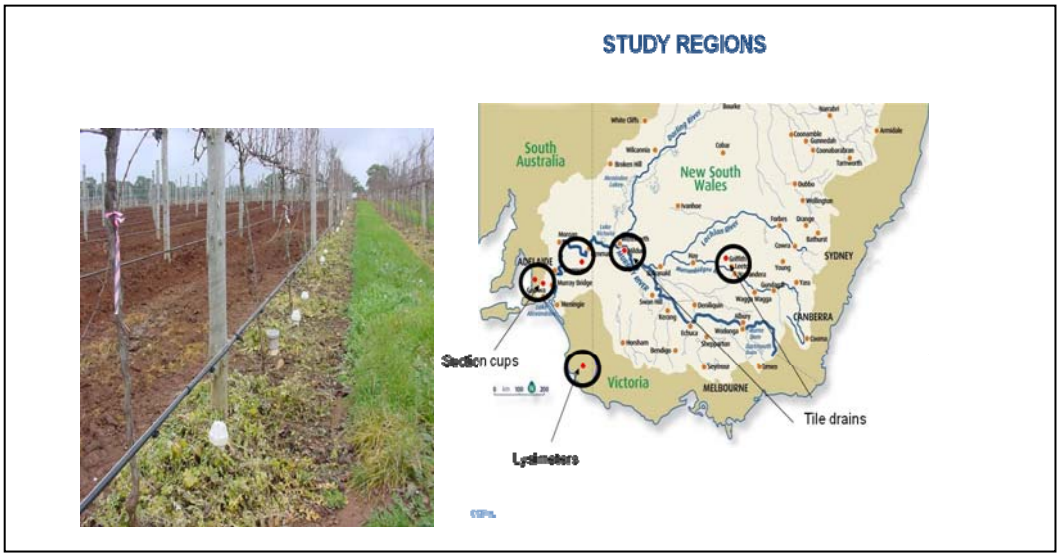
MANAGING ROOT-ZONE WATER QUALITY



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FINAL REPORT to

GRAPE AND WINE RESEARCH & DEVELOPMENT CORPORATION

Project Number: **CSL 06/02**

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Research Organisation: **CSIRO Land and Water**

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MANAGING ROOT-ZONE WATER QUALITY

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GLOSSARY

ANZECC	Australian and New Zealand Environment Conservation Council
APHA	American Public Health Association
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
AVPMA	Australian Pesticide and Veterinary Medicines Authority
AWIS	Australian Wine Industry Stewardship
BDL	below detection limit
CFA	continuous flow analyser
CMA	Catchment Management Authority
CSU	Charles Sturt University
DL	detection limit
DPI	Department Primary Industries
DW	dry weight
EC	electrical conductivity
FIA	flow injection analysis
FMIT	First Mildura Irrigation Trust
GC	gas chromatography
GC-MS	gas chromatography-mass spectrometry
GHD	
HPLC	High Performance Liquid Chromatography
ICP-OES	Inductively Coupled Plasma- Optical Emission Spectrometry
Koppen Csa	Koppen Classification : Mediterranean Climate
L	contaminant load
MDB	Murray Darling Basin
MIA	Murrumbidgee Irrigation Area
MIL	Murrumbidgee Irrigation Limited
ML	mega litres
NA	not available [analysed/ checking]
NM	not measured
NS	not sampled
PIRI	Pesticide Impact Rating Index
PTFE	[Teflon]
QL	quantifiable limit
SAR	Sodium Adsorption Ratio
SARDI	South Australian Research and Development Corporation
SPE	Solid Phase Extraction (cartridge)
TDN	total dissolved nitrogen
TDP	total dissolved phosphate
TN	total nitrogen
TSS	total soluble salts
UCS	Under canopy sprinkler
WHO	World Health Organisation
WQG	Water Quality Guidelines

1. ABSTRACT

This GWRDC/CSIRO project was commissioned to obtain a better understanding of the leaching of contaminants through the root-zone and to suggest management options to improve drainage water quality. In this project the quality of the drainage waters was assessed in several regions (Sunraysia, Riverland, Murrumbidgee Irrigation Area, McLaren Vale and Southeast of South Australia) during the period of 2007-09. Water samples were collected from the few tile drains that were still flowing, from suction cups deployed at different depths in vineyards and from the deep drainage from lysimeters. The data showed that little drainage past the root-zone was occurring, and as a result the load (but not concentrations) of agrochemicals in drainage water has declined dramatically in recent years. The project highlighted new challenges on root-zone salinity build-up and potential accumulation of other chemicals in the lower layers of soil profile. The accumulation is anticipated to affect both quantity and quality of grape harvest as well as presenting a threat to drainage water quality when a flushing event does occur. The occasional natural flushing can cause elevated concentrations of agrochemicals in the drainage water. A balance between adequate drainage and efficient water usage is therefore essential.

2. EXECUTIVE SUMMARY

Background

Viticulture industry is continuously striving for the fine-tuning of their production systems to address the 'triple bottom line' and to remain proactive in assessing new economic, social and environmental challenges. This is evident from the industry's adoption of its Australian Wine Industry Stewardship (AWIS) program, the broader public concerns regarding environmental toxicants, and the need for industry to be proactive in anticipating and addressing challenges to its environmental credentials. Viticulture industry is always keen to remain at the forefront of technologies and agronomic practices that ensure a minimal environmental footprint for the industry.

Considering the above, a three year project was conducted by GWRDC/CSIRO as a part of the Soil Water Initiative of GWRDC, to pursue the following specific objectives; (i) to better understand the root-zone water quality and (ii) to improve management of root-zone processes to ensure economically and environmentally sustainable production systems. In this project, the quality of the drainage waters was assessed in several regions (Sunraysia, Riverland, Murrumbidgee Irrigation Area – MIA, McLaren Vale and Southeast of South Australia).

Water quality trends in the tile-drains over the last decade

A literature review was conducted on volumes and quality of drainage waters from tile-drainage systems over last decade by bringing together data obtained by various agencies. Considerable data were available from Sunraysia and Riverina areas especially on flow volumes and nutrients but there were few data available on pesticides in drainage water.

The review revealed that the water scarcity has led to dramatic changes in the irrigation methods and practices in recent years and consequently flows from the tile drains have declined markedly. This was most prominent in South Australian viticulture regions (e.g. Riverland) where current drainage flows are negligible. In Sunraysia, tile drainage volumes have decreased by 4-10 times in various districts over the last decade, however some drains in a few districts were still flowing during the last three years. While tile drains in the Nangiloc-Colignan district of Sunraysia showed some flow, the drainage flow has virtually been negligible in FMIT. Similarly, in the MIA, out of the four study sites located in viticulture farms only two showed any significant drainage. The data from the southeast of SA from lysimeters (giving precise measures of drainage volumes) have shown that during the last 10 years significant drainage has occurred only in 4 years. The average drainage over the last eight years was just 9 mm/year. The water quality data showed that while the flow volumes in various regions have decreased markedly, the concentrations of chloride have increased with time but that of nitrate have not changed significantly. There is some evidence that, because of minimal or sporadic drainage events, accumulation of salts and chemicals is occurring in or below the root-zone.

Methodology used in this project

As a result of minimal tile-drainage in various regions, a mixture of methodological approaches had to be used in different regions to measure drainage and capture samples for water quality assessments. These included sampling the few tile drains that were still flowing (in Sunraysia and MIA), using suction cups deployed at different depths in vineyards (South Australia and Murrumbidgee Irrigation Area (MIA)) and studying the deep drainage from lysimeters (Southeast SA). In MIA, some sites allowed both types of measurements, i.e. drainage water from suction cups at different depths and from tile drains. Due to modest resources available in the project, the sites used by other related projects were utilised in collaboration with SARDI and Charles Sturt University (CSU), Wagga Wagga. Tile drain sites were instrumented to measure flow volumes in the MIA.

Here the drainage volumes through lysimeters were captured and the loads were quantified. Several hundred samples were collected during the study period (2007-2009), which were analysed for salts, nutrients and pesticides using standard methods. The limited volumes that were available from suction cup samplers were generally not enough for pesticide analysis (each analysis requiring up to a litre of sample) resulting in the need to composite samples collected to allow such analyses.

Lack of deep drainage and accumulation of salts in the root-zone

The measurements of drainage past root-zone by different methods and different regions revealed one consistent picture - the lack of adequate drainage at most sites. In the MIA, out of four tile drained sites, significant drainage occurred only on two sites, at South Australian sites little drainage was occurring at tile drained sites, and no drainage occurred in 2008-09 at the site in Southeast of SA. Even when some leaching occurred in 2007-08 at this site, only < 10mm of water passed the root-zone. In Sunraysia some tile drains (Nangiloc-Colignan) were flowing during the study period (2007-09), however, this was not typical of other districts where no flow occurred. Only occasional flows were recorded for other districts.

The data on chloride balance (most accurately measured through the mass balance studies on lysimeters) showed a consistent pattern of accumulation of salts in the soil profile. Even when some deep drainage occurred during last five years, more than half of the salt introduced through irrigation water accumulated in the profile. Our long term studies in the southeast of SA show that the chloride concentrations in the drainage water has increased nearly four fold over last 8 years. This may however, not be true for other sites, as the total mass of salt accumulation at a site would depend on the amount and quality of its irrigation water. It is noteworthy that the salinity of drainage waters in the MIA and Sunraysia were lower than the salinity of the irrigation water in the Southeast of SA. Clearly, the rootzone salinity is a growing problem, as acknowledged through other GWRDC projects (e.g. Schrale and Biswas 2009) and needs urgent attention.

Very high concentrations of boron in drainage water (> 3 mg/L) suggested that it may be accumulating in the soil profile at levels sufficient to affect crop productivity. The boron levels were highly correlated with the sodium levels. Previous research has shown an inverse link with yield and boron concentration in soil profile – other data from the Soil and Water Initiative support this finding. Boron toxicity and its association with increased salinity requires further research, as it has a direct impact on the crop productivity.

Nitrates and other nutrients in the drainage water

Mineral nitrogen (Nitrate + nitrite + ammonium) concentrations in the drainage water were highly variable from site to site, whereas phosphorus concentrations at all sites were very low (< 0.8 mg/L). Nitrates in drainage water at several sites were > 10 mg/L and sometimes as high as 100 mg/L (in suction cups at 75 cm depth) which is well above the water quality guidelines for ecosystem health (0.7 mg/L for protection of 95% species) but below the drinking water guideline. It must, however, be noted that because of low volumes of drainage flow the total loads of exported nitrates were low. For example, at a tile drained site in the MIA, it was estimated that only about 10 kg N/ha/yr was exported through the deep drainage. The suction cup samples from SA sites showed very low nitrate concentrations. In addition to direct fertilizer application, especially early in the season, the organic matter turnover in the deep-ripped soil profile may also contribute to the N load in the drainage water. There is scope for improvement in fertilizer use efficiency in viticulture.

Pesticides in drainage water

Generally there is very little published data available on pesticides in drainage water. In this project more than 200 samples of drainage water from viticultural/horticultural lands in

the five regions were analysed for 18 different pesticide active ingredients (including insecticides, fungicides and herbicides) using sensitive (sub parts per billion range) analytical techniques combining chromatography and mass spectrometry. Not all pesticides chosen for analysis were used in viticulture practice during the study period. Except on rare occasions, the samples showed no detectable level of pesticides in drainage water. In a very small number of samples (8 out of 200) trace levels of two pesticides (chlorpyrifos and diuron) were detected, both of which may have been used in other horticultural crops (e.g. citrus). Generally speaking, from the snapshot sampling in this project, pesticides do not appear to be a major issue in the drainage water from viticulture. However, the detection of chlorpyrifos should be taken seriously as chlorpyrifos is a very toxic compound with very low acceptance in the environment (ANZECC/ARMCANZ water quality guideline of 0.01µg/L for protection of 95% species) and still remains a compound registered for use in grapes. Anecdotal evidence suggests very little of it is now used in the wine industry but it is still being used in table grapes production systems. It would be desirable for the grape growers and horticulturists to minimize and eventually eliminate its use.

Conclusions and Recommendations

The study raises several questions that are not only important from the standpoint of the environmental footprint of the industry but also of direct productivity and long term sustainability of viticulture. Key conclusions and recommendations are listed below.

- Consistent lack of drainage across all viticulture regions and the evidence of increasing salinity of drainage water (especially where poorer quality irrigation water is being used) are symptomatic of salt build up in the root-zone. Measures should be taken to make allowance for leaching fractions, especially in areas with poor quality irrigation water.
- The concentrations of boron in drainage water at some sites indicate boron may be reaching toxic levels in the root-zone and may potentially affect productivity on some sites. This needs to be further investigated.
- Nitrate concentrations in drainage water at some sites exceeded environmental guidelines and therefore the fertilizer use in newly established vineyards needs to be carefully managed. The fertilizer use efficiency of early season application of N fertilizers on newly established vineyards needs to be better managed.
- While pesticides do not seem to be a major concern in the drainage water, the industry should establish the current use pattern of pesticides and explore mechanisms to eliminate toxic compounds such as chlorpyrifos. A risk-based approach should be used to enhance growers' awareness about toxic pesticides and they should be provided with easy to use "Chemical Reference Charts" as currently used in the Mt Lofty Ranges.
- To manage root-zone water quality, the industry must develop a strategy to deal with accumulation of chemicals in or below the root-zone and consequent unacceptable concentrations in drainage water that may eventuate during occasional episodic leaching events in a very wet year. Therefore, investigations on carefully chosen sites (e.g. lysimeters, some tile drain sites) should continue to develop a long term trend on water quality, including several dry and wet years.

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3. BACKGROUND

Viticulture industry is continuously striving to remain proactive to address new economic, social and environmental challenges. This is evident from the industry's adoption of its Australian Wine Industry Stewardship (AWIS) program, the broader public concerns regarding environmental toxicants, and the need for industry to be proactive in anticipating and addressing challenges to its environmental credentials. Viticulture industry is keen to remain at the forefront of technologies and agronomic practices that ensure minimum possible environmental footprint of the industry.

Since viticulture in Australia is often located in areas with important groundwater aquifers or linked with rivers and streams through subsurface drainage networks, the water quality of drainage water in terms of nutrients and other agrochemicals (e.g. pesticides) concentrations and loads can potentially affect the water quality of receiving environments and contribute to processes such as eutrophication of ecosystems (Australian Government 2004).

Currently there is limited information on the potential magnitude of nutrient exports from viticultural systems in Australia (Slattery et al. 2003). Slattery et al. 2003 highlighted the need of better understanding of the pathways and export of N from Australian vineyards and development of improved management strategies. More recently, Barlow et al. 2009 reported data on N in soil solution in one Rutherglen Shiraz and six MIA Chardonnay vineyards employing different methods of irrigation (flood, drip). The study highlighted the potential risk for N export by subsurface pathways. They showed that the average N (nitrate + nitrite) concentrations in soil solution (1 m) ranged from 0.64 to 82 mg N/L and surface run-off from <0.1 to 0.3 kg N/ha. Clearly these concentrations of N are significantly greater than Australian environmental trigger values (e.g. 0.5 mg N/L trigger value for Lowland rivers; ANZECC and ARMCANZ 2000).

