Improved industry capacity for wastewater management by small wineries in the Margaret River wine region

Project report

Prepared for Winewatch by Genevieve Hanran-Smith
and Mark Gibberd

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Curtin University of Technology

MARGARET RIVER WINE INDUSTRY ASSOCIATION INC

Cape to Cape Catchments Group

GeoCatch

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1. Introduction

This project was initiated by Winewatch - an informal partnership between Curtin University of Technology, the Margaret River Wine Industry Association, the Cape to Cape Catchments Group and GeoCatch with the Shires of Augusta-Margaret River and Busselton. The partnership was formed to enable information transfer and the collective development and implementation of projects which span across production and environmental issues for the wine industry in the south west of Australia.

In 2006 the partnership undertook a survey of wastewater management practices at small wineries in the Margaret River wine appellation. Small wineries are defined as those that produce less than 350 kL of wine and are not licensed through the Department of Environment and Conservation under the Environmental Protection Act Regulations 1987 (Part 5, schedule 1 – prescribed premises categories) yet form a significant proportion of the industry. Although not large in size these wineries represent a potential risk to the environment due to their high number, dispersal throughout the landscape and close proximity to environmentally sensitive areas (particularly waterways).

Key findings of the survey included:

- Wastewater disposal decisions are handled at the production level, they are orientated towards production issues and are unlikely to be based on conformation with regulatory requirements. The level of management scrutiny of the systems is low and respondents had a low level of knowledge with regard to regulatory requirements.

- Many of the wastewater systems being used are rudimentary and are rarely engineered specifically for the purpose (only 8% had a professionally engineered system) with minimal treatment (sedimentation or screening only) and no idea of potential for environmental impact (4% of respondents monitored quality of wastewater prior to disposal).

- It is unknown whether the wastewater systems currently being used are demonstrably robust and there is little or no data available to test this.

- The industry is ‘knowledge hungry’. Through the survey strong interest was expressed in accessing information about ways of reducing wastewater environmental impact, wastewater analysis methods, legislative and regulatory requirements, wastewater treatment systems, wastewater processes and more.

In response to the survey this project was developed to address the need to provide industry members in the sub-500 tonne production capacity with the knowledge, skills and techniques required to rigorously assess their current practices against a set of standards for best management.

There are a number of increasingly important reasons to ensure that wastewater disposal is done in a way that minimises environmental and social impacts including:

- Complying with current legislation and being prepared for increased regulation.

- Market pressure as environmental performance is becoming an important issue in the marketplace and buyers are increasingly imposing formal environmental requirements on suppliers.

- The desire of companies to protect the environmental values of their property and their region.

- Potential negative impacts on the industry of a pollution incidence.

- Meeting community expectation that the wine industry undertake its production in a responsible manner.

2. Project aims and objectives

The aim of the project was the development of practical solutions for wastewater monitoring, the promotion of self-assessment of winery wastewater management, and provision of information on wastewater management for small wineries.

Objectives of the project were to:

1. Assess systems currently in use by wineries in the Margaret River wine appellation crushing less than 500 tonnes, identify a current best practice system within each of the nominated size classes and undertake monitoring and evaluation of these systems.

2. Stimulate innovation and the development of skills and techniques required by industry members to rigorously assess their current practices against a set of standards for best management.

3. Extend findings on opportunities to improve best practice in winery wastewater management to the broader industry (sub-500 tonne wineries).

3. Background

3.1 Industry background

Within the Margaret River wine region there are currently 41 small wineries making wine on-site. A further two small wineries are being planned and constructed. The small wineries crush between 10 and 500 tonnes of grapes. In 2006 they were responsible for 23% of the total crush in the Margaret River wine region which was an estimated 6,500 tonnes.

Table 1: Number of enterprises producing wine on-site in the Margaret River wine region

Winery crush in tonnes	Number of wineries
0 - 99	17
100 - 199	11
200 - 299	3
300 - 399	4
400 - 499	6
500 - 2,499	15
2,500 – 5,000	1
5,000 – 10,000	1

Wastewater treatment and disposal methods currently being used by small wineries in the Margaret River wine region are usually rudimentary. They include: direct discharge into a swale/drain/evaporation pond; discharge to one or more sumps and disposal to waterway/ponds/leach drains/woodlot/soil; and small treatment systems with disposal to woodlot/soil. Coarse screening within the wineries occurs in most cases. A discussion of disposal methods can be found in Section 4.4.

3.2 Winery wastewater – variability, volume and composition

The following information from the *Winery Wastewater Handbook* (Chapman, Baker and Wills, 2001) provides a brief overview of winery wastewater.

Wineries are major producers of wastewater. Wastewater volumes vary considerably between wineries and may be between 1 and 5 megalitres per 1000 tonnes of grapes crushed. Winery wastewater is high in organic matter and salts, contains moderate nutrient loadings, and has an overall low pH. Water used for cleaning and rinsing may make up to two thirds of total wastewater volumes (Figure 1).

Winemaking is divided into vintage and non-vintage periods. Vintage is associated with the harvesting and crushing of grapes and fermentation of juice into wine, and non-vintage with stabilisation, maturation and blending of wine prior to bottling. Vintage occurs over a 6 to 20 week period, whereas non-vintage activities often occur year round. Small wineries that do not bottle their own wine may produce up to 80% of their annual volume of wastewater during vintage.

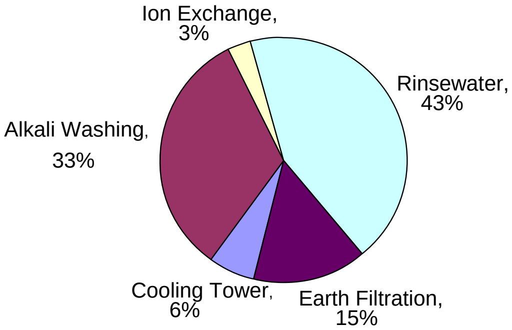

Figure 1: An example of the relative contributions of cleaning and processing activities to the generation of wastewater by a large winery (Source: Chapman et al., 2001)

Wastewater composition and volume varies considerably throughout the year (Table 2). Extraction and separation of juice from marc, its fermentation into wine, and separation of the wine from lees result in higher levels of product loss during routine processing, transfer and cleaning operations. As a result, wastewater produced during vintage always has a higher biological oxygen demand (BOD), total nutrient and electrical conductivity (salts), and is more acidic than wastewater produced during non-vintage times. The duration of early vintage and late vintage in many smaller wineries is often too short to warrant separating them from peak vintage. Peaks in caustic cleaning of equipment post and pre-vintage occasionally lead to the composite wastewater being highly alkaline and saline.

As small wineries undertake comparatively large numbers of separate fermentations it is a reasonable assumption that larger volumes of wastewater are produced per tonne of fruit processed in comparison to larger wineries.

Table 2: Description of winery wastewater production stages (Source: Chapman et al., 2001)

Production stage	Duration	Description
Pre-vintage	1-4 weeks	January-February; bottling, caustic washing of tanks, non-caustic washing of equipment in readiness for vintage.
Early vintage	2-3 weeks	February-March; wastewater production is rapidly rising to peak vintage flows and has reached 40% of the maximum weekly flow; vintage operations dominated by white wine production.
Peak vintage	3-14 weeks	March-May; wastewater generation is at its peak; impact of vintage only operations is at its maximum.
Late vintage	2-6 weeks	April-June; wastewater production is rapidly falling to non-vintage flows and has decreased to 40% of the maximum weekly flow; vintage operations dominated by production of red and ‘sticky’ wines; distillation of ethanol spirit may also coincide with this period.
Post vintage	6-12 weeks	May-September; pre-fermentation operations have ceased; impact of caustic cleaning, ion exchange etc is at its greatest, and wastewater quality may be poor.
Non-vintage	10-20 weeks	June-December; wastewater generation is at its lowest – generally less than 30% of maximum flows during vintage; wastewater quality is highly dependent on day-to-day activities.

3.3 Potential environmental impacts

The potential environmental and social impacts of winery wastewater include pollution of ground and surface water, soil degradation, damage to vegetation and odours. Some of the potential effects on the environment of the various constituents of waste by-products from the winemaking process are summarised in Table 3 below.

Potential environmental and social impacts of small wineries can be minimised provided wastewater utilisation or disposal is well managed.

Table 3: Potential environmental impacts of winery wastewater (Source: modified from South Australia EPA, 2004 and Chapman et al., 2001)

Winery waste characteristic	Indicators	Sources	Effects
Organic matter	BOD[1], TOC[2], COD[3]	• Product loss - juice, wine and lees. • Residues in cleaning waste. • Residues in DE filter waste. • Solids reaching wastewater drains including skins, seeds, etc.	• Depletes oxygen when discharged into water. • May cause oxygen imbalance in soil leading to inefficient removal of organic contaminants from soil or impacts on plant health. • Malodours if waste is stored in open lagoons or land applied.
Alkalinity /acidity	pH	• Ion exchange – acidic, pH around 2. • Product loss - juice and wine – acidic, pH 3.5 to 5.5. • Alkali/caustic • Microbial metabolism of organic substrates during storage of wastewater further acidifies the wastewater.	• Death of aquatic organisms at extreme pH ranges. • Affects microbial activity in biological treatment processes. • Affects the solubility of heavy metals in the soil and availability and/or toxicity in waters. • Affects plant growth.
Nutrients	nitrogen, phosphorus, potassium, sulphur	• Product loss - juice, wine and lees. • Proteins removed from wine to prevent haze are a source of nitrogen and to a lesser extent phosphorus. • Phosphate detergents and phosphoric acid.	• Eutrophication when discharged to water or stored in lagoons. • N as nitrate and nitrite can be toxic to infants. • Toxic to plants in large amounts. • Potassium may affect soil structure, resulting in decreased infiltration.
Salinity	EC[4], TDS[5]	• Alkali washing – caustic. • Saline groundwater used for cleaning. • Product loss – juice, wine and lees. • Ion exchange.	• Toxic to aquatic organisms. • Affects water uptake by crops.
Sodicity	SAR[6], ESP[7]	• Alkali washing – caustic. • Product loss – juice, wine and lees. • Saline groundwater used for cleaning.	• Affects soil structure, resulting in low infiltration and hydraulic conductivity, poor aeration, hard and dense subsoil. • May increase susceptibility of soil to waterlogging
Heavy metals		• Al, Cu, piping and tanks, Pb soldering, brass fittings	• Toxic to plants and animals.
Solids	TSS[8]	• Product loss - juice, wine and lees. • Residues in caustic/citric acid cleaning waste. • Residues in DE filter waste. • Solids reaching wastewater drains including skins, seeds, etc.	• Reduces soil porosity, leading to reduced oxygen uptake. • Can reduce light transmission in water. • Smothers habitats. • Odour generated from anaerobic decomposition.

[1] Biological oxygen demand
[2] Total organic carbon
[3] Chemical oxygen demand
[4] Electrical conductivity
[5] Total dissolved solids
[6] Sodium absorption ratio
[7] Exchangeable sodium percentage
[8] Total suspended solids

Decisions regarding wastewater treatment and disposal options need to be considered in context with the potential risk to the environment. The potential nutrient input from winery wastewater in context with other landuses is outlined in the tables below. The nutrient loading of winery wastewater varies considerably between wineries so the figures in table 6 are indicative only. The figures used have been taken from the Effluent Management Guidelines for Australian Wineries and Distilleries (NWQMS, 1998). Volumes and loadings on the high end of the scale have been used to determine these estimates. Winery practices to minimise wastewater volumes and organic and nutrient loadings would significantly reduce the potential environmental risk.

Table 4: Median input rates of phosphorus (P) and nitrogen (N) to different landuses in the Peel Harvey, Vasse, Geographe and Ellenbrook catchments (Source: Keipert et al., 2008)

Landuse	Median P input (kg ha $^{-1}$)	Median N input (kg ha $^{-1}$)
Annual Horticulture	205	150
Beef feedlot	19	112
Cattle for Beef	9.7	73
Cattle for Dairy	22.7	139
Horses	10.8	63.8
Mixed Grazing	7.2	74.8
Piggery	144	629
Poultry Eggs	74	727
Sheep Feedlot	7.9	66.6
Orchards	100	200
Urban sewered	43	138
Urban unsewered	75	260

Table 5: Comparison of phosphorus (P) and nitrogen (N) inputs from domestic septic tanks and a range of animal sources (Source: Gerritse, 2002)

Source	P input (kg/yr)	N input (kg/yr)
1 septic tank	3.5	18
1 cat	0.25	1
1 dog	1.3	5
1 horse	10 - 18	40 - 75
1 chook	0.4	0.7
1 pig (<20 – 110 kg)	0.65 - 3.1	2.7 - 12.9

Table 6: Estimates of phosphorus (P) and nitrogen (N) loadings in untreated wastewater from small wineries

	Size (tonnes grape crushed)	P in winery wastewater (kg)	N in winery wastewater (kg)
Vintage	100	7	24.5
	300	21	73.5
	500	35	122.5
Non-vintage	100	1.5	3.75
	300	4.5	11.25
	500	7.5	18.75

3.4 Best fit wastewater management

It is not possible to be prescriptive when advising wineries on how to treat and dispose of wastewater. Various factors will influence potential management options including whether there is a need for pre-treatment before disposal. Determining factors include wastewater volume, land availability, landform, soils, depth to groundwater and distance from environmentally sensitive sites, neighbours and places frequented by the public.

Wineries should consider wastewater end use or disposal options (ie. irrigation, subsurface disposal, constructed wetlands) before determining treatment requirements as the end use or disposal method will often dictate the treatment needs.

In small wineries in the Margaret River wine region the volume and timing of wastewater produced allows for the possibility of immediate utilisation or disposal of untreated wastewater. The need for storage and treatment is therefore reduced. However, disposal of untreated winery wastewater will only be acceptable if all potential environmental and social risks are addressed in planning and management of the disposal or reuse site. That is, the site needs to be suitable for the disposal method or reuse and managed to minimise potential risks.

Water use efficiency and cleaner production measures in the winery are integral components of a wastewater management plan. Reducing the volume of wastewater and the organic, nutrient and salt loadings is an important strategy in minimising the risk of environmental and social impacts associated with wastewater utilisation or disposal.

If a winery does not have the option of immediate disposal of wastewater because of site or other constraints then storage and/or treatment of wastewater will be required. Treatment options include screening, filtration, settlement, pH adjustment, aerobic systems, anaerobic systems, sequence batch reactors, combined anaerobic/aerobic systems and artificial wetlands. Considerations in selecting wastewater treatment and disposal methods include volume of wastewater, disposal options, environmental and social impacts, energy efficiency, and capital and operational expenses.

Within the wine industry in Australia there is a move towards treating wastewater to enable reuse on vines. Small wineries may be constrained in pursuing this reuse option due to the costs of storage and treatment of wastewater. Storage is required as the timing of peak wastewater production at vintage does not coincide with the growing season of winegrapes, and wastewater therefore needs to be stored for later use. Storage requires pre-treatment due to malodours derived from untreated winery wastewater.

4. Wastewater monitoring program

Project objective 1: Assess systems currently in use by wineries in the Margaret River wine appellation crushing less than 500 tonnes, identify a current best practice system within each of the nominated size classes and undertake monitoring and evaluation of these systems.

4.1 Participating wineries

The first stage of the monitoring program involved locating representative wineries to take part in the monitoring program. Discussions were held with thirty small wineries in the Margaret River wine region and nineteen of these were visited in order to find three wineries that met the requirements of size and disposal method, and willingness to be involved.

The three wineries chosen are briefly described below:

Winery 1:
The winery was developed in 1976. In 1999 substantial changes were made including a 3-fold expansion of the crushing capacity of the winery. The winery currently crushes approximately 250 tonnes of grapes. In 2008 the winery produced approximately 70% white and 30% red wine.

The current wastewater system was installed in 2000. It comprises two 5000 litre tanks and a 4000 litre pump tank. The first tank collects solids and is emptied every couple of years. Wastewater then flows over into a second and then third tank from where a submersible pump is initiated by a flotation device and pumps water from the final tank to an irrigation site (Figure 1). The irrigation site is approximately 0.2 ha and is planted with *Eucalyptus camaldulensis* (river redgums). The water is distributed through polypipe drilled with 1 cm holes at 1.5 m intervals and running down the length of every second row. The distribution system can be diverted to enable areas of the plantation to be rested. All trees appear to be healthy. The woodlot is on a slope with a creek 20 m from the first row of trees. Soils at the woodlot are loamy gravel duplex soils with a clay layer at approximately 60 cm.

Work areas at the winery are under cover and stormwater from hard surfaces surrounding the winery is not directed to the wastewater system. Cleaner production and water use efficiency measures implemented by the winery include screens in the winery that provide minimal reduction of larger solids entering the wastewater system, the use of brooms and high pressure cleaning equipment, and hot water for barrel cleanings. Bottling is not undertaken on site.

A magnetic flow meter was installed in 2008 to measure wastewater volumes at the point of disposal.

Figure 2: Irrigation site at Winery 1

Winery 2:
The winery was built in 1988 with the first vintage in 1999. The winery crushes approximately 120 tonnes of grapes. In 2008 the winery produced approximately 66% white and 34% red wine. The current wastewater system was constructed in February 2001. It comprises two 2650 litre tanks, a submersible pump with a flotation device and two 20 metre leach drains. The leach drains are located 30 metres from a small tributary and 60 metres from a dam (Figure 3). The soil at the leach drain site is a loamy sandy duplex with a clay layer at 60 cm. Imported gravelly clay from an excavated dam has been spread across some of the area surrounding the leach drains to a depth of 20 cm. Imported white sand forms a mound over the leach drains.

Management includes replacement of the pump every few years and the pumping out of solids in the first tank annually. Stormwater collected on paved surfaces surrounding the winery is not included in the wastewater stream.

Cleaner production and water use efficiency measures implemented by the winery include screens in the winery that are emptied twice weekly during vintage, hot water barrel cleaning, the use of brooms and shut-off nozzles on hoses and the reuse of caustic where practicable.

A magnetic flow meter was installed in 2008 to measure wastewater volumes at the point of disposal.

Figure 3: Subsurface disposal site at Winery 2

Winery 3
The winery was established in 1973 with the current winery and barrel room built in 1999. The winery crushes approximately 300 tonnes of grapes. During 2008 the winery produced approximately 52% red and 48% white wines.

The wastewater system currently in use was constructed in 2000. It comprises two approximately 4000 litre tanks with the sludge and accumulated solids pumped out of the first tank a couple of times a year. A submersible pump operated on a flotation device pumps wastewater to two 4 metre deep, clay lined ponds (Figure 4). A windmill operated aerator in the first pond achieves some mixing and limited aeration. The windmill aerator has resulted in a noticeable decrease in malodour from the pond. Bacteria have also been added to aid biological activity in the pond and lime is added a couple of times a year to increase pH. Some leakage from the pond has affected the health of the adjacent vines.

Stormwater collected on hard surfaces at the back of the winery is diverted away from the wastewater system during most of winter.

Cleaner production and water use efficiency measures implemented by the winery include screens in the winery to minimise larger solids entering the wastewater system, the use of brooms and shut-off nozzles on hoses and high pressure cleaning equipment. A non-sodium based cleaning product is used for cleaning to minimise sodium in the wastewater. Bottling is not undertaken on site.

A magnetic flow meter was installed in 2008 to measure wastewater volumes at the point of disposal.

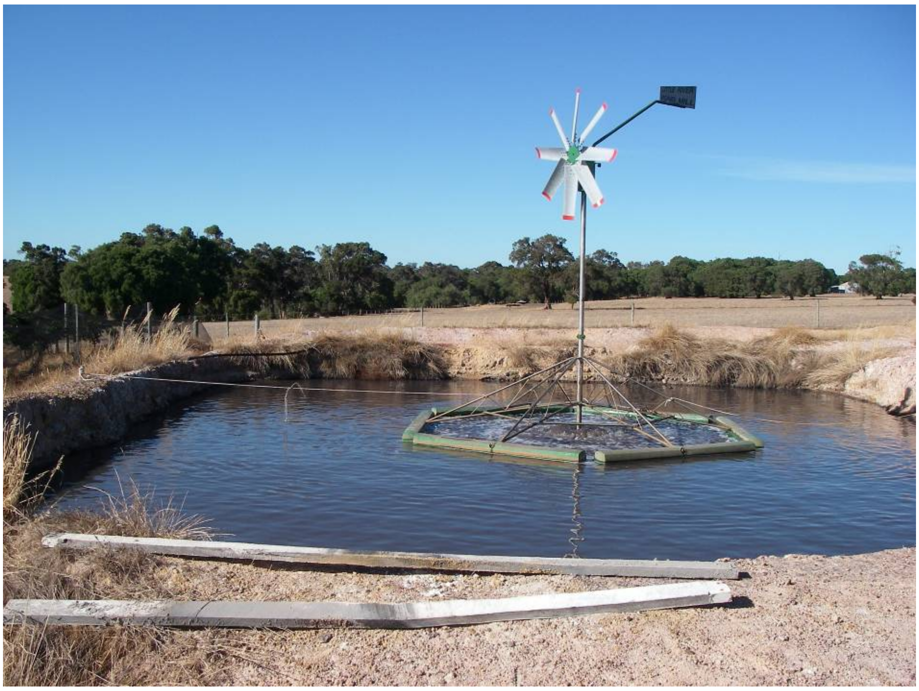

Figure 4: Wastewater ponds at Winery 3

4.2 Wastewater monitoring

Wastewater samples were taken from the sumps weekly from February 13th 2008 to April 16th 2008, fortnightly until the end of September 2008 and then once every three weeks until March 4th 2009.

As wastewater composition within the sumps can vary considerably both within and between days depending on activities in the winery, composite sampling containers were used rather than grab samples. The sampling containers have low flow emitters fitted in their base and fill gradually over time so giving a more representational sample. The sampling containers are positioned in the sumps and are thoroughly cleaned after each sampling occasion to ensure there is no build up of material within the container.

Samples were tested at a laboratory for pH, electrical conductivity, total suspended solids, total Kjeldahl nitrogen, total phosphorus, biological oxygen demand, calcium, magnesium and sodium. The sodium adsorption ratio (SAR) was calculated using the calcium, magnesium and sodium results and as an indication of the sodicity of the wastewater. The laboratory has NATA accreditation for these tests.

Graphs and a discussion of results are outlined below. Two graphs for each sampled parameter are included. The first graph shows the results of each sampling occasion. The second graph shows a moving average trendline to enable patterns or trends to be seen more clearly. A moving average uses a specific number of data points (two points are used in the graphs below), averages them, and uses the average value as a point in the line. That is, the average of the first two data points is used as the first point in the trendline, the average of the second and third data points is used in the second point in the trendline, and so on.

