below <200kPa after harvest, after which daily irrigation occurred. This result does not exclude the possibility that pre-harvest irrigation wetted soil above 0.3m depth to <200kPa suction. Subsequent use of the surface stored soil water by the vines and evaporation would explain the lack of pronounced inverted peaks in soil tension for many of the irrigated plots pre-harvest (e.g., Figure 5.7 C). A lag of 10-14, and 14 to >21 days occurred before the 0.6 and 1.2m layers respectively began wetting.

Hypothesis: Based on the wetting pattern exhibited by the soils, it is hypothesized that both irrigation of wastewater and mainswater treatments at the time of installation of the sensors and irrigation in response to pre-vintage cleaning operations will effect vine response. Results may therefore not be a true indication of effects of winery wastewater irrigation alone.

Soil Moisture Tensions and Vine Growth: Soil stored water is nominally available for plant uptake at soil moisture tensions between 8-1500 kPa. Establishment of the vines in dryland conditions promoted deep root development possibly to the depth of the water table (20m). Figure 5.7 showed that for all treatments soil moisture tension remained well beyond permanent wilting point, except during times effected by phases 1 and 2 irrigation, suggesting that the vines were reliant on their deep roots for water uptake.

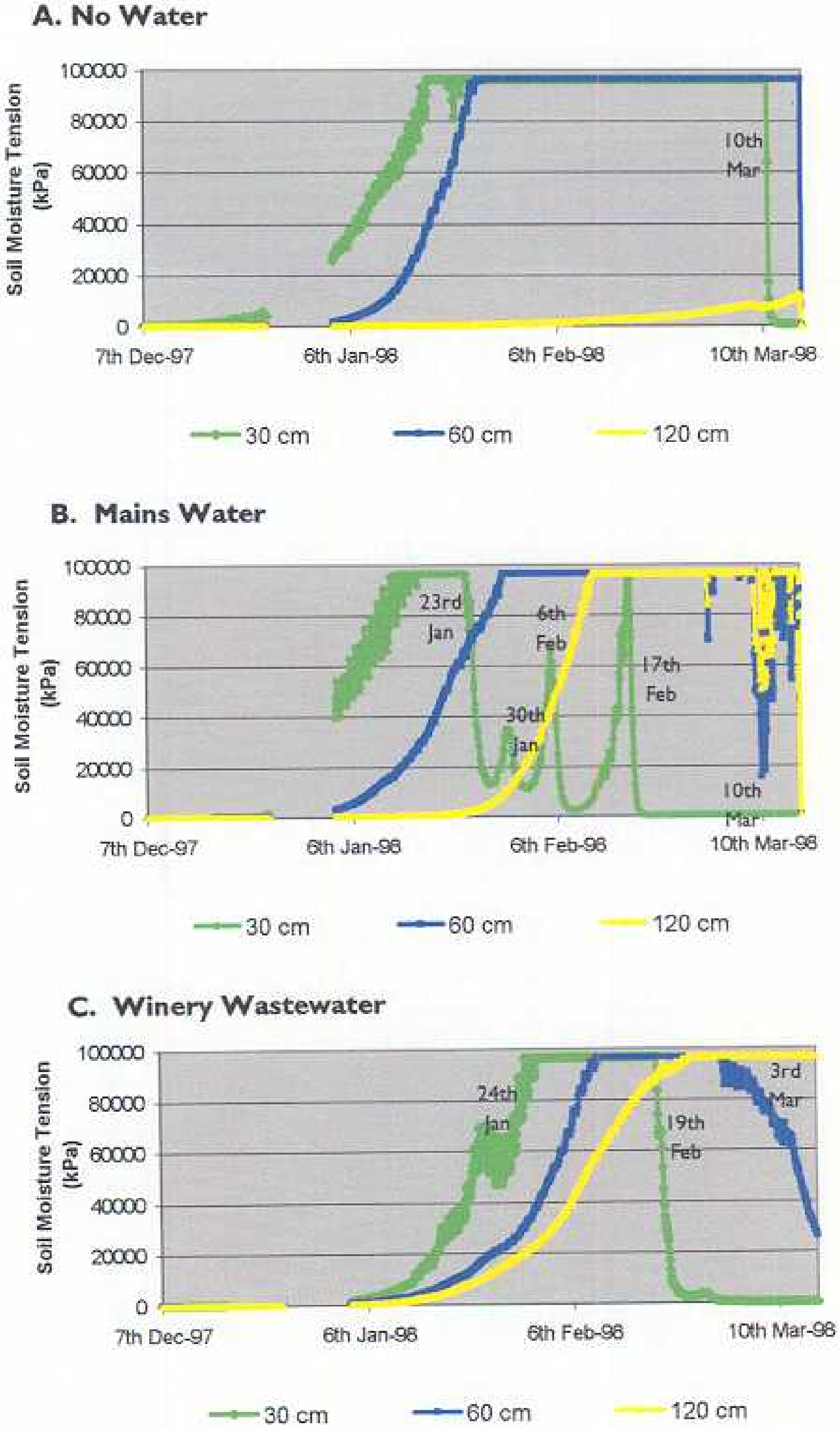


Figure 5.7 Soil moisture responses to irrigation and rainfall monitored by gypsum blocks.

5.3.2 Soil

Irrigation over the 3-week period did not effect soil chemistry (sampled at harvest), nor did parameters differ significantly from means obtained prior to experimentation (Table 5.2).

5.3.3 Vines

Irrigation increased yield by 22% and 32% respectively for the mains water and winery wastewater, compared with non irrigated vines, whilst fruit quality was not affected (Table 5.7).

Table 5.7 Effect of no irrigation and irrigation of Shiraz on Schwarzmann vines with mains water and winery wastewater on yield and juice quality in the 1997/98 vintage.

Parameter	Units	No Water	Mains Water	Wastewater	F.Pr[1]
Yield	t/ha	9.91$_a$	12.11$_b$	13.5$_b$	99.9
Brix		24.13	23.55	23.3	NS
pH		3.70	3.63	3.72	NS
Titratable Acidity	g/L	4.08	4.28	4.25	NS
Sodium	mg/L	14.3	13.3	15.5	NS
Potassium	mg/L	1685	1490	1700	NS
Chloride	mg/L	12.6	10.5	11.3	NS

1. NS not significant at 90% probability level

5.3.4 Soil Solute Composition –comments from the thesis of Mr. B Smith

Ceramic cups positioned at depths of 0.3 and 1.2m were used to extract soil solution at moisture tensions close to field capacity (10 kPa). Depths of sampling were chosen to represent the nominal treatment zone and buffer zone in which removal of organic carbon by microbial metabolism and adsorption in soil and by vine uptake according to the model of Chapman (1995).

It was discussed that information derived from this method of extraction can only be used as a guide due to a number of limiting factors including:

-non-filling of some extractors at given sampling dates,

-potential for exclusion of solutes by the ceramic materials

-'hit-and-miss' sampling in relation to passage of a solute front derived from periodic wastewater irrigation during the 3 month sampling period.

Despite these limitations a number of interesting observations were made.

Important Note: Concentrations of salts in extracted soil solution are similar to saturated paste extracts, and much higher than 1:5 soil:water extracts e.g., used in the Yalumba Wines study.

Total Organic Carbon (TOC): Between 40-70 mg/L TOC was extracted at 0.3m, which further declined to 30 mg/L. Using the estimate TOC content of non-vintage winery wastewater of 350 mg/L, this represents a 90% reduction in organic loading comparable to most secondary biological treatment systems (Metcalf and Eddy 1980). Soil solution extracted from mainswater irrigated plots at 1.2m depth contained 5-24 mg/L TOC.
Total Dissolved Salts (TDS): In contrast to TOC, the TDS of soil solution extracted from wastewater treatments at 1.2m was about 2-3 times higher (0.5-1 dS/m) than that

extracted from mainswater treatments (0.3 dS/m). The extra 0.3-0.6 dS/m contained in soil solution extracted from wastewater irrigated plots is below estimated levels of input 1.5-2.5 dS/m (Table 5.3).

Sodium Adsorption Ratio (SAR): SAR was extremely sodic (20-28) in soil solution extracted from both mainswater and wastewater irrigated plots at 0.3m. In mainswater irrigated plots SAR had dropped to 3 in soil solution extracted at 1.2m, while under wastewater irrigation soil solution extracted at 1.2m had SAR 4-22 (average 12.5).

5.3.5 Simulated Deep Drainage Loss –comments from the thesis of Mr. B Smith

The Soil Water Infiltration and Movement model developed by CSIRO was used to simulate deep drainage loss. The model uses both soil and crop parameters. Soil moisture status, hydraulic conductivity and retention curves were based on curves fitted from direct measurement of the soil. Similarly vine water use crop factors and leaf fall were also directly measured as practical.

Simulated Deep Drainage Loss: Continued irrigation during vine dormancy and winter rainfall increased deep drainage loss beyond 1.5m depth. Linear increases in the volume of application during this period would increase deep drainage by a greater than linear amount. The exact shape of a curve of irrigation volume versus cumulative deep drainage, and hence rate of increase will depend on the monthly pattern of wastewater irrigation, which is almost 'unique' for each winery (explained in Part A of Winery Wastewater: Production, Impacts and Management).

Actual Soil Moisture Levels (neutron moisture meter): The 1998 vintage of Evans and Tate Ltd lasted about 9 weeks (17th February to 16th April), beyond which only sporadic irrigation occurred. Irrigated treatments had similar moisture profiles to the non-irrigated treatment at all recording dates (May to August). Wetting of the soil profile towards field capacity therefore was dominated by rainfall.

Use of irrigation water by the vines (sapflow sensor, Figure 5.8): Water uptake by irrigated vines was higher than non-irrigated vines (not significant). Sapflow became negligible after 22 weeks (10th June) as the vines reached dormancy. Simulation of grapevine crop factor (fraction of pan evaporation transpired) emphasized the greater uptake of water during stages of active growth compared with the post harvest period.

Implications of the above summary on management will be outlined in the discussion.

Figure 5.8
Water flux analysis within vine stems using a heat pulse sapflow sensor.
Photograph courtesy Mr. B Smith

5.4 Discussion

5.4.1 Effects of Wastewater Irrigation on Grapevines

Increases in yield of 25-35% from irrigation compared with non-irrigated vines were not associated with a decline in juice quality measured by brix, acidity, and major salts. This effect was partly an artifact of irrigation associated with installation of soil moisture sensors, and of 3 applications during the 4 weeks prior to harvest. However like many small wineries, Evans and Tate Ltd generate very little wastewater outside vintage (<25% of the annual estimated volume). Thus sporadic spreading of wastewater across the vineyard during the active growth stage of vines in future seasons is most likely to provide the benefit of irrigation on yield compared with dryland production.

Effect of wastewater irrigation will depend on vine responses to post harvest irrigation. Post harvest irrigation is commonly used to delay leaf drop and increase storage of carbohydrates and nutrients within the stems and roots prior dormancy, to provide more rapid early growth post dormancy. Preventing excess vegetative growth and shading of grape bunches were major factors in maintaining dryland conditions at the Gnangara vineyard. Thus it is probable that continued disposal of winery wastewater would increase the 'risk' of excess vigour.

5.4.2 Impact of Wastewater Irrigation on Soil Chemistry

Insufficient wastewater had been applied to effect soil chemistry in 1998. However given the relative high salt content and SAR of the wastewater to that of the soil, it was anticipated that these parameters would have increased by vintage 1999. Irrigation of previously dryland managed sites normally changes soil chemistry as a result of extra leaching of salts and nutrients. It was regrettable that the field site was closed prior to 1999, as it represented a rare opportunity to quantitatively monitor these changes.

5.4.3 Impact of Wastewater Irrigation on Soil Solution Chemistry

TOC: The work of Mr. Brad Smith suggested that added total organic carbon could be effectively removed from the soil solution by:

1. an irrigation management strategy of **applying small volumes of wastewater** at a given irrigation, in combination with

2. long retention times within the combined treatment (nominally 0-0.3m) and buffer (0.3-1.2m) zones. For Evans and Tate Ltd, the elapsed time between initial measurement of the soil solution (6th June) and start (17th February) and end (16th April) of vintage wastewater irrigation was 16 and 10 weeks respectively. NMM probe readings indicated that the soil profile only became moderately saturated late July. Simulation of deep drainage from rain-fed vines indicated drainage beyond 1.2m beginning in July.

Total Dissolved Salts: Salts contained in irrigation water usually leaches from the rootzone. Storing salts within the rootzone during the irrigation season by preventing drainage only delays the inevitable. Salt levels in extracted soil solution from wastewater irrigated plots were around 30-50% of the estimated input levels in the wastewater. Sporadic irrigation after cessation of vintage and thus dominance of rainfall in generating drainage during the sampling period would lead to some dilution of salts. In addition sampling times could not be accurately coordinated with passage of a solute front following intermittent irrigation with wastewater.

However salt levels in the soil solution extracted from wastewater treatments remained 2-3 times higher than mainswater treatments, highlighting the inability of the soil system to remove substantial amounts of dissolved salts in irrigation water.

Sodium Adsorption Ratio: The substantial decrease in SAR between 0.3m and 1.2m in mainswater irrigated plots was attributed to exchange of sodium from the solution to colloidal surfaces. Higher starting concentrations of sodium within the soil solution from wastewater irrigated plots limited reduction of SAR between the 0.3m and 1.2m layer, which remained sodic (average of 12.5).

5.4.4 Implications for management

The inability of biological treatment systems to remove salts makes this parameter the most limiting factor to sustainable irrigation of wastewater, and arguably most water sources.

Sodium added through caustic washing is a major component of the total dissolved salt content winery wastewater. A direct result of higher starting concentrations of sodium in the soil solution was reduced exchange of the ion from solution to soil colloids within the subsoil layer. Thus by vintage 1999 an increase in SAR of the soil would be predicted. Closure of this site through the sale and dismantling of the winery meant that this prediction could not be measured.

In contrast to inorganic salts, organic substrates added in the wastewater could potentially be reduced by acceptable (>90%) percentages by keeping newly added substrates in the upper aerated zone where removal by microbial metabolism is highest (Chapman 1995 a, b), and (II) maximising residency times.

Simulating higher volumes of wastewater discharged per hectare of vineyard increased deep drainage beyond 1.5m depth by a greater than linear increase in input irrigation. Deep drainage also began earlier, therefore minimising potential residency time of organic substrates within the nominal treatment and buffer zone.

5.4.5 Recommendations for Winery Wastewater Management

Evans and Tate Ltd had outgrown the Henley Brook site primarily due to the lack of vineyard available for sustainable discharge of the wastewater.

Waste Management within the Winery: Management of the site would require a major effort in adopting Cleaner Production strategies to minimise:

1. water waste, due to potential excessive deep drainage from the vineyard, and to maximise residency time of organic substrates within the upper 1.5m soil depth.
2. use of caustic soda for cleaning, to minimise impacts of total dissolved salts and sodicity. Minimising production loss could also reduce total salt content of the wastewater. Good quality water (mains supplied) had always been used for winery operations at Evans and Tate Ltd –an example that other wineries should follow.

Pretreatment of the wastewater: The current system of solids separation and short-term storage to reduce variability of wastewater parameters by mixing would be regarded as a minimal standard, but one affordable to wineries of similar size as Evans and Tate Ltd (1700 tonnes).

Irrigation Management: The current system pitched at maximising removal of total organic carbon is recommended, viz.