Nitrates in ground waters have also been an issue in Australia and overseas (e.g. Nolan *et al.* 1997, Schmidt *et al*., 1998) Sources of contaminants in ground waters are often difficult to discern and ascribe to a particular land use. Studies have been conducted to assess the nitrate contamination of groundwater in the southeast of South Australia by sampling of existing bores located in different land uses (Schmidt et al., 1998). Their findings together with the data presented in Table 1.1 show that ground waters bores located under vines was among the land uses showing higher levels of nitrates, such as dairy, grazing and market gardens.

Table 1.1 Nitrate levels, mg/L, in ground water under different land uses in southeast South Australia from different data sets (Schmidt *et al.* 1998).

Data set	Dillon	Luigi	New bore
APPLES	*	8.17	5.30
DAIRY	12.1	8.67	7.80
FORESTS	3.82	2.79	1.56
GARDEN	11.30	*	10.2
GRAZING	9.41	7.44	4.24
INTENSE	*	7.20	4.21
POTATO	*	1.04	1.62
VINES	13.4	10.7	8.09

*no data

In addition to leaching of mineral fertilizer, organic matter turnover in the root-zone due to disturbance of the profile (e.g. through commonly practiced deep ripping at the time of plantation of vineyard) can also be an important contributing source of nitrates. Knowing the source of elevated nitrates in drainage water can facilitate to identify the management option available for minimizing their off-site transport.

As regards to pesticides, there is very little data available on drainage water quality as it is not routinely monitored due to high analytical costs. Some data from monitoring of surface drainage systems in irrigation areas (e.g. Murrumbidgee Irrigation Area) are available but these drains are impacted by drainage from multiple land uses in the catchments. Schmidt et al. 1996 carried out a survey of ground waters in the southeast of SA including samples from 20 bores located in viticulture area. In this study, chlorpyrifos was detected in two samples. In another study, Oliver and Kookana (2005) used a risk-based approach employing CSIRO's Pesticide Impact Rating Index (PIRI) and ranked pesticides used in viticulture in terms of their leaching potential. The targeted monitoring of tile drainage water, based on this approach, by the then Department of Water Resources in the Riverland region did not find any detectable levels of pesticides.

Considering the above, the water quality parameters covered in this project included nutrients, pesticides as well as inorganic ions (salts and metals). The project was linked to GWRDC's Soil Water Initiative and was carried out in collaboration with other projects under this initiative. This allowed the most cost-effective utilisation of the modest resources of this project (less than 1 full time equivalent person distributed among different skills and regions).

4. PROJECT AIMS AND PERFORMANCE TARGETS

The overall aim of the project was to minimise the environmental footprint of viticulture through improved root-zone management.

The specific objectives underpinning the above aim are as follows.

1. Develop better scientific understanding of water balance and drainage water quality assessment through the root-zone.
2. Apply scientific knowledge arising from the project to identify management strategies to improve water, fertilizer and pesticide management such that a productive root-zone is maintained without any negative environmental impact.
3. As a part of the Soil Water Initiative of GWRDC, communicate the project findings and contribute towards the adoption of best management practices.

Outputs and Performance Targets (July 2007 to June 2008)

Outputs	Performance Targets
1. Report from workshop on previous/current data on leachate to identify the sites to include in study.	Successful workshop within first 3 months of the project.
2. Seminar on results to the Soil Water Initiative (SWI) annual meeting.	SWI meeting held and results shared.
3. Project progress report.	Report on experimental sites (Tile drains), feasibility of multi-isotope source tracing for nitrate, submitted on time.

Outputs and Performance Targets (July 2008 to June 2009)

Outputs	Performance Targets
1. Workshop/Seminar at relevant industry forum(s)	Key results and trends emerging from the experimental sites are communicated effectively with the relevant industry representatives. Lysimeters results presented to the industry in southeast of SA – by July 2008. Tile-drain/deep soil water (suction cup drainage) results presented to the industry in Riverland/Sunraysia – by Dec 2008.
2. Presentation to the Soil Water Initiative (SWI) annual meeting	Up to date results on field trials are presented to the SWI.
3. Popular article for relevant industry magazine	One popular article on the salient findings from the project is published in the relevant industry magazine.
4. Progress report	Report containing data on laboratory trials, data from field trials and the assessment on the relationship of management practices with the levels of pesticides and nutrients leached is submitted on time.

Outputs and Performance Targets 2009 (July 2009 to December 2009)

Outputs	Performance
1. Workshop to discuss project results and draw out management options.	Considered and agreed set of management implications/guidelines.
2. Presentation to the Soil Water Initiative (SWI) annual meeting.	Positive stakeholder feedback.
3. Peer reviewed paper and presentation to the industry conference.	At least one peer reviewed paper is published in relevant journal or presented at conference.
4. Final report.	Final report accepted by GWRDC in time.

5. STUDY SITES AND STRUCTURE OF THE REPORT

5.1. Aims

In this project, the quality of the drainage waters was assessed on several sites (Sunraysia, Riverland, MIA, McLaren Vale and Southeast of South Australia). Due to lack of tile-drainage in various regions, a mixture of methodological approaches was used in different regions to measure drainage and capture samples for water quality assessments. These included tile drains that were still flowing (in Sunraysia and MIA), suction cups deployed at different depths in vineyards (South Australia and MIA) and the deep drainage from lysimeters (Southeast SA). In the MIA, some sites allowed both types of measurements on the same sites, i.e. suction cups at different depths above the tile drains. Due to modest resources in the project, the sites used by other related projects were utilised in collaboration with SARDI and CSU, Wagga Wagga. Tile drain sites were instrumented to measure flow volumes in the MIA. The drainage volumes through lysimeters were captured and quantified. Several hundred samples were collected during the study period (2007-2009), that were analysed for salts, nutrients and pesticides using standard methods. With limited volumes being available, in some cases it was necessary for samples to be composited to enable the analysis of pesticides.

5.2. Structure of this report

The report has been structured considering the study was conducted over five different regions (Sunraysia, Riverland, MIA, McLaren Vale and Southeast of South Australia) over three states (NSW, Victoria and SA). The methodology could not be common, for the reasons described above and needed to suit the state of drainage at different sites. Furthermore, the background situation and cropped areas contributing to the tile drainage at the monitoring points varied from region to region. During the workshop with stakeholders in Sunraysia in 2009, it was decided that rather than structuring the report based on salts, nutrients or pesticides as chapters, it would be more meaningful to have chapters based on regional contexts. Therefore, we have included common methodological section followed by the results from South Australian sites as one chapter, one each for Sunraysia and the MIA. Some specific methodological details are given in each chapter. Finally in the discussion section the trends and observations are drawn from data from all sites followed by conclusions and recommendations.

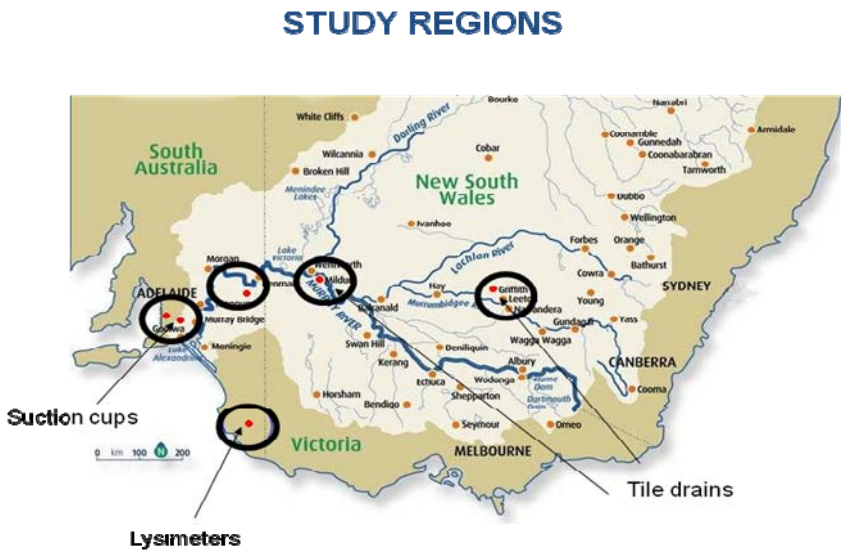


Figure 5.1 Location of study regions and methods of drainage collection in different regions.

6. GENERAL METHODS

6.1. Estimation of drainage

There would appear to be no recognized standard method for the estimation of drainage through a soil profile in a vineyard. Several methods that have been proposed are discussed below.

6.1.1. Development and testing of novel treatment technologies

Methods based on water balance require accurate measurement of water input (irrigation and rainfall) and an estimate of evaporation. Drainage can then be estimated by the difference between water input and evapotranspiration. Typically the drainage is only a fraction (say 10%) of the water input (Stevens 2002). The variance of the difference would be (assuming the measures were independent) equal to the variance of the input measurement plus the variance of the evapotranspiration measurement. The rainfall measurement can be measured quite accurately, but there is some error in the amount of irrigation applied - a CV of 5% would be realistic based on measurements taken in this project.

The estimation of evapotranspiration has improved, but would still be subject to an error of at least 5% (± 10% was suggested in Hutton *et al*. 2008 based on private communication with Dr Helen Cleugh, CSIRO). While these errors would appear small, because the difference between water input and evapotranspiration is small, (say 10%), the associated relative error becomes very large, (say 100%). Methods based on the water balance are therefore subject to large errors – errors so large that the method can, at best, give only approximate estimates of the amount of drainage.

6.1.2. Hydraulic gradient methods

The hydraulic gradient methods depend on measuring a hydraulic gradient between two points below the root-zone and the soil hydraulic resistance of the soil at that moisture content. Application of Darcy's law then enables an estimate of the rate of movement of water down the profile. The Drainage Meter (Hutchinson and Bond, 2001; Bond and Hutchinson, 2006) was developed by CSIRO. The method requires several assumptions including that soil has a uniform hydraulic resistance, (or that it can be estimated accurately), and that the measurement points are deeper than the root-zone.

In practice, it is impractical to know soil conductivity sufficiently over a study area to enable the application of Darcy's law. A realistic estimation of the leaching rate would require many, (perhaps 20), measurement points to give a stable estimate of the infiltration rate.

A further problem is that while the majority of roots may be within the top 600 mm (a depth interval designated as the root-zone), a small fraction of the roots may extract water from below that depth. The influence of roots below the measurement point would be indistinguishable from the measurement of leaching. While the fraction of deep roots may be small, it could cause a serious bias to any estimate of the leaching from the soil profile. This can become a major impediment to the measurement of soil leaching using hydraulic gradient methods.

Yet another problem is that a Drainage Meter can only provide a point estimate. This provides a problem in extrapolating from that point estimate to a vineyard, which is known to be heterogeneous because of the vines, rip lines and drippers as well as natural soil variation.

6.1.3. Chloride tracer method

The chloride tracer method relies on the principle that evapo-transpiration will remove water from applied irrigation and leave behind effectively all the salt. From the amount of water and chloride being applied (combined rainfall and irrigation) the concentration factor of the water beyond the root-zone would represent the fraction of water used in evapo-transpiration.

The theory requires an assumption of steady state, and that there is no removal of stored salt from the profile, and no chloride is accumulating in the profile. In some cases this assumption would seem reasonable, but in other cases (especially in the MIA), there is evidence that salt being leached has been resident in the soil and has not come from irrigation water (Hertzeg *et al*. 2001).

6.1.4. Direct measurement

There are two direct ways of quantifying drainage by direct measurement using tile drains or lysimeters.

Tile drains can be monitored for flow, and the volume logged. The amount of drainage per ha can then be calculated. The method does have some problems in that the drain system may be fed from a variety of land uses. A further challenge is that drains may intercept water tables and alternatively may not collect all the drainage water (see Hornbuckle 2003). A strong point in favour of this method is that an estimation of drainage can be obtained with low installation costs.

Lysimeters would appear to be an accurate method, but they require a massive installation effort (see Section 7.2.2). Few lysimeters meet the basic requirement of having the same area as that explored by other vines, the same length of vine row as other vines and sufficient depth. Because of their large size, the lysimeters are typically repacked rather than being intact cores. A check on the effectiveness of the repacking can be made by comparing vine size inside and outside the lysimeters and also comparing soil moisture levels inside and outside. In practice, several years may be required for repacked lysimeters to stabilize and to yield useful results.

6.1.5. Conclusions about measurement of leaching

The two most useful methods for assessing drainage through soils are the measurements based on tile drain flows, but these are only available where tile drains have been installed.

While lysimeter data may give more accurate data, the usefulness is limited by their cost and the time required for them to equilibrate.

6.2. Estimation of contaminant load in drainage water

The estimation of contaminant load (L) is calculated by the product of the concentration and flow. Ideally this calculation takes the form of

$$L = \int_{t1}^{t2} (fc)dt$$

where *t1* and *t2* represent the beginning and end of an interval, and *f* and *c* represent flow and concentration. In practice not in all cases flow and concentration can be measured continuously, both are required to estimate load. For example, the suction cup samplers only allow the measurement of concentration at a specific point in the soil profile.

An attempt to estimate load was made at the instrumented sites in the MIA where both flow and water quality were monitored. The lysimeters provided results that represented an integration of drainage volume and an averaging of water quality over the sampling interval.

6.3. Measurement of flow

The type of installation has been described by Samani (1991) and Hornbuckle (2003). The circular flume is a simple and low-cost water measuring device constructed from two pieces of pipes, one installed vertically inside the other. The ratio of the diameter of the inner column to the flume itself is approximately one-third. The presence of the inner column reduces the cross section of the flow, creating a critical flow condition. A gauge is installed at the upstream side of the inner column to measure the depth of the water upstream of the critical flow section. The reading on the gauge is directly related to the flow rate. Barriers are installed to prevent preferential flow around the sides. The height of water and the EC are normally recorded on a hourly or two-hourly basis.

For this project EC data was continuously measured using microCHEM TPS Quality System (certified in accordance with AS/NZS ISO9001 standards. Data were recorded on Intech four channel 12 bit data loggers, described at http://www.intech.co.nz/products/minipd/gphr.html .



Figure 6.1 Photo showing installation of flow monitoring equipment installed

Calibration of the flume, for the project, was based on laboratory data. The relationship between height and flow is shown in Appendix 5, Figure 13.5. A linear approximation offers a good fit to the data, but the quadratic was a slightly better fit, and has the advantage that it normally passes through the origin. The quadratic fit has the disadvantage in that it has a potential to produce large bias outside its range of calibration. Flow data used in the report was calculated using the quadratic calibration, (as recommended by the installer).

6.4. Soil moisture measurements

Soil moisture was monitored at the lysimeter site at Wrattonbully using capacitance moisture meters. Three ‘Diviner’ access tubes (Sentek 2009) were installed in each lysimeters, with one access tube mid row and two in the vine row. The inline access tubes were 50 cm from the vine trunk. In addition, four vines, termed pseudo-lysimeters, were

similarly instrumented so that each lysimeter was between two pseudo-lysimeters. Moisture was measured with a Diviner every two weeks.

6.5. Laboratory methods

6.5.1. Pesticide analyses

Pesticide analyses were conducted over the period 2006-2009. A list of the methods used and the detection limits for each pesticide is given in Table 6.1.

All solvents used were purchased from Mallinckrodt Chemicals, Phillipsburg, NJ, USA and were ChromAR grade. Individual stock standards (100 mg/L) were made for each pesticide in acetone. Triplicate blanks (Milli-Q) water were spiked with 10 µl of each stock standard and left to stand overnight at 4°C. The water samples were divided into two measured portions, as the GC and HPLC required different extraction solvents. Instrument standards were prepared in acetonitrile for the HPLC and 75% hexane / 25% acetone for the GC/MS, using the stock standards.