All results are included in Appendix 1.

4.2.1 pH

The pH of the wastewater at the three wineries ranged between 4 and 7.2, the mean vintage pH for the three wineries was 5 and the mean non-vintage pH for the three wineries was 5.2. There was no trend in pH values throughout the 12 month monitoring period. The pH of the wastewater at Winery 2 showed greater variation and was consistently higher than the other two wineries (Figures 5 and 6).

Sources of acidity and alkalinity include: product loss – juice and wine are acidic with a pH of 3.5 to 5.5; and alkali washwater – a 5% solution of caustic soda has a starting pH of 13.5 and becomes ineffective for alkali washing at around pH 10, at which stage it is discarded (Chapman et al., 2001).

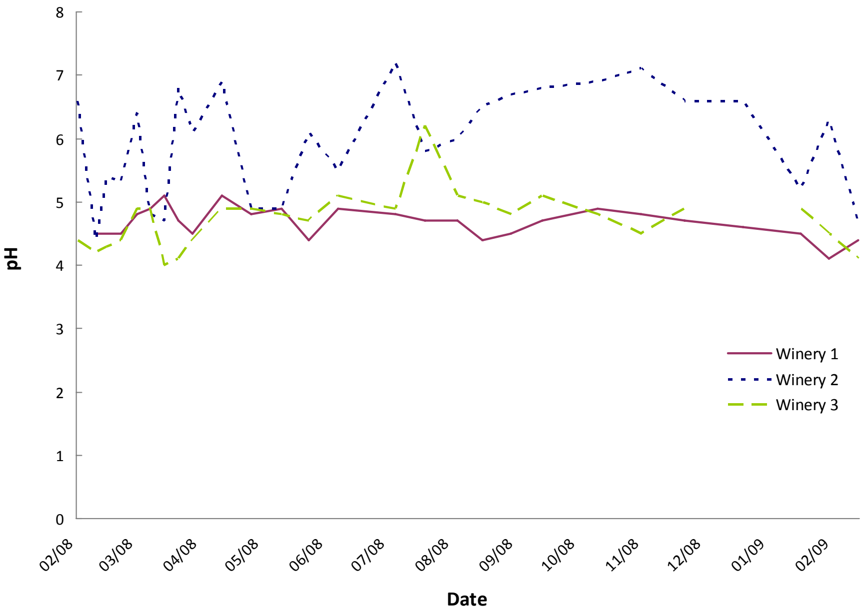

Figure 5: Measurement of pH of wastewater at three small wineries over 12 months

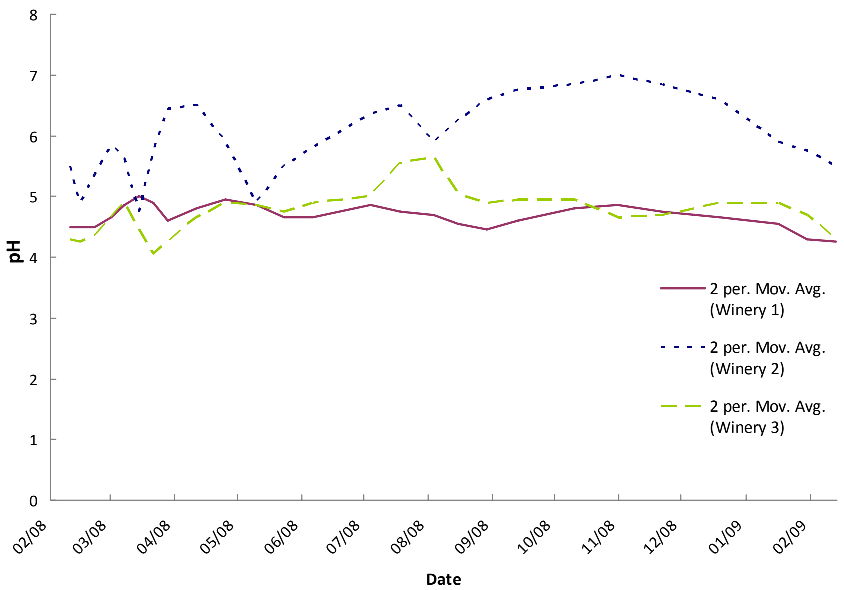

Figure 6: Measurement of pH of wastewater at three small wineries over 12 months (moving average)

4.2.2 Electrical conductivity

The electrical conductivity (EC) of the wastewater at the three wineries ranged from 99 to 455 mS/m with the mean vintage result for the three wineries 228 mS/m and the mean non-vintage result for the three wineries 212 mS/m. EC varied considerably throughout the sampling period. EC was consistently higher at Winery 1 and lower for most of the sampling period at Winery 3 (Figures 7 and 8). Winery 3 uses both potassium based and sodium based cleaning agents whereas Winery 1 and 2 primarily use a sodium based cleaning agent.

Electrical conductivity is a measurement of dissolved salt content. The types of ions causing salinity usually are sodium, potassium, magnesium, calcium, chlorides, sulphates and carbonates. Sources of salts in winery wastewater are alkali washwater, poor quality water used for cleaning, and to a lesser extent product loss (Chapman et al., 2001).

The general water salinity rating for irrigation of the wastewater from the three wineries ranges from low to high during the monitoring period with the mean vintage result having a high rating and the mean non-vintage result having a medium rating (Department of Environment and Conservation, 2004).

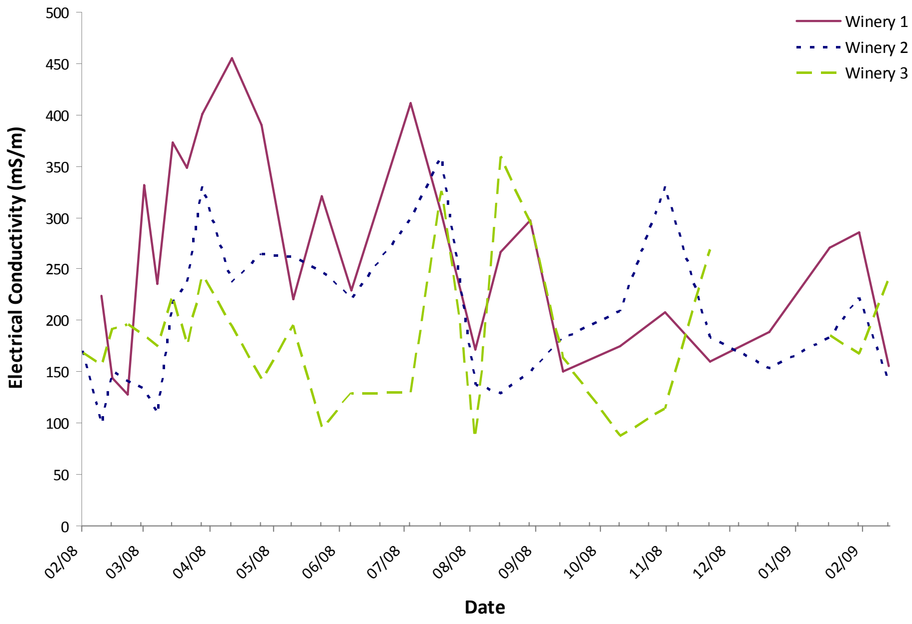

Figure 7: Electrical conductivity of wastewater at three small wineries over 12 months

Figure 8: Electrical conductivity of wastewater at three small wineries over 12 months (moving average)

4.2.3 Total Suspended Solids

The total suspended solids (TSS) of the wastewater at the three wineries ranged from 41 mg/L to 2475 mg/L with the mean vintage result for the three wineries 654 mg/L and the mean non-vintage result for the three wineries 203 mg/L. TSS was reasonably consistent between the three wineries and the trend was for TSS to show a strong peak during the vintage period and the month following vintage (Figures 9 and 10).

Sources of TSS are gross solids such as skins, seeds etc, product loss (juice, wine and lees), residues in cleaning water and DE filter waste. The clear peak at vintage is a result of crushing, pressing and racking during and following vintage.

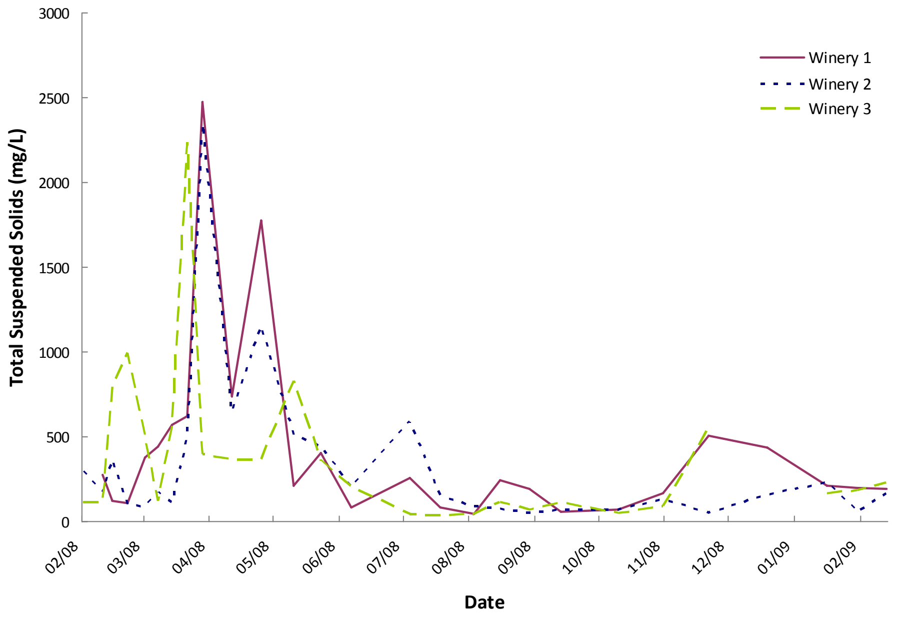

Figure 9: Total suspended solids in wastewater at three small wineries over 12 months

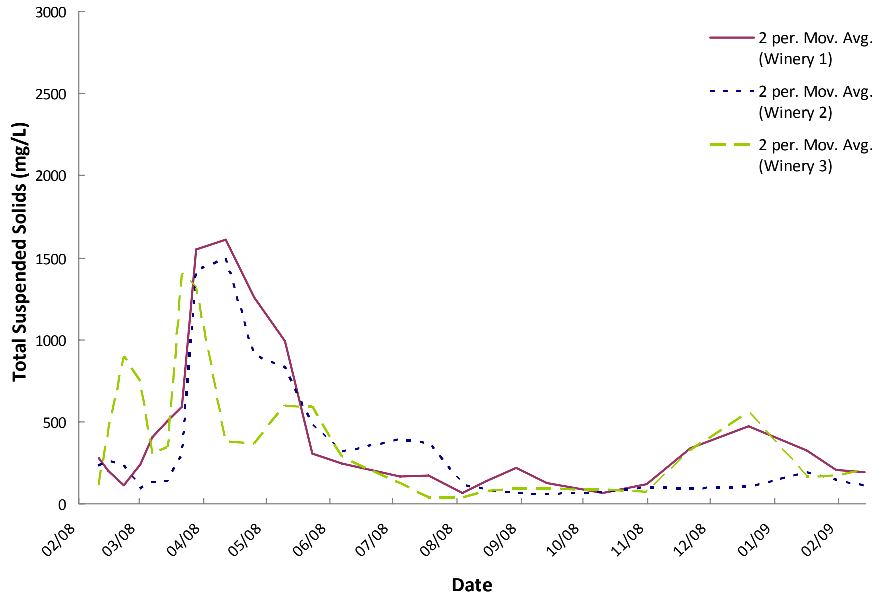

Figure 10: Total suspended solids in wastewater at three small wineries over 12 months (moving average)

4.2.4 Biological Oxygen Demand

The biological oxygen demand (BOD) of the wastewater at the three wineries showed considerable variation ranging from 123 mg/L to 9100 mg/L. The mean vintage result for the three wineries was 2787 mg/L and from the mean non-vintage result of 2065 mg/L. The BOD showed a peak from April to July. Although the mean from August onwards was lower there was still considerable variation with a range of 123 mg/L to 6565 mg/L (Figures 11 and 12).

Organic loading can remain relatively high post fermentation due to stabilisation activities and bottling that normally involves repeated transfers of wine and therefore losses to the wastewater system (Chapman et al., 2001).

Juice, wine and lees are the major contributors of organic carbon and BOD to winery wastewater. The total organic carbon may be in dissolved forms or as suspended solids. All the major organic materials in winery wastewater have high BOD, especially ethanol. By contrast, phenolic materials such as red pigments and tannins have relatively low BOD, which may lower the overall BOD of wastewater originating from red wine manufacture. Waste from citric acid rinsing of caustic soda is another important source of BOD. Since the chemical form of the organic substrate influences BOD, changes in relative amounts of dominant organic materials in winery wastewater – especially ethanol content – can significantly alter BOD (Chapman et al., 2001).

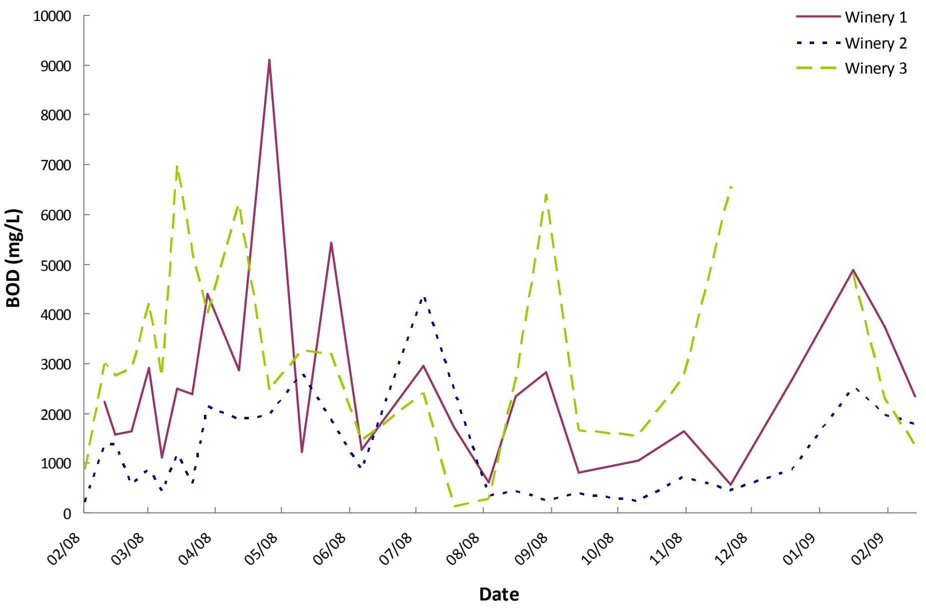

Figure 11: Biological oxygen demand of wastewater at three small wineries over 12 months

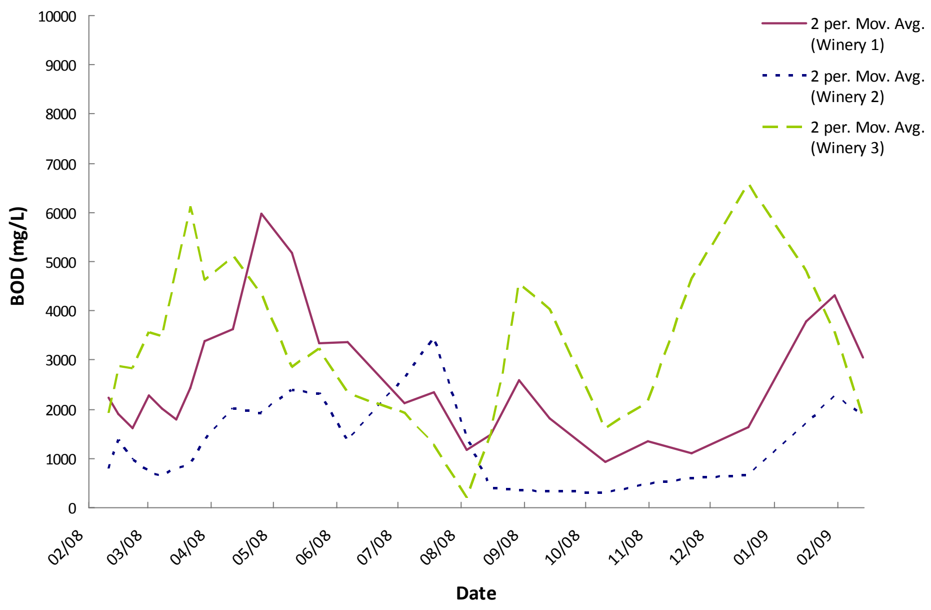

Figure 12: Biological oxygen demand of wastewater at three small wineries over 12 months (moving average)

4.2.5 Total Kjeldahl Nitrogen

The total Kjeldahl nitrogen (TKN) of the wastewater at the three wineries showed considerable variation ranging from 3.26 mg/L to 317.85 mg/L. The mean vintage result for the three wineries was 75.1 mg/L and the mean non-vintage result was 50 mg/L. TKN was consistently lower at Winery 3 where the mean vintage result was 43.7 mg/L and the mean non-vintage result was 23.95 mg/L. Dilution with stormwater may have lowered the non-vintage result at Winery 3. TKN increased significantly from mid March and overall remained high, though variable, until mid August (Figure 13 and 14).

Wineries 1 and 2 showed two clear peaks in TKN. Both peaks coincided with periods of high product loss from crushing, pressing and racking. Product loss during the first peak would have been juice, wine and lees. Product loss during the second peak would more likely have been primarily clarified wine. This may account for why total phosphorus (TP) and BOD did not follow a similar pattern to TKN. Both BOD and TP showed a clear peak during vintage but not a second non-vintage peak.

Chapman et al. (2001) state that there is no relationship between total organic carbon, total Kjeldhal nitrogen and total phosphorus. This is because of multiple and independent sources of each element. Sources of nitrogen are juice, wine and lees. Proteins removed from wine to prevent haze are important sources of nitrogen (Chapman et al., 2001).

The TKN results for Wineries 1 and 2 are high in comparison to expected TKN ranges listed in sources such as the Winery Wastewater Handbook (Chapman et al, 2001) and the Effluent Management Guidelines for Australian Wineries and Distilleries (Agriculture and Resource Management Council of Australia and New Zealand, 1995). Expected ranges outlined in those sources are 34 to 60 mg/L for vintage and 22 to 40 mg/L for non-vintage (Chapman et al., 2001) and 5 to 70 mg/L for vintage and 1 to 25 mg/L for non-vintage (Agriculture and Resource Management Council of Australia and New Zealand, 1995). In particular, the non-vintage results are high. It is likely that results from October to January will be lower as there is less activity in the wineries during that time, and the non-vintage mean may therefore decrease.

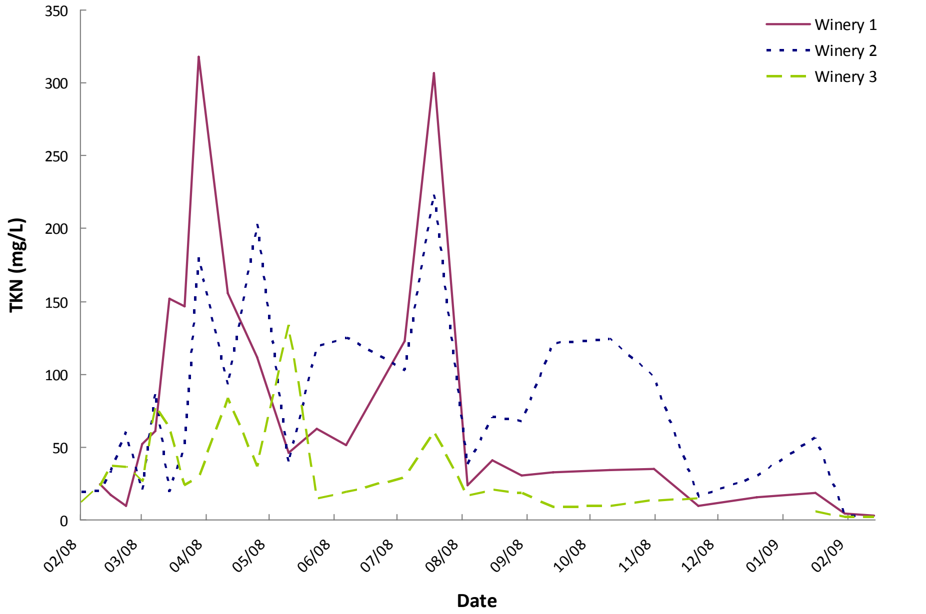

Figure 13: Total Kjeldahl nitrogen at three small wineries over 12 months

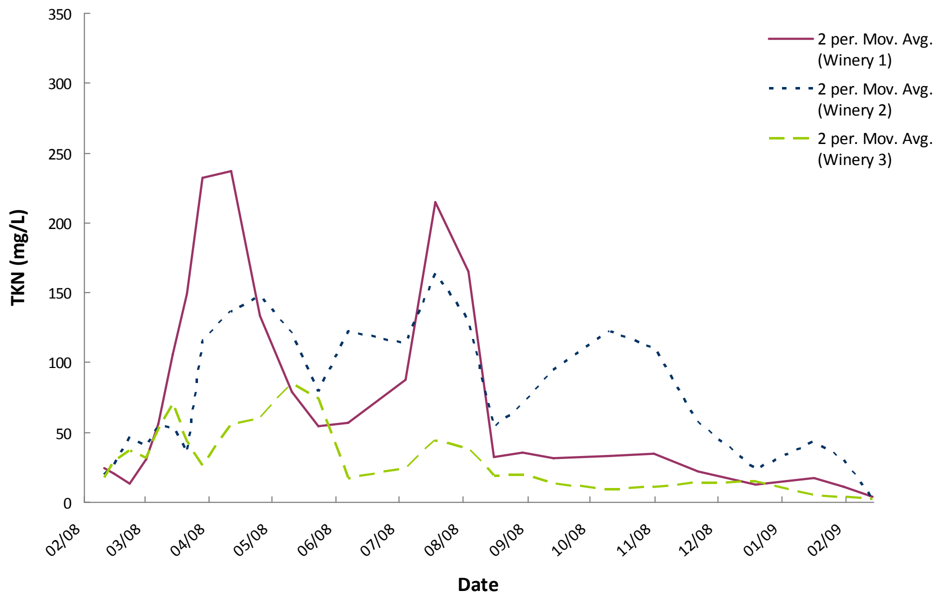

Figure 14: Total Kjeldahl nitrogen at three small wineries over 12 months (moving average)

4.2.6 Total Phosphorus

The total phosphorus (TP) of the wastewater at the three wineries ranged from 0.05 mg/L to 36.5 mg/L. The mean vintage result for the three wineries was 14.3 mg/L which was very similar to the mean non-vintage result of 14.13 mg/L. An overall trend was for TP to peak in the April to June period though there was not a significant decrease after this period. Unlike EC and TKN there was not a second peak during July/August (Figures 15 and 16).