1. applying small volumes of wastewater at a given irrigation to nominally keep the newly added water within the upper aerated zone.
2. maximising residency time within the rootzone before deep drainage occurs.

5.5 Acknowledgements

I wish to thank Mr Tony Devitt, West Australia Department of Agriculture, for initiating discussions with Evans and Tate Ltd and approaching me to undertake the field experiment in lieu of withdrawal of Orlando Wyndham. GWRDC is thanked for providing the additional funding.

Mr. Murray Edmonds, Evans and Tate Ltd. is thanked for his frank discussions on limitations of their past and waste management and major effort in obtaining local council approval for installation of a better treatment system (which included the irrigation network).

Mr. Bob Frayne and Mr. Barry Goldspink are thanked for their technical input towards choosing soil and juice parameters to analyse and undertaking the work at "in-house" prices.

Finally I thank Dr Judy Eastham in keeping regular contact with Evans and Tate Ltd, particularly during my maternity leave early 1998, and for initiating the student project. Within the confines of a "4th year bachelor degree project" valuable pieces of information came from the project that would have resulted in more intensive work in 1999, had the winery not been dismantled. The student, Mr. Brad Smith, is thanked for assisting with installation of the soil moisture sensors and undertaking work in the field during 1998.

Appendix V.I

ABSTRACT

"Investigation of the Groundwater Pollution Potential and Simulated Deep Drainage Loss associated with Winery Wastewater Disposal by Vineyard Irrigation."

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4th Year Student
Bachelor of Natural Resource Management
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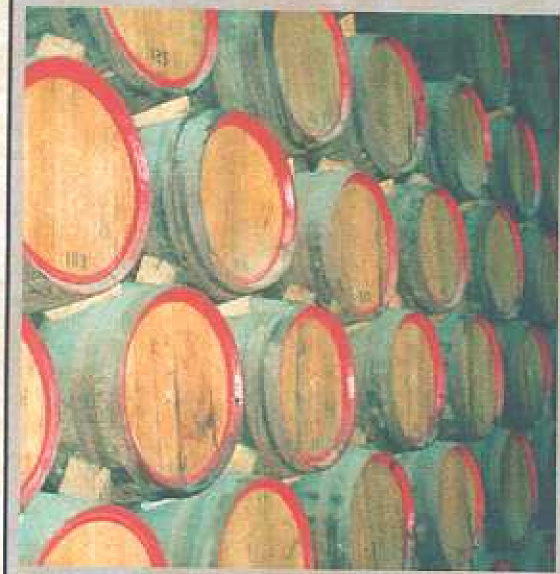
Rapid expansion of the wine-grape viticultural industry within Australia recently, has increased wine production within major wine-grape producing regions and consequently increased the amount of wastewater generated within wineries. A by-product of winery treatment operations, it is estimated that wineries generate between 2 and 5 kilolitres (kL) of wastewater per tonne of grapes crushed. The traditional method of wastewater disposal by most wineries, storage within evaporative lagoons, has more recently been over-shadowed by the general move towards wastewater disposal by vineyard irrigation. The Australian wine industry sought to review wastewater disposal and in doing so has targeted wastewater to be utlilised as a source of water for vine irrigation and for improved soil fertility and structure. However, since peak wastewater production and peak vineyard water demand are asynchronous in wine-grape producing areas worldwide, recycling wastewater by vine irrigation could generate deleterious effects on drainage water quality.

I examined soil solution at (0.3 and) 1.2m depth within the drip zone of wastewater and mainswater irrigation treatment plots in a trial site at the Evans and Tate Ltd vineyard at Henley Brook, to determine the effects of wastewater irrigation on solute concentrations within soil solution. Solution samples from porous ceramic extractor vessels were examined for total organic carbon concentration (TOC), sodium adsorption ratio (SAR) and electrical conductivity (EC) as a measure of potential groundwater pollution of winery wastewater

disposal by vineyard irrigation. The maximum observed TOC concentration in solution at 1.2m depth within wastewater treatment plots was approximately 30 mg/L, less than the proposed organic carbon threshold level of 50 mg/L. Observed SAR values were greater than observed within mainswater treatments at the same depth. A maximum SAR value of 23 was observed in solution at 1.2m depth for the wastewater treatment. The dissolved salt concentrations of solution at 1.2m depth were significantly greater ($P<0.05$) within wastewater treatment plots than mainswater, with a maximum electrical conductivity reading of 997 μS/cm. In lieu of a substantial amount of wastewater generated within the Evans and Tate Ltd winery being directly discharged onto the vineyard, outside of the experimental plot, due to filter blockages, measure solute concentrations are possible under-estimated values. Additionally, measured concentrations may not be representative of actual maximum solute concentrations since sample collection was not coordinated with the period of vertical drainage moving pass the sampler (too costly to undertake).

Additionally, I investigated drainage loss below 1.5m depth within the drip zone associated with hypothetical upper and lower limit wastewater irrigation scenarios. These were calculated based on the estimated annual grape crush of 1700 tonnes at Evans and Tate Ltd winery, and used to simulate drainage using the Soil Water Infiltration and Movement (SWIM) model. The range of potential annual wastewater production volumes according to the estimated 1700 tonne grape crush were between 34000 and 8500 kL. Simulated weekly drainage loss using SWIM were based on estimated volumes of weekly wastewater input determined from a wastewater production hydrograph. Simulated drainage loss within the drip zone in response to rainfall plus 1982 mm annual irrigation input (based on the upper estimated limit) was 2400 mm, approximately 24 times greater than was predicted under no irrigation (rainfall effect). Alternatively, rainfall plus 794mm annual irrigation input per dripper (lower limit) simulated drainage loss within the dripper zone of approximately 700mm. It appears that wastewater minimisation strategies with wineries have an important role for wastewater disposal by vine irrigation to be viable for wine-grape producing regions where shallow receiving groundwater environments already pose a threat of intrusion into the root zone. Similarity between simulated profile water contents for no irrigation and observed profile water contents within the drip zone over 9 measurement dates lends itself toward more comprehensive assessment for potentially assisting decision-making on the acceptableness of wastewater disposal by irrigation in these areas.

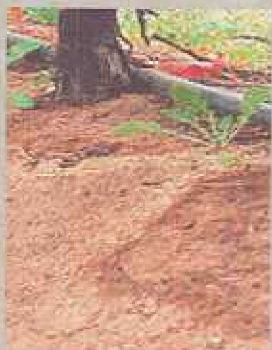


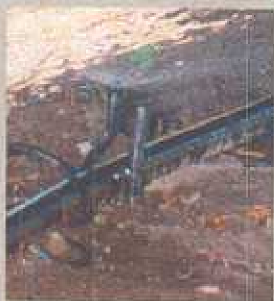
6.0

Yalumba Wines

Clockwise from top left

-barrels
-spray emitter
-coordinating harvest of split rows of vines!
-drip pattern
-Dr Judy Eastham in the Yalumba treelot





6.0 Yalumba Wines

6.1 Objective

Effects of winery wastewater as an irrigant of winegrapes on yield and quality were quantified. Impacts of wastewater irrigation on soil chemistry were also examined.

6.2 Methodology

6.2.1 Location and Site History

The experimental site is located in the Mexican Vale vineyards, Angaston, South Australia (Australian Map Grid (AMG) Reference: 54H UG 133829).

The Mexican Vale vineyards were established adjacent to the southern side of the winery in 19971/72 and occupy about 12 ha on an easterly aspect. Lower slopes (5-10%) are planted with Cabernet Sauvignon and upper slopes (10-20 %) with Shiraz. The experimental block is located adjacent to Angaston Creek in the southern Cabernet Sauvignon vineyard. Rows are spaced at 3.7 m and vines at 2.5 m using a tee trellis. The vineyard has been irrigated since planting with groundwater using a standard 4L/h drip system. Grapes from the vineyards are traditionally harvested in April-May and are used to make Yalumba Oxford Landing Cabernet Shiraz, a medium to lower price point wine.

6.2.2 Soil Types

Soil types are classified according to the texture and colour of the first subsoil layer, as vines are deep rooted. Two distinct soil types were identified in the experimental block:

1. Duplex yellowish red clay (plots 1,3,5,7,9,11,13-20)
2. Duplex black clay (plots 2,4,6,8,10,12)

Physical, chemical and plant nutrient status of the soil types is given in Tables 6.1 to 6.3 and a map showing their distribution within the experimental site in Appendix 6.1.
Since changes in soil type commonly occur within an area too small to separate into separate irrigation blocks, as in this case, it was decided to include both soil types within the experimental design.

Table 6.1 Soil physical status[1] –Yalumba Wines, Angaston SA.

Layer No.	Texture				Wet Colour	Structure			Mechanical Properties			Root Density	Stability		Layer Change	
	Sand	Silt	Clay	Class		Distinctness	Shape	Size	Hardness	Plasticity	Stickiness		Slaked	Dispersed	Abruptness	Shape
	%							mm								
Duplex Yellowish Red Clay																
1	81.5	7.8	10.7	Sandy Loam	Dark Reddish Brown	Moderate	Granular	2-5	Friable	Nil	Nil	Abundant	Yes	No	Diffuse	Smooth
2	77.2	8.5	14.3	Loam	Light Reddish Brown	Moderate	Granular	2-5	Hard (dry)	Nil	Nil	Few	Yes	No	Clear	Smooth
3	66.5	9.5	24.0	Light Clay	Yellowish Red	Weak	Blocky	50-100	Hard	Slight	Slight	Few	Yes	No		
Gradational Black Clay																
1	73.1	12.4	14.5	Loam	Dark Greyish Brown	Moderate	Granular	5-10	Firm	Moderate	Moderate	Many	Yes	No	Abrupt	Smooth
2	63.2	13.5	23.3	Light Clay	Black	Moderate	Blocky	5-20	Hard	High	High	Few	Yes	No	Abrupt	Smooth
3	53.2	14.3	32.5	Medium Clay	Dark Yellowish Brown	Weak	Massive		Very Hard	High	High	Very Few	Yes	No		

1. Field scoring system courtesy Alfred Cass.

Table 6.2 Soil chemical properties[1] –Yalumba Wines, Angaston SA.

Profile No.	Layer No.	$EC_{(1:5)}$	pH	Soluble cations				Total cations				SAR[2]	Exchangeable cations as			
			water	Ca	Mg	K	Na	Ca	Mg	K	Na		Ca	Mg	K	Na
		dS/m	-	mmol c+/kg				mmol c+/kg					% of Total cations			
Duplex Yellowish Red Clay																
1	1	0.07	6.9	3.63	1.07	1.91	3.57	26.31	6.22	2.88	8.02	0.60	86.19	82.84	33.84	55.43
	2	0.05	7.1	2.20	0.91	3.48	1.37	19.77	6.13	6.15	4.85	1.30	88.89	85.2	43.35	71.74
	3	0.10	7.5	6.17	3.41	8.40	0.86	30.32	9.42	13.10	5.53	1.80	79.64	63.82	35.85	84.39
Gradational Black Clay																
2	1	0.10	7.0	4.39	1.26	4.77	4.64	50.68	9.21	8.09	12.28	1.28	91.34	86.35	41.03	62.2
	2	0.06	7.0	4.63	1.65	5.84	1.78	56.55	12.94	10.85	8.41	1.47	91.66	87.22	46.21	78.88
	3	0.07	7.3	7.78	3.61	7.12	0.88	45.32	15.59	13.25	6.83	1.37	82.83	76.83	46.26	87.17

1. Table format courtesy Alfred Cass.
2. SAR: Sodium Adsorption Ratio

Table 6.3 Plant nutrient status[1] –Yalumba Wines, Angaston SA.

Profile No.	Layer No.	Plant nutrients					Organic Carbon	Extrac-table Fe
		NO_3-N	NH_4-N	P	K	S		
		mg/kg					%	mg/kg
Duplex Yellowish Red Clay								
1	1	5.7	1.6	76.68	215.8	13.51	1.112	1125
	2	2.2	1.4	12.35	161.7	22.9	0.397	888
	3	1.0	1.4	4.136	210.2	21.81	0.293	1285
Gradational Black Clay								
2	1	9.6	2.4	126.6	351.1	9.483	1.61	1637
	2	3.4	2.5	27.8	294.7	19.91	1.285	1713
	3	1.7	1.8	46.61	294	20.98	0.489	1520

1. Table Format courtesy Alfred Cass.

6.2.3 Water Quality[1]

Composition of the groundwater bore and winery wastewater sampled during vintage (approximately February to May) and non-vintage (June to January) are given in Table 6.4. Groundwater was sampled from the bore after a minimum 20 minutes pumping time had elapsed. Samples of winery wastewater were collected by a proportional flow sampler at the outlet point prior to distribution through the irrigation network. Frequencies of sampling were according to Yalumba Wines Wastewater License conditions, viz. 6-7 samples across each of vintage and non-vintage, and 6 monthly intervals for the groundwater. Analyses were conducted by the Australian Water Quality Center using Standard Methods (1989).

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[1] A detailed account of the production of individual winery wastewater characteristics and impacts on soil and winegrapes is provided in the Book: Winery Wastewater: Production, Impacts and Management.

Hypotheses:

Due to a lower content of inorganic salt irrigation with winery wastewater will result in smaller increases in soil salinity and levels of inorganic salts, than continued irrigation with the saline groundwater.

Since own rooted grapevines are more sensitive to effects of salts, it is further hypothesized that the wastewater irrigated vines will exhibit more superior yield and quality characteristics than when irrigated with the groundwater.

If irrigation is managed according to the model in Figure 1, it is hypothesized that the extra nutrients within the wastewater will be metabolised by soil dwelling micro-organisms and hence will not negatively impact on vine growth.

Table 6.4 Composition of the groundwater and winery wastewater produced during vintage (approximately February to May) and non-vintage (June to January).

Parameter		Groundwater Bore		Winery Wastewater Vintage		Winery Wastewater Non-Vintage	
	Units	Mean	Std.	Mean	Std.	Mean	Std.
pH	none	7.50	0.20	4.69	0.38	4.82	.49
Electrical Conductivity	dS/m	2.39	0.12	1.98	0.35	1.81	0.38
Total Organic Carbon	mg/L	1.6	1.2	1983.6	456.0	1570.5	432.2
Total Phosphorus	mg/L	0.10	0.08	9.02	8.63	7.03	2.26
Total Kjeldahl Nitrogen	mg/L	1.05	1.65	32.65	10.4	32.19	12.16
C:N:P	30:x:y	20:2	43:2	0.5:0.1	0.6:0.5	0.6:0.1	0.8:0.2
$NO_3^- + NO_2^-$	mg/L	1.22	0.18	0.28	0.34	0.11	0.13
SAR	mg/L	4.88	0.35	7.26	1.83	7.36	1.67
Na	mg/L	277.67	21.13	251.7	116.2	158.1	61.8
K^+	mg/L	14.7	0.9	182.18	43.78	159.12	50.46
Ca^{2+}	mg/L	107.53	4.74	86.46	61.17	61.73	22.75
Mg^{2+}	mg/L	83.77	3.39	25.17	11.62	15.81	6.18
HCO_3^-	mg/L	478.83	36.76	133.95	166.69	163.65	165.11
SO_4^{2-}	mg/L	77.22	4.72	248.82	210.28	153.54	138.6
Cl^-	mg/L	544.5	17.52	149.77	60.72	150.55	49.15
No Samples		6		20		24	

1. Yalumba Wines provided the analyses.

6.2.4 History of Wastewater Management

Yalumba has a long history and is regarded as a champion of wastewater management within the wine industry.