Samples were passed through SPE cartridges (Alltech C18 high flow 500mg/4ml). The cartridges were first conditioned with 5 ml methanol followed by 5 ml Milli-Q water. The SPE cartridges were eluted with 5 ml of acetonitrile for the HPLC analysis and 5 ml acetone for the GC/MS analysis. The HPLC samples were reduced to volume of 1 ml under a gentle stream of high purity nitrogen and then filtered with a 0.45 µm PTFE syringe filter into 2 ml vials. The GC/MS samples were reduced to a volume of 0.5 ml and then made up to 2 ml with hexane. The samples were then filtered into 2 ml vials.

HPLC instrument parameters, (Agilent 1100 series HPLC with diode array detector), Alltech Apollo C18 (250 mm x 4.6 mm x 5 µm) column, Mobile phase was 70% acetonitrile, 30% Milli-Q water with a flow rate of 1 ml/minute. Injection volume 20 µl, wavelength set at 220 nm.

GC/MS instrument parameters, (Agilent 6890 series with a 5973N mass selective detector), J & W Scientific DB-5MS (30 m x 0.25 mm x 0.25 µm) column was used. Inlet temperature 50°C with a constant flow rate of 1 mL/minute (helium). Oven temperature set at 75°C for 3 minutes, ramped to 180°C at 25°C/min., then ramped to 260°C at 4°C/min., held for 10 minutes. Transfer line was held at 280°C, injection volume was 2 µL.

External standards for the GC/MS were 0.005-1.0 mg/L and HPLC external standards were 0.05-2.0 mg/L. Detection limits varied for each pesticide (see Table 6.1)

Table 6.1 Methods used and detection limits for 18 pesticides.

Compound	Abbreviation	Instrument	Detection Limit (µg/L)
Chlorothalonil	CT	GC/MS	0.4
Beta-endosulfan	BE	GC/MS	0.005
Alpha-endosulfan	AE	GC/MS	0.005
Procymidone	PC	GC/MS	0.005
Metalaxyl	ML	GC/MS	0.02
Cyprodinil	CD	GC/MS	0.02
Penconazole	PZ	GC/MS	0.04
Chlorpyrifos	CF	GC/MS	0.005
Myclobutanil	MB	GC/MS	0.04
Carbaryl	CB	HPLC	0.2
Atrazine	AZ	HPLC	0.2
Clomazone	CZ	HPLC	0.2
Azinphos Methyl	AM	HPLC	0.2
Fenarimol	FM	HPLC	0.2
Iprodione	ID	HPLC	0.2
Molinate	MN	HPLC	0.2
Thiobencarb	TBC	HPLC	0.2
Diuron	DI	HPLC/MS	0.01

6.5.2. Inorganic analyses

- **Metals** were determined on an ICP-OES, (Spectro Arcos). Samples were filtered (0.45µm) prior to analysis if there was any visible colloidal and/ or organic debris, but normally filtration was unnecessary.

- **Chloride** was measured using APHA method 4500-Cl^- E for automated colorimetric determination for chloride. Initially an estimate of the chloride concentration was made from the sample EC value. Sample were diluted using 0.01M $Ba(NO_3)_2$ in order to have the chloride concentration within the analytical range of 5 – 150 mg/L. This matrix was used to remove sulfate ions which interfere with the colorimetric determination. The sample was mixed with a colour reagent of mercuric thiocyanate and ferric nitrate in an automated segmented flow analyser (Alpkem Flow Solution 3) to form coloured ferric thiocyanate, colour measured at 480 nm. The sample concentration determined from standards of known chloride concentration with allowance for the barium nitrate dilution.

- **Ammonia-Nitrogen** was determined by flow analysis (CFA and FIA) and spectrometric detection (1997) following International Standard ISO 11732. The sample was buffered to pH 12 and reacted with sodium salicylate and sodium nitroprusside before reaction with sodium dichloroisocyanurate solution (DCIC) in an automated segmented flow analyser (Alpkem Flow Solution 3). After reaction at 37°C, the intensity of the colour was measured at 640 nm. The NH_4-N

concentration was calculated from a set of calibration standards, measured at the same time as the samples.

- **Nitrate (plus nitrite) nitrogen** was determined using APHA method 4500-NO_3^- F. In this segmented flow analysis method, nitrate was reduced to nitrite in an open tubular cadmium column in an atmosphere of helium and then reacted with sulphanilamide and N-(1-naphthyl)-ethylenediamine dihydrochloride (NEDD) in phosphoric acid. The pink colour formed was determined colorimetrically using an automated segmented flow analyser (Alpkem Flow Solution 3) at 540 nm. The NO_3-N (also referred to as NO_X-N, the sum of nitrite and nitrate nitrogen) concentration was calculated from a set of calibration standards measured at the same time as the samples.

6.6. Sodium Absorption Ratio (SAR)

The sodium absorption ratio (SAR) is calculated as

$$SAR = \frac{[Na]}{\sqrt{\frac{[Ca]+[Mg]}{2}}}$$

where [Na], [Ca] and [Mg] indicate the concentrations in milliequivalents per litre. Guidelines of the effect of SAR values are shown in Table 6.2.

Table 6.2 Summary of effect of SAR on soil (source: NSW Department of Agriculture 2005).

SAR value	Effect on soil
<3	No problems as the water is non sodic.
3 to 6	Minor effect on clayey soils if ECw is <1.5 dS/m.
>6	Has increasing effect on all soils at low to moderate salinity (up to 2.5 dS/m) and starts to reduce growth of most crop and pasture plants.
>9	Severe risk of increasing soil sodicity on most soils.

7. SOUTH AUSTRALIAN DATA

In many vine growing districts there are no data available from neither tile drains nor lysimeters. In many cases, an approximation to the water quality that is passing through the root-zone can be obtained using suction cups. The South Australian component of this project considered samples from both suction cups and lysimeters.

7.1. Parameters of potential concern

The parameters of potential concern to the environment in the drainage water are

- Salinity;
- Sodicity or SAR;
- Nutrients; and
- Agricultural chemicals (pesticides)

7.2. Use of suction cups

Suction cups have been used by SARDI for many of their projects involving viticulture and citrus growing. The 'cups' have been commercialised as SoluSAMPLERs by SenTec Sensor Technologies (http://www.sentek.com.au/products/). The Sentek SoluSAMPLER™ draws moisture from the surrounding soil and stores it in the inert ceramic cup awaiting collection and analysis. A photograph of a sampler is shown in Figure 7.1.



Figure 7.1 SoluSampler used to sample sub-surface water from the South Australian viticulture sites for this project.

7.2.1. Data available to this study

While the study was designed to obtain samples at 90 cm, in many cases no samples could be obtained because the soil moisture content was too low which translated to too large a negative water potential to enable soil water extraction. This resulted in numerous

gaps in the data set, especially with respect to 90 cm suction cups. To supplement the data set 60cm and to a lesser extent, 30cm samples were included for analysis.

Table 7.1 Details of suction cup sites that were included in this study

Site ID	District	Variety	Root stock	Date panted	Soil Type	Irrigation
1	Loxton, SA	Chardonnay	Ramsey	1985	Sandy Loam	UCS
2	Loxton, SA	Colombard	Ramsey	1985	Sandy Loam	Drip
9	Barmera, SA	Chardonnay	Ramsey	1984	Sandy Loam	Drip
15	McLaren Vale, SA	Shiraz	Own Roots	1998	Loamy sand	Drip
16	McLaren Vale, SA	Shiraz	Own Roots	1998	Loamy sand	Subsurface drip
18	Currency Creek, SA	Cabernet Sauvignon	Own Roots	2002	Sandy Loam	Drip
19	Langhorne Creek, SA	Cabernet Sauvignon	Own Roots	1998	Loamy sand	Drip



Figure 7.2 Map of locations of South Australian sampling locations

7.2.2. Findings from suction cup data

EC data from the SARDI measurements indicated that the EC in the suction cup samples was driven by the EC of the irrigation water (Figure 7.3). Regression analysis indicated that the EC of the irrigation water alone explained 90% of the variation among the samples. The regression also indicated that for 2006-7 data, a change of 1 EC unit in the irrigation water corresponded to a change of 4.5 EC units in the soil water. This presumably reflects the concentration of the water by evapo-transpiration.

There was no effect of the age of the plantings, so these data do not provide evidence of accumulation of salt over years in the soil profile down to 90 cm.

Chemical analyses of samples from the suction cups indicated that the Loxton sites had much lower EC than the Langhorne Creek and McLaren Vale sites). SAR values were very high at Langhorne Creek with a median value of 13 at 90 cm, which presents a severe risk of soil structural damage (NSW 2005). SAR values at McLaren Vale were also high with a median value of 12. The median SAR values at Loxton were lower, particularly in Loxton C, (SAR of about 2).

Generally Nitrate levels were very low (<1 mg/L) at 90 cm depth – the exception was Loxton C where the median value was 2.5 mg/L. This value is still low and is not a cause for concern.

Phosphate levels were generally below the quantifiable limit (Figure 7.4). The exception was at McLaren Vale where the median value at 90 cm was 0.45 mg/L with one observation approaching 1 mg/L.

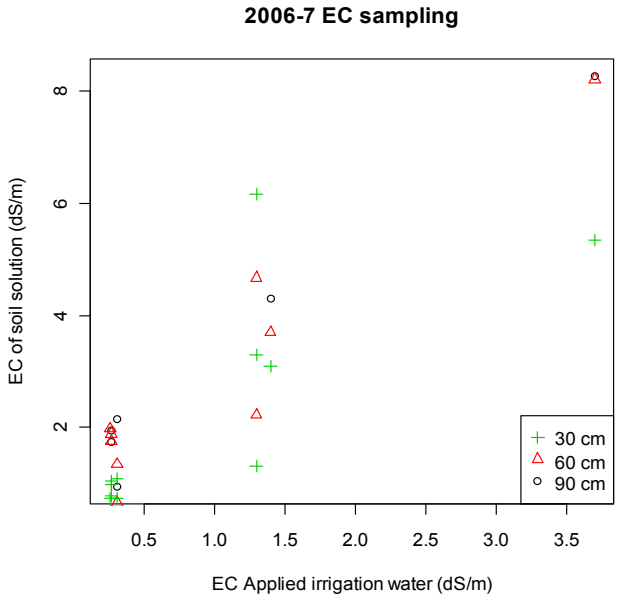


Figure 7.3 Effect of EC of irrigation water on EC of soil samples collected at 3 depths during the 2006-07 season.

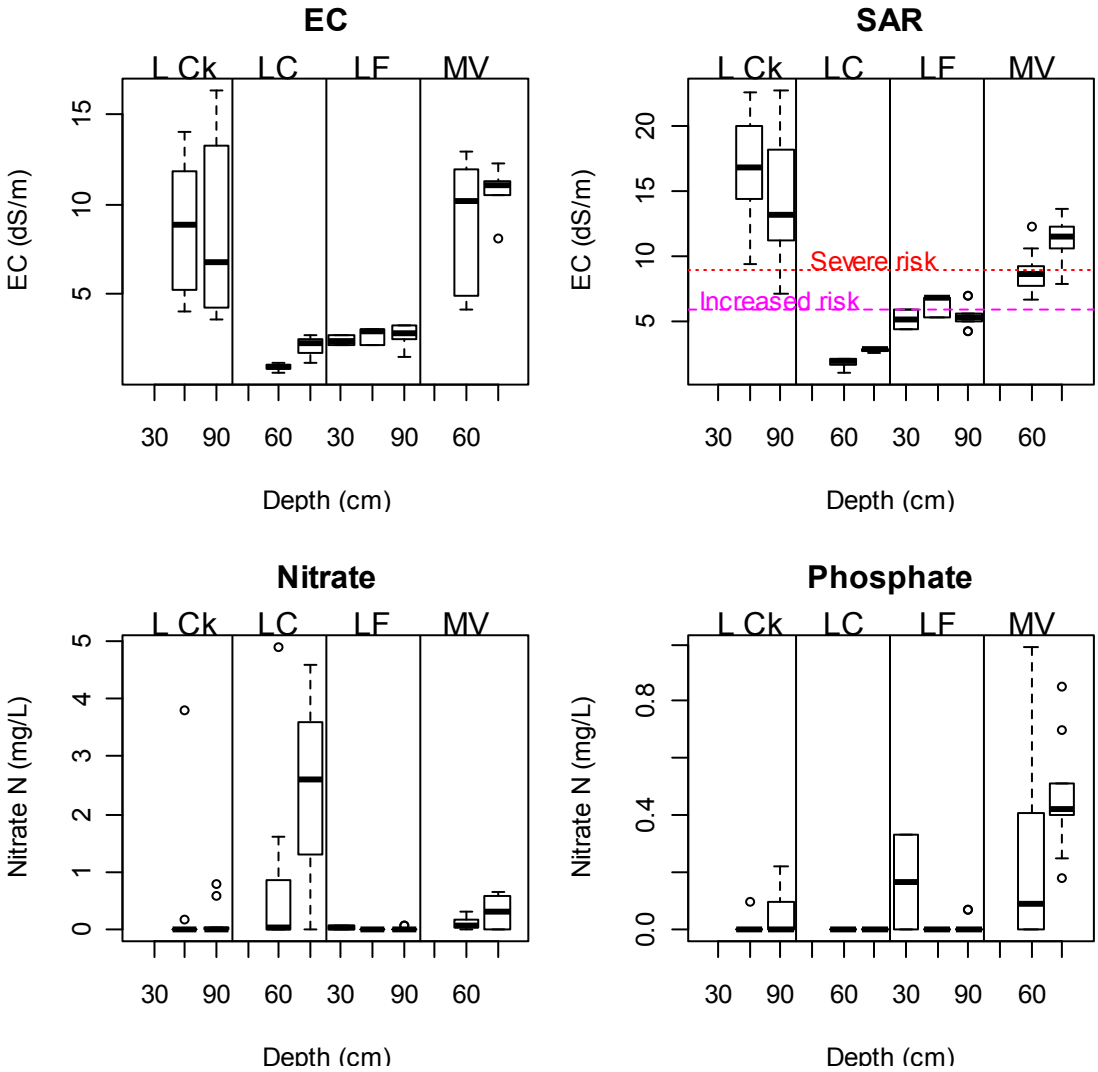


Figure 7.4 Boxplots of EC, SAR, nitrate and phosphate concentrations values encountered in the South Australian suction cup studies. The SAR risk levels are from Table 6.2.

7.3. Lysimeter data

Drainage lysimeters represent arguably the best method of assessing the influence of vines (or other crops) on the environment beyond the root-zone. Drainage lysimeters have several advantages over methods of assessing the influence on the environment. In particular

- They provide quantitative data on the rate of drainage, and that rate can be associated directly with the area of the lysimeter – this contrasts with tile drains that collect from a large area;
- The recording is complete and not contaminated by groundwater, nor are there losses to groundwater;
- The area sampled is large representing a complete vine – this contrasts with suction cups that sample only a single point that may be influenced by distance from the vine, whether it was on the vine row or its distance from the dripper;
- The volume of the sample is typically sufficiently large to enable analysis for pesticides.

The disadvantages of lysimeters are

- Cost – the lysimeters typically would cost about $10,000 each;
- The site has been disturbed and this affects soil properties, and in particular N mineralisation (Johnson *et al*. 1995);
- The equilibration time is typically several years.

The project was fortunate in having access to 3 lysimeters that were installed by Yalumba Wine Company 9 years prior to the commencement of the trial.