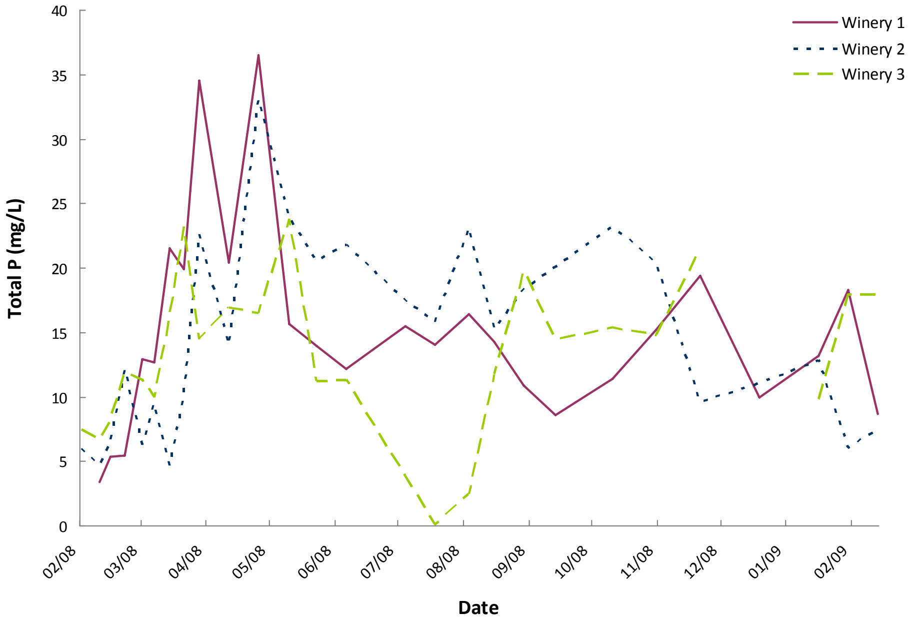

Figure 15: Total phosphorus in wastewater at three small wineries over 12 months

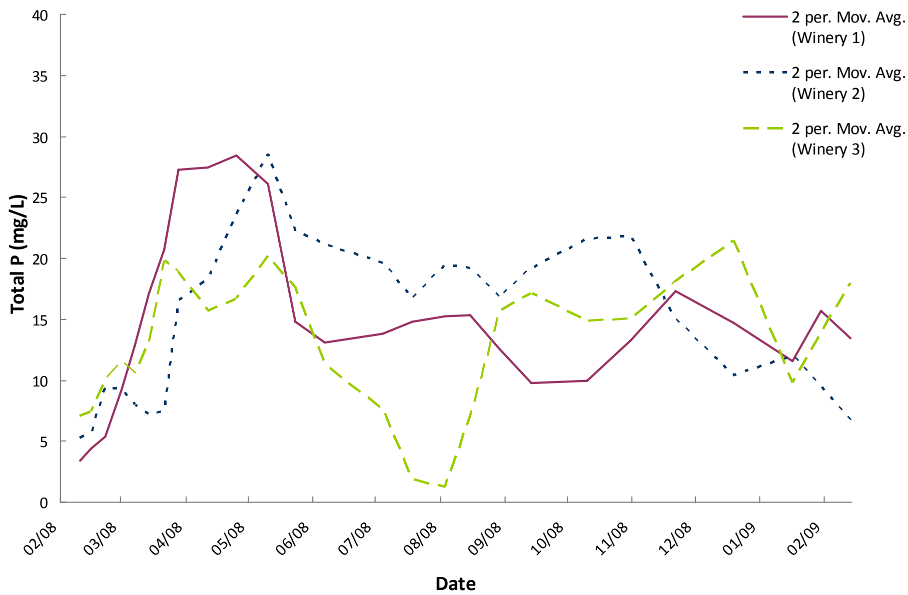

Figure 16: Total phosphorus in wastewater at three small wineries over 12 months (moving average)

4.2.7 Calcium

The calcium in the wastewater at the three wineries ranged from 10 mg/L to 96 mg/L. The mean vintage result for the three wineries was 37.7 mg/L and did not differ significantly from the mean non-vintage result of 43.49 mg/L. Winery 2 consistently had lower results and less variation from the mean than the other two wineries (Figures 17 and 18).

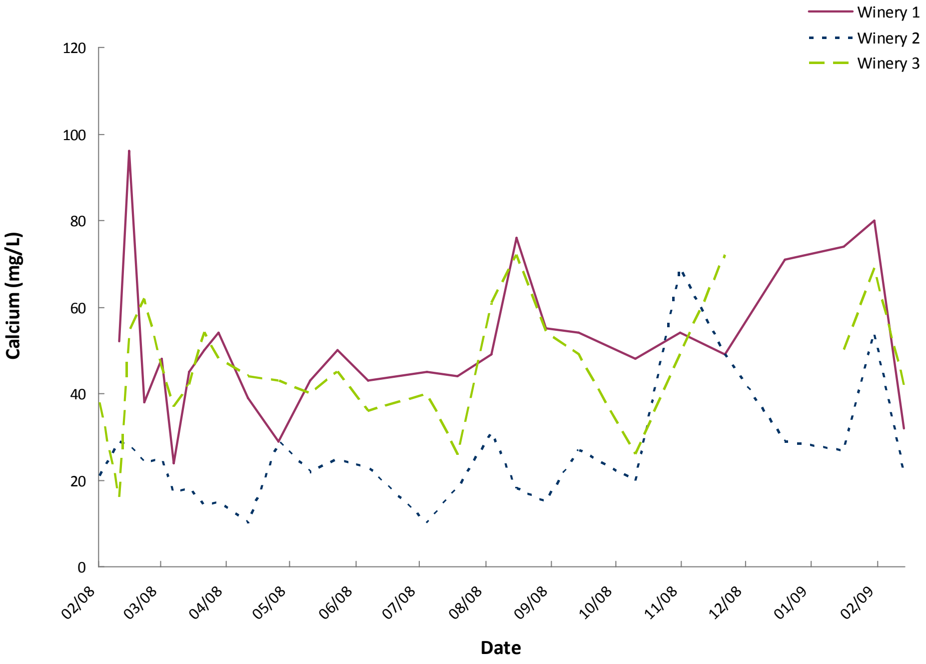

Figure 17: Calcium in wastewater from three small wineries over 12 months

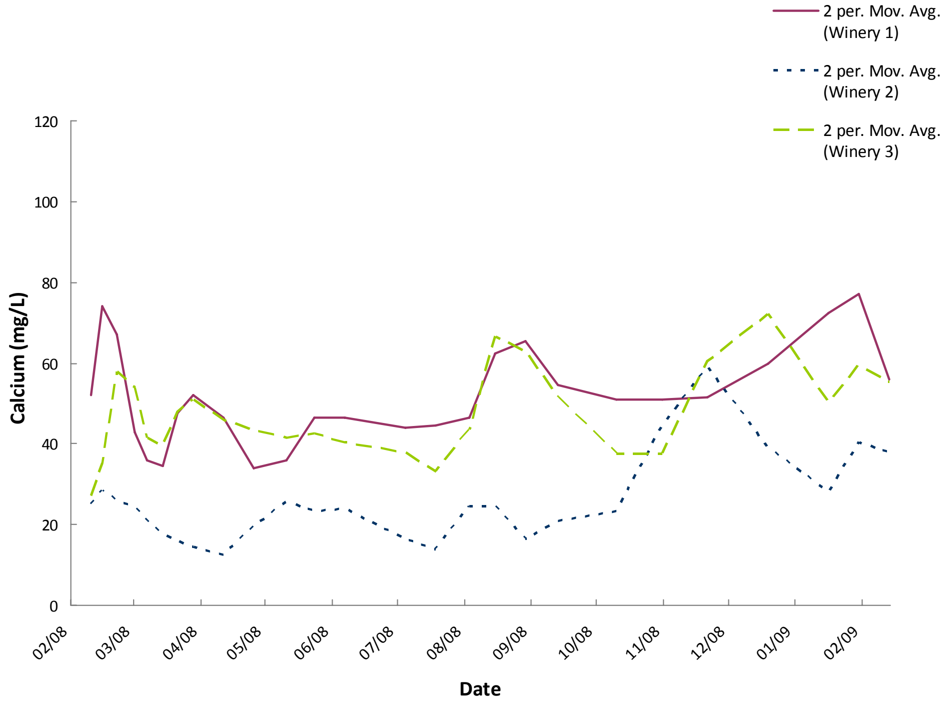

Figure 18: Calcium in wastewater from three small wineries over 12 months (moving average)

4.2.8 Magnesium

The magnesium in the wastewater at the three wineries ranged from 2.9 mg/L to 21 mg/L. The mean vintage result for the three wineries was 13.3 mg/L and did not differ significantly from the mean non-vintage result of 10.3 mg/L. Winery 2 consistently had a lower result and less variation from the mean than the other two wineries (Figures 19 and 20).

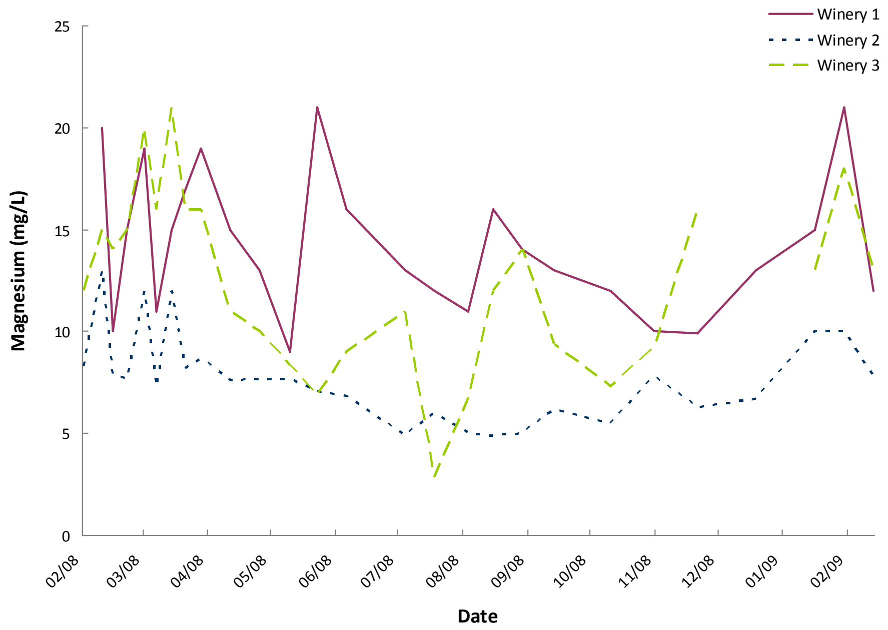

Figure 19: Magnesium in wastewater from three small wineries over 12 months

Figure 20: Magnesium in wastewater from three small wineries over 12 months (moving average)

4.2.9 Sodium

The sodium in the wastewater at the three wineries ranged from 12 mg/L to 850 mg/L. The mean vintage result for the three wineries was 263.9 mg/L and the mean non-vintage result was 197.6 mg/L. Winery 3 consistently had a lower result for sodium than the other two wineries with a vintage mean of 135 mg/L and a non-vintage mean of 93 mg/L (Figures 21 and 22). The results from Winery 3 also showed considerably less variability from the mean. Winery 3 uses both potassium based and sodium based cleaning agents whereas Wineries 1 and 2 use a sodium based cleaning agent.

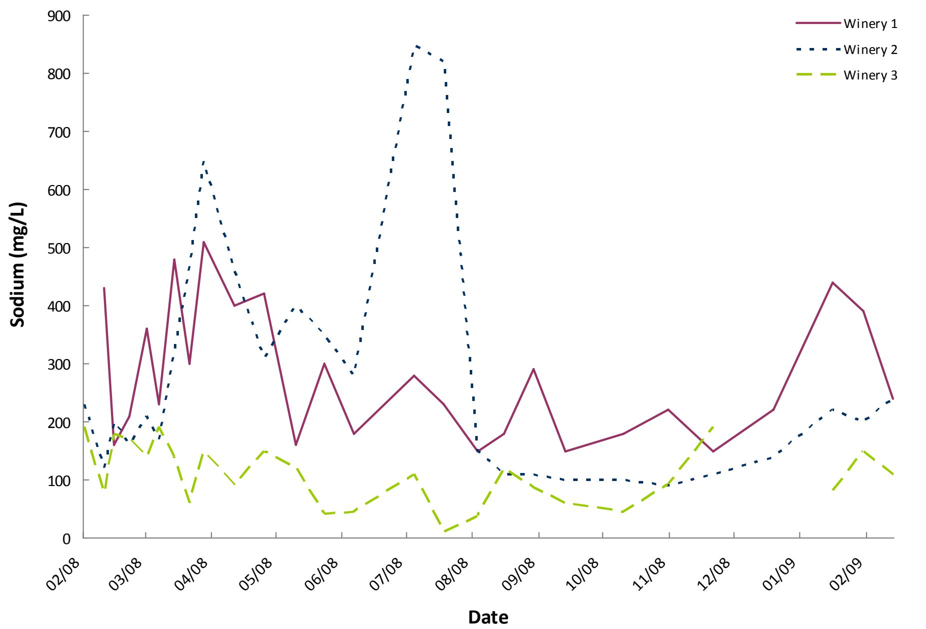

Figure 21: Sodium in wastewater from three small wineries over 12 months

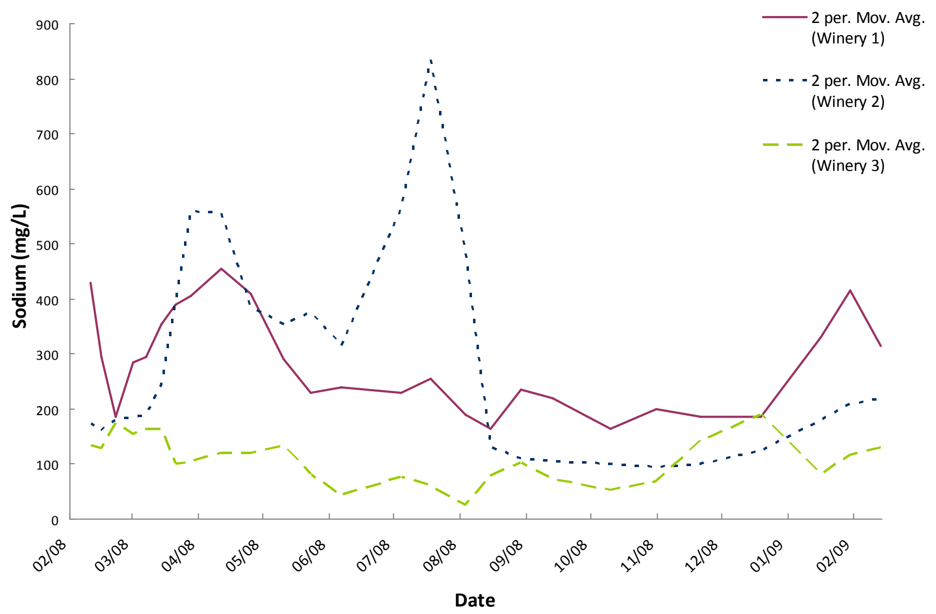

Figure 22: Sodium in wastewater from three small wineries over 12 months (moving average)

4.2.10 Sodium Absorption Ratio (SAR)

The SAR of the wastewater at the three wineries ranged from 0.6 to 54.9. The mean vintage result for the three wineries was 10.2 mg/L and the mean non-vintage result was lower at 8.06. Winery 3 consistently had a lower result for SAR than the other two wineries with a mean vintage result of 4.39 and a mean non-vintage result of 3.17 (Figures 23 and 24). Winery 3 uses a potassium based cleaner rather than a sodium based cleaner.

Soil permeability and aeration problems can occur when irrigation water has a SAR above 6, though this will depend on soil type (Department of Environment and Conservation, 2004).

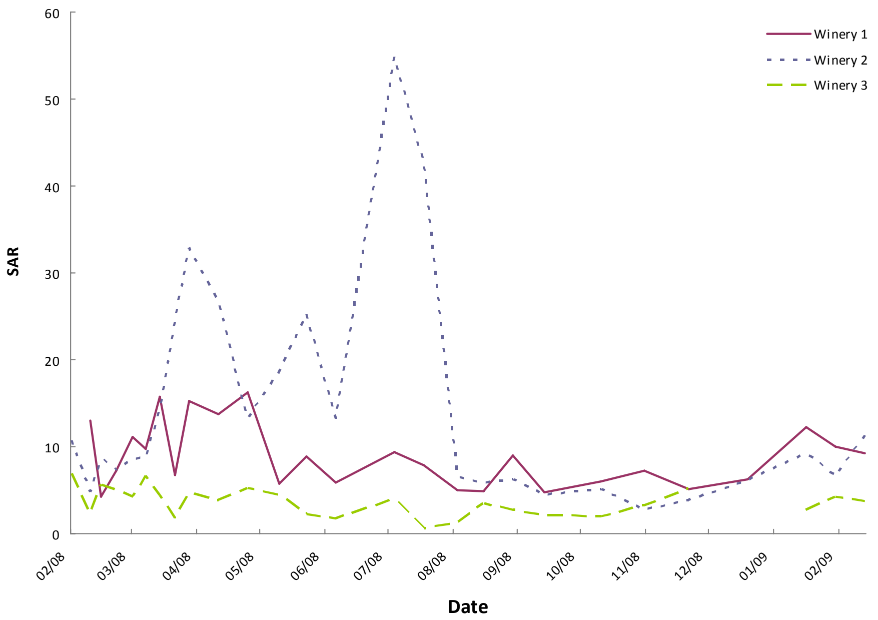

Figure 23: Sodium Absorption Ratio (SAR) of wastewater from three small wineries over 12 months

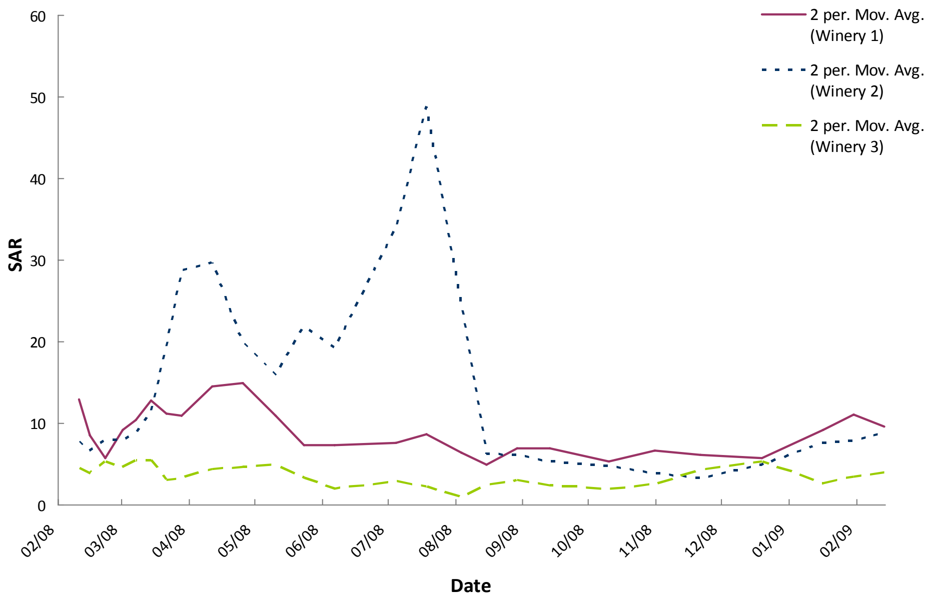

Figure 24: Sodium Absorption Ratio (SAR) of wastewater from three small wineries over 12 months (moving average)

4.3 Soil sampling at wastewater disposal sites

Soil sampling was undertaken at the wastewater disposal sites at the three small wineries participating in the Winewatch monitoring program. The aim of the sampling was to identify whether changes to soil properties and structure had occurred as a result of winery wastewater disposal.

Soil sampling was carried out on 21 April 2008 which coincided with the latter part of effluent disposal from vintage. Soil profiles were sampled to top of an impeding clay layer in areas that had received effluent, and in a reference area. Topsoil samples (0 to 10 and 10 to 20cm) were taken by combining material from 10 to 15 auger holes, and subsoil samples were combined from 6 auger holes. Samples were oven-dried at 40 degC to 50degC (moisture content) and sieved to less than 2 mm (gravel content). The fine-earth fraction was analysed for pH1:5 (in water pH_w and calcium chloride pH_{Ca}), salinity (EC1:5 and chloride), bicarbonate extractable phosphorus and potassium (Bic P and Bic K, Colwell method), phosphorus retention index (PRI, method by Allen and Jeffery, 1990) and exchangeable cations (Ca, Mg, K, Na and Al extracted in ammonium chloride solution). Topsoil samples were also analysed for organic carbon, Total P and Total N. About two-thirds of samples were subjected to a laboratory test to assess the potential for dispersion and erosion under waterlogged conditions.

A discussion on soil sampling and results is included in Appendix 2.

5. Assessment of wastewater disposal methods

The main disposal methods currently being used by small wineries include subsurface disposal, ponds, soil infiltration and irrigation. Table 7 details the number of small wineries in the Margaret River wine region using the various disposal methods.

Table 7: Wastewater disposal methods being used by small wineries in the Margaret River wine region

Wastewater disposal method	Subsurface	Ponds	Soil infiltration	Waterway	Irrigation	Unknown	Total
Number of wineries	16	7	10	1	4	3	41

An overview of these methods is outlined below.

5.1 Subsurface disposal

5.1.1 Background

Leachfields are currently known to be used at sixteen small wineries in the Margaret River wine region to dispose of winery wastewater. The wineries vary in size from <100 to 300 tonnes, but are predominantly <150 tonnes (Table 8).

Table 8: Size of wineries using subsurface disposal in the Margaret River wine region

Winery size (tonnes of grapes crushed)	Number of wineries using subsurface disposal for winery wastewater
< 100	8
100 - 149	4
150 - 299	3
> 299	1

A subsurface wastewater disposal system typically consists of one or two tanks followed by a leachfield. Systems for winery wastewater disposal often use the same design as those constructed for domestic purposes. In some of the smaller wineries domestic and winery wastewater are both disposed of through the same system. Subsurface disposal systems designed using domestic criteria and used for winery wastewater have been known to develop problems after only a few years. There are a number of reasons for this including:

- Winery wastewater volumes are usually significantly higher than domestic wastewater volumes for at least part of the year. The volume of winery wastewater varies considerably throughout the year with up to 80% of the annual discharge occurring during a few of months at vintage (Chapman et al., 2001). For example, a 100 tonne crush winery that produces 5 ML wastewater/1000 tonne of grapes crushed, may produce over 37,000 litres of wastewater per week during February, March and April. Standards Australia specifications for domestic subsurface disposal systems are based on a volume of up to 14,000 litres per week (AS/NZS 1547:2000).