Establishment of the winery on the side of a hill enables wastewater to gravitate to a single collection point. The winery also has approximately 1 hectare (ha) of open processing area that acts as a large catchment area for stormwater. Until the early 1970's wastewater was stored in a dam and directly released into the Angaston Creek at times of high flow.

Continual polluting of the creek became unacceptable and a unilateral decision was made at Yalumba to establish a formal waste management system.

The system consisted of solids separation prior to secondary treatment by a series of aerobic lagoons, with wastewater gravitating from one lagoon to another. Aerators placed in the first 2 lagoons keep the wastewater completely mixed and aerated to promote breakdown of the organic material by aerobic microbial metabolism. The remaining 2 lagoons were used to allow the sludge to settle out. Accumulation of sludge in the aerated dams led to wastewater being re-routed through the fourth large pond prior to aeration. The total treatment time was approximately 10 days. Treated wastewater was then spray irrigated onto 4 hectares of pasture.

By the late 1980's Yalumba began searching for economical uses of the treated wastewater. A 1 ha treelot of red gums trial in 1990, which was later concluded to provide little economic return. In 1994 Yalumba began irrigating a previously non-irrigated 2 ha vineyard known as the Triangle Block with the treated wastewater, which showed no adverse effects of using the treated wastewater on grape and wine quality.

Rapid expansion in production from approximately 10 000 tonnes in 1972 to >25 000 tonnes of grapes in 1996 resulted in a similar rapid increase in production of wastewater from about 30 megalitres (ML) per annum in the early 1970's to the current annual level of 50 ML. Unable to cope, the aerated lagoons were phased out in 1994, with wastewater directly irrigated from the settling lagoon. At that time continual rise in the salinity of groundwater used to irrigate the Mexican Vale vineyards adjacent to the winery became a major concern, and a decision was made to switch to winery wastewater as the irrigant.

The current pretreatment system, commissioned in vintage 1999, consists of solids separation by screening and settling in an enclosed tank. To assist in balancing the pH of the normally acidic wastewater, recycled caustic washwater (pH >10) is separated and added back at times of low pH (<5.5). Treated wastewater then gravitates to 2 large tanks capable of holding wastewater produced during peak flows in vintage for 24 hours, with longer holding periods in non-vintage. A backup lagoon assists in balancing shock loads of water, e.g., produced during heavy rainfall. Sand filtration and regular line flushing minimise blocking of emitters. Irrigation of a further 20 ha of new vineyards is proposed when established. Future plans aim to treat and store wastewater produced during the dormant period of vine to maximise its reuse for grape production.

6.2.5 Wastewater Irrigation Management at Mexican Vale

Winery wastewater is used as a substitute for groundwater, with weekly volumes applied based on normal vineyard practices that avoid excessive irrigation in premium quality vineyards. Excess wastewater can be redirected to the tree plantation/pasture discharge site.

Hypothesis:
Irrigating with winery wastewater to normal vine needs minimises impacts on grape and wine quality and, soil and groundwater quality.

6.2.5.1 Irrigation of the Experimental Block

Yalumba Wines wanted to assess two types of emitters they were currently using microjet spray, and the industry standard 4 L/h drip. As a result of greater evaporative losses and higher horizontal surface area of coverage, microjet spray enables higher volumes of wastewater to be discharged at a given irrigation. This is reflected in the calculated loading of salts and nutrients added in the groundwater and wastewater by the drip and spray emitters given in Table 6.5.

Shorter times and split applications were used whenever practical to keep the wastewater within the top 0.3m of soil for treatment of organic substrates by oxidative microbial metabolism, according to the model described by Chapman (1995a). Due to soil compaction along the wheel tracks, vine roots were rarely encountered in the upper 0.3m of soil in the inter-row area.

Table 6.5 Annual nutrient loading.

		TOC	TKN	TP	Na	K	Ca	Mg	Cl	SO_4
Groundwater					all units kg/ha					
Drip	1996/97	2	1	0	578	29	206	167	1095	151
	1997/98	1	0	0	315	16	122	93	599	82
	1998/99	2	1	0	771	39	293	242	1522	216
Spray	1996/97	3	1	0	785	40	280	227	1488	205
	1997/98	2	0	0	601	30	233	178	1141	156
	1998/99	4	2	0	1184	60	451	372	2339	332
Wastewater										
Drip	1996/97	2880	36	11	532	236	109	46	298	272
	1997/98	1434	29	8	224	124	66	22	159	209
	1998/99	3456	55	9	386	257	187	38	206	662
Spray	1996/97	3031	46	11	570	266	120	53	334	357
	1997/98	4016	81	22	622	351	184	62	435	591
	1998/99	7119	115	18	845	568	453	86	436	1551

6.2.6 Statistical Design

The statistical design was prepared as an 'in-kind' contribution by Dr Ray Correll, CSIRO Biometrics. The objective of any experimental design is to maximise the probability of detecting differences due to treatment effects on measured parameters above those caused by the natural variability of the site and error associated with measurement (together called the residual error).

A 2x2 Latin square design was used at Yalumba Wines as it allowed allocation of treatments along vine rows and different rows of vines as replicates. Each row of vines is divided into halves, called columns. Impacts of site variation, particularly that due to distribution of soil types, on treatments both along and between rows is reduced by restricting the number of times any given combination of water type/irrigation method is repeated within each column to a maximum of 3. Each plot consisted of four rows with only the middle two rows measured to remove edge effects. Using five replicates there was a 96% chance of detecting an interaction between the source of water and irrigation method, if one existed.

As with most field sites, establishing treatments according to a design on paper was not easy –several designs incorporating additional treatments requested by Yalumba Wines were prepared before the final one was accepted. Figure 6.1 shows the field layout of treatments and irrigation system installed by Yalumba Wines, which required new sub-mains for wastewater/groundwater to isolate the site from adjacent blocks, replacing and/or modifying existing irrigation lines along 40 rows of vines, and installing water meters[1].

[1] Planning to commissioning the site took about 15 months.

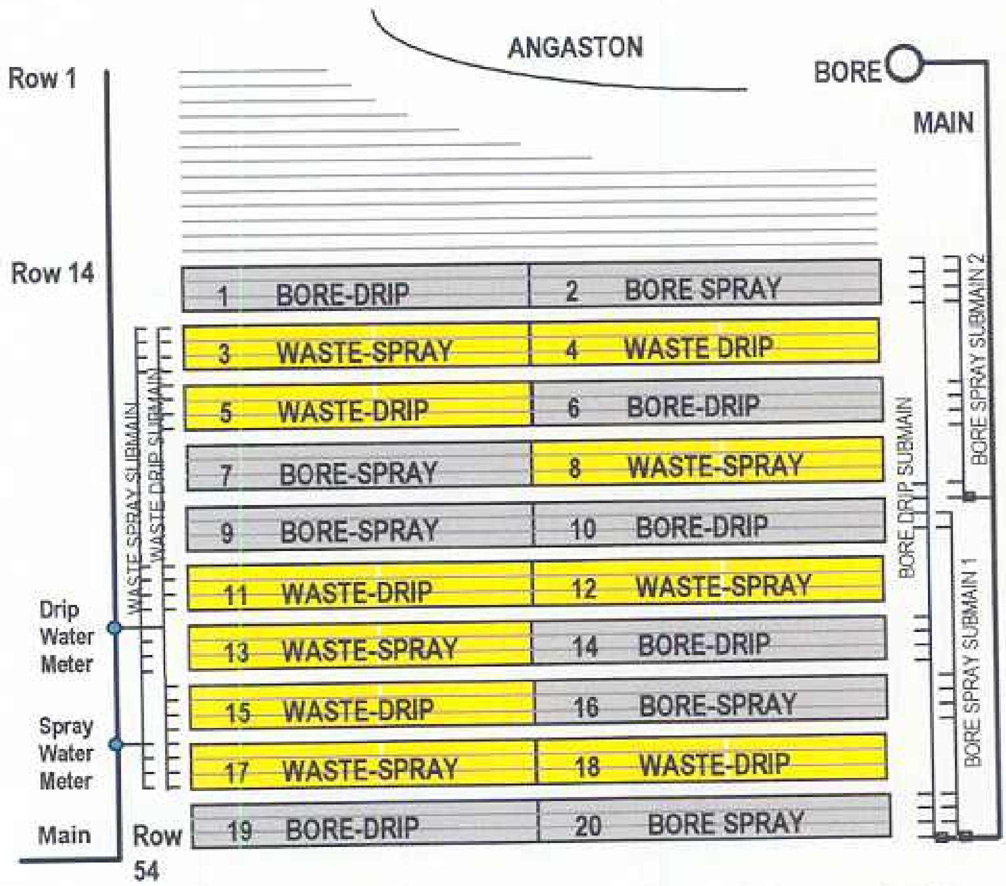


Figure 6.1 Field layout of treatments and required irrigation installations for the Yalumba Wines, Angaston site.
Statistical Design courtesy Ray Correll, CSIRO; Irrigation Design courtesy Bill Tapscott, Yalumba Wines.

6.2.7 Measurements-soil

6.2.7.1 Sampling

Distribution of water applied by drip and spray emitters, effects of winter leaching, and spatial and temporal variation in soil properties were assessed for their impact on parameters.

Horizontal distribution of wetting –drip emitters wet soil in a characteristic onion shape whereas spray emitters nominally provide even horizontal coverage over at least 80% of the surface (Figure 6.2), thus require higher volumes of water to wet the soil to a given depth. Drip irrigation often forms puddles under the emitter resulting in deeper penetration from saturated flow.

Hypotheses:

It is hypothesized that spray irrigation as a result of higher application volumes will result in greater increases of inorganic salts within the soil profile, and resultant impacts on juice and wine quality.

It is further hypothesized that better horizontal distribution of spray irrigated water and slower unsaturated flow within the 0-0.3m layer, will potentially enable more rapid and extensive microbial metabolism of added organic carbon and nutrients, than drip irrigation.

Two **distances** of sampling from the emitters were used, 0.6 m to coincide with the edge of the wetting zone of drip-irrigated plots, and 1.85 m mid-way between vine rows (Figure 6.2). Effects of past history of drip irrigation will also be detected.

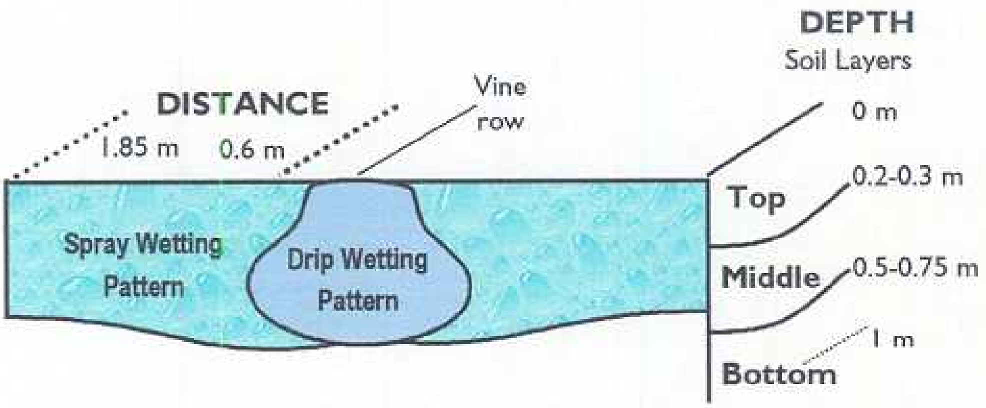


Figure 6.2 Theoretical distribution of water emitted by drip and spray systems and relationship to depth of soil layers.

Effects of irrigation and winter rainfall –The objective of the model system described by Chapman (1995a) is to keep the newly added irrigation water within the upper aerated zone (0.3-0.45 m) for at least 2 days to allow removal of the organic substrates by oxidative microbial metabolism before repeated irrigation. Furthermore, current irrigation management of the Mexican Vale vineyards by Yalumba Wines aims to keep added water within the rootzone during the growing season of the vines, with leaching to remove salts reliant on winter rainfall.

Hypothesis:

Irrigation with saline water usually requires a leaching fraction, an application of extra irrigation water to assist winter leaching. It is therefore hypothesized that irrigation of both the groundwater and winery wastewater, which both have salinities >1.9 dS/m, will be unsustainable without application of a leaching fraction (indicated by continual buildup of salts within the soil profile).

Sampling immediately **before** irrigation (November) and 2 weeks **after** the post-harvest irrigation (June) over three seasons will assess the impacts of irrigation and effectiveness of leaching.

Climatic differences between years will influence changes in soil chemistry both during and after irrigation. Variation of parameters within a sampling time, i.e., November-June and June to November, between years will be assessed against differences due to the irrigation method and water type treatments.

Soil textural and chemical change with depth –Both soil types contained 3 layers, hereafter referred to the Top (0 to 0.2-0.3 m), Middle (0.2-0.3 to 0.5-0.75 m) and Bottom (0.5-0.75 to 1 m). The treatment zone of the model includes the top layer and upper portion of the middle layer (Figure 6.2) wetted during irrigation. The lower portion of the middle layer and beyond to a depth of 1m acts as a buffer zone. The buffer zone receives water displaced from the treatment zone by subsequent irrigation and during winter leaching (which may move beyond 1m depth).

Hypothesis:

It is hypothesized that during irrigation greater increases in salts and nutrients will occur in the top and middle soil layers, while subsequent leaching during winter will result increase salt levels within the bottom layer.

Different soil textural layers differ in their capacity to retain salts. Organic matter and nutrients are typically concentrated in the topsoil. Structural arrangement of these layers, e.g., presence of a compacted layer within the middle layer, may influence water and salt movement modifying anticipated movement of salts and nutrients.

Distribution of different soil textural layers and structural arrangement of these layers across the four combinations of water type and irrigation method will therefore impart a residual error.

Sampling Program: Table 6.6 summaries the sampling program. In total 720 soil samples for taken for chemical analyses.

Table 6.6 Soil sampling positions and times for Yalumba Wine Company.

<table>
<tr><th colspan="2">TIME</th><th colspan="2">DISTANCE</th><th colspan="3">HORIZON</th></tr>
<tr><td>96/97 Before</td><td>(November 96)</td><td rowspan="6">0.6 m (edge of wetting zone of drip irrigation)</td><td rowspan="6">1.85 m (mid way between rows)</td><td rowspan="6">Top (0 to 0.2-0.3 m)</td><td rowspan="6">Middle (0.2-0.3 to 0.5-0.75 m)</td><td rowspan="6">Bottom (0.5-0.75 to 1m)</td></tr>
<tr><td>After</td><td>(June 97)</td></tr>
<tr><td>97/98 Before</td><td>(November 97)</td></tr>
<tr><td>After</td><td>(June 98)</td></tr>
<tr><td>98/99 Before</td><td>(November 98)</td></tr>
<tr><td>After</td><td>(June 99)</td></tr>
<tr><td colspan="7">REPLICATION: 5</td></tr>
</table>

6.2.7.2 Analyses

Analyses focussed on salts and nutrients that were most likely to impact soil fertility and quality of winegrapes, decided at a meeting of the 'Technical Committee' on site monitoring[1] following preparation of a discussion paper. Potential impacts on soil and winegrapes of wastewater components are described in the book Winery Wastewater: Characteristics, Impacts and Management. Soil parameters and methods of analyses used are summarised in Table 6.7. Analysis of soil sampled post harvest 1998/99 was conducted by CSBP Soil and Plant Laboratories, Perth.