7.3.1. Experimental site

Location of lysimeters

Wrattonbully is located in the southeast of South Australia 20 km southeast of Naracoorte near the South Australian – Victorian border (see Figure 7.2). The area is relatively flat but has some drainage hollows that assist in frost control. Previous land use has been used for mixed agricultural production. The site is located at 140^{o} 51.4'E, 37^{o} 04.9'S.

Climate at Wrattonbully

The climate is temperate with a dry warm summer (Köppen classification Csa). Rainfall average is 580 mm per year with a maximum in winter. Details of monthly average temperature and rainfall are shown in Table 7.2 for the closest official meteorological station at Naracoorte.

Table 7.2 Average maximum and minimum average temperature and average rainfall at Naracoorte weather station (www.bom.gov.au)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Max T	28.1	28.7	25.5	21.5	17.5	14.9	14.2	15.4	17.3	20.2	22.9	25.4	21.0
Min T	12.2	12.4	11.0	8.6	7.0	5.3	4.9	5.4	6.5	7.6	9.0	10.7	8.4
Rain	23.3	19.9	26.5	43.4	60.3	73.4	75.5	72.6	65	51.6	36.4	30.4	577.9

Soil at Wrattonbully

The local soil is a *terra rossa*, but is very variable, showing signs of incomplete sheet limestone, lateral flow and holes. Coring of the soil has shown that in places there is hard limestone close to the surface while close by it is possible to auger to over a meter depth. Previously the area was in pasture, and there may be residual effects of fertilisers, pesticides and other treatments from that land use.

A typical soil profile of the *terra rossa* soils in that region is shown in Figure 7.5.



Figure 7.5 Soil profile in a pit near the lysimeter site (photo Ray Correll)

Vineyard description

The vineyard was planted in 1998 to Shiraz with a spacing of 1.8 m with a row spacing of 2.75 m. The vineyard is irrigated by above ground drippers spaced at 0.7 m intervals, with each dripper delivering 2.3 L/hour. The amount of irrigation varies within the range of 1 – 1.5 ML/ha/year.

7.3.2. Field methods

Description of lysimeters

Three lysimeters were established in Smith's vineyard (Block M) at the time of planting in 1998. The lysimeters consisted of cylindrical tanks 2.5 m diameter and 1.83 m deep. The tanks were equipped with a drainage well which was plumbed to a sump. An access tube to the sump was used for removing any drainage that occurred (Figure 7.6).

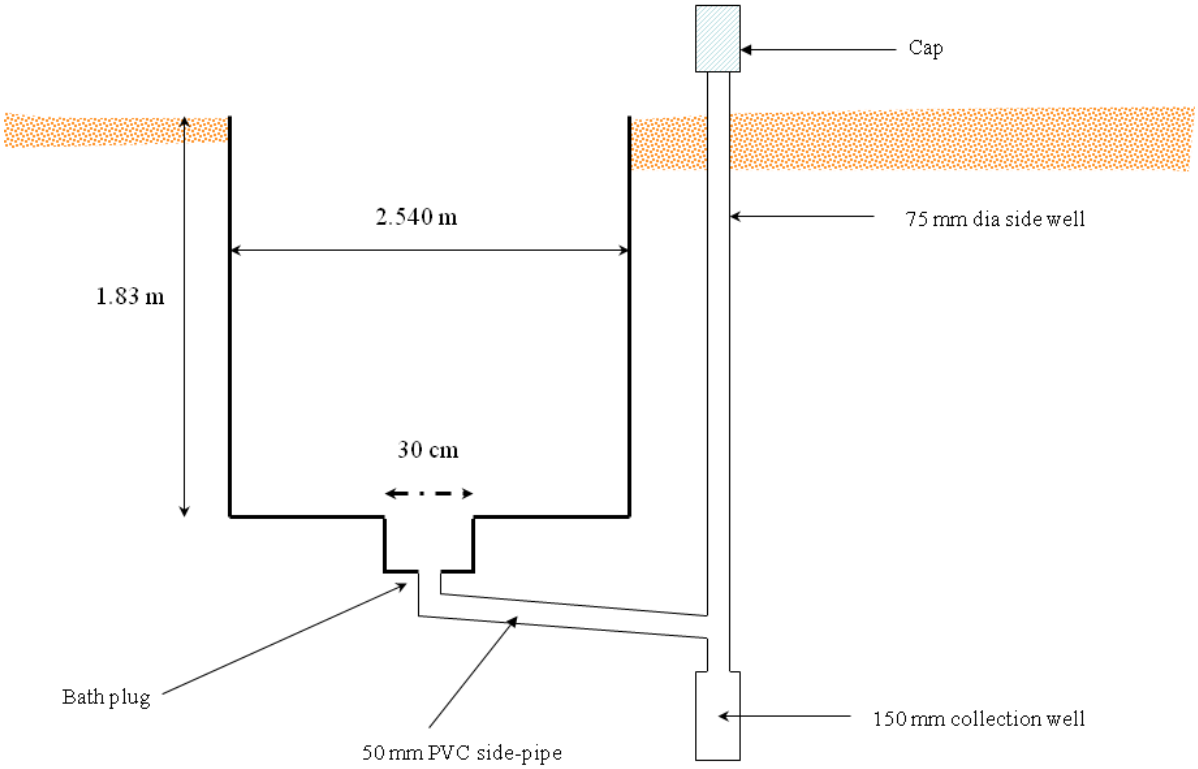


Figure 7.6 Diagram of the lysimeter construction (Source: Cecil Camilleri)

Excavations were made at the time of planting and the soil was removed in layers, which were kept separate for each lysimeter. Further details of the installation are shown in Figure 7.7 – 7.10. The lysimeters were offset from the vine row so that the length of vine row was 1.83 m across the lysimeter, which was the equivalent of the vine spacing. A single vine was planted in each lysimeter at the time of planting the vineyard. There were three drippers per lysimeter each delivering 2 L/hour, thus matching the application rate for each vine outside the lysimeters. All subsequent viticultural treatments applied to the vineyard were also applied to the vines in the lysimeter. There are no observable differences between the vines inside and outside the lysimeters.



Figure 7.7 Excavation for lysimeters prior to planting



Figure 7.8 Segregation of soil layers from each lysimeter excavation



Figure 7.9 Placing a lysimeter into excavated site. Note the pipe on the right that was to become part of the lysimeter drain.



Figure 7.10 Well at the bottom of the lysimeter.

Photos courtesy Dr Cecil Camilleri.

The lysimeters have been interspersed with ‘pseudo lysimeters’. These vines have the same moisture measurement device installed as the vines within the lysimeters.

The lysimeters were 11 m (6 vine spacings) apart in the same row. The three lysimeters were thus spaced well apart, had the same surface area as that explored by other vines, had the same length of vine trellis, and received the same amount of water as other vines.

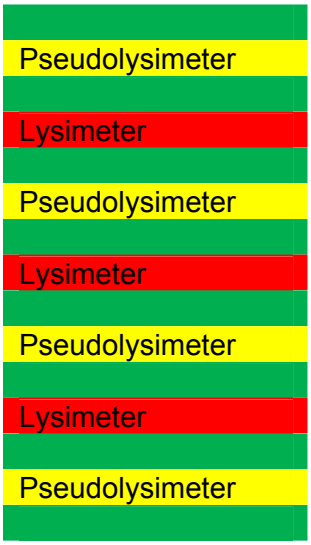


Figure 7.11 Interspersed lysimeters, pseudo-lysimeters and groups of other vines.

Sample collection

Drainage samples were taken every two weeks when drainage water was present. The volume of the sample was measured using a measuring cylinder. A sample of 100 ml was placed in an acid-washed plastic bottle. In addition two 500 ml samples were placed in dark glass bottles for pesticide analysis. The samples were refrigerated and transported to CSIRO Adelaide for analysis.

Regular samples of irrigation water were assessed for total soluble salts (TSS). Detailed chemical analysis of the irrigation water showed that 54% of the TSS was Cl, and this factor was used to calculate the Cl content of the irrigation water. A smoothing spline was used to obtain average Cl concentrations for each year’s irrigation.

Soil moisture measurements

Three ‘Diviner’ access tubes (Sentek 2009) were installed in each lysimeters, with one access tube mid row and two in the vine row. The inline access tubes were 50 cm from the vine trunk. In addition, four vines, termed pseudo-lysimeters, were similarly instrumented so that each lysimeter was between two pseudo-lysimeters. The location of the access tubes in each lysimeter is shown in Figure 7.12. Note that the lysimeter was offset from the vine row, so that the length of vine row intersecting the lysimeter corresponded to a vine spacing.

Moisture was measured with the installed diviner probes every two weeks.

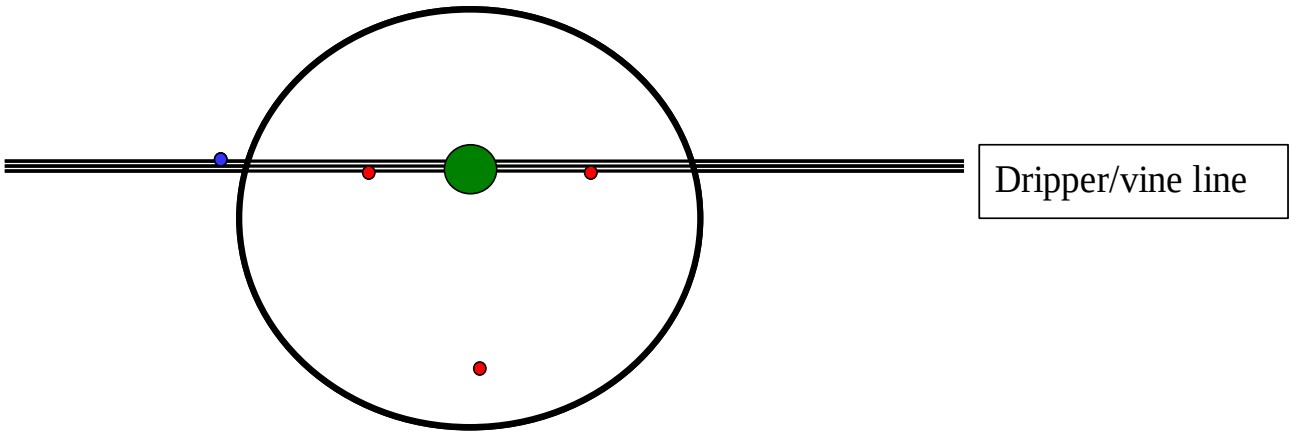


Figure 7.12 Layout of a lysimeter. The vine is shown in green and the moisture access tubes are in red and the access tube for the sump in blue.

The inclusion of the pseudo-lysimeters not only act as controls, but also allows sufficient degrees of freedom to enable statistical testing of differences between the lysimeters and the area explored by other vines in the vineyard.

There were 3 access tubes associated with each pseudo-lysimeter, thus making 12 tubes for the pseudo-lysimeters. The location of the access tubes are shown in, and summarized in Figure 7.12.

The precision of the Diviner readings was assessed by taking a second set of readings immediately following the routine measurement on 19 January 2006. This second set of readings was some 21 minutes later than the first data set. There was an apparent drop in moisture from 18.498 mm to 18.411 mm in the profile during the 21 minutes between readings. The standard error of this value was estimated using a paired t test and was found to be 0.037. Thus although the change in moisture was only 0.087 mm, it was still significant at the $p < 0.05$ level.

Comparison of lysimeters and pseudo-lysimeters

The behaviour of the vines in the lysimeters was found to be very similar to those outside the lysimeters in terms of canopy and butt circumference. Inspection of the site showed no visual differences between the vines in the lysimeters and those outside the lysimeters.

The moisture content of the soil (as measured by the Diviner probes) was also comparable. Figure 7.13 shows a comparison of the moisture content inside and outside of the lysimeters at a range of depths. The depth of the access tubes was limited by rocks in the profile, so there were fewer readings at depth. As a consequence the confidence intervals were larger for the deeper readings as compared to the surface readings.

The above findings indicate that the behaviour of the vines in the lysimeters is very similar to those vines outside the lysimeters.

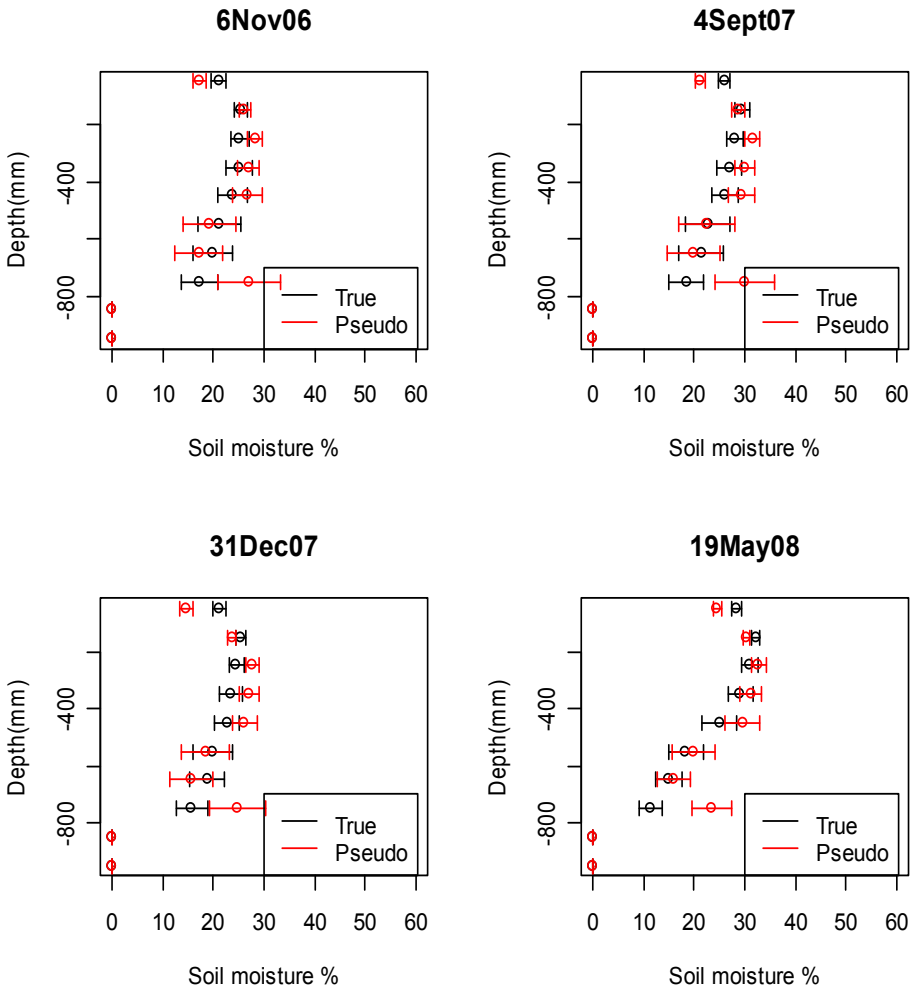


Figure 7.13 Comparison of moisture levels in the true lysimeters and pseudo lysimeters.

7.3.3. Quantifying drainage

Because the area of lysimeter was 5 m^2, and noting that it requires 1 L to cover 1 m^2 with 1 mm of water, the volume of drainage, measured in litres, is converted to mm by dividing by 5.

Drainage from the lysimeters occurred in the first three years but in only four of the last nine years (Figure 7.14). The first three years were atypical in that the lysimeters were still equilibrating and the vines were still establishing. For that reason we consider the last eight years of data as well as the overall data set.