- The type and concentration of organic matter likely to be found in winery wastewater differs significantly from domestic wastewater (Table 9). Winery wastewater is much higher in organic carbon than domestic wastewater, and has a higher biological oxygen demand (BOD). The organic composition of winery wastewater is dominated by simple dissolved compounds such as organic acids, sugars and alcohols. Total dissolved solids may be particularly high during vintage. Winery wastewater is also higher in suspended solids and has a lower percentage of settleable solids at 15 to 25% compared to domestic wastewater with 70 to 80% settleable solids (Storm, 2001). Settling alone will therefore not lead to a significant reduction in the total organic material. Solids and organic matter in the wastewater will have a negative impact on infiltration at the leachfield site.

Table 9: Typical composition of winery wastewater and untreated domestic wastewater (Source: National Water Quality Management Strategy, 1998 and Crites and Tchobanoglous, 1998)

	Winery wastewater mg/L		Untreated domestic wastewater mg/L
	Vintage	Non-vintage	
Total organic carbon	1000-5000	1000	80-290
Biological oxygen demand	1000-8000	<1000-3000	110-400
Total suspended solids	100-1300	100-1000	100-350
Total dissolved solids	<550-2200	<550-850	280-850

- Bentonite lees will impact on soil permeability at the leachfield site. Bentonite is used by wineries as a clarification aid for protein stabilisation. Bentonite particles, because of their colloidal size (generally less than 0.002 mm in diameter), tend to remain in suspension, unless natural agglomeration occurs or a cationic flocculent is added to produce the coalescence and settling of negatively charged clay particles (Storm, 2001). However, bentonite tends to flocculate and precipitate in the soil immediately surrounding the point of disposal and in doing so may reduce hydraulic conduction of the leach drain. Gross lees will also impact on soil permeability and fall into the category of winery waste products that are better removed in the winery.

- The use of caustic soda for cleaning in the winery often leads to wastewater having a high sodium absorption ratio (SAR). SAR is determined by the ratio of sodium relative to calcium and magnesium. Wastewater with a high SAR may cause swelling and dispersion of clay particles and can result in reduced soil permeability at the disposal site (Chapman et al., 2001).

Considerations for successful subsurface disposal of winery wastewater include:

- A robust design would include tank capacity with sufficient retention time to allow settlement of solids. Unfortunately, there is limited information available on calculating suitable tank sizing for winery wastewater treatment. Kennedy/Jenks Consultants discuss tank capacity sufficient to hold two days of wastewater flow during the peak month of wastewater production. They state that this would allow for sufficient time for solids settling as well as time for partial treatment of the wastewater through anaerobic processes. (Kennedy/Jenks Consultants, n.d.). Stefano et al. (2008) demonstrated that the level of suspended solids of winery wastewater retained in tanks can remain virtually unchanged after two days. They attributed the low sedimentation to the fact that for most of their experimental trial a stable hydraulic retention time (HRT) was not provided. They also demonstrated that a HRT of 5 days was effective in reducing up to 80% of the organic load. As settling alone could not account for this decrease in organic matter anaerobic biological processes must have been occurring.

- Design should be based on peak volumes and take into consideration the high organic content and high percentage of suspended and/or dissolved solids.

- Minimising the amount of gross solids (skins, seeds, leaves, stems etc), juice, wine and especially lees, caustic/citric acid cleaning waste and DE filter waste entering the wastewater system will significantly reduce the risk of failure of the leachfields. Keeping bentonite lees out of the wastewater system is highly recommended.

- Installation of effluent filters at the tank outlet will provide a failsafe way of preventing solids from passing into the leachfield. Although the filters will require considerable maintenance, especially during vintage, they will both encourage control of solids in the winery and significantly increase the life of leachfields.

- Reducing the use of caustic soda and/or using a potassium based cleaning agent to lower the wastewater’s sodium absorption ratio will minimise the risk of soil structural decline and loss of permeability at the disposal site.

- A detailed soil profile evaluation should be used to give an accurate assessment of soil permeability at the leachfield site rather than standard percolation tests.

- Duplicate leachfields should be constructed and wastewater switched between the two leachfields regularly to allow resting and the breakdown of material that may result in soil clogging.

- Adequate separation from ground and surface water are essential to minimise risk of contamination.

- Storm (2001) strongly recommends that wineries separate sanitary and winery process water. He states that the logic of separation can be readily understood if the consequences of a combined system failure are analysed from both a winery operations and a public health hazard standpoint. Failure of a combined system would require ceasing operations at the winery as a result of the public health and environmental consequences of surfacing effluent. If on the other hand, the systems were separate and the sanitary system failed, there would not be the statutory public health requirement to have the winery cease production operations and temporary arrangements could be made, such as portable chemical toilets, until the failed system was replaced or repaired.

5.1.2 Potential environmental impacts

The environmental risks associated with subsurface disposal relate both to leaching of nutrients and salts to groundwater and the possible overland flow to surface water of effluent that has surfaced as a result of leachfield failure.

The potential risk of ground and surface water contamination from subsurface disposal will depend on the size of the winery, the nitrogen and phosphorus levels and sodicity of wastewater, soil type, depth to groundwater and distance to surface water.

The information in tables 4, 5 and 6 above put the nutrient inputs from a winery wastewater in context with other landuses. For example, the nutrient input from a winery that crushes 100 tonnes is similar to that from approximately 1.5 to 2.5 domestic septic tank systems. Practices in the winery to reduce gross solids, juice, wine and lees entering the wastewater system could significantly reduce the nutrient load.

Physical, chemical and biological processes occurring within leachfields, such as nitrification and denitrification and adsorption of phosphorus, will affect the nitrogen and phosphorus export from the site. Greater than 80% of nitrate can be lost from subsurface disposal to the atmosphere through nitrification and denitrification under certain conditions (Gerritse, 2002). Quantifying the level of these processes is difficult.

5.1.3 Conclusion on subsurface disposal

Subsurface disposal of winery wastewater may be problematic unless the considerations outlined above are included in design and management. Such problems have been highly apparent at some sites currently using subsurface disposal. The size of tanks and leachfield that would be required to ensure adequate settlement and drainage may result in subsurface disposal being prohibitive for all but smaller wineries.

A formal operation and maintenance plan is necessary to minimise risks of system failure and environmental impacts. The plan should include cleaning filters, checking sludge level in tanks, removing sludge, checking for surface water spots in leachfield area and diverting wastewater regularly between two leachfields.

5.2 Disposal to ponds

5.2.1 Background

Ponds are currently known to be used at seven small wineries in the Margaret River wine region to retain wastewater for disposal via percolation/evaporation. The size and location of these wineries is outlined in Table 10 below.

Table 10: Size of wineries disposing to ponds in the Margaret River wine region

Winery size (tonnes of grapes crushed)	Catchment
50	Carbanup
120	Carbanup
170	Wilyabrup
200	Wilyabrup
300	Wilyabrup
300	Wilyabrup
400	Wilyabrup

In the Margaret River wine region where the rate of evaporation is less than rainfall the majority of wastewater in ponds is lost through percolation or overflow as demonstrated in the following example.

Water balance for a winery wastewater pond:

Winery A crushes 300 tonne of grapes each year and produces 900,000 litres of wastewater (3 megalitres of wastewater per 1000 tonnes of grapes crushed). No stormwater from the winery is included in the wastewater stream. The winery has two wastewater ponds with a combined volume of 1300 m^3 and surface area of 200 m^2.

Wastewater volume/year = 900,000 litres (= 900 m^3).

Rainfall/year = 1140 mm.

Evaporation rate/year = 1375 mm x pan correction factor[9] of 0.85 = 1168.75 mm.

Inputs
Rainfall inputs:
1096 mm ÷ 1000 (to express in metres) = 1.096 m
1.096 m x pond surface area of 200 m^2 = 219.2 m^3
Wastewater effluent:
900,000 litres = 900 m^3
Total inputs = 1119.2m^3

Output
Evaporation losses:
1168.75 mm ÷ 1000 = 1.169 m
1.169 m x pond surface of 200 m^2 = 233.8 m^3
Total outputs = 205.5 m^3

As can be seen in the table below monthly inputs exceed outputs in every month of the year with the total net annual input to the pond being over 892.46 m^3. As the pond empties throughout the year it can be assumed that the water loss is occurring through percolation.

Table 11: Monthly inputs and outputs to wastewater pond at Winery A

Month	Evaporation from pond m^3	Rainfall into pond m^3	Wastewater input m^3	Inputs minus outputs/month m^3
Jan	34	2.72	32.13	0.85
Feb	29.75	2.3	102.85	75.4
March	25.5	5.98	270.00	250.48
April	17	13.78	270.00	266.78
May	10.2	31.64	32.13	53.57
June	8.5	45.64	25.70	62.84
July	8.5	45.18	32.13	68.81
Aug	10.2	32.4	25.7	47.9
Sept	13.6	22.14	25.7	34.24

[9] Water evaporates faster from a Class A Pan than from a larger water surface. Pan correction factors generally vary from 0.7 to 0.9 depending on the size of the waterbody. In this example a correction factor of 0.85 was selected as appropriate for 2 x 100 m^2 ponds.

Oct	17	14.22	25.7	22.92
Nov	29.75	8.38	25.7	4.33
Dec	29.75	3.66	32.13	6.04
Total	233.75	228.04	899.87	892.46

A very large surface area would be required for significant loss to evaporation. For example, in the above example a surface area of 5000 m² would be required to allow evaporation of approximately 80 % of the wastewater/rainfall in the pond. A surface area of 100 to 200 m² is more usual for wastewater ponds used by small wineries.

Interestingly in a number of instances operators have claimed that evaporation from ponds is much higher than would be anticipated from environmental data. It is possible to enhance evaporation by disrupting the boundary layer of unmixed air that is above a water mass. However, total evaporation is largely determined by solar energy inputs and humidity. Any gain that potentially may be made by the mixing of the surface of ponds is minimal.

5.2.2 Potential environmental impacts

Percolation/evaporation ponds present a risk to ground and surface water quality as a result of leaching of nitrogen and phosphorus as outlined below.

Nitrogen

Nitrogen can be in organic or inorganic (ammonium, nitrate or nitrite) forms. The majority of nitrogen in winery wastewater is organic. Organic nitrogen can be converted to inorganic nitrogen by microbial action. Organic nitrogen is initially converted to ammonium (NH4+) and then to nitrate (NO3). Ammonium is not leached readily from most soils (Moore, 2004) whereas nitrate is readily leached through the soil profile. The rate of nitrification varies considerably and is affected by pH, temperature, moisture and other factors. The optimum pH for nitrification is between 7.5 and 8.5 and nitrification stops at or below 6 (Nitrogen in wastewater treatment [n.d.] Retrieved October, 2008, Florida Rural Water Association: http://www.frwa.net/TRAINING/WASTEWATER/general_information_on_nitrogen%20A.htm) Nitrate can be transformed to gas and lost to the atmosphere by denitrification. This occurs in anaerobic conditions and requires soluble carbon. Greater than 80% of nitrate can be lost to the atmosphere through nitrification and denitrification under certain conditions (Gerritse, 2002).

Nitrification and denitrification can occur in ponds and soil given the right conditions. However, quantifying the level of these processes is difficult. For example, Gerritse, Adeney and Hokings (1995) determined losses of nitrogen in leachate from a septic tank by comparing ratios of dissolved N to an added inert tracer in effluent and in groundwater. This experimental procedure, however, is involved and easier alternative approaches are not available (Gerritse, 2002).

Pathways of leakage may also be complex and may be rapid if through sandy soils, preferred pathways and in elevated, undulating areas.

Phosphorus

Phosphorus will accumulate in soils and sediments until a saturated state is reached and then it will leach through the soil profile to groundwater. The capacity of soils to adsorb phosphorus varies considerably, sandy soils having very low phosphorus retention capacity and lateritic and clayey soils having a higher phosphorus retention capacity (Moore, 2004). The travel time is independent of soil water content (Gerritse, 2002).

Risk of ground and surface water contamination

The potential risk of ground and surface water contamination from winery wastewater ponds will depend on many factors including the size of the winery, the nitrogen and phosphorus levels in the ponds, soil type at the pond, depth to groundwater, groundwater hydrology, distance to surface water and connection between ground and surface water.

Tables 4, 5 and 6 above put the nutrient input from a winery wastewater pond into context with nutrient inputs from other landuses. Within the pond nutrients can undergo a number of physical, chemical and biological processes so nitrogen and phosphorus levels within the ponds may be significantly less than levels in winery wastewater leaving the winery site.

5.2.3 Literature review

No studies on winery wastewater ponds and groundwater impacts have been located. A study on groundwater contamination due to leakage of dairy effluent ponds provides some information on potential risk[10]. George et al. (1999) monitored groundwater at eight dairy effluent ponds to study the influence of soil type, water table depth and wastewater characteristics on the chemistry and microbiology of groundwater. Their results confirmed that groundwater underlying a number of sites had elevated levels of nitrates, phosphorus and bacteria. It was determined that primary risk factors included soil type and depth to groundwater. Risk of groundwater contamination significantly increased where ponds were constructed in permeable soils. It was highly recommended that ponds only be constructed in soils with a saturated hydraulic conductivity (Ksat) of less than 10mm/day. Sites with deep watertables (>3 m) and a 1 metre separation between the watertable and the pond floor were recommended.

The relevance of this information in assessing the potential risk of groundwater contamination from percolation from winery wastewater ponds is questionable as the researchers believe there was no leakage from dairy effluent ponds in soils with a Ksat of less than 10 mm/day as the organic solids in dairy effluent are known to create sealing in even quite permeable soils (D. Bennett, personal communication, 6th October 2008).

George et al. (1999) also discuss the risk of leakage in soils with high clay content and low Ksat due to the occurrence of sandy layers. If these layers are intersected there may be significant increases in leakage from ponds. They recommend that site assessment prior to installation of ponds include excavation of test holes using a backhoe to 1 metre below pond depth to ensure there are no sandy layers at the site.

5.2.4 Conclusions on ponds as disposal method

Given the limited understanding of the potential risk of ground and surface water pollution from wastewater ponds it is recommended that a precautionary approach is taken. Ponds are not recommended as a disposal method for winery wastewater.

Important risk factors in regard to ground and surface water contamination from percolation/evaporation ponds include size of winery, nutrient levels in ponds, soil permeability, phosphorus retention capacity of the soil, the presence of sandy layers, depth to groundwater, groundwater hydrology and distance to surface water. For example, a 100 tonne crush winery with a pond located in soils of low permeability with a 2 metre separation from groundwater and 100 metres separation from surface water may present a low ground and surface water contamination risk. Any winery with a pond located in sandy soils in an area with a high water table may present a high risk of ground and surface water contamination.

Groundwater at all wastewater evaporation/percolation ponds should be monitored up and down gradient from the ponds to enable level of environmental impact to be demonstrated or groundwater contamination to be detected.

Ponds are also used by larger wineries for storage and treatment of wastewater with the treated wastewater often being disposed of by irrigation. Many of these ponds are lined and therefore should not present a ground and surface water contamination risk. Pond leakage can be determined by undertaking a water balance.

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[10] Biological oxygen demand (BOD) is higher, and nitrogen and phosphorus much lower in winery wastewater ponds than in dairy effluent ponds. Data from sampling of eight dairy effluent ponds by George et al (1999) and winery wastewater ponds by Winewatch are outlined below.

	Dairy effluent ponds			Winery wastewater ponds		
	BOD mg/L	TN mg/L	TP mg/L	BOD mg/L	TKN mg/L	TP mg/L
Mean	308	593	79	1946	31	9
Min	170	255	23	1300	0.5	2
Max	685	1015	213	3300	52	17

5.3 Disposal to soil infiltration

Ten small wineries dispose of winery wastewater by soil infiltration. Eight of these are disposing of untreated wastewater and two of wastewater that has been through a small treatment system. In most instances wastewater is being piped to an area where it is left to infiltrate. Some wineries discharge wastewater onto marc composting piles. One winery discharges through a roughened channel into a broad swale.

Table 12: Size of wineries using disposal by soil infiltration in the Margaret River wine region

Winery size (tonnes of grapes crushed)	Number of wineries using soil infiltration for disposal of winery wastewater
< 100	5
100 - 149	2
150 - 299	2
> 299	2

The environmental impacts of this disposal method will depend on many factors including the size of the winery, volumes and loadings of wastewater, topography of the disposal area, distance to ground and surface water, vegetation and soil type.

Potential environmental impacts of disposal by soil infiltration include:

- Sodic wastewater may degrade soil structure and lead to decreased soil permeability and increased risk of waterlogging and run-off.
- Ground and surface water contamination through leaching and run-off.
- Plant death resulting from saline/acidic wastewater and nutrient toxicity.

The level of risk with soil infiltration may be quite high as it is often undertaken without consideration of potential impacts. That is, disposal is not carefully designed and managed, and no monitoring of potential impacts occurs.

5.4 Disposal to waterways

There is one known example of winery wastewater being disposed of to surface water via overland flow in the Margaret River wine region. Disposal of untreated wastewater to waterways presents a high environmental risk. The biological oxygen demand of winery wastewater may result in oxygen depletion when discharged into water, leading to the death of fish and other aquatic organisms. The low pH of winery wastewater may also affect aquatic organisms. The nitrogen and phosphorus in the wastewater can contribute to eutrophication and algal blooms.

5.5 Disposal to irrigation

5.5.1 Background

Four small wineries in the Margaret River wine region dispose of winery wastewater through irrigation. The wineries, with an annual crush of 250, 300, 400 and 450 tonnes of grapes, irrigate with untreated wastewater throughout the year.

Minimising the environmental risks associated with irrigation requires careful consideration of inputs and outputs to the irrigation area including wastewater volume, loadings of nutrients, salts and organic matter, rainfall and evaporation. In the example outlined below it can be seen that year round disposal of wastewater requires irrigation during months when rainfall exceeds plant water use. There is a risk of nutrient export from the site during these months as not all wastewater being applied will be used by plants. The level of this risk is discussed below.

Other environmental risks associated with irrigation include soil degradation from saline and sodic wastewater, wastewater runoff to surface water, soil clogging resulting in waterlogging and malodours, nutrient, salt and pH toxicity to plants and soil acidification. These risks are discussed following the example below.

Irrigation example:

Winery B crushes 250 tonne of grapes annually and produces 750,000 litres of wastewater (3 ML of wastewater per 1000 tonnes of grapes crushed). No stormwater from the winery is included in the wastewater stream.

The wastewater system is comprised of three 5000 litre tanks. Irrigation is not scheduled but occurs when wastewater reaches a specified level in the final tank. Approximately 1000 litres of wastewater is pumped to the irrigation site at a time.

The irrigation site of 0.4 ha is planted with *Eucalyptus camaldulensis* (river red gum). John Clarke of Forest Products Commission (personal communication, 12 November 2008) notes that the estimated annual accumulation in biomass of this species is 20 to 25 tonnes fresh weight. The soils at the irrigation site are loamy, gravel duplex soils with a clay layer at 60 cm. The soils have a Phosphorus Retention Index of approximately 200.

The wastewater production and effluent composition are outlined in Table 13.

Table 13: Wastewater volumes and composition for Winery B

Wastewater Production												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Monthly effluent production kL	40	150	150	150	40	40	40	30	30	28	26	26
Effluent Composition												
BOD (mg/L)	1,790	2,716	1,907	3,368	3,477	2,344	3,258	929	2,496	953	1,697	2,531
Total N (mg/L)	23	17	35	110	95	66	85	112	42	55	48	14
Total P (mg/L)	10	10	10	18	25	15	12	12	15	15	17	17
K (mg/L)	300	150	150	150	300	300	300	300	300	300	300	300
EC (dS/m)	1.7	2	1.7	2.8	2.5	2.1	2.8	2.3	2.5	1.6	2.2	2
pH (mg/L)	5.6	4.8	4.8	5.1	4.8	5.1	5.6	5.4	5.3	5.5	5.4	5.4

Table 14 details the water balance for the irrigation site in an average rainfall year including the proposed irrigation to be applied each month. As can be seen the wastewater applied in April, May, June, July, August and September is surplus to the plantation water needs.

Table 14: Water balance for Winery B irrigation site in an average rainfall year

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Irrigated Crop Factor (Cf)	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Monthly Plantation Water Use	186.1	160.9	135.9	82.4	58.5	45.0	47.4	56.3	69.3	97.4	125.7	163.2
Average Effective Rainfall at Site (mm)	8.8	8.6	18.2	39.8	102.7	145.5	145.8	106.3	70.7	46.6	23.9	11.8
Monthly Irrigation requirement (mm)	177.3	152.3	117.7	42.6	-	-	-	-	-	50.8	101.8	151.4
Monthly Irrigation Applied (mm)	10	37.5	37.5	37.5	10	10	10	7.5	7.5	7	6.5	6.5
Surplus/deficit	-167.3	-114.8	-80.2	+5.1	+10	+10	+10	+7.5	+7.5	-43.8	-95.3	-144.9

5.5.2 Nutrients

Tables 15, 16 and 17 put the environmental risk associated with potential nutrient export and organic matter in context by showing the nutrient and BOD inputs to the site and the expected nutrient removal through plant use and soil storage. It can be seen that annual nitrogen and phosphorus inputs are significantly lower than the potential plantation use. BOD is also lower than the Department of Environment and Conservation (NSW) recommended average loading rate of 1500kg/ha/month (NSW Department of Environment and Conservation, 2004) and the Department of Water recommended rate of less than 30 kg/ha/day (DoW, 2006) in all months except February and April.

Irrigation during April, May, June, July, August and September will present a potential environmental risk as inputs to the site will exceed outputs. However, the nitrogen and phosphorous input during these months is fairly minimal, for example, similar to that of between one and two domestic septic tanks (see Table 5, Gerritse, 2002).

The projected potassium loading exceeds the potential removal. The impact of excess potassium loading is not clear. Arienzo et al., 2008, discuss the fate of potassium after land application of wastewaters and state that:

> 'Application of wastewaters with high potassium levels has been found to increase the overall soil fertility, with the exception of alkaline effluents which can dissolve soil organic carbon. Long-term application of such wastewaters may cause the build up of soil potassium, affect soil structure and decrease the hydraulic conductivity of the receiving soil. The effect of wastewater application on soil structure depends on the composition of the water, the exchange complex, the ionic strength of the soil solution and the clay mineralogy, within the soil. These potential impacts are uncertain and have been inadequately researched.'