Table 6.7 Soil parameters analysed and methods used.

Parameter	Method	Reference
Acidity/alkalinity	pH meter (1:5 soil:water)	Heanes (1981)
Salt	Electrical Conductivity	Rhoades (1982)
Organic Carbon	Dichromate digestion	Walkely and Black (1965)
Total Nitrogen	Kjeldahl digestion	Heanes (1981)
Ammonium	Spectroscopic	Heanes (1981)
Nitrate	Spectroscopic	Heanes (1981)
Plant Available Phosphorus	Bicarbonate extraction	Heanes (1981)
Plant Available Potassium	Bicarbonate extraction	Heanes (1981)
1:5 Na, K, Ca, Mg	Spectoscopic	Heanes (1981)
1:5 Chloride	Silver Nitrate Titration	Heanes (1981)
Texture	Hydrometer	Day (1965)

[1] The objective of the meeting was to determine monitoring requirements of the wastewater, discharge sites, groundwater and nearby rivers and creek, required under State Environmental Protection Agency Winery Wastewater License agreements.

6.2.8 Measurements –Juice and Wine

6.2.8.1 Sampling

Approximately 100 vines from the middle 2 rows were harvested for yield and preparation of laboratory scale wines after the 1996/97 season. Juice was obtained from about 300 grapes picked according to (P. Ireland pers. comm.) that accounts for variation within and between bunches harvested from both sides of the vines.

Note that in1997/98 the plots were not harvested separately, due to a misunderstanding by contractors.

6.2.8.2 Analyses

Analysis of juice and wine was an 'in kind' contribution by Yalumba Wines. Parameters and methods used are summarised in Table 6.8.

Table 6.8 Juice and wine parameters analysed and methods used[1].

PARAMETER	METHOD	REFERENCE
Alcohol (%V:V)	Distillation/Refractometry	Yalumba Wines
Sugar (g/L)	Enzymatic	
Specific Gravity	Density Meter	
Brix	Hydrometry	
Baume (1996/97)	Hydrometry	
pH	pH meter	
Titratable Acidity (8.2, g/L)	Titration	
Total Glycosyl Glucose (GG, μmol/fresh berry wt)	Assay	Williams et al. (1995)
Red Free GG (μmol/fresh berry wt)	Assay	Ireland et al. (1996)
Total Anthocyanin	Spectroscopic (Spec)	Ireland (1998)
Total Phenolic	Spectroscopic	Ireland (1998)
Na (mg/L)	Atomic Absorption Spec.	AWRI
K (mg/L)	Atomic Absorption Spec.	AWRI
Cl (as NaCl mg/L)	HPLC	AWRI
SO_4 (as K_2SO_4 mg/L)	HPLC	AWRI

1. Information courtesy Yalumba Wines.

Benchpress used by Yalumba Wines to extract juice for lab-scale winemaking.

6.3 Results

6.3.1 Soil

Wetting Pattern –Chloride

Distribution prior to experimentation: Chloride was significantly higher in soil sampled at 0.6m than at 1.85m from the vine row, and significantly increased with depth of soil layer (Figures 6.3-6.4). Higher chloride in soil sampled 0.6m from the vine row was an artifact of past drip irrigation with saline groundwater as covariate analysis using 1996 data removed significance from subsequent sampling dates compared with analysis without the covariate (Figure 6.3). Leaching of salts from upper to lower soil layers during the winter rainfall period accounted for higher chloride with depth of soil layer, as this trend continued throughout the experiment (Figure 6.4).

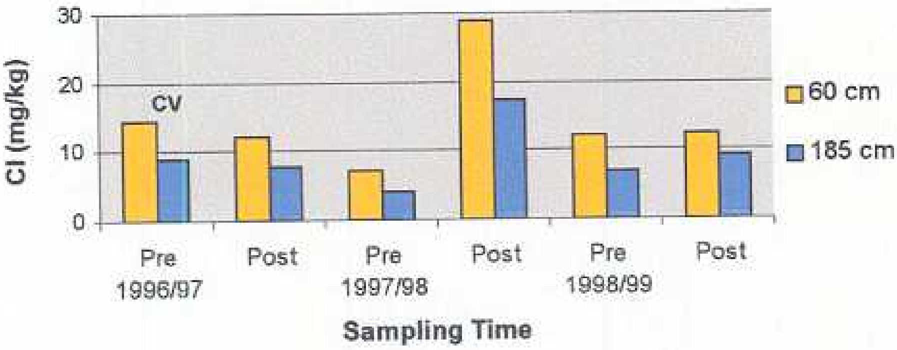


Figure 6.3 Distribution of chloride in soil sampled 0.6m and 1.85m from the vine row pre and post irrigation with saline groundwater and winery wastewater. Covariate analysis with pre 1996/97 data (cv) accounted for variation in future sampling dates.

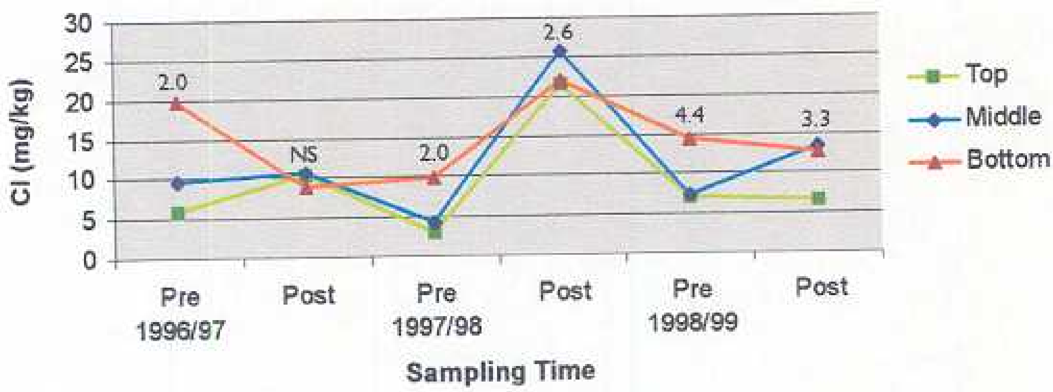


Figure 6.4 Variation of Cl with sampling depth pre and post irrigation with saline groundwater and winery wastewater (LSD 95% given, NS not significant).

Effect of drip and spray irrigation: Spray irrigation resulted in higher soil chloride than drip irrigation. Within drip irrigated plots greater increases in chloride occurred in the top soil layer, whereas spray irrigated plots showed greater net increases in chloride in the middle and lower soil layers (Figure 6.5). Differences became non-significant or less pronounced after winter leaching.

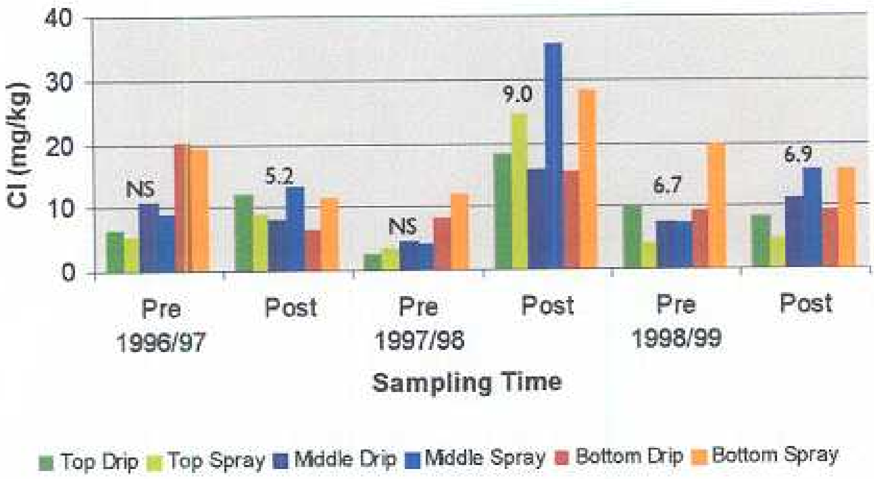


Figure 6.5 Effect of drip and spray irrigation and leaching during winter on distribution of chloride with depth of soil layer (LSD 95% given, NS not significant)

Effect of water type: Groundwater added significantly higher amounts of chloride than winery wastewater during irrigation in 1996/97, with differences remaining significant (Figure 6.6). No interactions of water type with irrigation method, sampling depth or distance were observed.

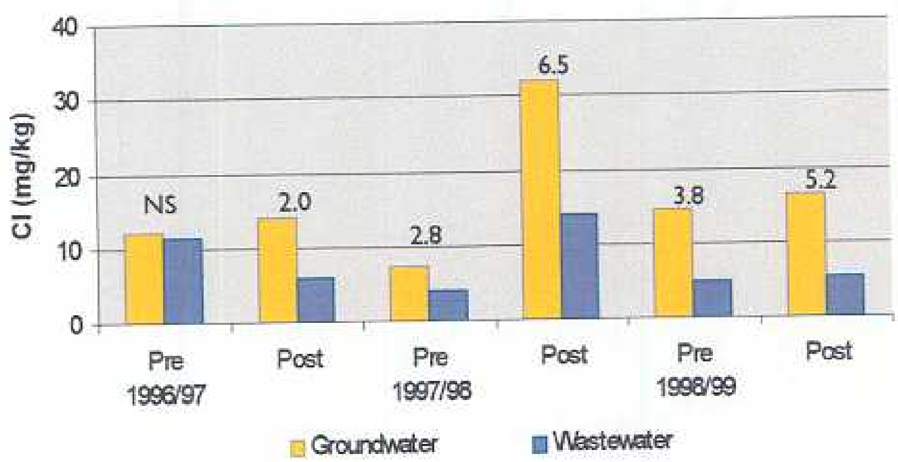


Figure 6.6 Effect of irrigation with saline groundwater and winery wastewater on soil chloride (LSD95% given, NS not significant).

Seasonal Effects and Weather Events: Leaching during winter resulted in significant falls in chloride from the top and middle layers and often accumulation in the bottom layer. The high mobility of chloride in soil made the parameter susceptible to seasonal differences and weather events. For example, dry conditions were experienced during the 1997/98 irrigation season, whilst a high rainfall of >50 mm occurred immediately after the post-harvest irrigation in 1998/99, prior to sampling. Thus no long-term trends in soil chloride were observed.

Salt

Distribution prior to experimentation: The salt content of soil was significantly higher in samples taken 0.6m from the vine row than at 1.85m (data not shown), and from the top and bottom soil layers than middle layer (Figure 6.7). Higher salt content closer to the vine row was an artifact of past drip irrigation as outlined for chloride.

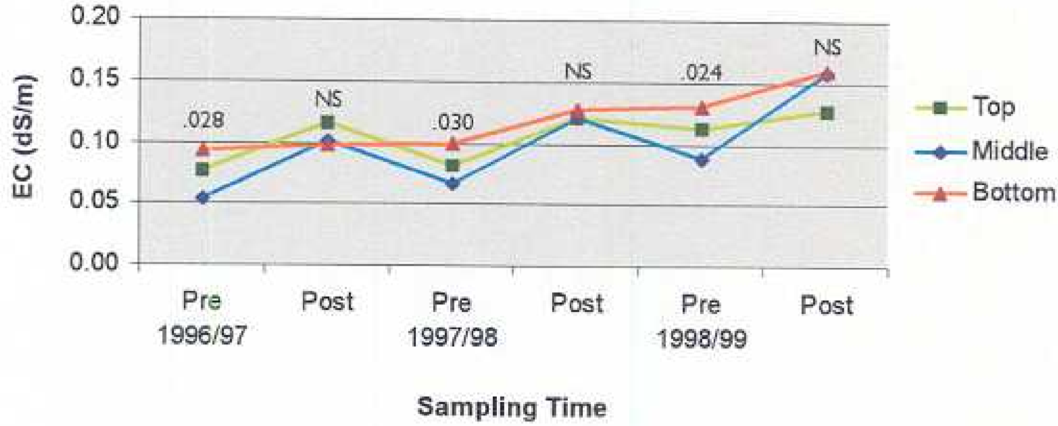


Figure 6.7 Variation of electrical conductivity with sampling depth of soil, pre and post irrigation with saline groundwater and winery wastewater (LSD 95% given, NS not significant).

Seasonal Effects: Leaching during winter rainfall reduced salinity in the upper top and middle soil layers (Figure 6.7). In contrast to the upper soil layers the salt content of the bottom layer gradually increased. Average rates of increase in subsoil salinity are shown for the combinations of irrigation method and water type in Figure 6.8. Regression analysis of the slopes was not significant (high variability between replicates). Differences in subsoil salinity only became significant after the1998/99 season (indicated by a, b, c in Figure 6.8).

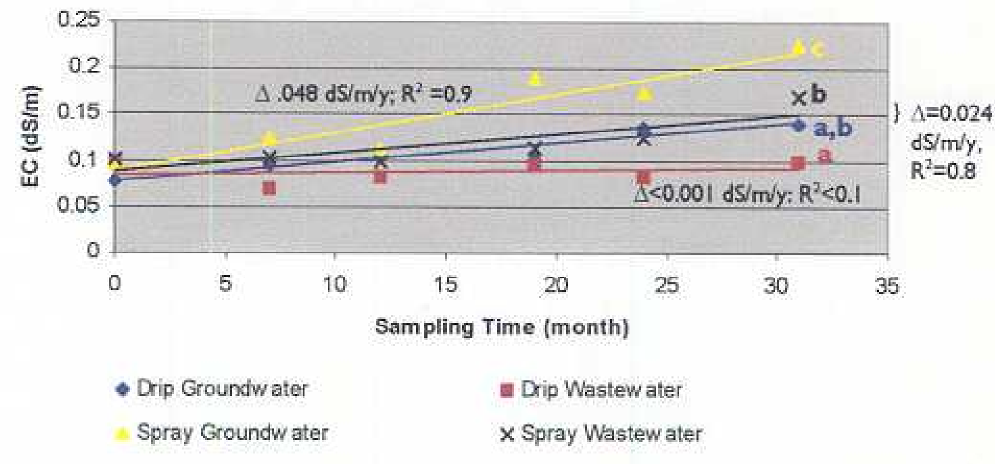


Figure 6.8 Influence of drip and spray irrigation with saline groundwater and winery wastewater on long-term trends in subsoil salinity levels.

Effects of irrigation method and water type: Spray irrigation resulted in significantly higher soil salinity than drip irrigation after the 1997/98 and 1998/99 seasons (Figure 6.9), differences were not significant after subsequent winter leaching. Irrigation with saline groundwater also led to higher soil salinity than wastewater irrigation, but differences were only significant for soils sampled in 1998. As mentioned above, small gradual increases in salt content in the order of wastewater drip <groundwater drip and wastewater spray <groundwater spray showed up as significant interactions with depth in 1999 (Figure 6.8).