The average drainage rate overall was 12.0 mm/year, but only 8.7 mm/year over the last 8 years. Drainage, when it occurred, was mainly in late spring or early summer (Figure 7.15). This represents a lag of about 4 months compared to the occurrence of the maximum rainfall (Table 7.2).

Drainage has occurred in the 2009-10 season, but at the time of writing volume data corresponding to the chemical data were not available.

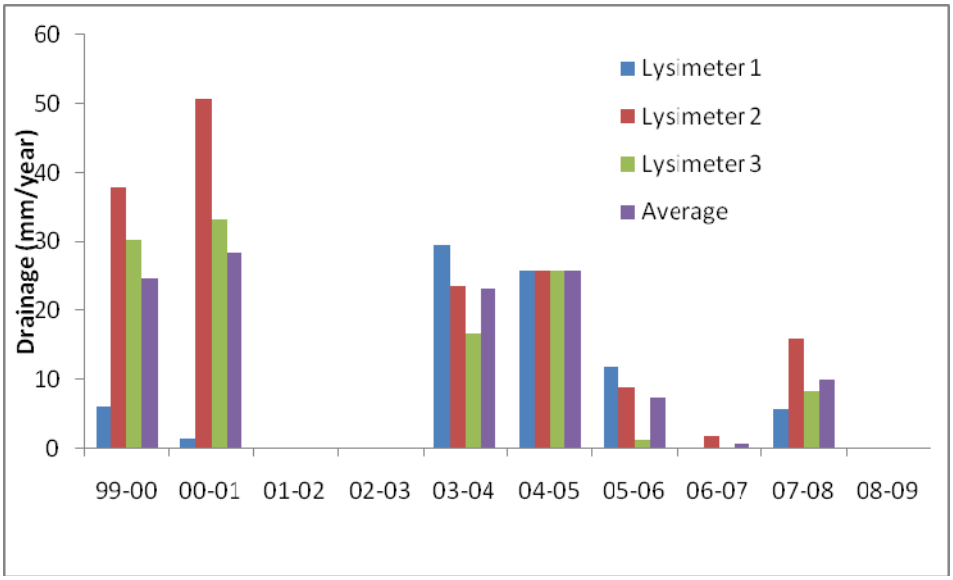


Figure 7.14 Observed drainage in each year in each lysimeter.

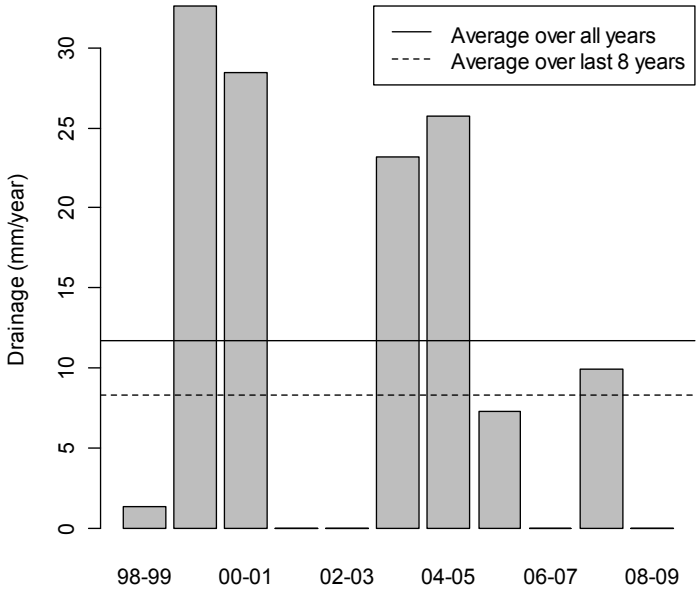


Figure 7.15 Drainage from the lysimeters expressed in mm. The solid line is the overall average and the broken line is the average of the last eight years.

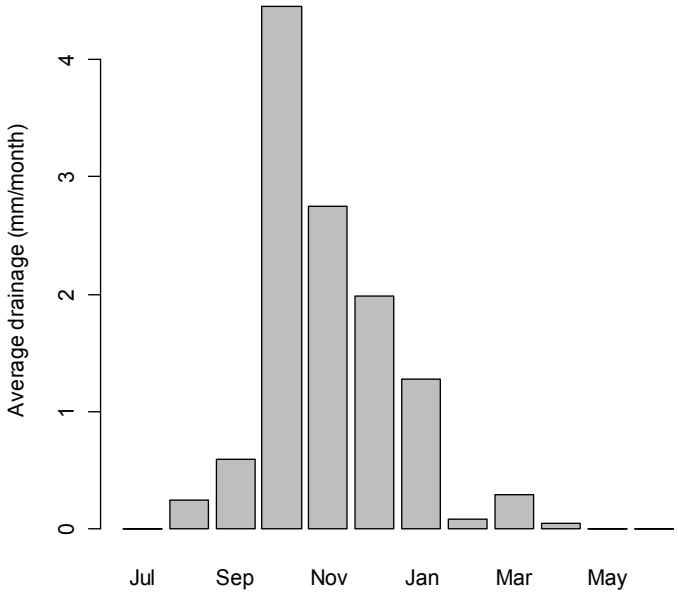


Figure 7.16 Average drainage from the lysimeters in each month.

7.3.4. Chloride in the drainage water

Chloride concentrations

The chloride concentration in the drainage water continued to increase over the project period (Figure 7.17). The increase is approximately linear, with a slope of approximately 400 (Table 7.3).

Table 7.3 Details of regression fit relative to increase of chloride concentration with time.

Lysimeter	Lysimeter 1	Lysimeter 2	Lysimeter 3
Slope	401 ± 27	465 ± 22	396 ± 24
Adjusted R^2	0.823	0.884	0.828

The units of slope are mg/L per year.

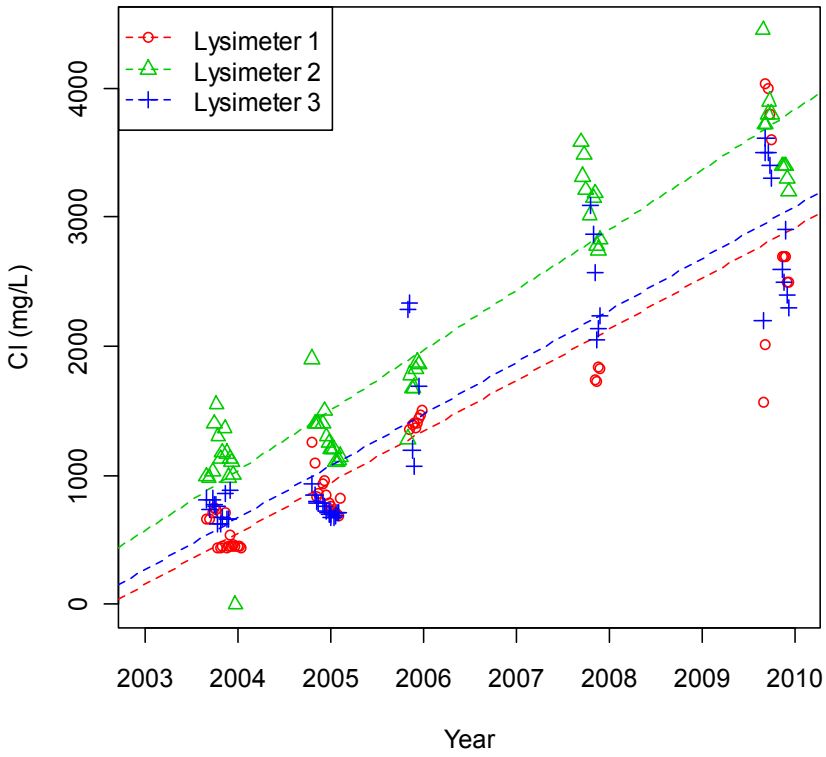


Figure 7.17 Changes in chloride concentration in drainage water over time.

Chloride balance

The TSS of the irrigation water remained fairly constant apart from a decline in 2003-4 (Figure7.18). Analyses of the irrigation water indicated that approximately 54% of the TSS was Cl. The Cl concentration of the water, combined with the volume of irrigation water applied, were used to estimate of the amount of Cl added to the soil on a per ha basis through irrigation. Drainage data, together with the Cl content of the drainage water, provided an estimate of the amount of Cl leached from the lysimeters. Because the lysimeters have been shown to perform in a similar manner to the rest of the vineyard, the amount of Cl removed can be used as an estimate of Cl leached on a per ha basis. Details of the calculations are shown in Table 7.4.

The data shown in Table 7.4 shows that there has been a large increase in the amount of Cl in the system. In years with no drainage, the accumulation was estimated to be an average of 834 kg Cl per ha per yr (range 593-1022kg/ha) There would have been some losses through harvest and prunings, but those components would be small compared to the size of the input. The effect of the imbalance would be cumulative and over the period of observation, the imbalance totalled approximately 4500 kg/ha.

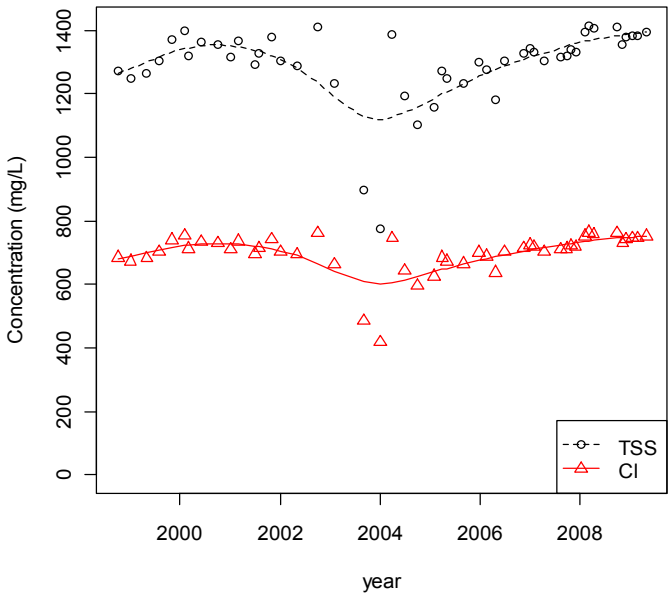


Figure 7.18 Change in total soluble salts (TSS) over the study period. The Cl data were taken as 54% of TSS. The fitted lines are splines with 7 degrees of freedom.

Table 7.4 Rainfall, irrigation applied, drainage, Cl concentrations.

Year	Rainfall (mm)	Irrigation mm	Irrigation Cl (mg/kg)	Irrigation Cl (kg/ha)	Drainage mm	Drainage Cl (mg/kg)	Drainage Cl (kg/ha)	Increase in profile Cl (kg/ha)
98-99		0	689	0	1	NM	NM	0
99-00	540	50*	722	361	33	NM	NM	NM
00-01	531	100*	728	728	28	NM	NM	NM
01-02	683	143	706	1012	0	NM	0	1012
02-03	681	92	648	593	0	NM	0	0
03-04	608	96	603	580	23	804	186	393
04-05	598	98	635	620	26	987	254	366
05-06	457	100*	677	677	7	1567	115	562
06-07	288	100*	709	709	0	NA	0	709
07-08	400	100*	734	734	10	2630	348	385
08-09	380	137	749	1022	0	NA	0	1022

*indicates estimated values ; NM, not measured ; NA, not available

7.3.5. Nitrate

Nitrate in the drainage water

Nitrate levels were initially very high (Figure 7.19) with values well over guideline levels. The concentrations fell in the following years, which could indicate that the high nitrate levels were an outcome of the disturbance from repacking the lysimeters. That experience would be consistent with the findings of Johnson *et al*. (1995) who warned against using repacked lysimeters for nitrate studies for that reason.

Although there was a fall in the nitrate concentrations up to 2008-9, this trend was not evident in the 2009-10 data (Figure 7.19). Lysimeter 1 behaved differently from Lysimeters 2 and 3 in that there was no observed initial fall (but this may have occurred before measurements were commenced). A logistic model was therefore fitted with the equation

$$C_t = a + \frac{b}{1 + \exp k(t - m)}$$

where C_t is the concentration of nitrate at time t, a is a bottom asymptote estimated at 161 mg/L, b is the increase above the base line concentration (estimated as 375) mg/L, t is time in years and m was the time when have the decline had occurred. The estimates of m and k were almost completely confounded so that standard errors of the parameters were not available.

The data from lysimeters 2 and 3 could be modeled with an exponential curve,

$$C_t = a + b \exp(-kt)$$

where C_t is the concentration of nitrate at time t, a is a bottom asymptote (mg/L), b is the increase above the base line concentration t is time in years after 2003 (the date of the first data). Details of the parameters and their standard errors are given in Table 7.5. Note that the estimate of the maximum increase is very dependent on the chosen starting time although the bottom asymptote and fitted values are not affected.

Table 7.5 Parameter estimates used n fitting nitrate models.

Parameter	Interpretation	Units	Lysimeter 1	Lysimeter 2	Lysimeter 3
a	Lower asymptote	mg/L	161	97±55	173±41
b	Maximum increase	mg/L	375	906±77	1180±200
k	Rate of decline	none	-4.14	0.47±0.11	0.87±0.21
m	Centering parameter	years	2006.6	Not applicable	

While it is clear that there has been a large decline in the nitrate concentrations in each lysimeter, it would appear that there is high lower asymptote. This may be a result of lack of drainage in the preceding years, but it may indicate that high levels of nitrate will persist in the drainage water.

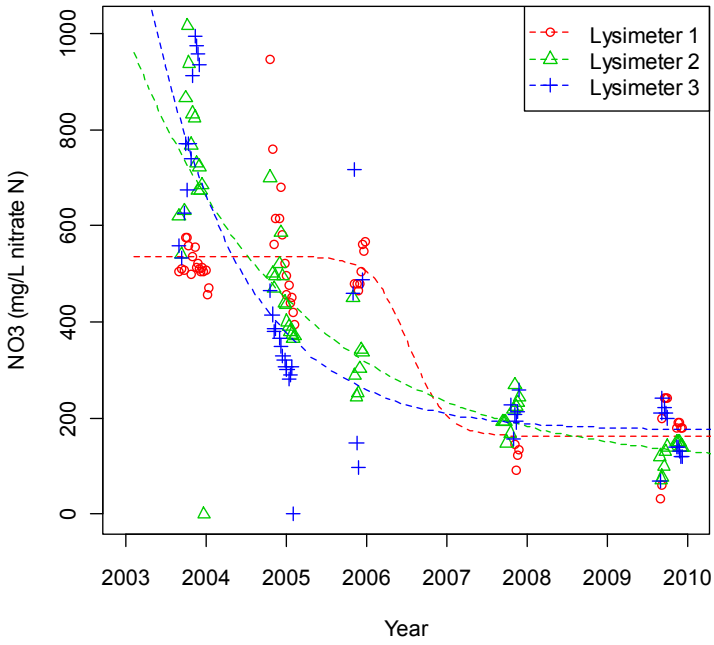


Figure 7.19 Changes in nitrate concentration in drainage water over time.

Nitrogen in petioles

Data were obtained on the total nitrogen and nitrate N content of the petioles and blades (Table 7.6). There were no statistically significant differences between the lysimeters, pseudo-lysimeters and surrounding vines (controls).The total nitrogen levels were all in the 0.8 – 1.1%, which represent the moderate to high range as indicated by Robison *et al*. (1997).