Table 15: Monthly nutrient and BOD inputs to the 0.4 ha irrigation site at Winery B

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Total N kg	0.92	2.55	5.25	16.5	3.8	4	2.64	3.36	1.26	1.54	1.25	0.36	43.43
Total P kg	0.4	1.5	1.5	2.7	1	0.6	0.6	0.48	0.45	0.42	0.442	0.442	10.54
Total K kg	12	22.5	22.5	22.5	12	12	12	9	8.4	8.4	7.8	7.8	160.5
Total BOD kg	71.6	407.4	286.05	505.2	139.08	93.76	130.32	27.87	74.8	26.68	44.12	65.8	1872.68

Table 16: Nutrient removal through plant use and soil storage and nutrient input limits as calculated by Wastload

	N kg/0.4 kg/ha	P kg/0.4/kg/ha	K kg/0.4/ha
Expected nutrient removal by plants/soil storage	88.8	29.4	59.2
Input limit	124.32	29.4	118.4

Table 17: Monthly BOD loading per hectare

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Total BOD /ha kg	179	1018	715	1263	348	234	326	70	187	67	110	165	4682

5.5.3 Salinity

Irrigating with water of higher salinity than the irrigated plants can tolerate will result in yield loss and affect the nutrient and water uptake by the plants. Plants vary greatly in their tolerance to irrigation with saline water. Most eucalypt species can tolerate salinities up to 4 dS/m with some species such as *Eucalyptus camaldulensis* (river red gum) able to tolerate salinity up to 8 dS/m (Myers et al, 1999).The electrical conductivity of winery wastewater sampled during the Winewatch sampling program ranged from 1 dS/m to 4.55 dS/m, with a vintage mean of 2.3 dS/m and a non-vintage mean of 2.13 dS/m.

There are many factors that influence the affect of salinity on plants including soil type and drainage, the frequency and timing of irrigation, the stage of plant growth, the method of irrigation and rainfall. These factors should all be considered when determining the potential impact of wastewater on a plantation.

5.5.4 Sodicity

Australian soils are generally classified as sodic if they have an exchangeable sodium percentage (ESP) of 6 to 15 and highly sodic if their ESP is more than 15 (Moore, 2004). The actual ESP at which soil dispersion increases depends upon the soil properties. However, any soil ESP determination of 6 and above should trigger investigation. The Sodium Absorption Ratio (SAR) of the wastewater will affect the sodicity of the soil. Effluent with a SAR of greater than 6 is likely to raise ESP in non sodic soils (Department of Environment and Conservation, NSW, 2004). Soil sodicity can be reduced by ameliorating with gypsum (Moore, 2004).

The SAR of winery wastewater sampled during the Winewatch sampling program ranged from 0.6 to 54.9, with a vintage mean of 10.16 and a non-vintage mean of 8.06.

The potential for the development of soil sodicity needs to be investigated when planning and designing an irrigation site and the need for monitoring and amelioration assessed.

5.5.5 Acidity

Acidification may occur as a result of irrigation and affect plant vigour and yield. Effluent with a pH between 5 and 8.5 is generally acceptable for use in irrigation (Department of Environment and Conservation, NSW, 2004). Winery wastewater is generally acidic and may need to be amended before application.

The SAR of winery wastewater sampled during the Winewatch sampling program ranged from 4 to 7.2, with a vintage mean of 5 and a non-vintage mean of 5.2.

5.5.6 Conclusions

Irrigation in April, May, June, July, August and September presents an environmental risk as rainfall during these months negates the need for irrigation. However, as there is a significant decrease in wastewater production after vintage, the level of risk may be acceptable provided the site is well designed and managed.

Using irrigation to dispose of untreated wastewater from small wineries requires careful consideration of the volume and loadings of wastewater, soil type, plant water use, area of land required, distance to ground and surface water. Careful planning and management is essential to minimise environmental risks.

6. Extension program

Project objective 2: Stimulate innovation and the development of skills and techniques required by industry members to rigorously assess their current practices against a set of standards for best management.

Project objective 3: Extend findings on opportunities to improve best practice in winery wastewater treatment and disposal to the broader industry (sub-500 tonne wineries).

Project outputs to meet objectives 2 and 3 are described below.

6.1 Communication

Communication activities undertaken through the project include:

- Media promotion through local newspapers, ABC radio, ABC Landline, Department of Agriculture and Food WA Wine Industry newsletter, Margaret River Wine Industry Association email newsletter, R & D Now and Australia’s Wine Business Monthly.

- One-on-one discussions and site visits with thirty small wineries in the Margaret River wine region. The site visits and discussions with wastewater managers provided an opportunity to develop a clear understanding of current practices, level of knowledge and issues needing to be addressed. It also enabled sharing of project information and the development of a network of wastewater managers in the Margaret River wine region.

- Wastewater management workshop held in partnership with the CSIRO, Swan Catchment Council and Wine Industry Association of WA.

- ‘Wastewater management for small wineries’ workshops held in Margaret River, Swan Valley, Denmark and Busselton.

6.2 Wastewater management fact sheets

Fact sheets were developed to provide information and advice that would facilitate informed decisions on wastewater management. The preliminary survey and communication activities undertaken through the project indicated that the current level of knowledge on best practice wastewater management was low. It was also clear that too much information or information that was too detailed may not be well used by the industry. It was therefore considered most beneficial to develop concise fact sheets outlining the most important considerations and suggestions for where to seek further information. The following fact sheets were prepared:

Winewatch fact sheet 1: Winery wastewater composition and potential environmental impacts of wastewater disposal from small wineries
Winewatch fact sheet 2: Reducing winery wastewater volumes and pollution loads from small wineries
Winewatch fact sheet 3: Winery wastewater disposal to land from small wineries
Winewatch fact sheet 4: Subsurface disposal of winery wastewater for small wineries
Winewatch fact sheet 5: Ponds for percolation/evaporation and storage of winery wastewater from small wineries
Winewatch fact sheet 6: Disposing of winery wastewater from a small winery using irrigation

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Appendix 1: Wastewater monitoring results

		pH			Electrical conductivity mS/m			Total Suspended Solids mg/L			BOD mg/L		
		Winery 1	Winery 2	Winery 3	Winery 1	Winery 2	Winery 3	Winery 1	Winery 2	Winery 3	Winery 1	Winery 2	Winery 3
Vintage	**29/02/2008**	4.5	4.4	4.2	224	99.2	156.4	277	175	113	2230	1370	3000
	5/03/2008	4.5	5.4	4.3	144.3	150.7	192.4	120	363	800	1585	1375	2765
	12/03/2008	4.5	5.3	4.4	127.5	140.5	196.5	106	104	996	1650	570	2890
	20/03/2008	4.8	6.4	4.9	332	133.2	184.4	377	88	497	2920	870	4220
	26/03/2008	4.9	4.8	4.9	236	108.5	175	440	173	120	1110	410	2730
	2/04/2008	5.1	4.7	4	373	217	224	570	108	575	2490	1180	7000
	9/04/2009	4.7	6.8	4.1	349	237	176.4	620	500	2235	2380	581	5260
	16/04/2008	4.5	6.1	4.4	401	331	243	2475	2347	395	4400	2150	4000
	30/04/2008	5.1	6.9	4.9	455	237	194.3	740	650	365	2865	1890	6220
	14/05/2008	4.8	4.9	4.9	390	264	142.1	1775	1155	365	9100	1960	2450
	Mean	**4.7**	**5.5**	**4.5**	**303**	**192**	**188**	**750**	**566**	**646**	**3073**	**1235**	**4053**
	Minimum	4.5	4.4	4	127.5	99.2	142.1	106	88	113	1110	410	2450
	Maximum	5.1	6.9	4.9	455	331	243	2475	2347	2235	9100	2150	7000
	Standard deviation	0.2	0.91	0.36	112.96	76.43	29.57	770.73	709.5	621.8	2303	625	1609
Non-vintage	**20/02/2008**	no sample	6.6	4.4	no sample	170.6	168.3	no sample	293	117	no sample	210	870
	29/05/2008	4.9	4.9	4.8	221	262	194.7	209	510	830	1235	2800	3255
	11/06/2008	4.4	6.1	4.7	321	247	95.1	405	445	360	5437	1855	3195
	25/06/2008	4.9	5.5	5.1	229	221	128.6	81	198	208	1280	855	1440
	23/07/2008	4.8	7.2	4.9	412	298	130.5	258	590	45	2958	4403	2413
	6/08/2008	4.7	5.8	6.2	304	359	326	86	153	41	1720	2495	123
	22/08/2008	4.7	6	5.1	171.4	137.8	84.8	42	89	43	610	347	280
	3/09/2008	4.4	6.5	5	266	128.5	359	244	78	118	2350	440	2700
	17/09/2008	4.5	6.7	4.8	297	149.5	295	193	50	73	2815	264	6405
	2/10/2008	4.7	6.8	5.1	150.8	182.5	163.6	59	68	116	820	383	1660
	29/10/2008	4.9	6.9	4.8	174.5	209	87.5	69	72	51	1050	251	1550
	19/11/2008	4.8	7.1	4.5	208	330	113.6	168	134	91	1635	732	2725
	10/12/2008	4.7	6.6	4.9	159.7	183.7	269	508	54	560	565	464	6565
	7/01/2009	4.6	6.6		188.4	154		436	160		2700	880	
	4/02/2009	4.5	5.2	4.9	271	183.5	185.7	210	228	164	4885	2515	4805
	18/02/2009	4.1	6.3	4.5	286	222	167.7	196	60	185	3745	1977	2300
	4/03/2009	4.4	4.7	4.1	155.6	140	240	190	166	232	2340	1800	1362
	Mean	**4.6**	**6.2**	**4.8**	**238**	**210**	**188**	**209**	**196**	**202**	**2259**	**1333**	**2603**
	Minimum	4.1	4.7	4.1	150.8	128.5	84.8	42	50	41	565	210	123
	Maximum	4.9	7.2	6.2	412	359	359	508	590	830	5437	4403	6565
	Standard deviation	0.22	0.75	0.45	73.89	68.89	86.48	138.3	167.9	215.9	1461	1199	1921

		TKN mg/L			TP mg/L			Calcium mg/L			Magnesium mg/L		
		Winery 1	**Winery 2**	**Winery 3**	**Winery 1**	**Winery 2**	**Winery 3**	**Winery 1**	**Winery 2**	**Winery 3**	**Winery 1**	**Winery 2**	**Winery 3**
Vintage	**29/02/2008**	24.38	20.08	22.93	3.37	4.72	6.7	52	29	16	20	13	15
	5/03/2008	17.18	33.44	36.94	5.36	6.59	8.24	96	28	54	10	7.9	14
	12/03/2008	9.35	60.22	36.72	5.43	12.21	11.88	38	24	62	15	7.7	15
	20/03/2008	51.9	20.13	25.99	12.96	6.33	11.28	48	25	46	19	12	20
	26/03/2008	60.75	88.12	78.46	12.66	9.57	9.97	24	17	37	11	7.3	16
	2/04/2008	151.55	19.33	63.82	21.55	4.7	16.32	45	18	42	15	12	21
	9/04/2009	146.9	51.01	23.66	19.94	10.31	23.27	50	14	54	17	8.2	16
	16/04/2008	317.85	180.14	28.78	34.55	22.64	14.45	54	15	48	19	8.7	16
	30/04/2008	155.5	92.7	83.35	20.41	14.02	16.93	39	10	44	15	7.6	11
	14/05/2008	111.48	203.3	36.59	36.49	33.11	16.52	29	29	43	13	7.7	10
	Mean	**104.6**	**76.8**	**43.7**	**17.2**	**12.4**	**13.5**	**47.5**	**20.9**	**44.6**	**15.4**	**9.21**	**15.4**
	Minimum	9.35	19.33	22.93	3.37	4.7	6.7	24	10	16	10	7.3	10
	Maximum	317.85	203.3	83.35	36.49	33.11	23.27	96	29	62	20	13	21
	Standard deviation	94.2	66.3	22.8	11.6	9	4.9	19.6	6.9	12.3	3.4	2.2	3.4
Non-vintage	**20/02/2008**	no sample	19.1	11.78	no sample	5.95	7.51	no sample	21	38	no sample	8.3	12
	29/05/2008	46.46	38.68	133.95	15.67	23.94	23.82	43	22	40	9	7.7	8.3
	11/06/2008	62.8	119.2	15.14	13.98	20.48	11.27	50	25	45	21	7.1	6.9
	25/06/2008	51.74	125	19.65	12.17	21.79	11.36	43	23	36	16	6.8	9
	23/07/2008	123.15	103.05	28.76	15.51	17.47	3.8	45	10	40	13	4.9	11
	6/08/2008	306.77	224.02	60.25	14.07	15.84	0.05	44	18	26	12	6	2.9
	22/08/2008	23.69	37.39	16.6	16.45	23.17	2.47	49	31	61	11	5	6.7
	3/09/2008	41.24	70.7	21.11	14.27	15.24	11.71	76	18	72	16	4.9	12
	17/09/2008	30.21	67.97	18.45	10.89	18.33	19.76	55	15	54	14	5	14
	2/10/2008	32.79	121.5	8.93	8.59	20.06	14.43	54	27	49	13	6.2	9.4
	29/10/2008	34.27	124.02	9.55	11.41	23.23	15.37	48	20	26	12	5.5	7.3
	19/11/2008	35.05	97.2	13.16	15.22	20.38	14.77	54	69	49	10	7.8	9.2
	10/12/2008	9.35	16.65	15.21	19.44	9.64	21.45	49	49	72	9.9	6.3	16
	7/01/2009	15.9	30.1		9.94	11.1		71	29		13	6.7	
	4/02/2009	18.68	56.45	5.85	13.16	12.89	9.79	74	27	50	15	10	13
	18/02/2009	4.15	3.77	2.37	18.29	6.04	17.99	80	54	69	21	10	18
	4/03/2009	3.26	1.44	2.54	8.66	7.45	17.92	32	22	42	12	7.8	13
	Mean	**52.4**	**73.8**	**23.9**	**13.6**	**16**	**12.7**	**54.1**	**28.2**	**48**	**13.6**	**6.8**	**10.5**
	Minimum	3.26	1.44	2.37	8.59	5.95	0.05	32	10	26	9	4.9	2.9
	Maximum	306.77	73.89	23.95	19.44	23.94	23.82	80	69	72	21	10	18
	Standard deviation	73.65	58.44	32.3	3.19	6.18	6.84	13.8	15.25	14.58	3.52	1.62	3.84

		Sodium mg/L			SAR		
		Winery 1	**Winery 2**	**Winery 3**	**Winery 1**	**Winery 2**	**Winery 3**
Vintage	**29/02/2008**	430	120	78	13	4.7	2.2
	5/03/2008	160	200	180	4.2	8.6	5.6
	12/03/2008	210	160	170	7.3	7.3	5
	20/03/2008	360	210	140	11.1	8.6	4.3
	26/03/2008	230	170	190	9.7	8.7	6.6
	2/04/2008	480	320	140	15.8	14.3	4.4
	9/04/2009	300	470	60	6.7	24.6	1.8
	16/04/2008	510	650	150	15.2	32.9	4.8
	30/04/2008	400	460	91	13.8	26.6	3.9
	14/05/2008	420	310	150	16.2	13.2	5.3
	Mean	**350**	**307**	**134.9**	**11.3**	**14.9**	**4.3**
	Minimum	160	120	60	4.2	4.7	1.8
	Maximum	510	650	190	16.2	32.9	6.6
	Standard deviation	119.7	171.2	44.2	4.2	9.64	1.47
Non-vinatge	**20/02/2008**	no sample	230	190	no sample	10.7	6.9
	29/05/2008	160	400	120	5.8	18.6	4.5
	11/06/2008	300	350	42	8.9	25.2	2.3
	25/06/2008	180	280	46	5.9	13.2	1.8
	23/07/2008	280	850	110	9.4	54.9	4
	6/08/2008	230	820	12	7.9	42.6	0.6
	22/08/2008	150	150	38	5	6.6	1.2
	3/09/2008	180	110	120	4.9	5.9	3.5
	17/09/2008	290	110	86	9	6.3	2.7
	2/10/2008	150	100	60	4.8	4.5	2.1
	29/10/2008	180	100	45	6	5.1	2
	19/11/2008	220	90	93	7.2	2.7	3.2
	10/12/2008	150	110	190	5.1	3.9	5.2
	7/01/2009	220	140		6.3	6.1	
	4/02/2009	440	220	82	12.2	9.2	2.7
	18/02/2009	390	200	150	10	6.6	4.2
	4/03/2009	240	240	110	9.2	11.2	3.8
	Mean	**235**	**264.7**	**93.3**	**7.3**	**13.7**	**3.16**
	Minimum	150	90	12	4.8	2.7	0.6
	Maximum	440	850	190	12.2	54.9	6.9
	Standard deviation	86.4	233.1	52.9	2.2	14.5	1.5

Appendix 2: Soil sampling report by Soil Management Consultants Pty Ltd

1. Introduction

Soil sampling was undertaken at the wastewater disposal sites at the three small wineries participating in the Winewatch monitoring program. The aim of the sampling was to identify whether changes to soil properties and structure had occurred as a result of winery wastewater disposal.

2. Methodology

Sampling was carried out on 21 April 2008 which coincided with the latter part of effluent disposal during vintage. The three wineries use different methods for disposing of winery effluent, as described below.

Soil profiles were sampled to include the top of an impeding clay layer in areas that had received effluent, and in reference (unaffected) areas. Topsoil (0 to 10 and 10 to 20cm, A and B samples) were taken by combining material from 15 and 10 auger holes respectively, and subsoil (C, D and E samples) were combined from 6 auger holes. Sampling depths and sample identification are outlined in Table 1.

2.1 Description of disposal areas being sampled

Winery 1

At Winery 1, effluent is distributed to a block of approximately 0.2ha of trees, via irrigation pipes with 1cm holes drilled at 1.5m intervals. The distribution system allows for irrigation to be alternated between the northern and southern halves of the block. There are 10 rows of trees with irrigation pipes running downslope within alternate midrows. All trees appeared healthy. There is a creek about 20m from the bottom of the disposal area. Winery wastewater has been disposed of on in this area since 2000.

At the time of sampling, distribution of effluent was not uniform, so that much of the area was unaffected (dry), with occasional small wet areas around pipes. Some dripper holes were blocked with sludge. There was one area in the centre of the block where effluent distribution appeared to be about optimum, and this was classed as moderate exposure to effluent. At the bottom of the slope in the north-east corner, there was a very wet area (high exposure to effluent) across four rows of trees that supported much undergrowth compared with the rest of the block. This excessively wet area resulted from preferred outflow under gravity. The dripper holes in the pipes in this area had eroded so that they were larger than 1cm allowing an increased flow. Effluent could be heard trickling onto the ground, and excess liquid ran past the lower perimeter of the block and onto the bank of the creek.

Reference Site: Samples to 80cm were taken within several midrows with no irrigation. The soil is loamy gravel duplex, with clay at 60cm.
Moderate Exposure Site: Samples were taken along the third row from the south side, in moist soil at a distance of about 30cm from outlets. Several wetter areas were avoided. The soil is similar to the reference site.
High Exposure Site: Samples were taken near the boundary of the wettest area. The soil here is brown loamy duplex. Rock was encountered at 90cm in several auger holes. An extra clay subsoil sample was taken at this site to assess whether effluent had penetrated deeper than just the top of the clay layer.

Winery 2

At Winery 2, disposal is to two leach drains which have imported white sand forming a 1m mound over the outlets. There are a number of small trees on the mound, but some of these appeared to be dead. The leach drains are located 30 metres from a small tributary and 60 metres from a dam. Kikuyu grass surrounds the leach drain to the north, east and south, although the latter area had been sprayed to facilitate tree planting. On the west side is natural bush. This is upslope and receives no overflow from the leach drain. Imported clay from an excavated dam had been spread across some of the area surrounding the leach drain. The leach drain system was constructed in February 2001.

The capacity of the leach drain appeared to have been exceeded by a considerable degree, as there was a significant area of outwash to the north, east and south. This had affected kikuyu growth variably, with patches of luxury growth, normal growth and dead grass.

Reference Site was 12-15m to the north-east of the leach drain, with kikuyu grass that appeared to be growing without extra water or nutrients from effluent outwash. The soil is a brown loamy sand duplex, possibly natural.
Moderate Exposure Site: Samples were taken in a scald area to the south-east of the leach drain, where topsoil was moist but not saturated. There is about 20cm of imported clay above the natural soil.
High Exposure Site: Due east of the leach drain there was a scald area with saturated topsoil, with about 25-30cm of imported clay soil.
Leach Drain Sample: A sample of white sand was taken from the top 15cm of the leach drain, adjacent to the dead trees. The subsoil was saturated, so deeper sampling was not possible with a hand auger.

Winery 3

At Winery 3, effluent is pumped to an excavated primary pond, with an outlet to a secondary pond. The primary pond had a small breach in the wall just below water level, and effluent had flowed onto an adjacent row of vines, many of which were dead. The ponds have been used for wastewater disposal since 2000.

Reference Site was four rows downslope from the affected zone, with healthy vines. The soil is yellow-brown sandy gradational over rock at 75cm.
High Exposure Site: Samples were taken next to dead vines. Soil is yellow sandy gradational, strongly mottled at 70cm. Clay subsoil had been stained blue-grey.

Table 1: Soil descriptions and sample details for winery effluent disposal sites

Winery	Disposal Area	Soil description	Depth cm	Samples
1	**Reference**	Loamy gravel duplex, clay at 60cm	0-10 10-20 25-50 60-80	1 A-D
	Moderate	Loamy gravel duplex, clay at 60cm	0-10 10-20 25-50 60-80	2 A-D
	High	Brown loamy duplex over rock at 90cm in several holes	0-10 10-20 25-45 50-70 70-90	3 A-E
2	**Reference**	Natural brown loamy sand duplex, clay at 60cm	0-10 10-20 25-50 60-80	4 A-D
	Moderate outwash	Artificial profile, 20cm of imported gravelly clay spread on natural soil	0-10 10-20 20-30 35-50	5 A-D
	High outwash	Artificial profile, 25cm of imported gravelly clay spread on natural soil	0-10 10-20 20-30 35-50	6 A-D
	Leach drain	Imported white sand, saturated	0-15	7 A
3	**High overflow**	Yellow sandy gradational, strong mottles at 70cm, subsoil stained blue-grey	0-10 10-20 25-45 50-70	8 A-D
	Reference	Yellow-brown sandy gradational	0-10 10-20 25-45 50-70	9 A-D

2.3 Sample Preparation and Analysis

The majority of analyses were carried out on the fine-earth fraction of dried, sieved soil. However for analysis of Inorganic-N (ammonium and nitrate nitrogen) a special procedure was used for field-moist soils, to avoid potentially large changes to the amount and composition of Inorganic-N that can occur during drying of soils (SMC, 2007 and SMC, 2008).