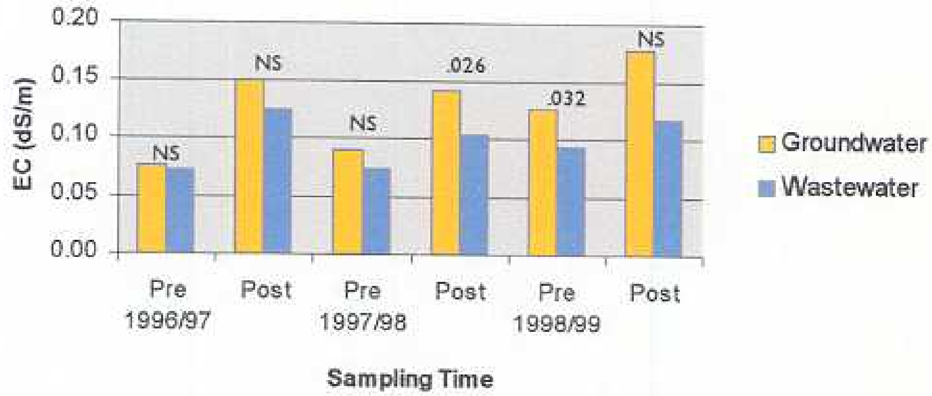


Figure 6.9 Effect of irrigation with saline groundwater and winery wastewater on soil salinity (LSD 95% given, NS not significant).

Sodicity

Distribution pattern and seasonal effects: SAR tended to increase with depth of soil layer after leaching of salts during the winter rainfall period, with the trend reversed after irrigation (Figure 6.10). Levels of sodicity post irrigation 1998/99 were comparable to pre irrigation levels in 1996/97. Thus long-term effects of treatments on sodicity were inconclusive.

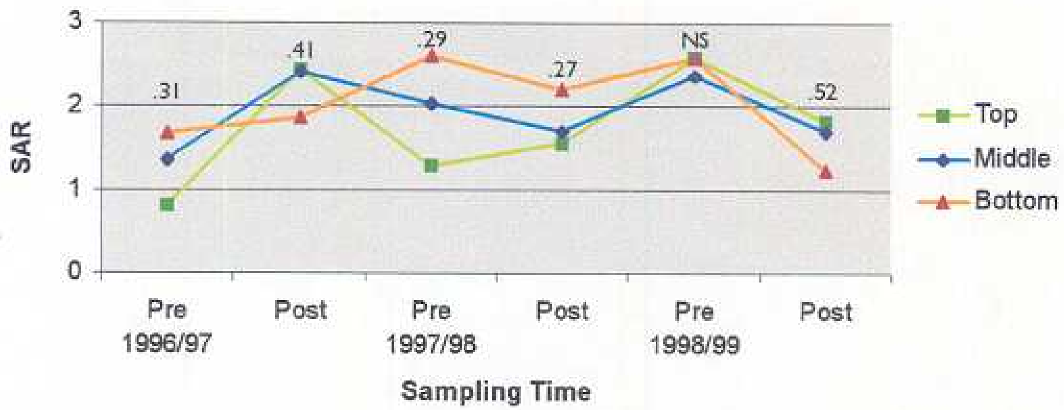


Figure 6.10 Variation of SAR with sampling depth pre and post irrigation with saline groundwater and winery wastewater (LSD 95% given, NS not significant).

Effect of irrigation method and water type: Following irrigation in 1996/97, sodicity became significantly higher in spray than drip irrigated plots, with differences remaining significant thereafter (Figure 6.11). Irrigation increased sodicity in 1996/97 but lowered sodicity in 1997/98 and 1998/99 compared to pre-irrigation levels. Water type did not effect this parameter.

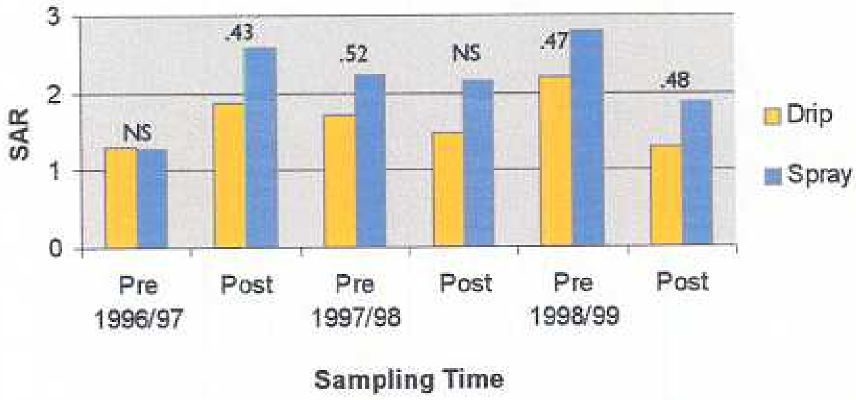


Figure 6.11 Effect of drip and spray application on sodicity of soils irrigated with saline groundwater and winery wastewater (LSD 95% given, NS not

Sodium:

Distribution Pattern Prior to Irrigation: Sodium levels in soil showed a similar pattern of distribution outlined for chloride, viz. 0.6m>1.85m; top<middle<bottom (Figures 6.12-6.13).

As with chloride and salinity, higher levels of sodium in soils sampled at 0.6m from the vine row were mostly an artifact of previous irrigation with the saline groundwater, as covariate analysis using the 1996 data removed significance from most of the subsequent sampling periods (Figure 6.12).

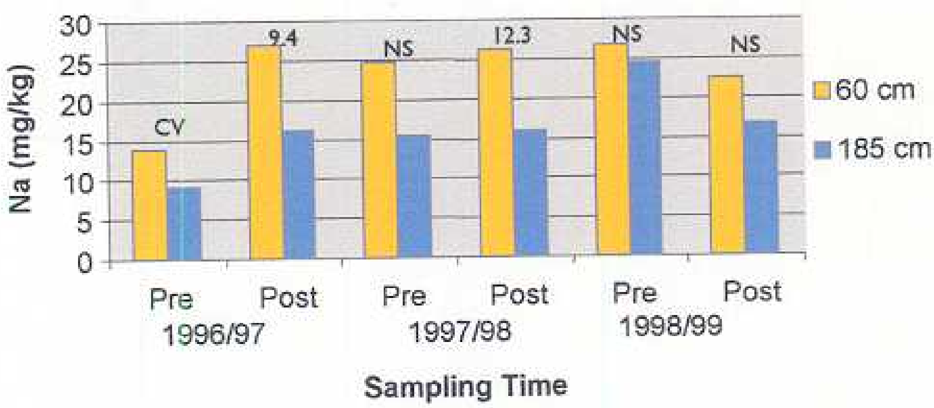


Figure 6.12 Distribution of sodium in soil with sampling distance from vine row pre and post drip and spray irrigation with saline groundwater and winery wastewater (LSD95% given, NS not significant).

Variation of sodium decreased with depth of soil layer and showed no consistent response to irrigation and leaching (Figure 6.13).

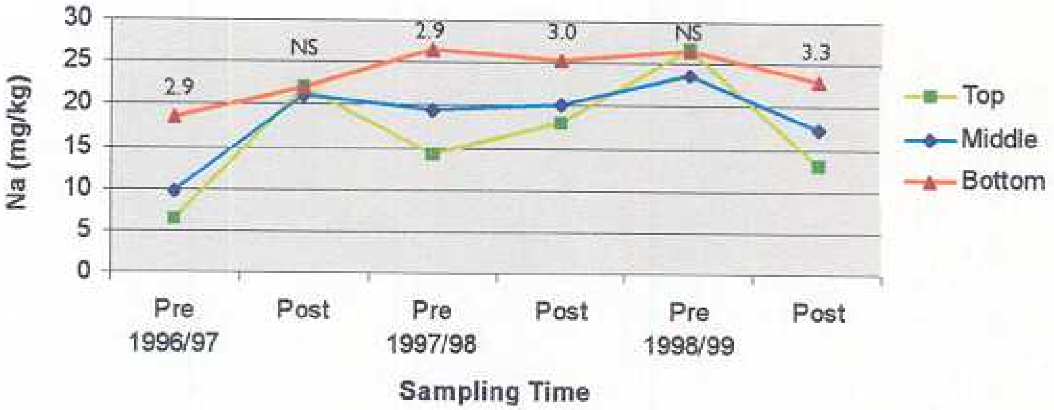


Figure 6.13 Variation of sodium with depth of soil horizon pre and post drip and spray irrigation with saline groundwater and winery wastewater (LSD95% given, NS not significant).

Following irrigation in 1996/97 sodium was significantly higher in spray irrigated soil; effects remained significant with the exception of soil sampled prior to irrigation in 1997/98 (Figure 6.14). Soil irrigated with saline groundwater contained higher levels of sodium than when irrigated with winery wastewater, but differences were only significant after irrigation in 1998/99 (data not shown).

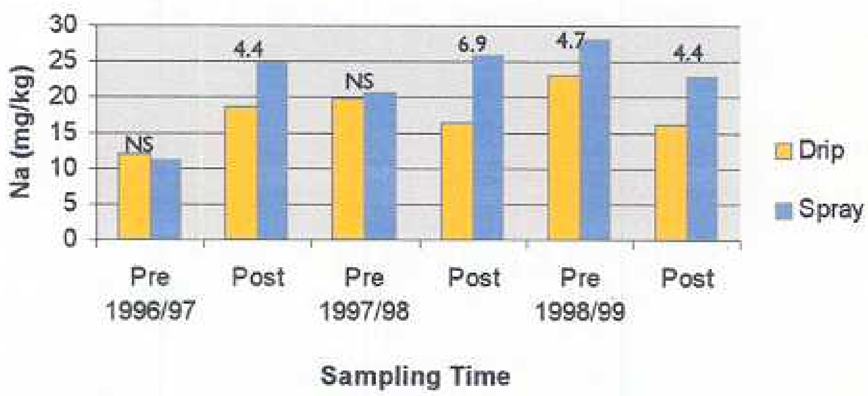


Figure 6.14 Effect of drip and spray irrigation with saline groundwater and winery wastewater on sodium levels of soil (LSD95% given, NS not significant).

Wetting pattern of drip emitters – Yalumba Wines.

Nutrients –Organic carbon, total Kjeldahl nitrogen (TKN) and bicarbonate extractable phosphorus (AvaP):

Organic carbon significantly decreased with depth of soil layer (Figure 6.15); TKN and AvaP were significantly higher in the top soil layer than middle and bottom layers (Figures 6.16-6.17). There were no effects of irrigation method and water type on these parameters, nor were any long-term trends observed over the 3 seasons.

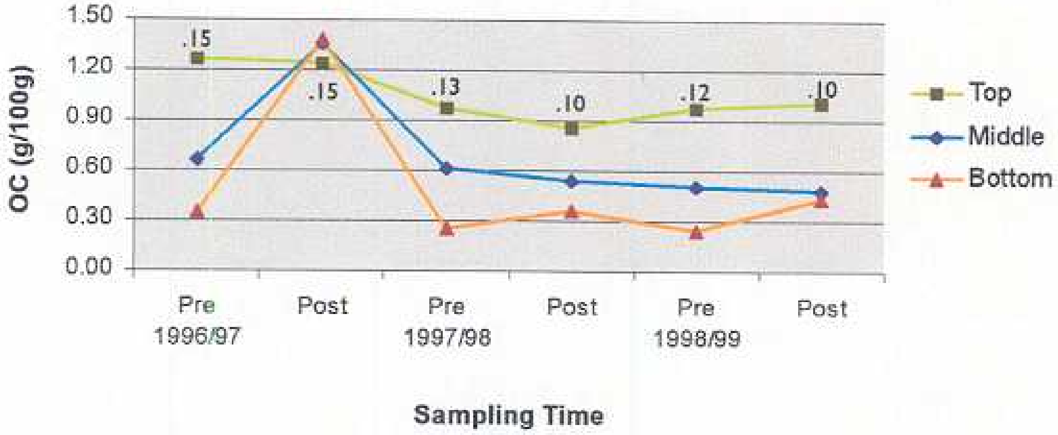


Figure 6.15 Variation of organic carbon with sampling depth pre and post irrigation with saline groundwater and winery wastewater (LSD95% given).

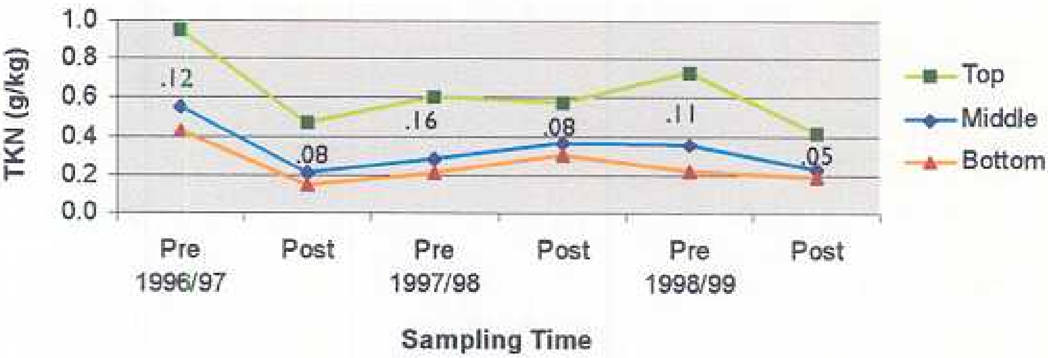


Figure 6.16 Variation of total Kjeldahl nitrogen with depth of soil pre and post irrigation with saline groundwater and winery wastewater (LSD 95% given).

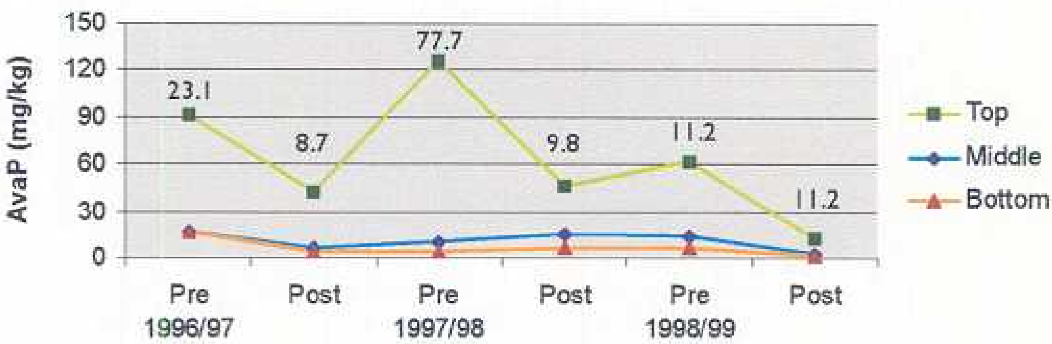


Figure 6.17 Variation of bicarbonate extractable phosphorus with depth of soil pre and post irrigation with saline groundwater and winery wastewater (LSD 95% given).

Carbon: Nitrogen: Phosphorus Ratio: Relative to organic carbon, amounts of nitrogen and phosphorus remained consistently low over the 3 seasons –C:N:P 30: 1-3: 0.05-0.15. Higher relative amounts of nitrogen and phosphorus occurred pre-irrigation, and for lower soil horizons where organic carbon levels were very low, and hence close to limits of detection.

Nitrate and Ammonium: Both these parameters were occasionally significantly higher in the top, soil layer than middle and bottom layers (Figures 6.18-6.19). Irrigation method and water type had very occasional and inconsistent interactions with sampling distance and depth. No long-term trends were observed for these parameters.