Table 7.6 Nitrate and total nitrogen (TN) levels of petioles and blades in lysimeters, pseudo-lysimeters and control vines.

Date	28/11/2005		28/11/2008	1/03/1009			
Organ	Petiole		Petiole	Petiole		Blade	
	NO_3 (mg/kg)	TN (%)	TN (%)	NO_3 (mg/kg)	TN (%)	NO_3 (mg/kg)	TN (%)
Control	1330 ± 392	1.08 ± 0.03	1.18 ± 0.23	740 ± 133	0.61 ± 0.03	283 ± 74	2.01 ± 0.07
Lysimeter	1223 ± 226	1.04 ± 0.02	1.40 ± 0.19	613 ± 77	0.60 ± 0.03	480 ± 74	2.00 ± 0.06
Pseudo-lysimer	NA	NA	1330 ± 392	295 ± 94	0.56 ± 0.03	418 ± 74	2.00 ± 0.07

Numbers shown are means and standard errors.

Soil mineral N

Some data on mineral N were obtained from samples taken near the lysimeters taken in 2005. The control samples were taken at the end of a (lysimeter) row, where no fertiliser would have been applied in recent years, nor would there have been soil disturbance. A summary of those data are given in Appendix 5, Figure 13.1.

- The surface nitrate concentrations were high, and declined with depth. There was a calcrete layer at 30 cm depth that often restricted augering.

- The lowest nitrate concentrations were under the vines, especially under a dripper. The low levels at that point may have been due to leaching or uptake by the vines.

- While the nitrate levels near the lysimeters were high (especially if they were converted to a pore water basis) they were less than those encountered in the drainage water.

- A second series of soil samples were taken in September 2009, partly to compare the behaviour inside and outside the lysimeters and partly to examine whether there had been accumulation of chloride in that part of the profile that could be sampled using an auger.

- One restriction on the sampling was that samples could not be taken from inside the lysimeters because these unique facilities should not be disturbed by augering (having taken approximately 10 years to settle). The compromise was to sample soil at the outer edge of the lysimeter which had been disturbed in a similar manner to the soil inside the lysimeter. Samples were taken at the drip line (D) and away from the drip line (L).

- Where possible, samples the same locations were used for the 2009 samples as were used for the 2005 samples. Inter-row samples were taken either side of the lysimeter row (labelled M and N). Further controls were taken from the pseudo-lysimeters.

- Samples depths to about 70-80cm were generally accessible, but in some cases the calcrete layer restricted sampling. Where samples could be taken below 50 cm, the sample closest to 70 cm was classified as a subsoil sample. The data were displayed as separate box plots for the surface and subsoil layers and these results are shown in Appendix 5, Figure 13.2 and Figure 13.3

- A comparison of the soil nitrate levels in 2005 and 2009 is given in Figure 7.20. There appears to have been an increase in nitrate in the control samples, but the 2005 data are based on only 2 control samples. The median values of nitrate levels had not changed in the inter-row samples but there was one value in the 2009 data of 55 mg/kg. All values in the subsoil were less than 10 mg/kg. All values below the drippers were less than 10 mg/kg. Overall there has been little change in the nitrate status between 2005 and 2009, The most marked feature is the low nitrate values under the drippers.

- The nitrate values described in Figure 7.20 are in mg/kg. If there was 30% water in the soil, the high value of 55 mg/kg would be the equivalent of almost 200 mg/L averaged over all the soil water. It is unknown how that concentration would change with the soil pore size and the corresponding sampling methods of suction cups or free draining.

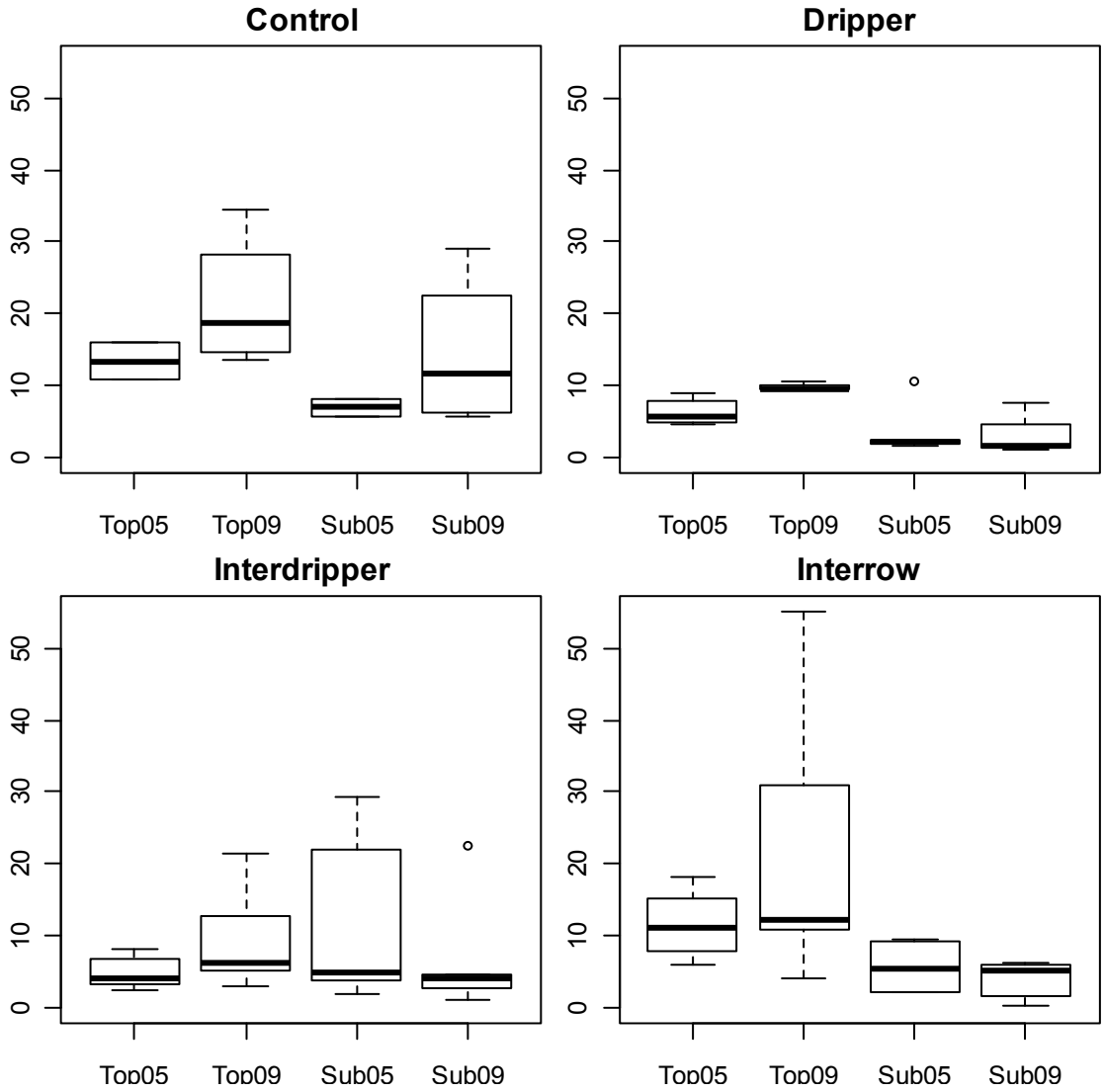


Figure 7.20 Comparison of nitrate levels in surface soil (Top) and subsurface soil for 2005 and 2009 sampling times.

Chloride levels in the surface soil were all less than 70 mg/kg, apart from an outlier of 142 mg/kg that was measured in a mid-row sample. Chloride levels were generally higher in the subsoil with a maximum of 380 mg/kg.

Nitrate levels in the lysimeters and the pseudo-lysimeters were very similar. The nitrate levels were higher than in the surface soil (mean 16 mg/kg) than in the subsurface (mean 5.3 mg/kg) with an overall mean of less than 10 mg/kg.

7.3.6. Identifying the source of mineral N

In view of the high nitrate levels that have been described in Section 7.2.5, and in particular recent data that indicates the levels may be asymptoting to an unacceptably high level, and in view of other high levels reported (Section 9.4), it is important to understand the source(s) of nitrate entering the groundwater. Several lines of investigation are currently being pursued.

There could be an enhanced release of mineral N due to soil disturbance. There are relatively high total N values in the soil (Table 7.7), and there are relatively high values down to 60 cm. Note that at the surface there is more nitrate-N than ammonium-N but this reversed at depth.

Table 7.7 Nitrogen levels in bulked cores taken from a local soil.

Depth (cm)	Total N (%)	NH_4-N (mg/kg)	NO_3-N (mg/kg)
0-10	0.22	3.4	6.6
10-20	0.16	1.6	1.4
20-30	0.13	1.7	2.0
30-40	0.11	2.6	1.8
40-60	0.09	1.3	1.1
60-80	0.04	2.9	0.6
80-100	0.04	1.8	0.3
100-105	0.03	3.8	0.6

7.3.7. Isotopic signature of N

In many soil processes, ^{14}N is used preferentially to ^{15}N and this provides some possibility of tracing soil N movements. Organic N and fertiliser N have different ^{15}N signatures and this offers some hope to identify the source of the mineral N (Figure 7.21). Differences between fertiliser N and the nitrate N obtained from the lysimeters is shown in Figure 7.22, however, the signature differences represent only small changes in the ^{15}N:^{14}N ratio. It is also feasible that the mineralisation of organic N happens selectively with the ^{14}N fraction, and that could affect the ^{14}N:^{15}N ratio, so the interpretation may be ambiguous.

Preliminary results suggest that the ^{14}N:^{15}N ratio does vary between the mineral N components so the results obtained to date are inconclusive. Further testing of components of the soil N and of the drainage water organic N, NH_4^+ and NO_3^- for their ^{15}N enrichments may help in determining the source of the nitrate in the drainage water. Ideally dual isotope ratio approach presented in Figure 7.21 is recommended but we do not have facilities for analysis of both isotopes in our laboratory and may require services of overseas laboratories.

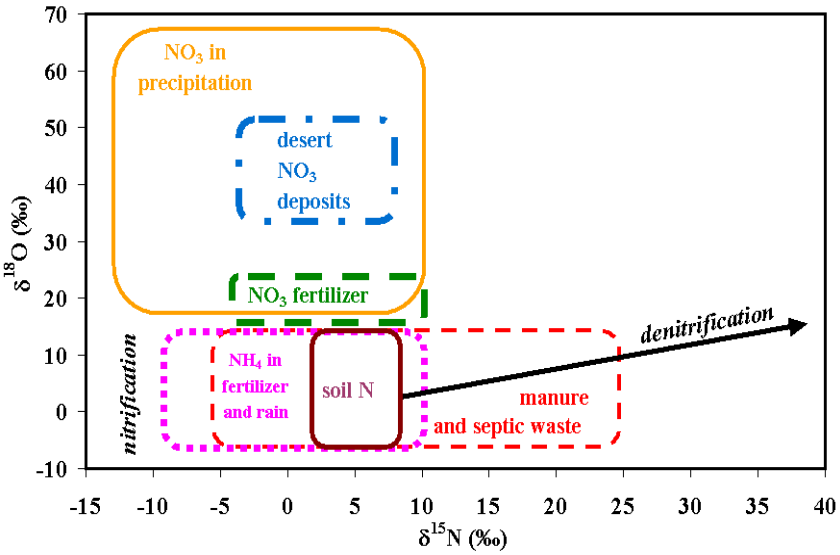


Figure 7.21 ^{15}N and ^{18}O signatures used to identify sources of nitrate (after Granger et al. 2008).

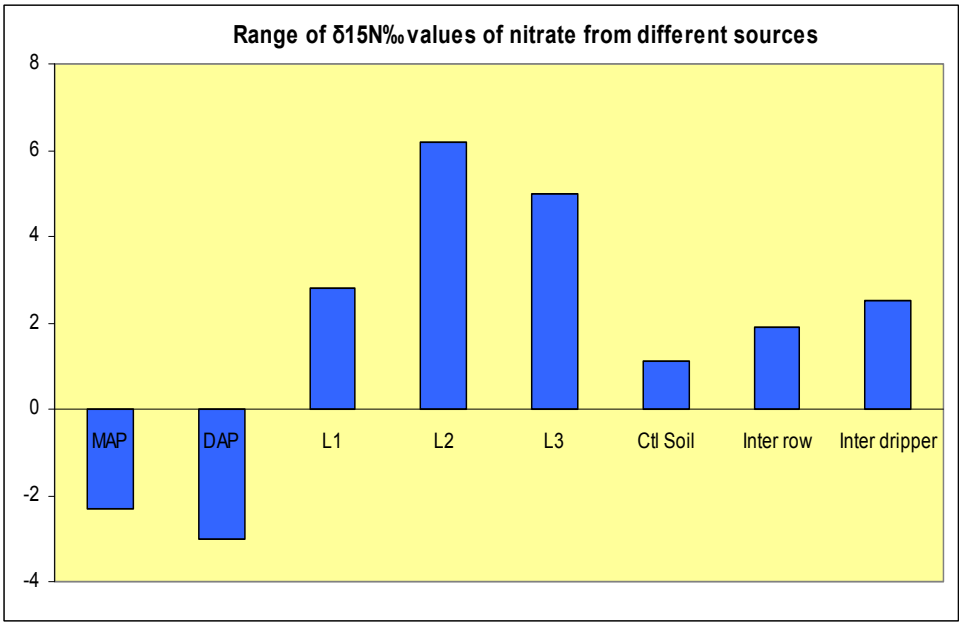


Figure 7.22 Results of ^{15}N isotope analyses of nitrate samples from fertiliser, lysimeter drainage samples, and three soil samples.

7.4. Pesticide residues

Details of the methods used for pesticide analyses are given in Section 6.5.1 and the list of pesticides and their detection levels are given in Table 6.1. Despite the numerous analyses of suction cup data (as detailed in Appendix 5, Table 13.1) no traces of pesticides were detected. There were also no detections in the lysimeter samples.

There are several possible reasons why there were no detections in the suction cup data, whereas pesticides were detected in both MIA and in Sunraysia. These reasons include,

- Losses of pesticide in the soil due to long residence time induced by the lack of drainage.

- Averaging effect of the compositing of the suction cup samples is required to obtain sufficient volume for pesticide analysis – the averaging effect would remove any pesticide concentration spikes.
- The location of suction cups may not coincide with the maximum pesticide concentration
- The water sampled obtained by suction cups are from water with higher water potential than the water obtained in tile drains or from a lysimeter – the difference would correspond to obtaining water from different pore sizes.

8. SUNRAYSIA

8.1. Background data

The Sunraysia consists of five areas as shown in Table 8.1 – these districts are centred on the inland city of Mildura, with the first irrigation trust commenting in 1887. A map showing these areas is given in Figure 8.1. All the areas have been established for over 60 years. Approximately 90% of the irrigated area is planted to grape vines – Colignan to Karadoc area differs from the other areas in having approximately 30% of the area planted to citrus.