2.3.1 Inorganic-N Analysis

On the day after collection, subsamples of moist soil were mixed with 1M KCL solution and shaken frequently over 24 hours. The supernatant was separated and delivered to the analysis laboratory within 48 hours for analysis of ammonium and nitrate-N. The measured values were adjusted for the extraction ratio and the soil moisture content, and were converted to concentrations in mg/kg on a dry whole soil basis.

2.3.2 Other Analyses and Physical Tests

Samples were oven-dried at 40-50degC (moisture content was determined) and sieved to less than 2mm (gravel content was determined). The fine-earth fraction was analysed for soil reaction (pH1:5 in water pHw and calcium chloride pHCa), salinity (EC1:5 and chloride), bicarbonate extractable phosphorus and potassium (Bic P and Bic K, Colwell method), phosphorus retention index (PRI, Allen and Jeffery 1990 method) and exchangeable cations (Ca, Mg, K, Na and Al extracted in ammonium chloride solution). Topsoil samples were also analysed for organic carbon, Total P and Total N. Selected samples were subjected to a laboratory gypsum response test to assess the potential for topsoil dispersion or subsoil swelling under waterlogged conditions.

3. Results

The figures referred to in the text and the results of chemical analysis and physical tests are presented at the conclusion of the report.

3.1 Gravel

The proportions of gravel by weight were 19-53% for Winery 1 samples, 10-34% for Winery 2 samples, and 4-10% for Winery 3 samples. These proportions are typical of loamy gravel duplex (Winery 1) and sandy gradational (Winery 3) soils of the Margaret River region (eg. profiles MR4 and MR3 in McArthur 1991).

3.2 Moisture

Moisture content at sampling is reported on a dry soil basis (DSB). At each winery, effluent sites had average profile moistures that were 5-9 %DSB higher than reference sites, with the biggest difference being at Winery 2 for the high effluent exposure site (24% v 15%). Effluent site topsoils had 21-26 %DSB and 13-26 %DSB respectively for 0-10 and 10-20cm samples, and clay subsoil samples had 15-25 %DSB. The latter samples appear to have been below field moisture capacity. Clay subsoils for similar gravel duplex soils at Albany were reported to have indicative values for the upper water limit (UWL or field capacity) and lower water limit (LWL or wilting point) of 52% and 25 %w/w respectively (ERG, 2001).

3.3 Salinity (EC1:5 and Chloride)

Salinity was low at all sites with EC1:5 values of no more than 18 mS/m. At Winery 1 and Winery 3, effluent site topsoil samples had EC1:5 values that were marginally higher (4-8 mS/m) than reference sites, and there was no difference at Winery 2. At the three wineries there was no significant difference in EC1:5 for clay subsoil samples, all of which had very low values of 6-9 mS/m. In line with EC1:5 data, chloride concentrations were also low in all samples (2-72 mg/kg).

3.4 Soil reaction (pHw)

At Winery 1 and Winery 2, effluent disposal had a minimal effect on soil pH (**Figure 1**), with soils maintained at about neutral or slightly acid in reaction. The mean profile pHw values for reference and effluent sites respectively were 7.1, 7.3 and 7.3 at Winery 1, and 6.6, 6.2 and 6.8 at Winery 2.

However at Winery 3, effluent site subsoil samples were about 1 pH unit higher than reference site samples. The higher pHw was in contrast with analysis results that indicated a strongly acid effluent from Winery 3, with a pH range of 4.0-4.9 over the vintage period.

3.5 Organic C

There was no clear trend for differences in the concentrations of organic carbon between reference or effluent site topsoil samples. The mean results for 0-10 and 10-20cm samples from reference sites at each of the wineries were 2.5%, 3.5% and 2.2% organic carbon, and by comparison the effluent sites had 3.0%, 1.9% and 2.0% organic carbon.

3.6 Total N

At Winery 1 the moderate effluent exposure site had nearly 50% more Total N (0.51%) in the top 10cm of soil compared with the reference site (0.35%). The high exposure site at Winery 1 and effluent sites at the other wineries showed only minor differences (<=0.03%) with the respective reference sites.

The **ratio of organic carbon to Total N** (C/N) was not significantly different for topsoil samples from reference or effluent sites, except for the Winery 1 moderate effluent exposure site (**Figure 2**). The C/N ratio of 12.3 for all but one sample was within the range for topsoils under legume based pastures (CSIRO, 1983). The C/N ratio of 5.6 for the Winery 1 moderate exposure site indicates topsoil that has been relatively enriched with organic-N that would become available under conditions that favour decomposition of organic matter and mineralisation reactions.

3.7 Inorganic Nitrogen

Profile data for inorganic-N are shown in Figure 3 (ammonium-N) and Figure 4 (nitrate-N).

Ammonium-N concentrations were <1-5 mg/kg at reference sites. At effluent sites they were a maximum of 18 mg/kg in topsoil at Winery 1, and 29 mg/kg in topsoil at Winery 3. Such concentrations are typical of fertile topsoils, and would not represent an environmental risk because ammonium-N is adsorbed on the cation exchange complex. For example topsoil samples from under turf at Margaret River (SMC, Sept 2008) or from the midrows of an effluent-irrigated woodlot on old farming land (SMC, Oct 2008) had ammonium-N concentrations of 5-29 mg/kg.

At Winery 1 moderate and high effluent exposure sites, and at Winery 2 moderate exposure site there was not a significant difference in subsoil ammonium-N compared with reference sites.

At the high exposure sites of Wineries 2 and 3, subsoil ammonium-N concentrations were slightly higher than the reference sites by 5-7 mg/kg. At Winery 3 this would have been a function of the waterlogging and leaching conditions that would have existed following the pond wall breach. At both sites some ammonium leaching appears to have occurred, but only under conditions of excessive effluent loading.

Nitrate-N concentrations were considerably higher (3-26 mg/kg) in the soil profile at the moderate effluent exposure site at Winery 2, and slightly higher (1-7 mg/kg) at the moderate exposure site at Winery 1, compared with reference site sample concentrations of 0.7-3.1 and 0.1-1.1 mg/kg respectively. At these two effluent sites most of the nitrate-N was in topsoil samples to 20cm, but some nitrate had been leached to 50cm and 30cm respectively.

At Winery 3, only the 0-10cm sample had a slightly higher nitrate-N concentration of 8.5 mg/kg compared with 3.3 mg/kg for the reference site sample.

At the Winery 2 moderate exposure site, the higher concentrations of nitrate-N would be equivalent to at least 55 kg/ha more of plant-available N in soil to 30cm compared with the reference profile. There was no nitrate-N in the one-off effluent sample taken in May, so soil nitrate-N would have come from mineralisation of organic-N in effluent and subsequent nitrification of ammonium-N. Up to the time of sampling in April, soil temperatures would have been conducive to those reactions.

Nitrate is rapidly leached, either vertically or laterally with excess rainfall, irrigation or runoff, because it is not adsorbed by soil colloids. Some degree of vertical leaching had occurred at the moderate exposure sites at both Winery 1 and Winery 2, but not to beyond the root zone of either the trees at Winery 1 or the kikuyu grass at Winery 2.

For the high effluent exposure sites at Winery 1 and Winery 2, all samples had extremely small concentrations of nitrate-N (<1 mg/kg), lower than the reference site samples. This suggests that any nitrate derived from mineralisation of effluent organic N was lost by a combination of plant uptake, leaching or denitrification from saturated surface soils. There was evidence of some vertical leaching at the Winery 2 site because subsoil samples (from 20-50cm) had ammonium-N concentrations that were 5-6 mg/kg higher than the reference samples. Given the relatively low permeability of clay soil at this site and obvious signs of runoff, then lateral leaching may have been the major mechanism for nitrate loss from this sampling area.

3.8 Phosphorus

When assessing the effects of effluent on soil P levels, the concentrations of Total P and bicarbonate-extractable P (Bic P), together with phosphorus retention properties (PRI), all need to be considered.

The **Phosphorus Retention Index (PRI)** test was developed specifically for WA soils, and the P-retention capacity was classified according to criteria established by the Chemistry Centre of WA (Allen and Jeffery, 1990). These classifications are:

PRI <2 very low P-retention   2-5 low   5-20 moderate   20-70 high   >70 very high

The PRI test has been used by various agencies to assess the environmental risks associated with nutrient inputs to soils from wastewater. For example, a PRI value of 10 is used to separate coarse-grained (sand or gravel) and fine-grained (loam or peat) soils for assignment of a 'Vulnerability Category' to the environmental risk of nutrient export (DEC, 2006). Similarly a PRI value of at least 20 is specified by the Health Department for amended soils used in on-site domestic wastewater systems.

The **Total P** method dissolves organic and inorganic forms of P, including fertiliser or effluent P that has been 'fixed' by soil and not readily available for plant uptake. For the majority of virgin soils in the southwest of WA, topsoil samples have Total P concentrations of 10-250 mg/kg (McArthur, 1991), with lower or similar concentrations in subsoils. However there are examples of a yellow gradational soil with much higher topsoil Total P (270-440 mg/kg), and a yellow duplex soil with Total P that increases down the profile from 260 in topsoil to 1700 mg/kg at a depth of 60cm (Profiles MR5 and PTN 2 respectively in McArthur, 1991).

Bicarbonate-extractable P (Bic P) indicates the amount of adsorbed (exchangeable) P in soil. Concentrations of Bic P are usually <5 mg/kg in virgin southwest soils (McArthur, 1991) which are acutely deficient in P for agriculture. Therefore Bic P data, in conjunction with PRI results, are generally more sensitive to the effects of applied effluent and the environmental risks from P leaching. One exception to this is where soil erosion is a potential factor in waterways pollution, where Total P concentration would be more important.

Total P, Bic P and PRI results are summarised in **Table 2** and the concentrations of Total P and Bic P for topsoil samples are compared graphically in **Figure 5**.

Table 2: Summary of Total P, Bic P and PRI results for <2mm soil samples

	Depth	**Winery 1**			**Winery 2**			**Winery 3**	
	cm	**Ref**	**Mod**	**High**	**Ref**	**Mod**	**High**	**Ref**	**High**
Total P mg/kg	0-10	417	876	467	347	365	284	355	460
	10-20	170	408	144	472	338	299	190	112
	subsoil								
Bic P mg/kg	0-10	29	122	22	12	10	10	28	112
	10-20	9	47	8	3	9	7	14	18
	subsoil	7-3	6-2	3-3	2-2	7-8	9-8	5-2	5-2
PRI	0-10	240	139	143	>1000	509	322	70	47
	10-20	102	200	125	650	>1000	>1000	58	26
	subsoil	89-617	150-810	130-690	1000	>1000	750	28-35	28-108

PRI values for sieved samples were 100-240, 320->1000 and 26-70 respectively for Winery 1, Winery 2 and Winery 3 topsoils, and the corresponding subsoils had PRI values of 89-810, 650->1000 and 28-108. Based on these data, all sites would be classified as having soil profiles with very high P-retention capacity.

At the Winery 1 moderate exposure site, Total P in topsoil samples was higher than reference samples by 410 mg/kg for 0-10cm and 240 mg/kg for 10-20cm. The corresponding Bic P concentrations were 122 and 47 mg/kg, compared with 29 and 9 mg/kg for the reference site. All subsoil samples had Bic P concentrations of <10 mg/kg.

Similarly at the Winery 3 high exposure site, there appeared to be complete retention of effluent P within the topsoil, with no indication of P leaching beyond 20cm. For the 0-10cm sample, Total P and Bic P were respectively 105 and 84 mg/kg higher than the reference sample. Subsoil sample Bic P concentrations were identical.

The above Bic P results suggest that a significant proportion of effluent Total P may be exchangeable, more than was indicated by the effluent orthophosphate-P data. This could be of environmental concern for runoff and leaching where soils have limited P-retention capacity.

At the Winery 1 high effluent exposure site, there was no significant difference in Total P or Bic P compared with the reference site. The respective averages for 0-10 and 10-20cm samples were 305 and 295 mg/kg for Total P, and 15 and 19 mg/kg for Bic P.

At both Winery 2 effluent exposure sites, the concentrations of Total P and Bic P were not higher than the reference site results. The respective average concentrations for 0-10 and 10-20cm samples from high, moderate and reference sites were 290, 350 and 410 mg/kg for Total P, and 8, 10 and 8 mg/kg for Bic P.

For all soil samples from Winery 2 (except from the leach drain), Bic P was a smaller proportion of Total P compared with the other winery samples (**Figure 5**). Winery 2 samples had the highest PRIs of all, so applied P would be more strongly adsorbed, resulting in a smaller fraction of exchangeable Bic P. However there was no evidence of significant P accumulation at either of the effluent exposure sites. Another explanation is that the excavated dam clay that was spread across the Winery 2 disposal site had an abnormally high natural Total P concentration, similar to material from the yellow soil profiles mentioned above.

The leach drain sample from Winery 2 had a PRI value of 0.8. This sandy soil was almost completely 'saturated' with P, and thus would no longer be effective as a nutrient trap. It is estimated that the initial PRI of this soil would have been about 4, and hence classified as low P-retention capacity, and well below the minimum PRI of 20 that is specified for material used in domestic on-site wastewater treatment systems.

3.9 Potassium

Soil potassium was measured by two procedures, bicarbonate extractable K (Bic K) and exchangeable K (1M ammonium chloride extract). The relationship between them was:

$$\text{Bic K} = 9 + 410 * \text{Exchangeable K} \qquad r^2 = 0.95$$

which is not significantly different to the theoretical relationship (Bic K = 390 * Exch K), and confirmed the generally good agreement between the methods.

Profile trends in **Bic K** are shown in **Figure 6**. Compared with reference sites, there were higher concentrations of Bic K at the Winery 1 moderate exposure site, at the Winery 2 high exposure site and at Winery 3. The profile means for Bic K were 640, 280 and 360 mg/kg respectively compared with 320, 160 and 60 mg/kg for the reference sites.

For the Winery 1 high exposure site a significantly greater concentrations of Bic K (920 mg/kg) was only measured in the 0-10cm sample compared with 360 mg/kg for the reference sample. The mean subsoil sample results for this site were 340 and 300 mg/kg respectively.

At the Winery 2 moderate exposure site, Bic K concentrations were not significantly different to the reference site with profile means of 180 and 160 mg/kg respectively.

3.10 Cation Exchange Capacity

The effective cation exchange capacity (ECEC) was calculated by summation of the exchangeable cations (calcium, magnesium, potassium, sodium and aluminium). Profile trends in ECEC are shown in **Figure 7**.

The mean ECEC values for topsoil samples from each winery were 11 (range 5-16), 7.5 (range 6-14) and 5.2 (range 3-8) me/100g respectively. The variations within and between wineries reflect differences mainly in the topsoil concentrations of organic carbon (higher OC = higher ECEC), but also clay content, mineralogy and pH. There may also have been some degree of 'contamination' of effluent site topsoils which can cause false high readings for exchangeable cations. This is a common effect in agricultural topsoils where lime, gypsum or phosphate fertiliser residues cause contamination of exchangeable calcium results.

Ratio of ECEC to Organic C: The ratios of ECEC/OC for winery topsoil samples were in the range 2.6-5.5, although all but one were between 2.6-4.0, which is similar to both the ratio range for topsoil samples from reference soils in the SW of WA (McArthur 1991), and also the range of 2.5-4.0 given for humified organic matter (Purdie 1998). The highest ECEC/OC ratio of 5.5 was for the 0-10cm sample from the Winery 1 moderate effluent exposure site. This sample also had a much higher Total N, indicating recent accumulation of organic matter from effluent.

For clay subsoil samples the ECEC indicates the likely major type of clay mineral in the clay fraction (McArthur 1991), and this is important for consideration of the potential negative effects of sodic effluent on soil profile permeability. The mean ECEC values of subsoil samples were 3.6, 6.6 and 2.2 me/100g respectively for Wineries 1-3, and these indicate that kaolinite is the dominant clay mineral.

3.11 Exchangeable Sodium and Potassium (ESP and EPP)

The effects of effluent on soil sodium and potassium are shown in **Figures 8** and **9** where the profile trends in ESP and EPP are plotted.

Exchangeable Sodium (Potassium) Percentage (ESP or EPP) = 100 * Exch Na (K) / ECEC

ESP: There were large increases in ESP at the Winery 1 moderate effluent exposure and Winery 2 high exposure sites, with values up to 27% and 17% respectively compared with reference profile ESP levels of 7-12 and 1-12%. At the former site ESP was very high (21-27%) in all subsoil samples, whereas at the latter site high ESPs were not measured in samples deeper than 20cm. These effects were consistent with the high levels of effluent sodicity for these wineries.

There was a lesser effect on ESP at the Winery 1 high effluent exposure site, where the mean profile ESP was 12 compared with 21 at the moderate site and 8.8 at the reference site. At the Winery 2 moderate exposure site the mean profile ESP of 4.0 was not significantly different to that of 5.0 for the reference site.

At Winery 3, there was no difference in ESP between the effluent and reference sites. Profile mean values were 7.1 and 6.9. Effluent from this winery had a very low to low sodicity rating throughout vintage.

EPP: At Winery 1 EPP was higher in samples from both effluent sites, with profile means of 15% and 17% compared with 10% EPP for the reference site. Reference site subsoil EPP values were 16-18%, compared with 24-26% at the moderate exposure site and 26-31% at the high exposure site. At the Winery 1 high exposure site, the effect of effluent potassium on EPP was more marked than the effect of effluent sodium on ESP.

At Winery 2, the mean profile EPP values were 5.1, 6.1 and 10 respectively for reference, moderate and high exposure sites. As was the case with ESP, the effect at the latter site was confined to the top 20cm of soil.

At Winery 3, the effect of effluent on EPP was most marked, with profile mean values of 3.7 and 28 for reference and high exposure sites. At the effluent site, EPP increased gradually with depth from 20 to 38%. This was the only winery that used potassium based cleaning chemicals exclusively.

At winery effluent disposal sites, the **combined effects of higher ESP and EPP** were to reduce considerably the proportions of exchangeable calcium and magnesium. The levels of ESP+EPP varied from <10% at reference sites to as much as 50% at effluent sites. At Wineries 1 and 2 both ESP and EPP increased, whereas at Winery 3 only EPP increased while ESP remained at the same level of <10%. The proportion of exchangeable calcium was lowered from 60-80% in reference samples to 30-40% at effluent sites, and exchangeable magnesium from 20-30% to 5-25%.

3.12 Gypsum Response Test

This test compares the degree of dispersion of topsoil samples or swelling of subsoil samples in suspensions of soil in either water or saturated gypsum solution, as an indication of poor surface soil structure (Dellar et al., 1988) or potential reduced permeability of clay subsoils.

Topsoil Samples: For Winery 1 there was no difference between the topsoil samples from the moderate effluent exposure site and the reference site, with both recording a negligible degree of dispersion. However the sample from the high exposure site had a moderate degree of dispersion.

At Winery 2, samples from the reference site and high exposure site respectively had a slight-moderate and moderate degree of dispersion, while the moderate exposure site was non-dispersive. Topsoil from the Winery 3 effluent site had a slight-moderate degree of dispersion.

Given the topsoil disturbance at the Winery 1 high exposure and both Winery 2 effluent sites plus the low level of salinity, it was not surprising that some degree of dispersion was measured (Cass, 1999). The high level of EPP may have contributed to the dispersion of the Winery 3 topsoil sample.

Subsoil Samples: No sample showed any degree of swelling. This indicated that the high levels of ESP+EPP had probably not been detrimental to soil permeability at any site. The dominance of kaolinite as the clay mineral in subsoils would have been an important factor.

4. ESP, EPP and Soil Structure

High levels of exchangeable sodium can have a deleterious effect on the physico-chemical properties of soils (Keren and Shainberg, 1985), depending on the clay mineralogy. In south-west WA the majority of clay subsoils have kaolinite as the major clay mineral (McArthur, 1991). Kaolinite is an inactive clay mineral (very low CEC) and there is evidence to suggest that even very high levels of ESP do not result in the swelling of clay subsoils that would reduce soil permeability (SMC, 2007).

However there are vineyards in the SW of WA with soils that have highly active clay minerals. *SMC* has investigated two vineyards with structured swelling clay soils (vertisols) where the ECEC of subsoil was about 30 me/100g, consistent with the presence of active clay minerals such as illite and smectite. There are several examples of such soils (Profiles SCP4 and SCP6) described in McArthur (1991).

It is not common for both sodium and potassium to be dominant factors in determining the composition of the exchangeable cation complex associated with organic matter and clay colloids. The effect of increased EPP alone on aggregate stability (dispersion) or on subsoil permeability has generally proved to be less than ESP, including in studies with the highly active clay mineral montmorillonite (Keren, 1985). It has been suggested that potassium acts similarly to magnesium. High levels of exchangeable magnesium (especially in conjunction with high ESP) were reported to have a negative effect on soil structure for some Eastern States clay soils (Rengasamy and Churchman, 1999), although those soils usually have clay minerals more active than kaolinite. Therefore it is likely that high EPP would exacerbate any effect of high ESP in soils with more active clay minerals.

5. Summary of the effects of effluent disposal

The effects of effluent on changes to the various soil chemical properties at each winery, compared with the reference sites, are summarised in **Table 3**.

Table 3: Summary of the effects of effluent compared with reference sites

Effluent Input	Winery 1 Mod	Winery 1 High	Winery 2 Mod	Winery 2 High	Winery 3	Comment
	Mean change in profile relative to Reference Site					
EC1:5 mS/m	+6	+2	+1	+2	+3	
pH	+0.2	+0.2	-0.4	+0.2	+1.1 (sub)	
Total N %	+0.16	-0.03	-0.02	-0.01	+0.03	Top 10cm
NH4-N mg/kg	+2.6	+4.2	0	+2.3	+12	
NO3-N mg/kg	+2.0	-1.4	+15	-0.2	+1.0	
Total P mg/kg	+350	+7	-60	-120	+15	Top 20cm
Bic P mg/kg	+66	-4	+2	+1	+44	Top 20cm
Bic K mg/kg	+320	+170	+29	+120	+240	
ESP %	+13	+3	-1	+6	+0.2	
EPP %	+8	+12	+1	+5	+24	
ESP+EPP	+21	+15	0	+11	+24	

5.1 Winery 1

Moderate Exposure Site: The results, especially for P, indicate that there had been effective infiltration of effluent at this site. Both Total P and Bic P had accumulated to a significant level to a depth of 20cm, but there was no leaching of P beyond 20cm in the very high PRI soil. Total N had accumulated in the top 10cm, and there were slightly elevated concentrations of inorganic-N, but it appears nitrate-N had been effectively taken up by trees or ground cover. Both ESP and EPP had increased throughout the soil profile. There was no increase in the degree of dispersion of topsoil or swelling of subsoil indicating that permeability had not been affected.