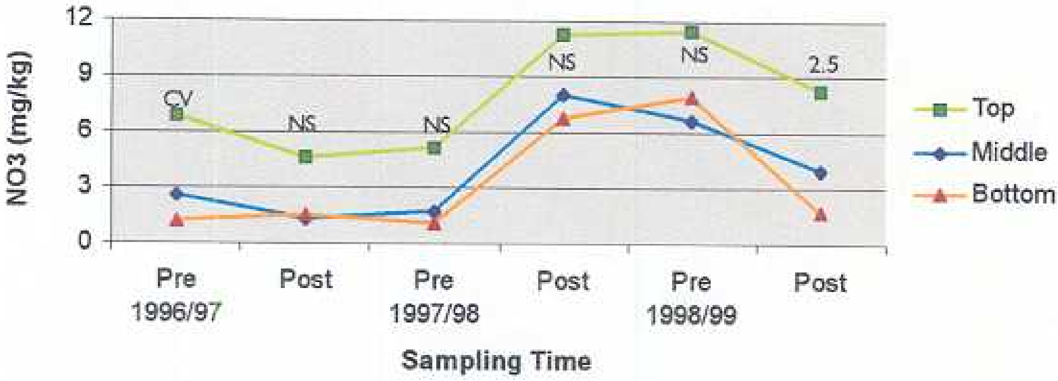


Figure 6.18 Variation of nitrate with depth of soil sampled pre and post irrigation with saline groundwater and winery wastewater (LSD 95% given, CV covariate, NS not significant).

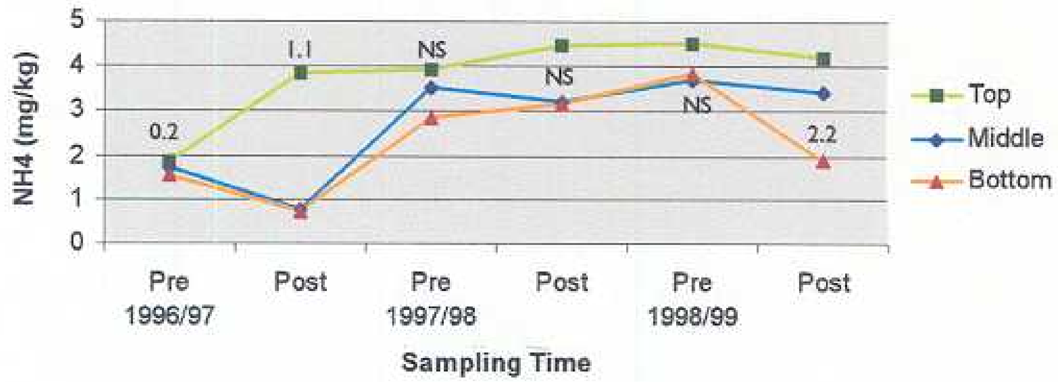


Figure 6.19 Variation of ammonium with depth of soil sampled pre and post irrigation with saline groundwater and winery wastewater (LSD 95% given, NS not significant).

Bicarbonate Extractable Potassium (AvaK): AvaK was significantly higher in the top soil layer than middle and bottom layers (Figure 6.20). There were no significant effects of irrigation method or water type or any significant long term trends in this parameter.

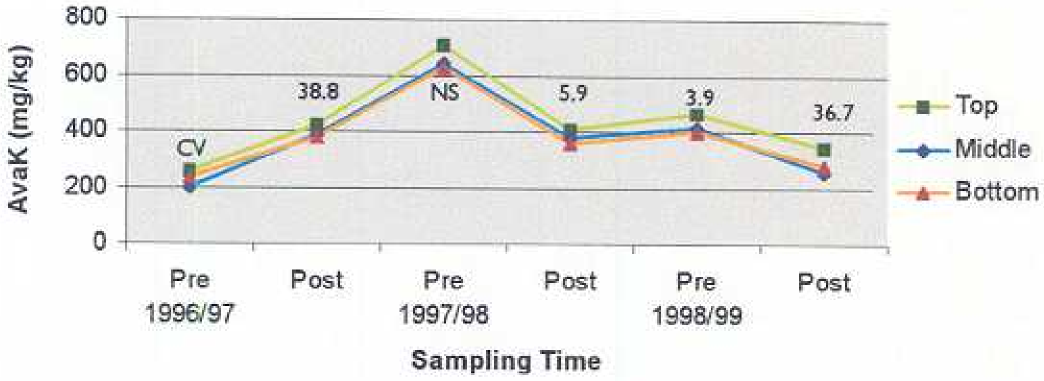


Figure 6.20 Variation of bicarbonate extractable potassium with depth of soil sampled pre and post irrigation with saline groundwater and winery wastewater (LSD 95% given, CV covariate, NS not significant).

Acidity: Acidity decreased with depth of soil layer; significant differences were only observed prior to irrigation in all seasons (Figure 6.21). There were no significant effects of irrigation method or water type or any significant long term trends in this parameter.

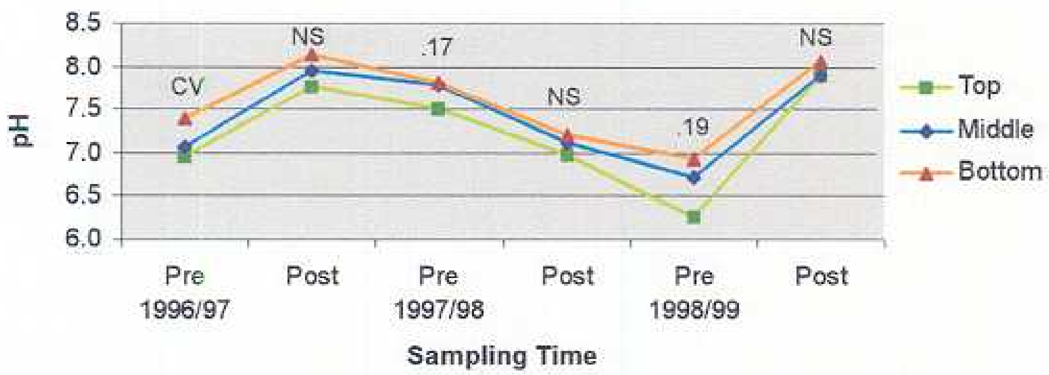


Figure 6.21 Variation of pH with depth of soil sampled pre and post irrigation with saline groundwater and winery wastewater (LSD 95% given, CV covariate, NS not significant).

6.3.2 Winegrapes

Yield

Vines irrigated with winery wastewater yielded about 15% higher than groundwater irrigated vines (Figure 6.22) with differences significant at the 90%, and 95% probability levels respectively in the 1996/97 and 1998/99 seasons. Irrigation method did not significantly influence differences in yield above those due to water type, although vines drip irrigated with winery wastewater yielded highest, >20% higher than vines spray irrigated with groundwater.

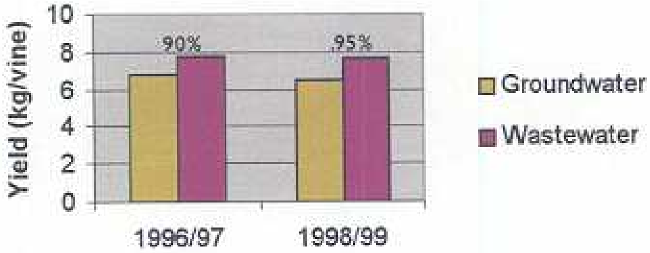


Figure 6.22 Effect of irrigation with saline groundwater and winery wastewater on vine yield; levels of significance are shown.

Juice Quality

Berry Size: Size of berries was unaffected by the treatments in 1996/97 (Tables 6.9, 6.10). Berries harvested in 1998/99 were significantly larger in wastewater treatments (Figure 6.23), which were significantly higher again in drip irrigated treatments (Figure 6.24). For groundwater treatments, spray irrigated vines had the larger berries in 1998/99 (Figure 6.24).

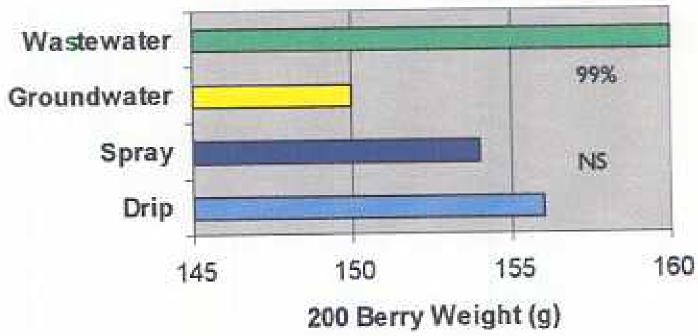


Figure 6.23 Effect of application of winery wastewater and groundwater and spray and drip irrigation on 200 berry weight in the 1998/99 season.

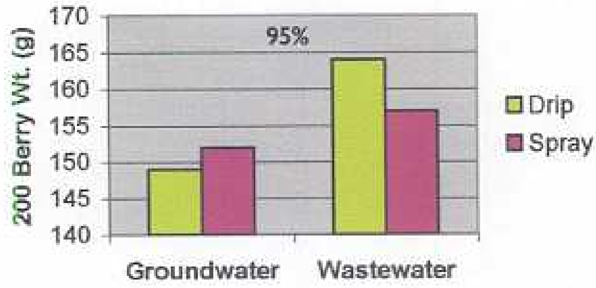


Figure 6.24 Effect of drip and spray irrigation with saline groundwater and winery wastewater on 200 berry weight in 1998/99.

Quality Parameters: Juice quality was occasionally effected by water type and almost entirely unaffected by irrigation method (Tables 6.9-6.10). The fall in total phenolics in berries from wastewater treatments (8%) is similar to the relative increase in berry size (7%) compared to groundwater treatments.
Levels of sodium, calcium and chloride were exceptions, as outlined below.

Table 6.9 Effects of irrigation with saline groundwater and winery wastewater averaged for irrigation method on fruit quality, 1998/99 season unless indicated, significance: NS <90%, * 95%, ** 99%, *** >99.9% probability level.

PARAMETER	GROUNDWATER	WASTEWATER	SIGNIFICANCE
200 Berry (1996/97, g)	179	182	NS
200 Berry (g)	150	160	**
Brix (1996/97)	25.08	26.35	NS
Brix	26.35	26.04	NS
Baume (1996/97)	13.93	14.02	NS
Titratable Acidity (g/L)	6.45	6.64	NS
pH	3.93	4.00	*
Total Glycosyl Glucose (GG, μmol)	2.87	2.87	NS
Red Free GG (μmol)	2.63	2.63	NS
Total Anthocyanin	58.95	56.1	NS
Total Phenolic	124.5	115.5	*
Na (mg/L)	49.6	66.6	***
K (mg/L)	3812	3830	NS
Ca (mg/L)	121.2	108.2	***
Cl (as NaCl mg/L)[1]	1267	979	*
SO_4 (as K_2SO_4 mg/L)	685	683	NS

[1] Chloride is quoted as sodium chloride for convenience: re legal limit of 1 g/L for export.

Table 6.10 Effects of drip and spray irrigation averaged for water type on fruit quality, 1998/99 season unless indicated, significance: NS <90%, * 95%, *** >99.9% probability level.

PARAMETER	DRIP	SPRAY	SIGNIFICANCE
200 Berry (1996/97, g)	178	183	NS
200 Berry (g)	157	154	NS
Brix (1996/97)	25.23	26.09	NS
Brix	26.17	26.21	NS
Baume (1996/97)	14.02	13.93	NS
Titratable Acidity (g/L)	6.41	6.68	NS
pH	3.96	3.98	NS
Total Glycosyl Glucose (GG, µmol)	2.83	2.91	NS
Red Free GG (µmol)	2.60	2.67	NS
Total Anthocyanin ($OD_{520}HCl$)	56.7	58.4	NS
Total Phenolic (OD_{280}-4)	118	122	NS
Na (mg/L)	51.8	64.4	***
K (mg/L)	3779	3863	NS
Ca (mg/L)	113.8	115.6	NS
Cl (as NaCl mg/L)	1079	1167	*
SO_4 (as K_2SO_4 mg/L)	665	683	NS

Sodium (1998/99): Sodium was significantly higher in juice from vines spray irrigated than drip irrigated **or** irrigated with winery wastewater than groundwater (Figure 6.25). Thus the **separate** effects of irrigation method and water type resulted in vines spray irrigated with winery wastewater having the highest sodium levels (6.26). This result **contrasts** concentrations of sodium in the wastewater and groundwater (Table 6.4) and in the respective soil treatments (data not shown), but is consistent with the higher sodicity of the wastewater than groundwater (Table 6.4).

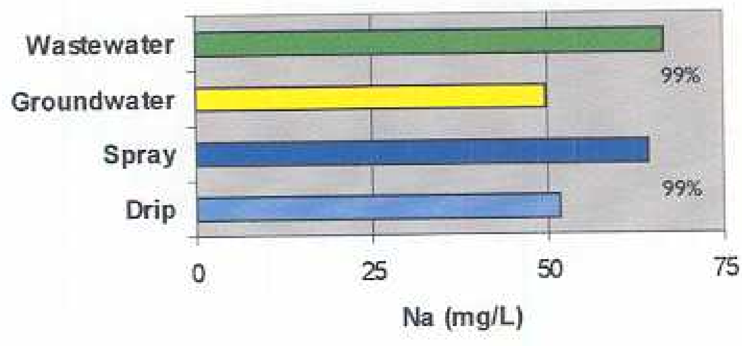


Figure 6.25 Effects of spray and drip irrigation, and of irrigation with saline groundwater and winery wastewater on sodium in juice from grapes harvested in 1998/99, level of significance shown.

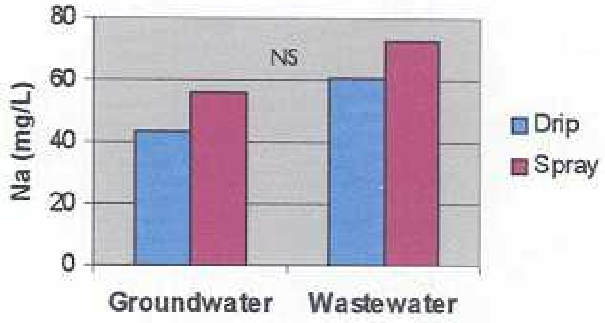


Figure 6.26 Differences in sodium levels in juice from vines spray and drip irrigated with saline groundwater and winery wastewater (interactions were not significant NS).

Calcium 1998/99: Calcium was significantly higher in juice from vines irrigated with groundwater than winery wastewater (Figure 6.27). Irrigation method did not effect calcium levels no interacted with water type.

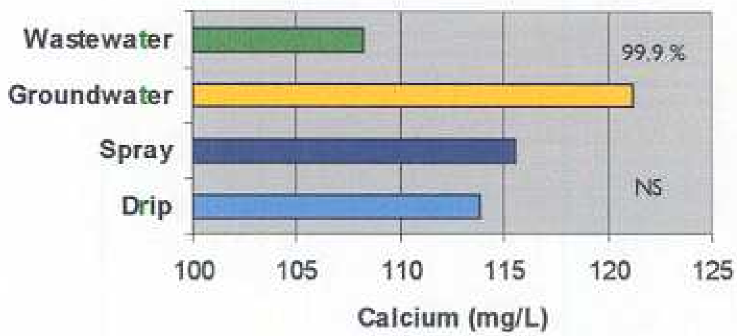


Figure 6.27 Effect of application of winery wastewater and saline groundwater and of spray and drip irrigation on calcium levels in juice samples obtained in 1998/99. Level of significance shown (NS <90% probability).