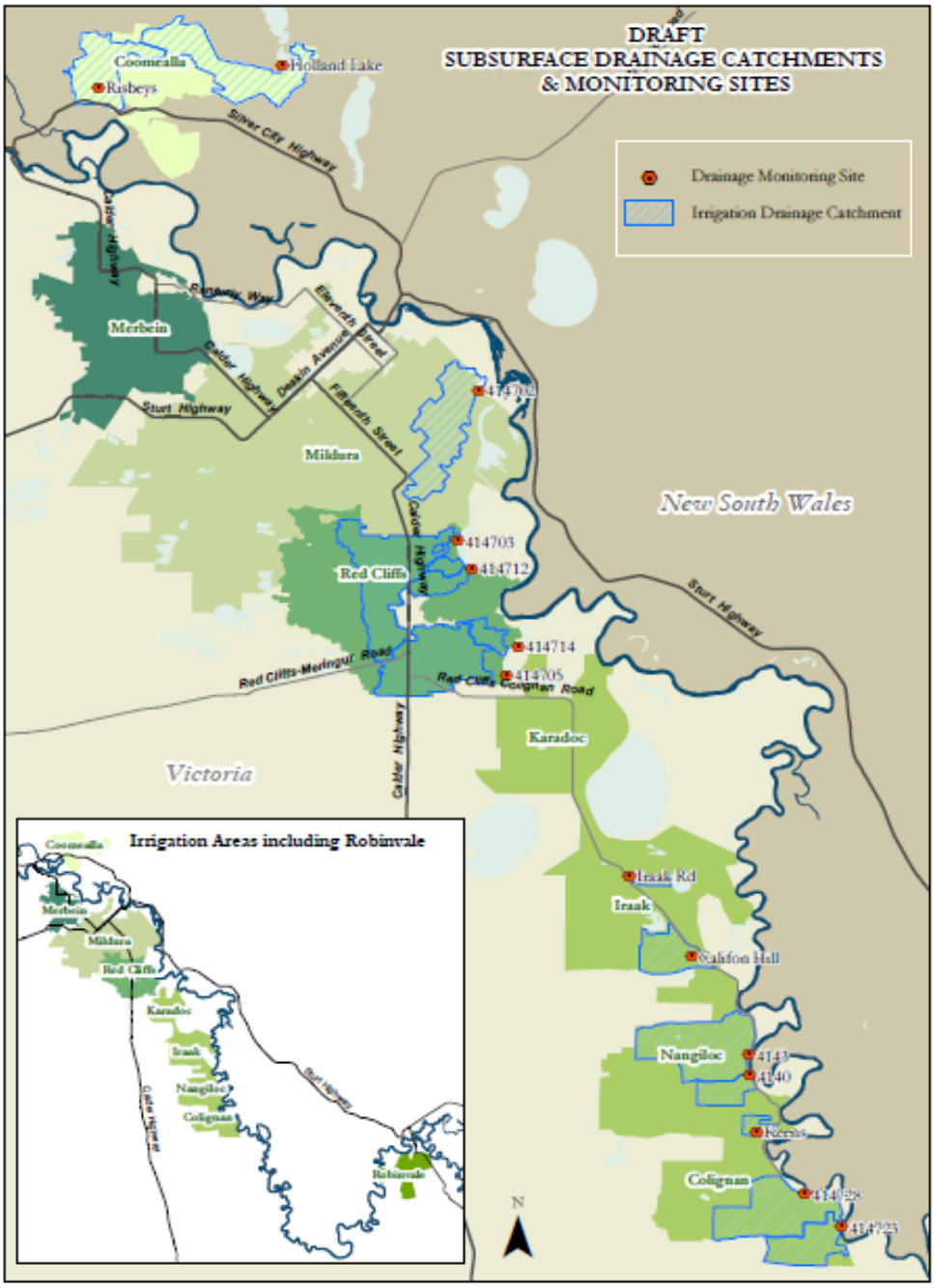


Figure 8.1 Map of irrigation areas in the Sunraysia Irrigation region.

Table 8.1 Details of the five irrigation areas in Sunraysia.

	Robinvale	Colignan to Karadoc	Red Cliffs	FMIT (Mildura)	Merbein
Area (ha) District	3905	15000	6370	15100	4200
Area (ha) Irrigated 1997	2320	6760	4445	6485	3130
Area (ha) Irrigated 2006	2300	8610	4225	5530	2800
History (Established)	1947	1920	1920	1887	1909
Soil Type	Nookamka loam Coomealla loam	Berri sand Murray sand	Barmera sand Berri sand	Sandilong loam Irymple loam	Coomealla sandy loam Barmera sandy loam
Land Use 1997	97% grapes	43% grapes 37% citrus	87% grapes 3% citrus	87% grapes	87% grapes
Land Use 2006	98% grapes	55% grapes 31% citrus	89% grapes	89% grapes	88% grapes

8.1.1. Soils

Some description of the soils in each irrigation area is given in Table 8.1. The soils are mainly sand (shown as brown) or loams (shown as yellow) in Figure 8.2. The low lying areas are dominated by clays (shown in blue). Further details of the soils are available from the DPI Victoria website.

8.1.2. Climate

The climate in the Sunraysia district is semi-arid with an average rainfall of 268 mm which is more or less evenly spread across the year but with a maximum average rainfall in June. While the mean rainfall in summer is moderate, the median is much lower. For example mean January rainfall is 18.2 mm whereas the median January rainfall is only 8.9 mm. This contrasts with the June rainfall that has a mean of 29.6 mm and a median of 28.7. The winter rainfall is thus more reliable than the summer rainfall. Average summer temperatures are approximately 33^{o}C, resulting in high evaporative potential. Horticulture in the district is therefore heavily dependent on irrigation.

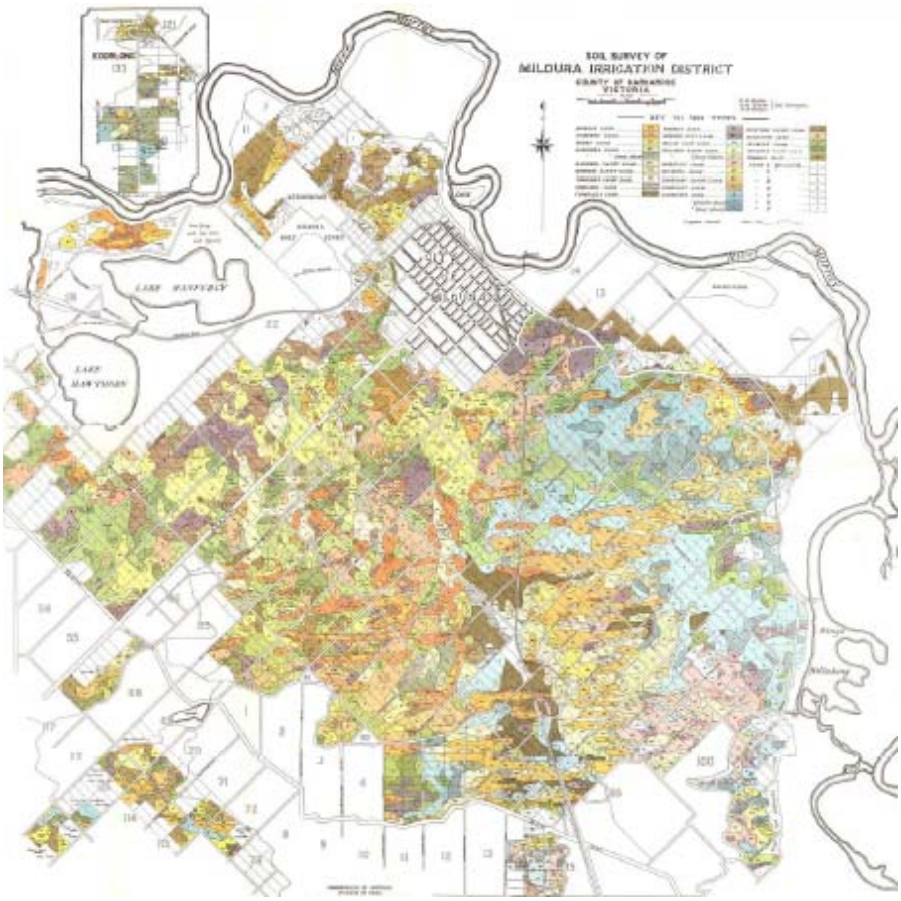


Figure 8.2 Soil map of Mildura Irrigation District. Downloaded from website http://www.dpi.vic.gov.au/dpi/vro/soilsurv.nsf.

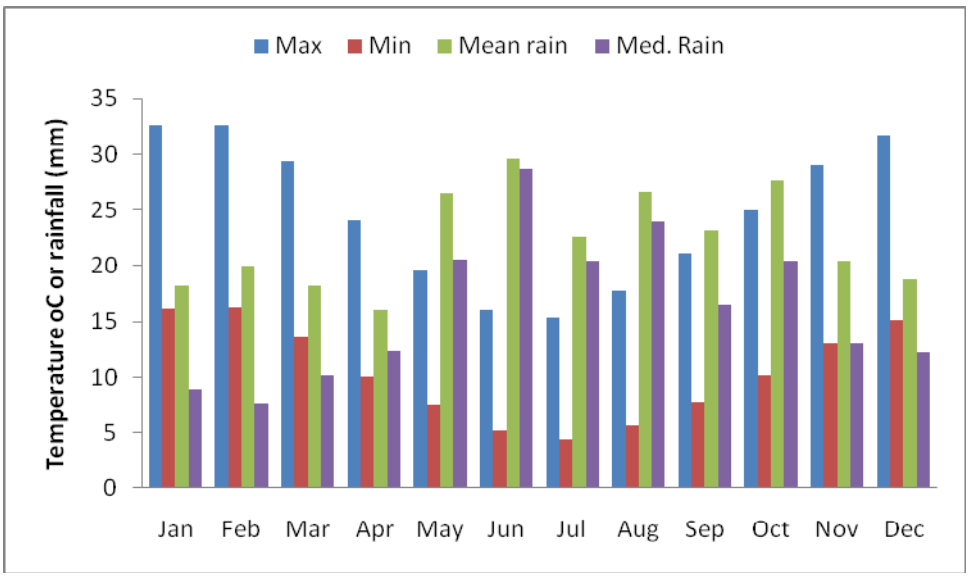


Figure 8.3 Long-term average temperature and rainfall at Mildura post office. Source www.bom.gov.au

8.1.3. Irrigation type

There is a variety of irrigation types used in Sunraysia, ranging from flood irrigation to drip. Over the 10 year period 1997 to 2006 there was a decrease in the proportion of flood irrigation in all districts with an increase in drip irrigation. There has been a large increase

in the percentage of irrigation by low level sprinklers in Robinvale. Typically there has been a move toward more efficient irrigations systems which implies that a greater percentage of water applied is used by the plants resulting in a smaller leaching fraction.

Table 8.2 Changes in percentage of irrigation type between 1997 and 2006.

	Robinvale		**Colignan to Karadoc**		**Red Cliffs**		**FMIT (Mildura)**		**Merbein**	
Irrigation type	1997	2006	1997	2006	1997	2006	1997	2006	1997	2006
Furrow/Flood	47	14	4	2	45	13	55	24	70	40
Overhead	11	8	64	43	35	39	29	32	14	17
Low level	41	74	7	9	11	21	13	26	14	30
Drip	1	4	25	46	9	27	3	18	2	13

8.1.4. Drainage

A drainage fraction is a necessary component of an irrigated horticultural landscape to remove the salt that enters the system with the irrigation water (Stevens 2002). Each of the irrigation districts described in Table 8.1 has a system of drains that remove drainage water, together with salt, nutrients, other contaminants and possibly pesticides. A list of the drainage basins is given in Table 8.3.

Each of the drainage basins listed in Table 8.3 includes a network of smaller drains that feed into main drains. An example of the locations of drains is shown in Figure 8.4. Similar networks exist in all the irrigation areas. There may be several drainage basins in the same irrigation area. Monitoring of the outfalls of these drains has occurred providing a good historic record. These data are considered in the next section.

There has been a been a steady decline in the drainage discharge since 1998 in all five areas, but the largest relative declines occurred in the FMIT and Merbein areas, where discharges have been reduced to a much reduced flow as compared to previous seasons.

Table 8.3 Drainage catchments and monitoring points in the Sunraysia district, including the Coomealla area which is in NSW.

Location	Catchment Name	Monitoring spot	Area ha
FMIT	FMIT-7	414702	1090
RED CLIFFS	RED-03	414712	233
RED CLIFFS	RED-08	414714	171
RED CLIFFS	RED-10	414705	1249
RED CLIFFS	RED-01	414703	1496
Coomealla	Risbey's Pump Station	Risbey	791
Coomealla	Holland Lakes	Holland Lake	1159
Nangiloc-Colignan	Kulkyne	414723	543
Nangiloc-Colignan	Browns at Reids Road	414728	1067
Nangiloc-Colignan	Colignan at Castles Cross	4140_Ca	285
Nangiloc-Colignan	Colignan at Graces Bend	Keens	52
Nangiloc-Colignan	Lake Iraak	Iraak_Road	22
Nangiloc-Colignan	Doerings Basin	Califon_Hill	12
Nangiloc-Colignan	Nangiloc	Camalduli	17

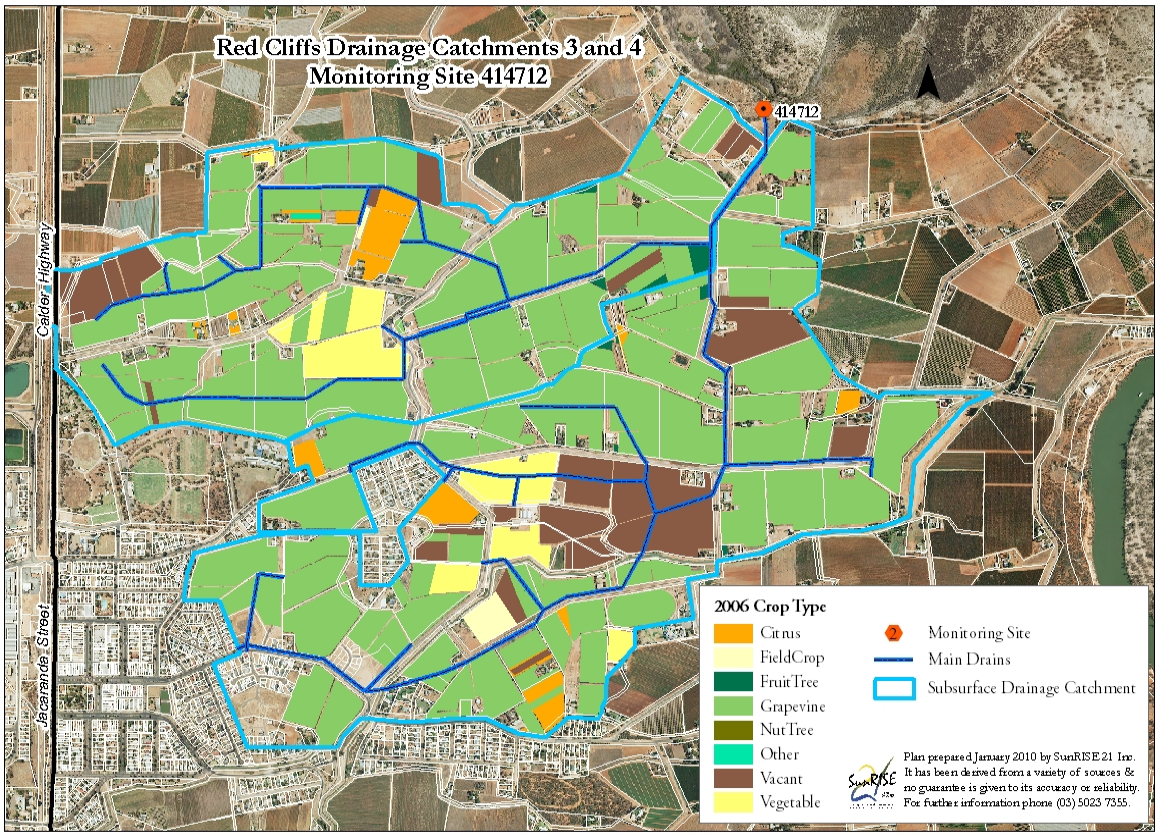


Figure 8.4 Details of land use, drainage basins and main drains in the Redcliff irrigation area.