High Exposure Site: In contrast to the moderate exposure site, the results indicate that there was ineffective infiltration of effluent at this site. Both Total P and Bic P were not significantly different to the reference site. EPP had increased somewhat throughout the soil profile, but not ESP. A moderate degree of dispersion of topsoil was noted at this site. It would appear that much of the effluent that reached this part of the disposal area had run off towards the creek. This would explain the very low concentrations of nitrate-N at this site as a result of lateral leaching.

5.2 Winery 2

At Winery 2, the results for P cannot be used to assess the effectiveness of infiltration because much of the effluent-P would have been retained within the leach drain soil or the immediate surrounds.

Moderate Exposure Site: As well as P, there was also no indication of accumulation of salt (EC), sodium (ESP), potassium (EPP) or ammonium-N at this site. Yet the concentrations of nitrate-N were highest at this site, and there was an indication of leaching to a depth of at least 30cm. During a period of no effluent disposal and warm conditions, there may have been a flush of inorganic-N from organic matter previously deposited on the soil surface. With a rainfall event, some nitrate would have been leached. Soluble effluent components such as sodium and potassium would have been largely removed in runoff during earlier effluent disposal events.

High Exposure Site: There was an obvious increase in ESP and EPP in the top 20cm of soil, but not in subsoil samples. Ammonium-N was also higher than the reference site, with evidence of leaching to a depth of 50cm, in contrast to the results for ESP and EPP. Whereas nitrate-N was highest at the moderate exposure site, it was very low at this site, similar to the high exposure site at Winery 1. It may have been that denitrification was an important factor given the saturated surface soil and a supply of carbon (OC = 4.38%).

Leach Drain: The leach drain design capacity appears to have been based on wastewater inputs spread evenly (daily) over a full year, such as for a domestic situation, and not for the inputs to be concentrated into several months. Consequently there was significant overflow during periods of effluent disposal. The PRI of leach drain soil was not high enough.

Although the leach drain capacity had been grossly exceeded and results indicate that there was ineffective soil infiltration of the outwash, there was no environmental risk at this site because the surrounding grass cover would have intercepted nutrients that escaped in runoff from the areas sampled.

5.3 Winery 3

All results were consistent with effective infiltration of effluent derived from use of potassium based chemicals, except for the elevated subsoil pH levels which were in contrast to the strongly acid reaction of effluent samples. Waterlogging may have been the cause of vine death.

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Fig. 1 Winery Effluent Project Profile pHw

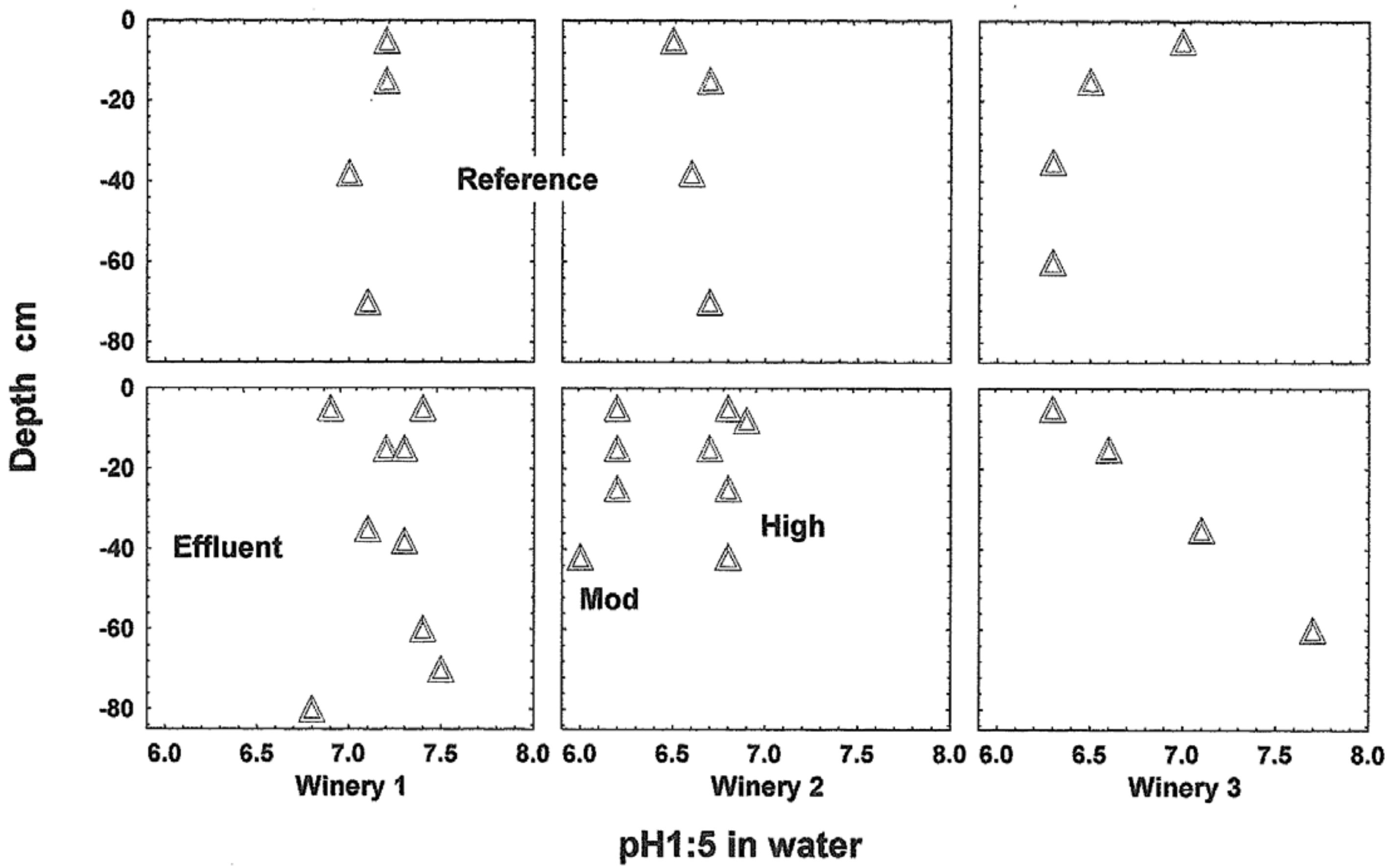
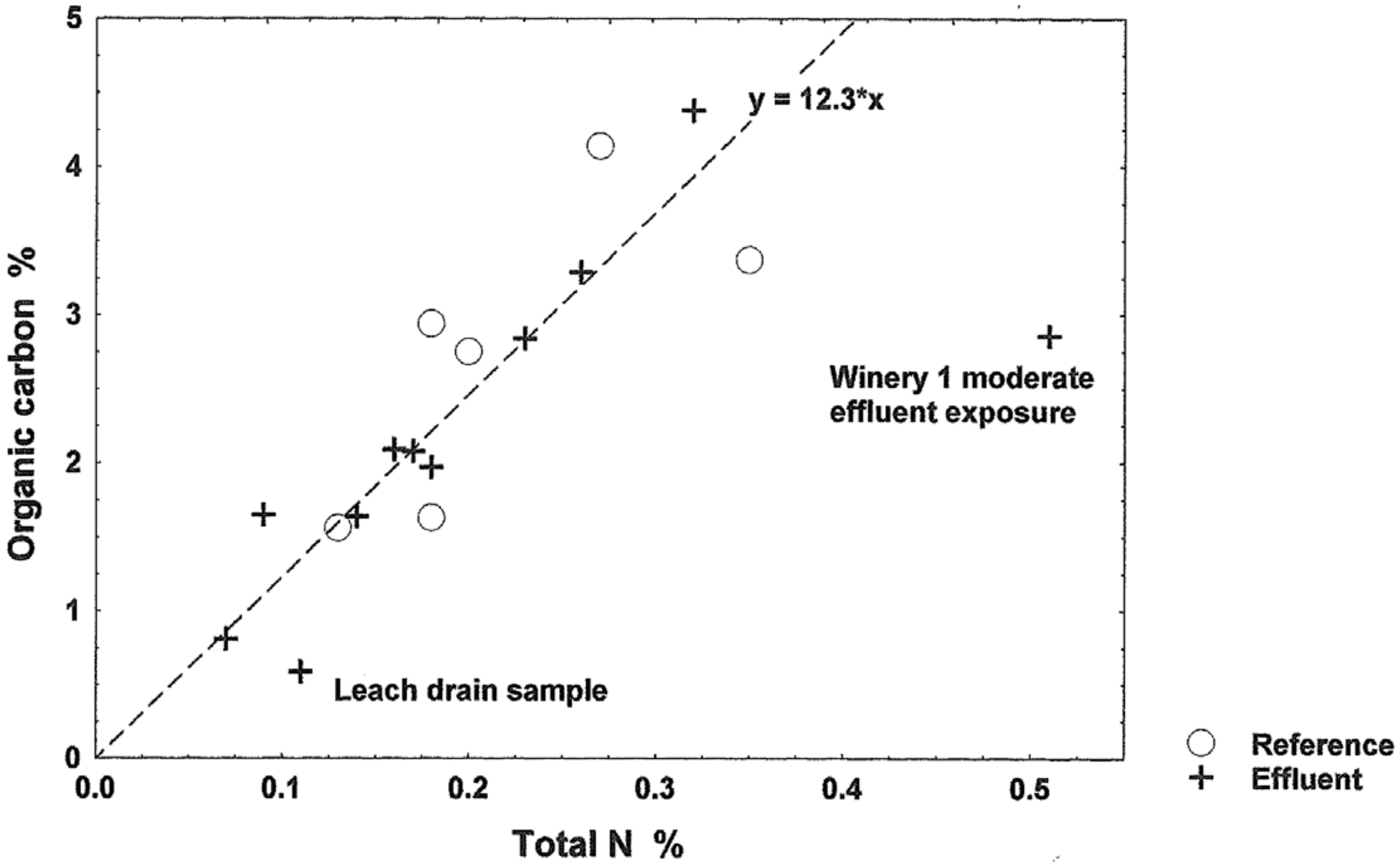


Fig 2. Winery Effluent Project Org C v Total N for topsoils



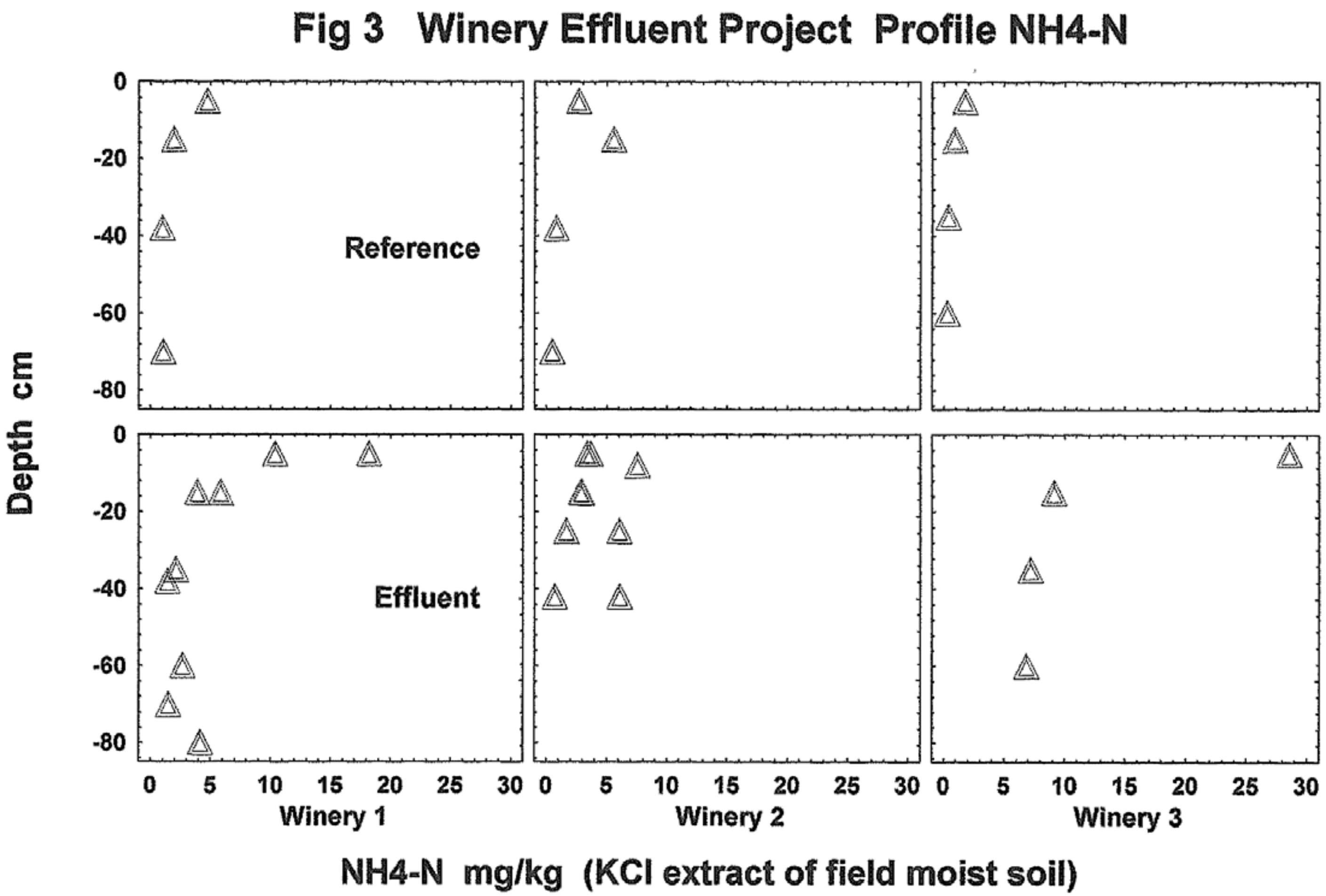


Fig 3 Winery Effluent Project Profile NH4-N
Depth cm
0
-20
-40
-60
-80
Reference
Effluent
0 5 10 15 20 25 30
Winery 1
Winery 2
Winery 3
NH4-N mg/kg (KCl extract of field moist soil)

Fig 4 Winery Effluent Project Profile NO3-N

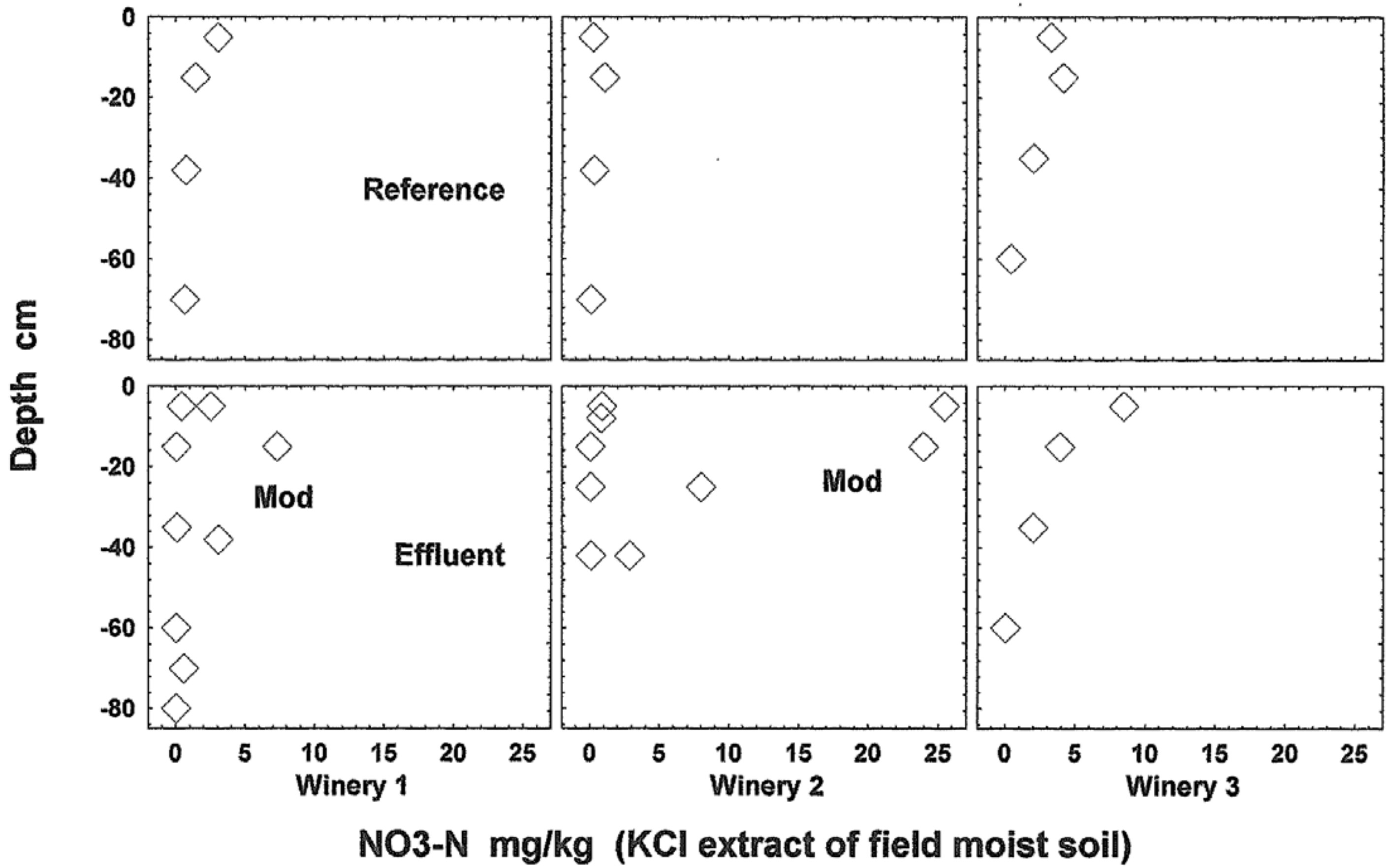
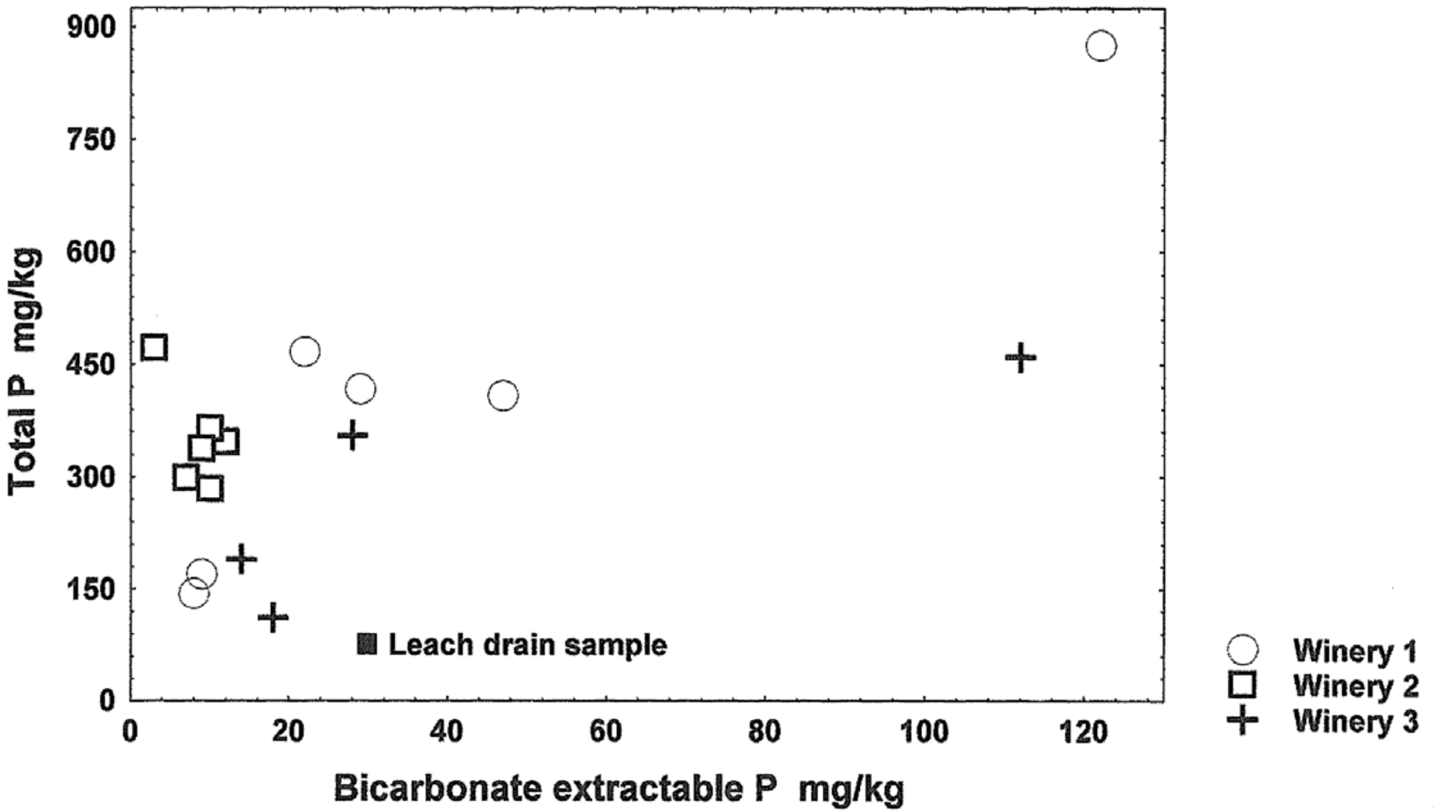