Chloride 1998/99: Chloride was significantly higher in juice from vines drip-irrigated with groundwater, than spray irrigated with groundwater or drip and spray irrigated with wastewater (Figures 6.28-6.29). These results concur with chloride levels in soil.

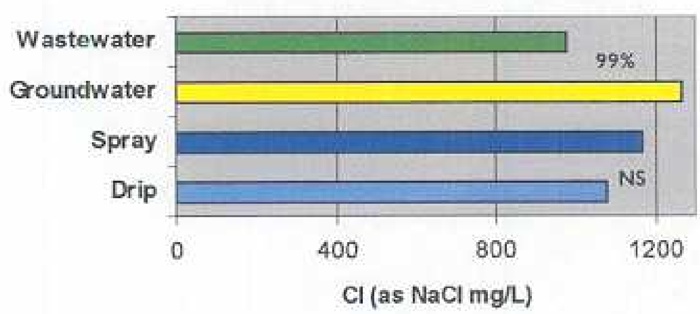


Figure 6.28 Effect of application of wastewater and saline groundwater and of drip and spray irrigation on chloride in juice from vines harvested in 1998/99 (levels of significance shown: NS <90%).

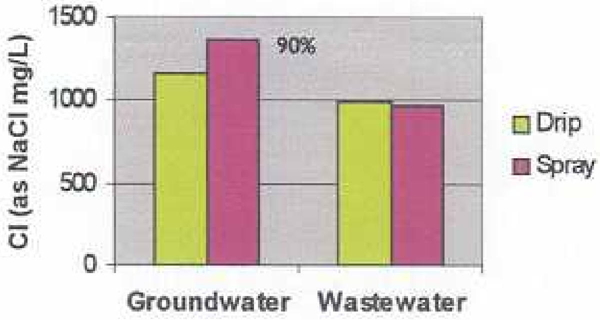


Figure 6.29 Differences in chloride levels in juice from vines spray and drip irrigated with saline groundwater and winery wastewater (level of significance shown).

Wine quality 1996/97 season

Wine made from grapes irrigated with winery wastewater had significantly superior levels in a number of quality indices: alcohol, colour, total anthocyanin, and phenolics (higher) and chloride (lower), but inferior (higher) levels of sodium (Table 6.11). Irrigation method only effected sodium and chloride (Table 6.12). Differences in wine quality were not associated with berry size, which varied by about 2% between all treatments (Tables 6.9 and 6.10).

Table 6.11 Effects of irrigation with saline groundwater and winery wastewater averaged for irrigation method on wine quality made from grapes harvested in 1996/97, significance: NS <90%, + 90%, * 95%, ** 99% probability level.

PARAMETER	GROUNDWATER	WASTEWATER	SIGNIFICANCE
Alcohol (%V:V)	14.51	14.86	*
SG	0.99	0.99	NS
Sugar (g/L)	0.18	0.11	+
Titratable Acidity (g/L)	6.03	6.18	NS
pH	4.11	4.01	NS
Total Anthocyanin	13.96	16.26	**
Total Phenolic	23.9	26.2	*
Colour	6.57	7.64	*
Na (mg/L)	39.2	47.1	*
K (mg/L)	1994	1903	NS
Ca (mg/L)	66.7	65	NS
Cl (as NaCl mg/L)	501	419	*
SO_4 (as K_2SO_4 mg/L)	411	396	NS

Table 6.12 Effects of drip and spray irrigation averaged for water type on wine quality made from grapes harvested in 1996/97, significance: NS <90%, + 90%, * 95%, ** 99% probability level.

PARAMETER	GROUNDWATER	WASTEWATER	SIGNIFICANCE
Alcohol (%V:V)	14.77	14.60	NS
Specific Gravity	0.99	0.99	NS
Sugar (g/L)	0.14	0.15	NS
Titratable Acidity (g/L)	6.03	6.18	NS
pH	4.11	4.01	NS
Total Anthocyanin	15.37	14.85	NS
Total Phenolic	25.3	24.82	NS
Colour	7.20	7.00	NS
Na (mg/L)	39.3	47.0	*
K (mg/L)	1957	1940	NS
Ca (mg/L)	66.0	65.7	NS
Cl (as NaCl mg/L)	434	487	+
SO_4 (as K_2SO_4 mg/L)	391	418	NS

Sodium: Sodium was significantly higher in wine made from vines spray irrigated than drip irrigated **or** irrigated with winery wastewater than groundwater (Figure 6.30). As with the juice samples, wine made from grapes harvested from sites spray irrigated with winery wastewater contained the highest levels of sodium (Figure 6.31).

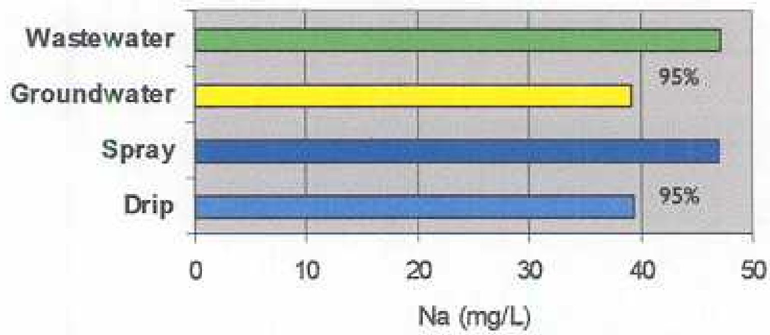


Figure 6.30 Effects of spray and drip irrigation, and of irrigation with saline groundwater and winery wastewater on sodium in wine made from grapes harvested in 1996/97 (level of significance shown).

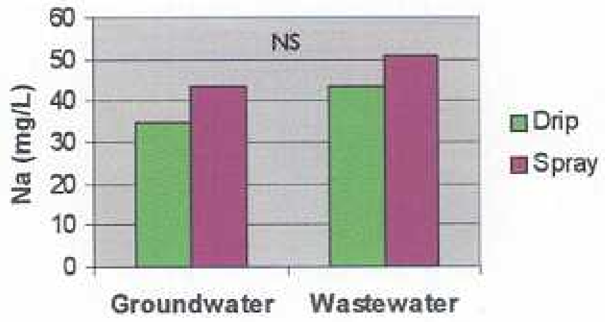


Figure 6.31 Effect of drip and spray irrigation with saline groundwater and winery wastewater on sodium in wine made from vines harvested in 1996/97 (differences between pairs of means were not significant).

Chloride: Drip irrigation with groundwater resulted in significantly higher chloride in wine than spray irrigation with groundwater or drip and spray irrigation with wastewater (Figures 6.32-6.33). These results concur with both juice samples and chloride levels in soil.

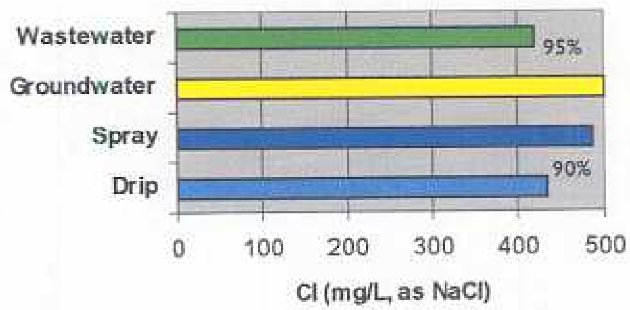


Figure 6.32 Effect of drip and spray irrigation and irrigation with saline groundwater and winery wastewater on chloride in wine made from vines harvested in 1996/97 (levels of significance shown).

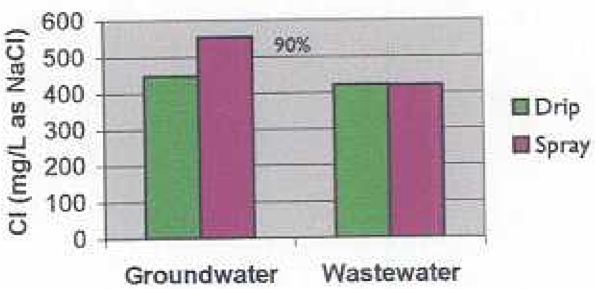


Figure 6.33 Effects of drip and spray irrigation with saline groundwater and winery wastewater on chloride in wine made from vines harvested in 1996/97 (level of significance is shown).

6.3 Discussion

6.3.1 Effects of Wastewater Irrigation on Grapevines

Application of winery wastewater via the industry standard 4L/h drip system realised a 15% increase in yield from the own rooted Cabernet Sauvignon, attributed to a combination of lower inorganic salts and additional nutrients contained in the wastewater.

Increased yield was associated with variable quality. Wine made from the wastewater treatments in the 1996/97 vintage exhibited superior indices of anthocyanin, total phenolics and colour. Berry size varied little between treatments in 1996/97, whereas berries from the 1998/99 vintage were larger for the wastewater irrigated treatments. In this season larger berry size from wastewater treatments was associated with a similar percentage decrease in total phenolics compared with groundwater treatments.

Lower chloride concentrations in the wastewater significantly reduced chloride in both the juice and wine. However, chloride levels in the juice samples in 1998/99 were close to the legal limit of 1 g/L as NaCl.

Sodium concentrations remained significantly higher in juice and wine from wastewater irrigated treatments. This effect is contrary to lower concentrations of sodium found in the wastewater produced particularly during non-vintage used for irrigation of the vines from December to early January. It is likely higher uptake of sodium under wastewater irrigation is related to the high sodium adsorption ratio -concentration of sodium relative to those of calcium and magnesium, which is almost 2-times higher than in the groundwater.

6.3.2 Impacts of Wastewater Irrigation on Soil Chemistry

Salts

Yalumba Wines chose to use winery wastewater to irrigate the Mexican Vale vineyards partly because of its lower inorganic salt content compared with the saline groundwater (Table 6.4). As anticipated, soil irrigated with wastewater contained significantly lower amounts of chloride and total salts, particularly when applied by 4L/h drip. Levels of sodium in soil and sodicity were unaffected by water type.

Nutrients

Amounts and distribution of nutrients with distance and depth were unaffected by water type, despite the disparity in loading particularly of spray irrigation with wastewater (Table 6.5). Total amounts of organic carbon, nitrogen and phosphorus added annually through wastewater irrigation remained low in comparison to soil levels (Tables 6.2 and 6.3).

Chapman (1995a) noted that after 20 years wastewater irrigation of the original pasture site of Yalumba Wines, organic carbon content of the soil had only increased by 0.8 of a per cent compared with non irrigated soil under similar management. Most of the organic carbon was most likely lost as carbon dioxide.

6.3.3 Effect of Spray and Drip Irrigation on Soil Chemistry

Salts

The spray system enabled discharge of higher volumes of wastewater than drip emitters due to a much greater horizontal spread of water and lower efficiency in delivering water to the surface layer of soil. Higher loading of salts under spray irrigation was reflected in significantly higher levels of inorganic salts remaining in the soil profile than under drip irrigation and unsustainable increases in sub-soil salinity.

6.3.4 Seasonal Effects and Long Term Trends

Salts

Distribution of salts within the soil often varied by a greater amount between successive sampling dates, than differences resulting from treatment effects, emphasizing the importance seasonal effects on impacts of irrigation.

Winter rainfall was only effective in leaching salts from the rootzone (i.e., >1m depth) of the drip wastewater treatment. Ineffective leaching resulted in accumulation of salt in the bottom clay layer at annual rates of 0.024 dS/m for wastewater spray and groundwater drip, and 0.048 dS/m for the groundwater spray treatment. By the last sampling time in June 1999 salinity levels in the bottom clay layer had sufficiently diverged between treatments to show up as a significant interaction with depth of soil layer (Figure 6.8).

Nutrients

Nitrate and ammonium exhibited the greatest seasonal variation indicative of their higher mobility in soil compared with most other nutrients, no trends were observed.

Higher plant available phosphorus in the topsoil at the November, pre-irrigation sampling may be due in part to a post vintage decline of microbial populations in response to lower organic and nutrient loading and lower activity during the colder months. Turnover of the biomass during a more rapid phase of microbial activity in spring may release previously microbial assimilated phosphorus and other non-available forms of phosphorus. Subsequent decline in topsoil phosphorus may be attributed to use of the phosphorus by the vines and by new microbial populations metabolising organic substrates especially during vintage.

6.3.5 Implications for Management

Irrigation of winery wastewater by 4L/h drip was the only environmentally sustainable management system. This system though potentially results in larger berry size and thus reduced quality. A number of management options could be adopted to reduce berry size:

1. Calculate the fertiliser value of the wastewater and balance loading with normal vineyard requirements of nutrients.
2. Reduce product loss in the winery, which is the main source of major nutrients.
3. Maintain a sward of grass on the mounds.

Spray irrigation with winery wastewater was not sustainable under current management practices due to accumulation of salts within the soil profile. Annual application of a leaching fraction using the groundwater to assist winter leaching of the salts will be essential. An initial high application is necessary to flush out salts that have accumulated over the 5 seasons of wastewater irrigation by this method.

Success of the leaching irrigation can be assessed by either maintaining the twice-yearly soil sampling at 60 cm from the vine row as described in section 6.1.7, using a minimum 10 sites to reduce effects of soil variability. Routine monitoring of the vineyards occurs as part of the wastewater license agreement.

6.3.6 Economic Evaluation (D. Zimmermann pers. comm.)

Cabernet Shiraz from the Mexican Vale vineyards is sold to the domestic market in a medium to low price point blend. Occasionally the Shiraz has been of sufficient quality to be incorporated in higher price point fsignatureg blends.

Increases in yield associated with increased berry size (e.g. 1998/99 vintage), result in poorer quality blends. As a result income from the additional cases available for sale is offset by lower prices, hence revenue neutral.

Yield increases in 1996/97 that were associated with better quality fruit, realised the benefits of higher volumes of wines that attracted higher prices.

Successful use of the wastewater for irrigation of winegrapes enabled development of an additional 20 ha of new vineyard on the Northern side of the Yalumba Wines winery at a site that had questionable availability of suitable groundwater (groundwater from the bore at Mexican Vale has been used during establishment).

6.3.7 Further Research

Results of this study suggest that the salinity and sodicity of irrigation water affect juice quality. Other researchers examining effects of salinity on winegrapes usually kept sodicity constant, or allowed SAR to vary with EC in a non-uniform manner (R. Walker pers. comm.) A glasshouse study is recommended to test effects of irrigation water of variable salinity and sodicity on sap composition of salts for a small selection of red and white cultivars, own-rooted and 1-2 commonly used rootstocks is therefore recommended. Sap composition is preferred as many differences between cultivars and rootstocks in uptake of salts are due to exclusion by roots. Sap composition may be related to yield and/or quality via field measurements using existing experiments (This may also require determining effect of rate of sap flow on composition).

Potential effects of salt and sodicity may depend on growth stage. This may have important consequences for targeting application of better and poor quality water where more than once source could be used for irrigation (e.g, dam and groundwater). A secondary study on effects of salt and sodicity at different growth stages of vines is also recommended.