Fig. 5 Winery Effluent Project Total P v Bic P in topsoil samples



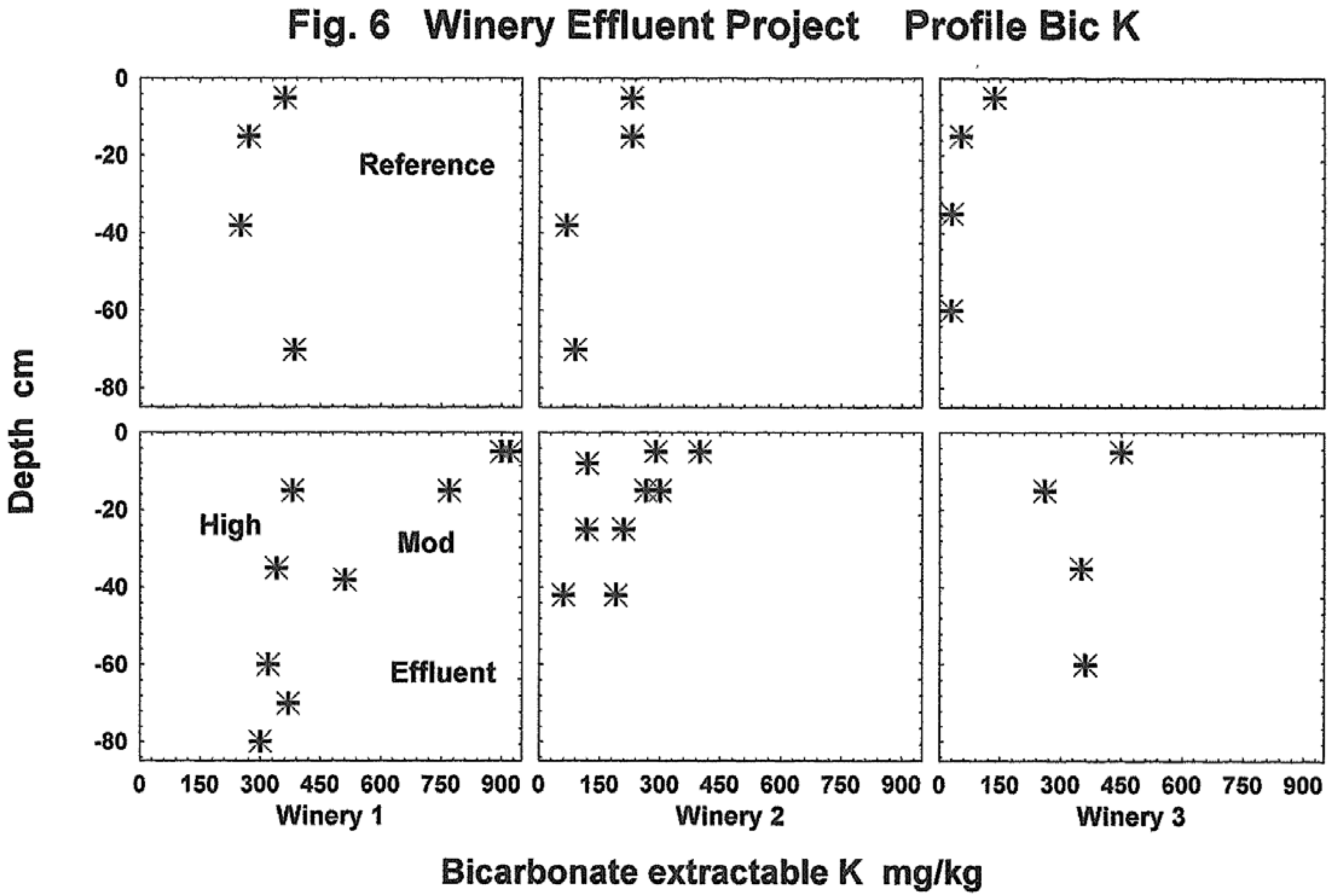
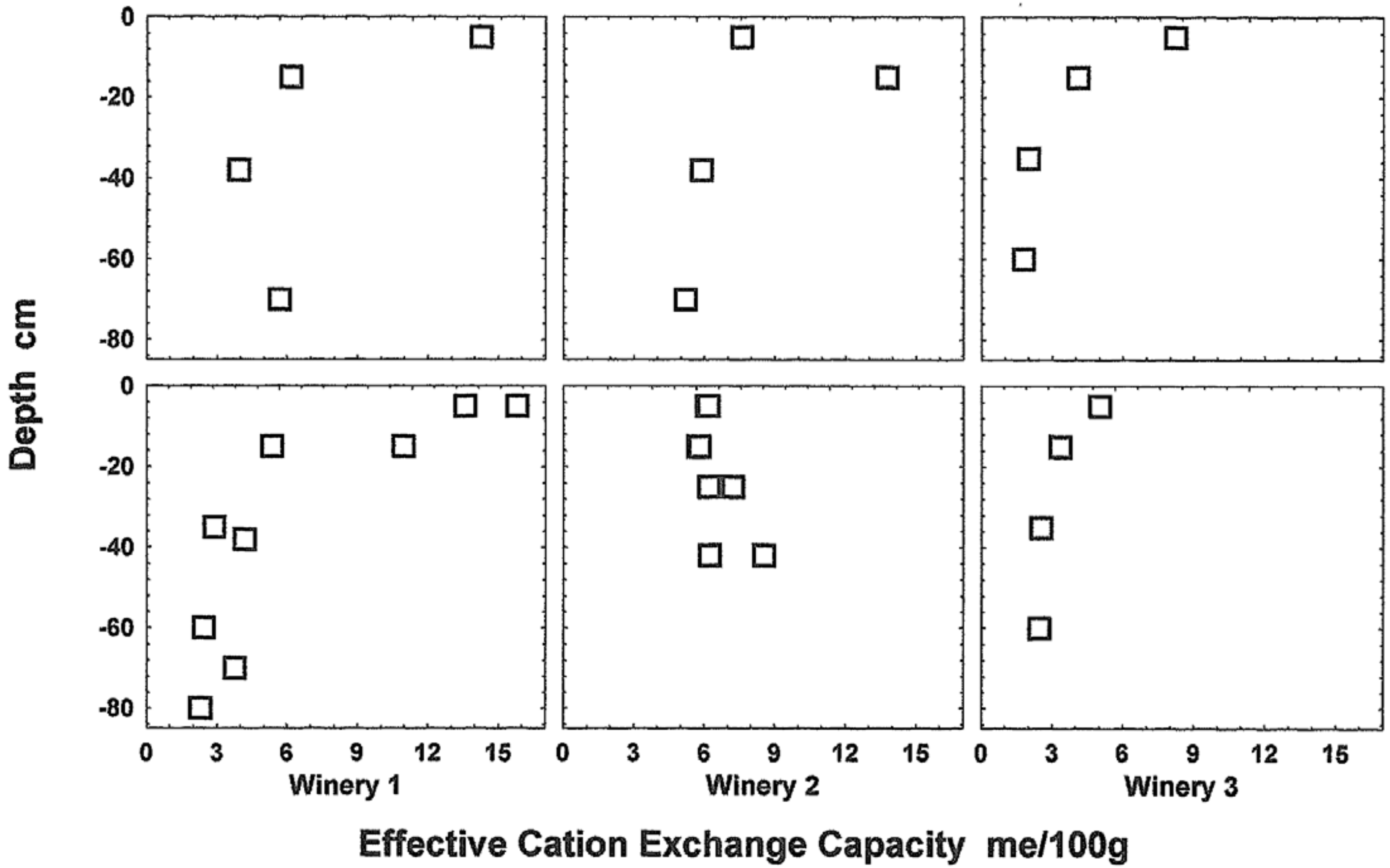


Fig. 6 Winery Effluent Project Profile Bic K
Reference
High
Mod
Effluent
Depth cm
0
-20
-40
-60
-80
0 150 300 450 600 750 900
Winery 1
Winery 2
Winery 3
Bicarbonate extractable K mg/kg

Fig. 7 Winery Effluent Project Profile Values of ECEC



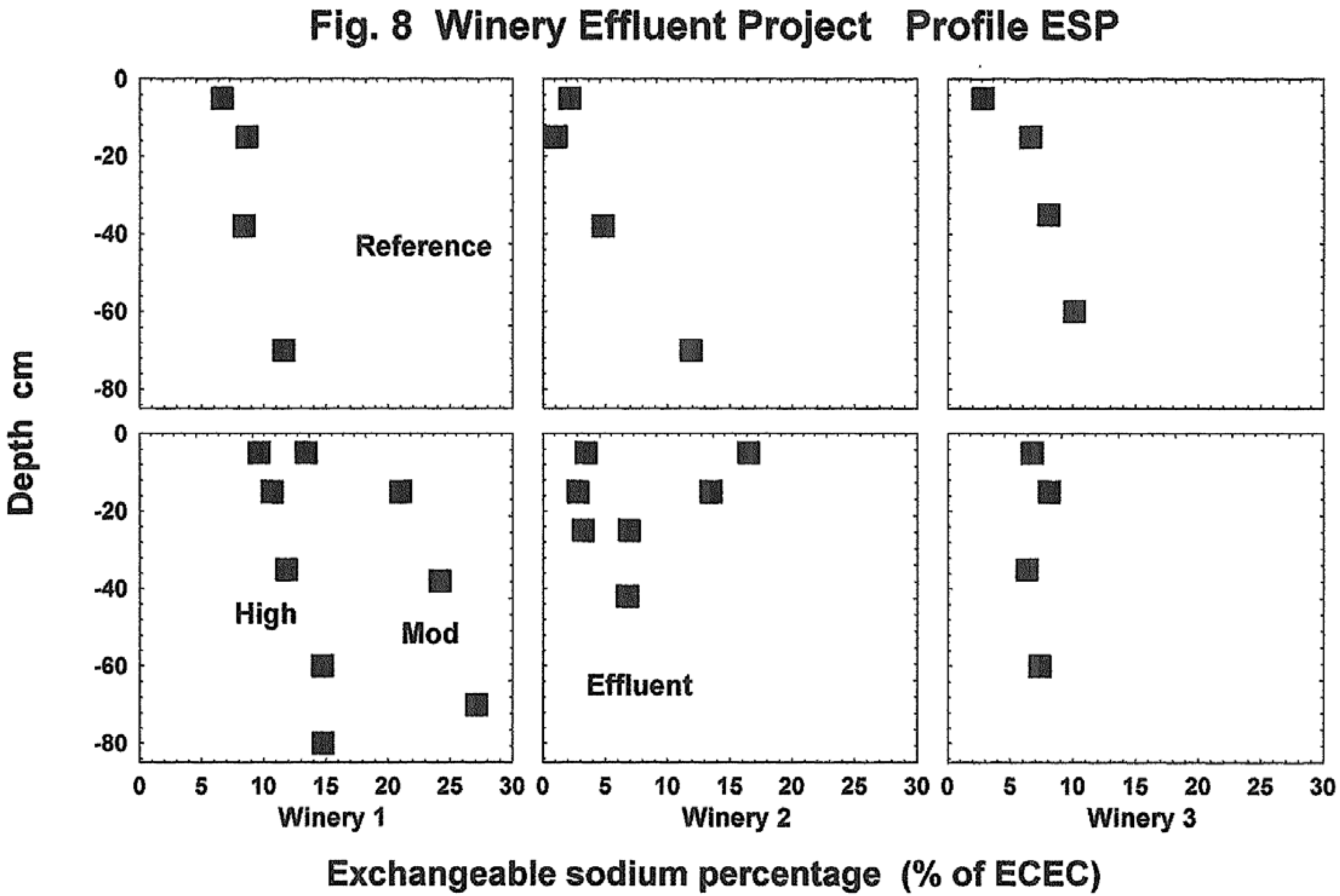


Fig. 8 Winery Effluent Project Profile ESP
Depth cm
0
-20
-40
-60
-80
Reference
High
Mod
Effluent
0 5 10 15 20 25 30
Winery 1
Winery 2
Winery 3
Exchangeable sodium percentage (% of ECEC)

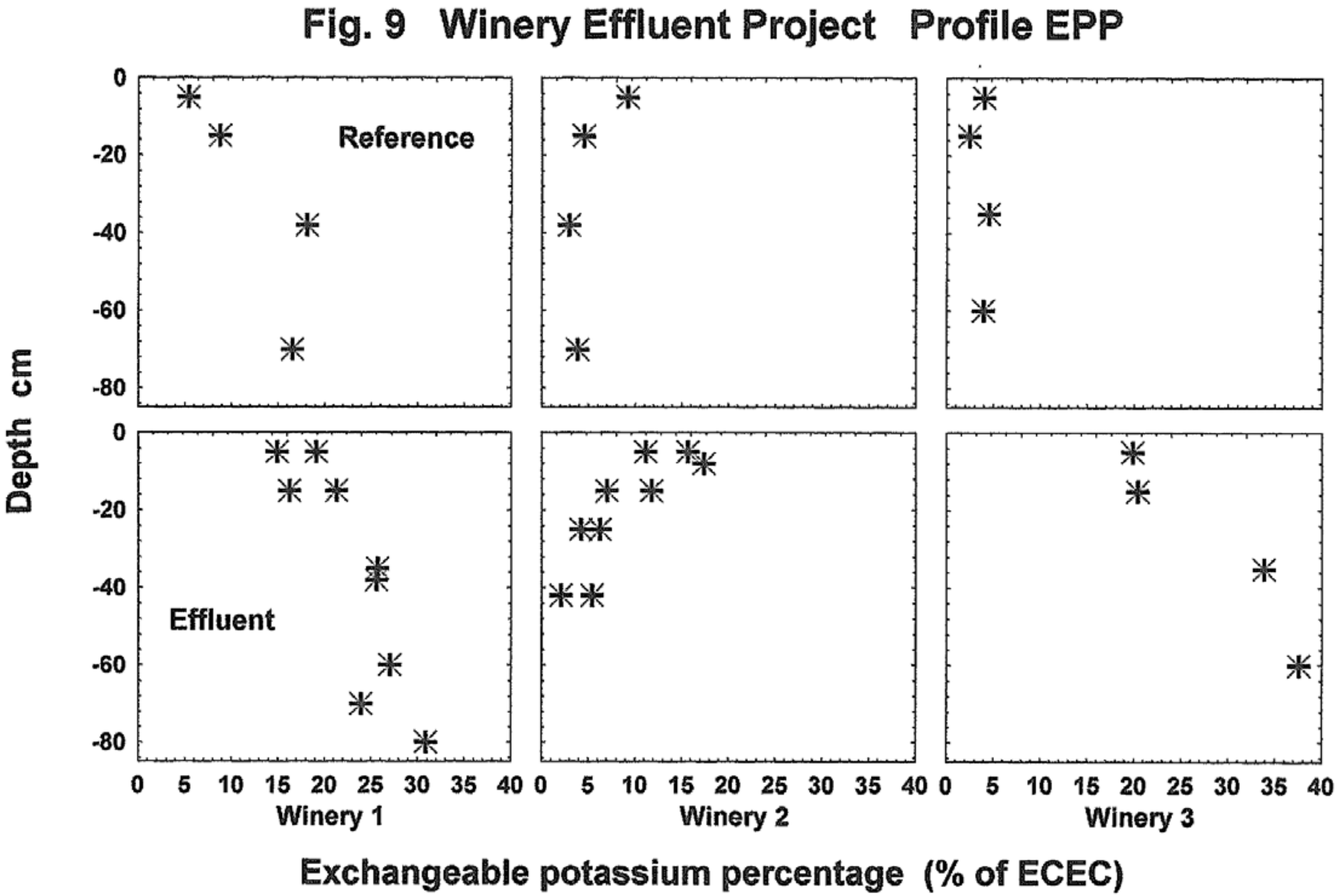


Fig. 9 Winery Effluent Project Profile EPP
Reference
Effluent
Depth cm
0
-20
-40
-60
-80
0 5 10 15 20 25 30 35 40
Winery 1
Winery 2
Winery 3
Exchangeable potassium percentage (% of ECEC)

Soil sampling results

Sample	**Winery**	**Site**	**Depth** cm	**Gravel** %	**EC1:5** mS/m	**pH H2O**	**Bicarb P** mg/kg	**Total P** mg/kg
1A	1	Reference	-5	26	11	7.2	29	417
1B	1	Reference	-15	33	6	7.2	9	170
1C	1	Reference	-38	50	4	7	7	
1D	1	Reference	-70	35	6	7.1	3	
2A	1	Moderate	-5	26	18	6.9	122	876
2B	1	Moderate	-15	40	15	7.3	47	408
2C	1	Moderate	-38	53	8	7.3	6	
2D	1	High	-70	35	9	7.5	2	
3A	1	High	-5	19	15	7.4	22	467
3B	1	High	-15	34	9	7.2	8	144
3C	1	High	-35	30	5	7.1	3	
3D	1	High	-60	28	5	7.4	3	
3E	1	High	-80	44	7	6.8	8	
4A	2	Reference	-5	15	8	6.5	12	347
4B	2	Reference	-15	18	7	6.7	3	472
4C	2	Reference	-38	10	5	6.6	2	
4D	2	Reference	-70	14	6	6.7	2	
5A	2	Moderate	-5	22	9	6.2	10	365
5B	2	Moderate	-15	30	8	6.2	9	338
5C	2	Moderate	-25	34	7	6.2	7	
5D	2	Moderate	-42	25	6	6	8	
6A	2	High	-5	23	8	6.8	10	284
6B	2	High	-15	29	8	6.7	7	299
6C	2	High	-25	42	8	6.8	9	
6D	2	High	-42	24	8	6.8	8	
7A	2	High	-8	18	5	6.9	30	76
8A	3	High	-5	9	12	6.3	112	460
8B	3	High	-15	10	8	6.6	18	112
8C	3	High	-35	7	4	7.1	5	
8D	3	High	-60	8	8	7.7	2	
9A	3	Reference	-5	4	6	7	28	355
9B	3	Reference	-15	4	7	6.5	14	190
9C	3	Reference	-35	6	4	6.3	5	
9D	3	Reference	-60	9	4	6.3	2	

Sample	**PRI**	**Bicarb K** mg/kg	**Ca exch** me %	**Mg exch** me %	**Na exch** me %	**K exch** me %	**Al exch** me %	**Moisture** %DSB
1A	240	360	9.22	3.32	0.95	0.77	0.01	14
1B	102	270	3.64	1.43	0.53	0.54	0.01	7
1C	89	250	2.03	0.84	0.33	0.71	0.01	6
1D	617	385	2.67	1.4	0.66	0.94	0.01	12
2A	139	900	9.33	1.99	2.12	2.36	0.01	24
2B	200	770	5.71	1.15	2.3	1.78	0.01	13
2C	150	510	1.66	0.43	1.01	1.07	0.01	8
2D	807	370	1.18	0.65	1.02	0.9	0.01	15
3A	143	920	7.7	1.97	1.31	2.6	0.01	25
3B	125	380	2.87	0.76	0.57	1.14	0.01	15
3C	127	340	1.3	0.49	0.34	0.74	0.01	15
3D	64	320	0.91	0.5	0.36	0.66	0.01	14
3E	691	300	0.68	0.56	0.34	0.71	0.01	14
4A	1100	230	4.8	1.92	0.16	0.7	0.01	17
4B	655	230	11.6	1.4	0.14	0.62	0.01	15
4C	851	68	4.38	1.02	0.28	0.17	0.01	14
4D	1020	90	2.6	1.78	0.62	0.2	0.01	15
5A	509	290	3.19	2.02	0.21	0.68	0.01	22
5B	1620	265	3.41	1.73	0.16	0.4	0.01	21
5C	1570	118	3.45	2.28	0.2	0.26	0.01	17
5D	2000	60	2.48	3.12	0.42	0.13	0.08	20
6A	322	400	2.55	1.63	1.02	0.97	0.01	24
6B	1210	300	2.62	1.69	0.78	0.68	0.01	26
6C	929	210	4.64	1.63	0.5	0.45	0.01	21
6D	622	190	6	1.5	0.58	0.46	0.01	25
7A	0.8	120	0.64	0.15	0.48	0.27	0.01	15
8A	47	450	3.29	0.32	0.34	1	0.08	21
8B	26	260	2.22	0.15	0.27	0.68	0.01	15
8C	28	350	1.41	0.1	0.16	0.86	0.01	15
8D	108	360	1.24	0.1	0.18	0.92	0.01	16
9A	70	135	6.71	0.94	0.23	0.33	0.01	19
9B	58	52	3.05	0.65	0.27	0.1	0.01	12
9C	28	30	1.26	0.39	0.16	0.09	0.09	9
9D	35	29	0.97	0.55	0.18	0.07	0.01	8

Sample	NH4-N mg/kg	NO3-N mg/kg	Inorg-N mg/kg	Org C %	Total N %	pH Ca	Chloride mg/kg	Dispersion rate 0-10	Swelling rate 0-10
1A	4.7	3.1	7.8	3.37	0.35	6.2	72	0	0
1B	2.0	1.4	3.4	1.63	0.18	6.2	32		
1C	1.0	0.7	1.7			5.8	7		
1D	1.1	0.7	1.8			6.1	54	5	0
2A	10.4	2.5	12.9	2.86	0.51	5.9	45	0	0
2B	5.9	7.3	13.2	3.29	0.26	6.3	44		
2C	1.4	3.1	4.5			6.3	45		
2D	1.5	0.6	2.1			6.5	67	7	0
3A	18.2	0.4	18.7	4.38	0.32	6.4	52	5	0
3B	3.9	0.0	4.0	1.65	0.09	6.2	25		
3C	2.1	0.1	2.2			6.1	30		
3D	2.7	0.0	2.7			6.4	26	5	0
3E	4.2	0.0	4.2			6.2	30	0	0
4A	2.7	0.3	3.0	2.94	0.18	5.7	53	3	0
4B	5.6	1.1	6.7	4.14	0.27	6	43	5	0
4C	0.8	0.3	1.1			5.8	31		
4D	0.5	0.1	0.6			5.7	50	3	0
5A	3.7	25.5	29.1	2.09	0.16	5.4	32	1	0
5B	3.0	23.9	26.9	1.97	0.18	5.5	30	0	0
5C	1.7	8.0	9.6			5.5	22		
5D	0.7	2.8	3.6			5.3	46	0	0
6A	3.4	0.9	4.3	2.08	0.17	5.8	35	5	0
6B	2.9	0.0	2.9	1.64	0.14	5.7	62	5	0
6C	6.1	0.0	6.1			5.9	52		
6D	6.1	0.1	6.2			5.9	61	5	0
7A	7.6	0.8	8.4	0.59	0.11	5.9	4		
8A	28.6	8.5	37.0	2.84	0.23	5.3	29	3	0
8B	9.1	3.9	13.0	0.81	0.07	5.6	20	5	0
8C	7.2	2.0	9.2			6.1	14	7	0
8D	6.9	0.0	6.9			6.7	6	1	0
9A	1.8	3.3	5.1	2.75	0.2	6	2		
9B	0.9	4.2	5.1	1.56	0.13	5.7	22		
9C	0.4	2.0	2.4			5.4	25	5	0
9D	0.3	0.4	0.7			5.6	19	5	0