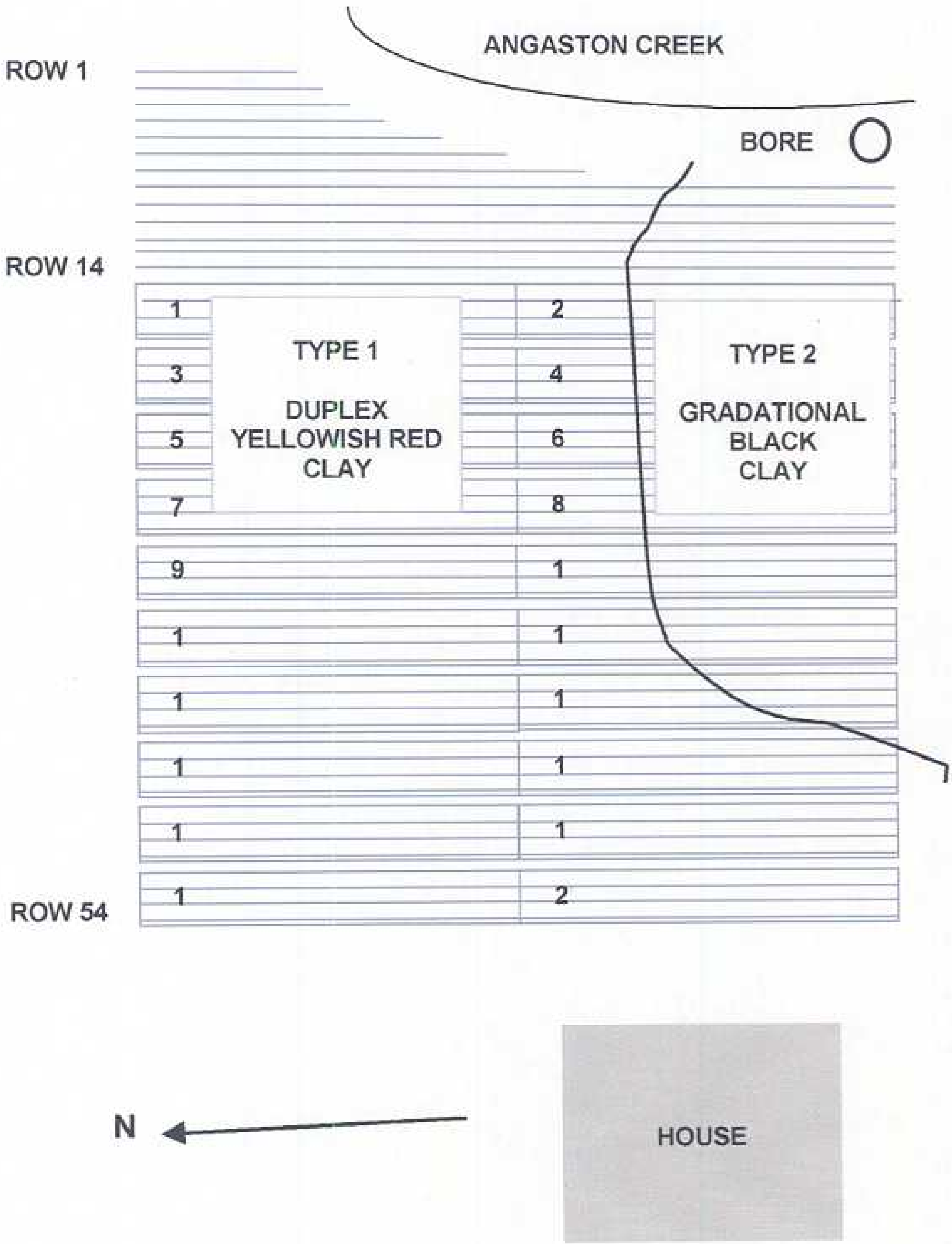
Potential collaborators would be Dr R. Walker (CSIRO Plant Industry), and Mr R. Stevens (PIRSA).

6.4 Acknowledgements

I have enjoyed a 10-year association with Yalumba Wines, a company that continues to set new benchmarks on environmental management for the Australian Wine industry. Yalumba Wines substantial commitment of employees, capital outlay, analyses of wastewater and all vine, grape and wine parameters is acknowledged. Peter Wall, Geoff Linton and David Zimmermann are thanked for their endless discussions of issues of wastewater management and interpretation of experimental results. Bill Tapscott is thanked for managing the irrigation of the experimental site. Special thanks to Peter Smith for his dedication for keeping accurate daily records of water use over many years, his down-to-earth education on waste streams produced by the different processing and cleaning operations, and endless enthusiasm and support of the project.

I thank the Grape and Wine Research and Development Corporation for providing my salary, the former Cooperative Research Center for Soil and Land Management for providing the operating, and the Department of Soil Science, the University of Adelaide for providing laboratory facilities for the soil analyses. Dr Alfred Cass is thanked for his technical input and Karin Thomson for her technical assistance in the final year.

Appendix 6.1 Distribution of soil types at Yalumba Wines Mexican Vale Vineyard.



7.0 General Discussion

The prominence of **environmental management** has substantially increased during the past decade.

I strongly recommend that the National Australian Wine Industry develop an Environmental Management Awareness statement (an example is given in the book Winery Wastewater: Production, Impacts, Management).

State **Environmental Protection legislation** exists across Australia. In some states wineries above a minimum production capacity are licensed for waste management that requires an agreed management program. Environment Management Systems (EMS) are outlined in the book Winery Wastewater: Production, Impacts, and Management. EMS development requires an understanding of local, state and national laws and by-laws effecting management and discharge, for which there is considerable inconsistency across States.

I recommend that at Federal and State legislation on water use and wastewater management be reviewed for similarities, differences, cost of administering, and effectiveness in achieving environmental outcomes. This will enable the industry to position itself to influence review of legislation to ensure better consistency across States.

Audit of waste management and **monitoring** of discharge environments are required components of license agreements. Information on these subjects is in Chapman (1996) and EPA-SA (1996). The major problem in obtaining data is making use of it, and the lack of a national data base that could assist wineries and others in obtaining general wastewater parameters.

I recommend that a national wine industry data base on wastewater characteristics be established. This may require providing assistance to State Environment Protection Authorities (EPA) in data entry and establishing links to established systems.

The audit and review of relevant legislation enables wastewater characteristics to be **ranked** in **importance of management priority**. All current State EPA legislation base licensing on **water waste**, which then becomes the **major focus of management systems**.

Fact: Reduction in water waste is not being matched by concurrent reduction in salt and nutrient loading.

This research identified **salt loading as the second most important management issue** behind water waste. Using sodium hydroxide (caustic soda) for cleaning equipment is the major source of salt and sodium. Use of caustic soda is based on a perception that all residues on the walls of equipment must be removed to prevent tainting of juice and wine. Some newer wineries have **successfully** used high pressure and temperature cleaning to minimise use of caustic.

I strongly recommend: that a study on the feasibility of high pressure and temperature spraying as a partial substitute for caustic washing of tanks be conducted. The study would compare the effectiveness of the two cleaning systems in removing residues off the walls by examining what is left behind (usually protein). Subsequent batches of juice or wine would be tested for contamination by the residues (laboratory analysis and taste). The Australian Wine Research Institute would be the potential collaborator.
A practical guide on tank cleaning would be produced.
The environmental aim could be to reduce caustic use by 20-40 % across the industry.
Savings in citric/tartaric acid rinsing, used to neutralise caustic residues, will also occur.

Salts are also added through product loss.

I recommend an industry awareness program on the economic and environmental benefits of reducing product loss. The program could assist wineries to estimate current losses and identify practices leading to unnecessary loss.

Management is based on the hierarchy of Cleaner Production.

Important Fact: Objective of irrigation management is a major determinant of potential environmental impact. Two distinct objectives of winery wastewater irrigation are currently used:

1. Evans and Tate Ltd example: irrigation is used to discharge wastewater; minimal site area, volume and/or frequency of application are dictated by volume generated in the winery. **Higher** potential risk of environmental harm.
2. Yalumba Wines example: wastewater is used as a source of water for economic use in irrigating vineyards, application volumes based on vine needs, excess wastewater can be re-routed to a treelot used as back-up. **Lower** risk of environmental harm.

Given the distinct objectives of irrigation management, **monitoring is essential**. This research highlighted a number of important aspects of **soil** monitoring:

1. **Irrigation always impacts the environment**, the question is **which direction**: positive or negative? **Site history** will be a major determinant. Yalumba Wines is an example of positive effects, particularly salts, due to past irrigation using a groundwater of poorer quality than the wastewater. Evans and Tate Ltd irrigation of a past dryland site had negative effects on salinity and sodicity.
2. **Different monitoring programs will be necessary for discharge/reuse sites.**
3. Wastewater irrigation at Yalumba Wines had relatively immediate effects on inorganic salts than nutrient levels. Thus **different monitoring programs will be needed for salts** (more intensive) **and nutrients** (less intensive)-an article on this issue will be published.
4. **Long-term effects: e.g.,** salt buildup within bottom clay soil layer due to incomplete leaching by winter rainfall at the Yalumba Wines site.

The research project also highlighted the value of **multiple component monitoring**, e.g., plants and soil, in detecting unexpected effects of wastewater irrigation. The sodicity of the water source appeared to effect grape quality at Yalumba Wines.

I recommend a review of state winery wastewater audit and monitoring procedures for consistency between States, cost of complying, environmental importance, and effectiveness in reviewing management strategies.
I further recommend an education program on the value of site monitoring.

Environmental management is **perpetual, and should be available for external auditing**.

8.0 BIBLIOGRAPHY

Anon (1990) Waste management. Aust. and N. Z. Wine Industry Journal 5(3) 190-198.

Brunton, N. (1995) The South Australian Environment Protection Act 1993. Environmental and Planning Law Journal. 12(1): 3-10.

Campbell Clause, J. and Moore, G. A. (1991) Land Capability Study for Horticulture in the Swan Valley. Land Resource Series No. 6 (Department of Agriculture dWestern Australia) 58 pp.

Cass, A. and Chapman J. (1996) Long Term Viability of the Tanunda Steds Effluent Reuse Scheme. Acer Wargon Chapman (SA) Pty Ltd. 20 pp.

Chapman, J. A. (1993) Land disposal of winery and distillery effluents. Proceedings 8th Australian Wine Industry Technical Conference, Eds C. R. Stockley, R. S. Johnston, P. A. Leske and T. H. Lee. Melbourne, Australia (Winetitles: Adelaide) 49–53.

Chapman, J. A. (1994) Impact of winery effluent on soil. Proceedings of the Sustainable Management Seminar for the Australian Wine Industry. Tanunda, Barossa Valley, 7–8 November 1994. Ed. T. H. Lee (Winetitles: Adelaide) 29–36.

Chapman, J. A. and Sefton, M. A. (1994) Characteristics of winery and distillery wastewaters and implications for treatment of carbon in the wastewaters by application to soil. Proceedings, International specialised Conference on Winery Wastewaters, Narbonne France, 20–24 June 1994. (Cemagref: Bordeaux) 239–244.

Chapman, J. A. (1994) Waste Management Strategy for the Roberston Distillery. KWV Suider Paarl, South Africa. 25 pp.

Chapman, J. A. (1995) Land Disposal of Winery and Distillery Wastewaters. The University of Adelaide. 191 pp.

Chapman, J. A., Correll, R. L., and Ladd, J. N. (1995a) Removal of extractable organic carbon from winery and distillery wastewaters by application to soil. Australian Journal of Grape and Wine Research. 1, 39–47.

Chapman, J. A., Correll, R. L., and Ladd, J. N. (1995b) The removal of soluble organic carbon from synthetic winery wastewater by repeated application to soil. Australian Journal of Grape and Wine Research. 1, 76–85.

Chapman, J. A. (1996) Management of winery production wastewater. New Zealand Land Treatment Collective, Proceedings of Technical Session 14, Land Application of Wastes in Australia and New Zealand: Research and Practice. (CSIRO Forestry and Forest Products) 94–98.

Chapman, J. A. (1996) Cleaner Production for the Wine Industry Handbook. (SA Wine and Brandy Industry Association) 32 pp.

Correll, R. L. and Chapman, J. A. (1996) Use of the logistic curve in winery wastewater management. Proceedings, International Environmetrics Conference, Kuala Lumpur, Malaysia, 17-19 December 1995. 82–89.

Goss, P. (1994) Winery wastewater and stormwater dtreatment and disposal. The Australian Grapegrower and Winemaker 365(20) 22-24.

Heanes, D. L. (1991) Laboratory Methods of Soil and Plant analysis. 3rd edn. (Land Use Division, Soil and Water Management Report No. 2/81)

Jolly, D. R. P. (1975) Winery waste disposal. Proceedings of a Hunter Valley field Day. AWRI reprint No. A0811.

Jones, M., Morain, M., Houlihan, A., and Dennien, G. (1998) Reducing Waste in Dairy Factories. Environment Matters. February 1998: 35-36.

McCarthy, M. G., and Downtown, W. J. W. (1981) Irrigation of grapevines with sewage effluent. Effects on yield and petiole composition. Am. J. Enol. Vitic. 32(3): 189-195.

McCarthy, M. G., and Downtown, W. J. W. (1981) Irrigation of grapevines with sewage effluent. Effects on wine composition and quality. Am. J. Enol. Vitic. 32(3): 197-199.

Metcalf and Eddy Pty. Ltd. (1980) Land application of stillage waste: odour control and environmental effects. Report to the Wine Institute, Fresno California. (Metcalf and Eddy Pty. Ltd.)

Mitchell, B. (1994) Control of contaminated waste water. AGWM 365: 20.

NWQMS d National Water Quality Management Strategy. (1995) Draft Effluent Management Guidelines for Wineries and Distilleries. (Commonwealth of Australia) 31 pp.

Northcote, K. H. and deMooy, C. J. (1957) Soil and Land Use in the Barossa District. Part A. The Angaston-Springton Area. Soil and Land Use Series No. 22 (CSIRO Division of Soils)

Oster, J., Weber, E., Christensen, L., Matthews, M., Pritchard, T., and Schwankl, L. (1993) Using Napa Sanitation District Wastewater for Irrigation of Grapes in the Carneros Region. Report for the Carneros Recycled Water Task Force and Napa Sanitation District. 17 pp.

Pelekani, C., Colby, C. B., James, T., and OgNeill, B. K. () A comprehensive study of winery wastewater quality.

Page, R. H., Miller, R. H., and Keeney, D. D. (1982) Methods of Soil Analysis. Part 2: chemical and Microbiological Properties. (American Society of Agronomy, Soil Science Society of America, Madison, Wisconsin)

Rengasamy, P. and Olsson, K. A. (1991) sodicity and soil structure. Aust. J. Soil Res. 29, 935-952.

Rudd, C. L. (1987) Land disposal of winery effluent. Water June 1987, 38-40.

Rump, H. H. and Krist, H. (1988) Laboratory Manual for the Examination of Water, Wastewater and Soil. 2nd edn. (VCH Weinheim)

Standard Methods (1989) Standard Methods for the Examination of Water and Wastewater. 17th edn. (American Public Health Association, American Water Works Association, Water Pollution Control Federation, Washington DC)

Storm, D. R. (1988) (Un) treatability of winery waste water: mysteries dispelled. Practical Winery 5(6) 20-23.

Storm, D. R. (1997) Winery Utilities: Planning, Design, and Operation. (Chapman-Hall)

Tcholbanoglous, G. and Burton F. L. (1991) Wastewater Engineering: Treatment, Disposal and Reuse. 3rd edn (McGraw-Hill: New York)

Thomas, J. W. M. (1991) Guidelines for Wastewater Management. (Environmental Protection Authority Victoria, Publication No. 168)