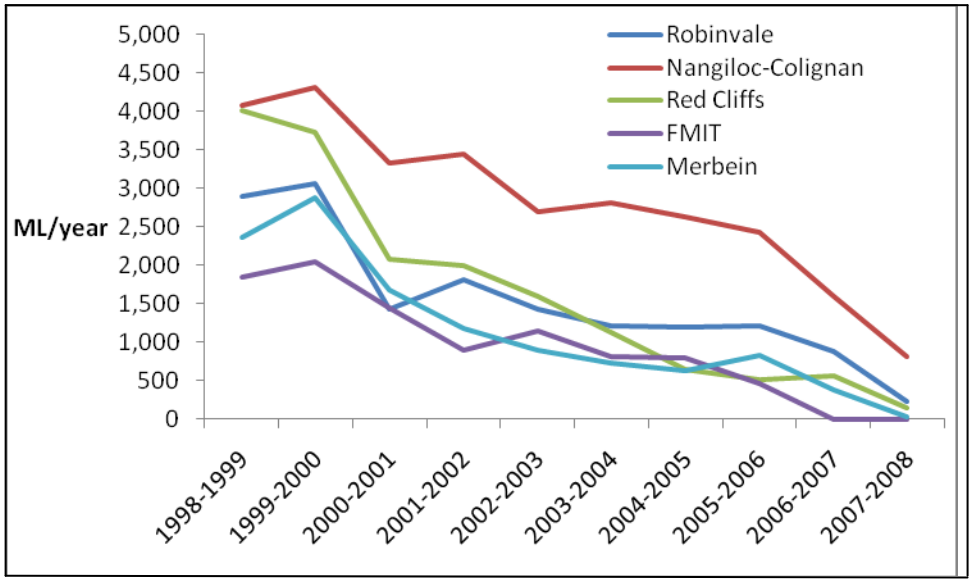


Figure 8.5 Discharge rates (ML) of drainage water in each drainage catchment in Sunraysia.

8.2. Parameters of potential concern

The parameters of potential concern to the environment in the drainage water in the Sunraysia district are the same as in the other study areas, namely

- Salinity;
- Sodicity or SAR;
- Nutrients; and
- Agricultural chemicals (pesticides)

These contaminants are discussed in the following sections.

8.2.1. Discharge of salt

The amount of salt being discharged with the drainage water has decreased markedly in all five irrigation areas from over 20,000 t/year in 1998-1999 to 1100 t/year in 2007-8. In FMIT there was only 20 t of salt removed due to the low flow conditions (Table 8.4).

Figure 8.6 shows a contrast between the declines in Red Cliffs and Nangiloc-Colignan areas. In Red Cliffs the flow decreased to almost zero as did the load of salt. By contrast in Nangiloc-Colignan the flow was reduced by a lesser amount and there is a corresponding smaller reduction in the salt load. There has been no increase in concentration to compensate for the reduced volume of drainage.

Table 8.4 Tonnes of salt discharge by the drainage system in Sunraysia.

	Salt (tonnes)					
Year	**Robinvale**	**Nangiloc-Colignan**	**Red Cliffs**	**FMIT**	**Merbein**	**Total**
1998-1999	–	4800	4600	1900	9200	20900
1999-2000	–	4800	4300	2300	5200	17000
2000-2001	_	3800	2500	2300	3200	12200
2001-2002	_	3200	1900	1500	2000	8800
2002-2003	_	2500	1500	1000	1900	6900
2003-2004	1400	2700	1100	1000	2300	8600
2004-2005	1200	2200	600	800	1000	5900
2005-2006	1000	2100	700	500	1800	6200
2006-2007	800	1200	400	250	900	3400
2007-2008	200	600	100	20	200	1100

Data were unavailable for Robinvale before 2002-2003.

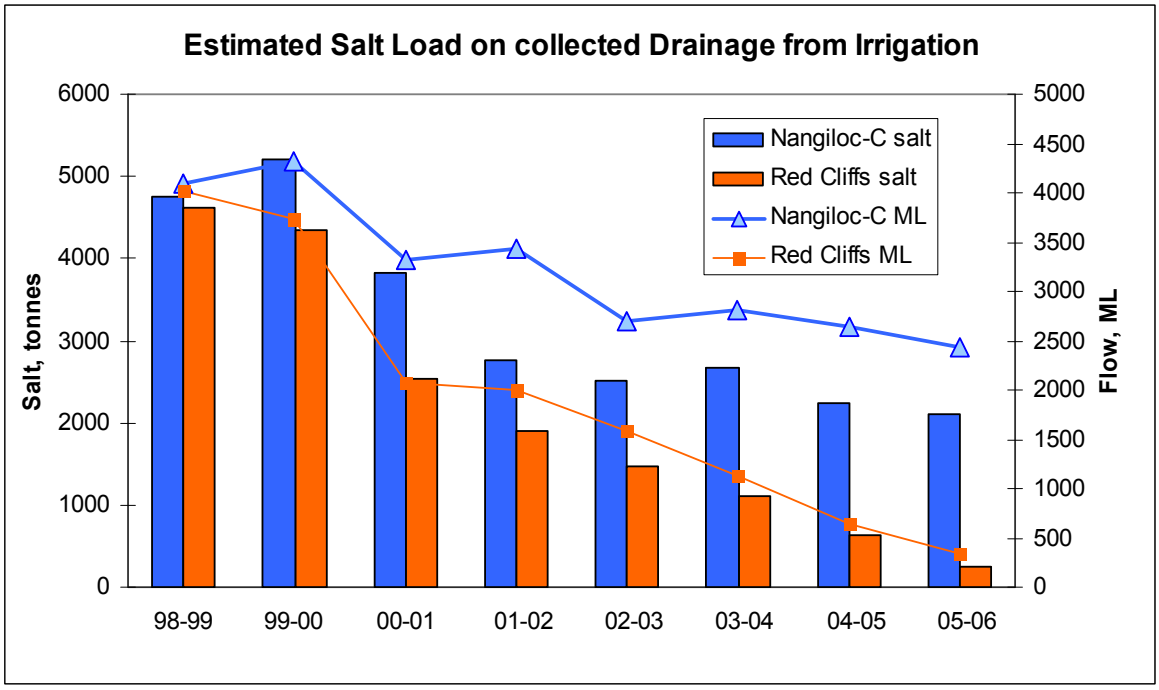


Figure 8.6 Comparison of drainage volume and salt discharge Nangiloc-Colignan and Red Cliffs.

8.2.2. Discharge of nutrients

Discharge of nitrate

The changes in concentrations of nitrate from 1998-1999 to 2005-2006 for each area are shown in Table 8.5. There was little change in concentration of nitrate in the drainage water from Robinvale but there was a significant ($p < 0.01$) increase in the nitrate concentration in the drainage water from Nangiloc-Colignan of about 0.7 mg/L per year. The lowest concentrations of nitrate were at Mildura and Merbein but the values of 4.1 and 3.2mg/l respectively exceed the environmental guidelines (WQG 2000) for freshwater.

Table 8.5 Historic data showing yearly average nitrate N concentration (mg/L) for 5 irrigation areas in the Sunraysia district (after Mallee CMA).

Year	Robinvale	Nangiloc-Colignan	Red Cliffs	Mildura	Merbein
1998-1999	13.9	14.5	8.4	4.2	3.5
1999-2000	17	15.6	11.7	5.8	4.6
2000-2001	13.4	18.2	11.6	4	4.2
2001-2002	11.8	17.4	7	2	2.5
2002-2003	11.8	18.6	8.6	2.1	1.9
2003-2004	9.7	18	10.7	3.7	1.8
2004-2005	11.8	18	10	1	2.1
2005-2006	12.4	21	8.5	4.1	3.2

Data after 2005-2006 are not available.

There has been an overall decrease in the load of nitrate in the drains, particularly at Red Cliffs, but to a lesser extent in the other areas. The contrast between Red Cliffs and Nangiloc-Colignan is highlighted in Figure 8.7 where the reduced load at Red Cliffs has been driven by the decreased volume of drainage, whereas for Nangiloc-Colignan a smaller decrease in drainage and a small increase in the concentration of nitrate in the drainage water resulted in only a modest decrease in the nitrate-N load. Overall there has been a reduction in nitrate-N load in the drains from almost 200 tonnes in 1999-2000 to approximately 80 tonnes in 2005-2006.

The proportion of the TN load that is discharged as nitrate-N varies among the irrigation areas, with the lowest proportion being in Mildura and Merbein, while at Robinvale, Nangiloc-Colignan and Red Cliffs the proportion discharges as nitrate-N remained at about 95% (Appendix 5, Table 13.2). This observation suggests that there is a base load of organic N that is persisting while the nitrate load is decreasing.

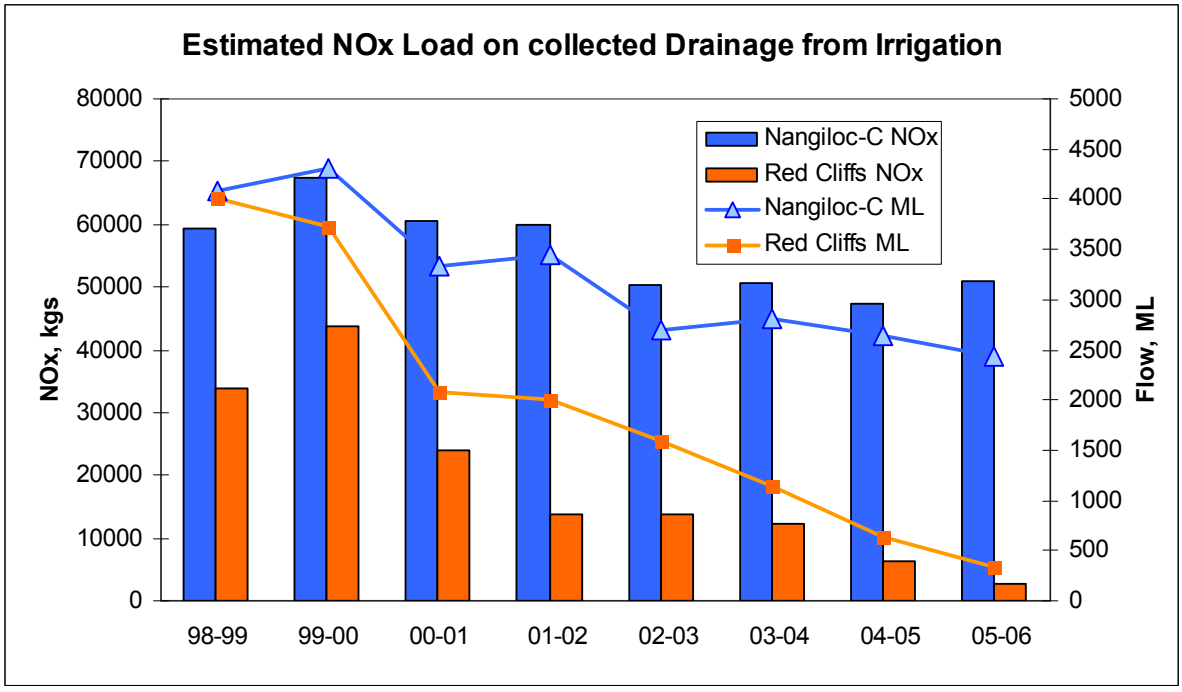


Figure 8.7 Comparison of drainage volume and nitrate-N discharge Nangiloc-Colignan and Red Cliffs.

Table 8.6 Tonnes of TN discharged by the drainage system in Sunraysia.

Year	Robinvale	Nangiloc-Colignan	Red Cliffs	FMIT	Merbein	Total
1998-1999	41.9	62.3	35.1	9.0	10.3	158.6
1999-2000	53.6	70.6	45.5	13.3	15.9	198.9
2000-2001	20.0	62.9	25.4	6.9	8.8	124.0
2001-2002	22.4	62.5	14.0	2.3	4.0	105.2
2002-2003	17.6	52.0	14.5	3.1	2.6	89.8
2003-2004	12.4	53.3	12.8	3.8	2.0	84.3
2004-2005	14.7	49.2	6.8	1.4	1.9	74.0
2005-2006	16.0	53.0	4.6	2.2	3.6	79.4

Discharge of phosphate

The rate of discharge of phosphate has decreased but not as strongly as the decline noticed for salt and even less than the decline than noted for nitrate-N. The reduction was apparent in four areas but there was an increase in Nangiloc-Colignan despite the discharge flow halving from 1998 to 2006.

Table 8.7 Kg of total phosphate discharged by the drainage system Sunraysia.

Year	Robinvale	Nangiloc-Colignan	Red Cliffs	FMIT	Merbein	Total
1998-1999	163	217	104	72	71	627
1999-2000	106	161	133	104	101	605
2000-2001	85	177	86	73	61	482
2001-2002	100	183	75	21	23	402
2002-2003	62	185	76	106	24	454
2003-2004	85	229	47	50	16	427
2004-2005	57	160	20	49	10	296
2005-2006	64	346	19	13	25	467

8.2.3. Pesticides

No historic data were available for inclusion in this report.

8.3. Monitoring of tile drain caissons[1]

All the monitoring sites were in the Nangiloc-Colignan irrigation area. Those sites were chosen because at the time they were flowing. Some details of the four sites are given below and some further details are in Table 8.8. Typical of the region, each small catchment includes a mosaic of land uses.

The monitoring points are a reflection of the drainage from the entire catchment. The results may not be representative of the area immediately around the collection sites as the contaminants could have travelled kilometers before reaching the sampling point.

- Califon Hill is situated off the Red Cliffs Colignan road approximately 4 km southwest of Iraak. The monitoring site collects from an area of about 12 ha. A detailed map is given in Figure 8.8.

[1] A Caisson (French for box) is a junction box of underground drains that can be used for measuring flows.

- Camalduli monitoring site is near the Red Cliffs-Colignan Road, approximately 2 km south of Nangiloc and close to the River Murray. The monitoring site collects from an area of about 17 ha. A detailed map is given in Figure 8.9.
- Iraak Road monitoring site is on the Iraak Road some 250 m from the Red Cliffs – Colignan Road. The monitoring site collects from an area of about 22 ha. A detailed map is given in Figure 8.10
- Keens monitoring site is approximately 500 m WNW of the junction of Red Cliffs-Colignan Rd and Grace Rd – the site is near Colignan and Grace's Bend. The monitoring site collects from an area of about 52 ha. A detailed map is given in Figure 8.11.
- The above sites do not represent viticulture exclusively but include the drainage from the horticultural productions systems of the area

A series of up to 7 samples were collected from the sampling points as shown by SRHS between September 2007 and February 2008. The series were incomplete for Califon Hill and Camalduli because of lack of flow. Samples were forwarded to CSIRO Urrbrae laboratories for analysis as described in Section 6.5.

The series of samples was terminated because of the lack of flow in several caissons, resulting in a series that ran only from September 2007 to February 2008. The data are not analysed as a time series because they are less than a yearly cycle.

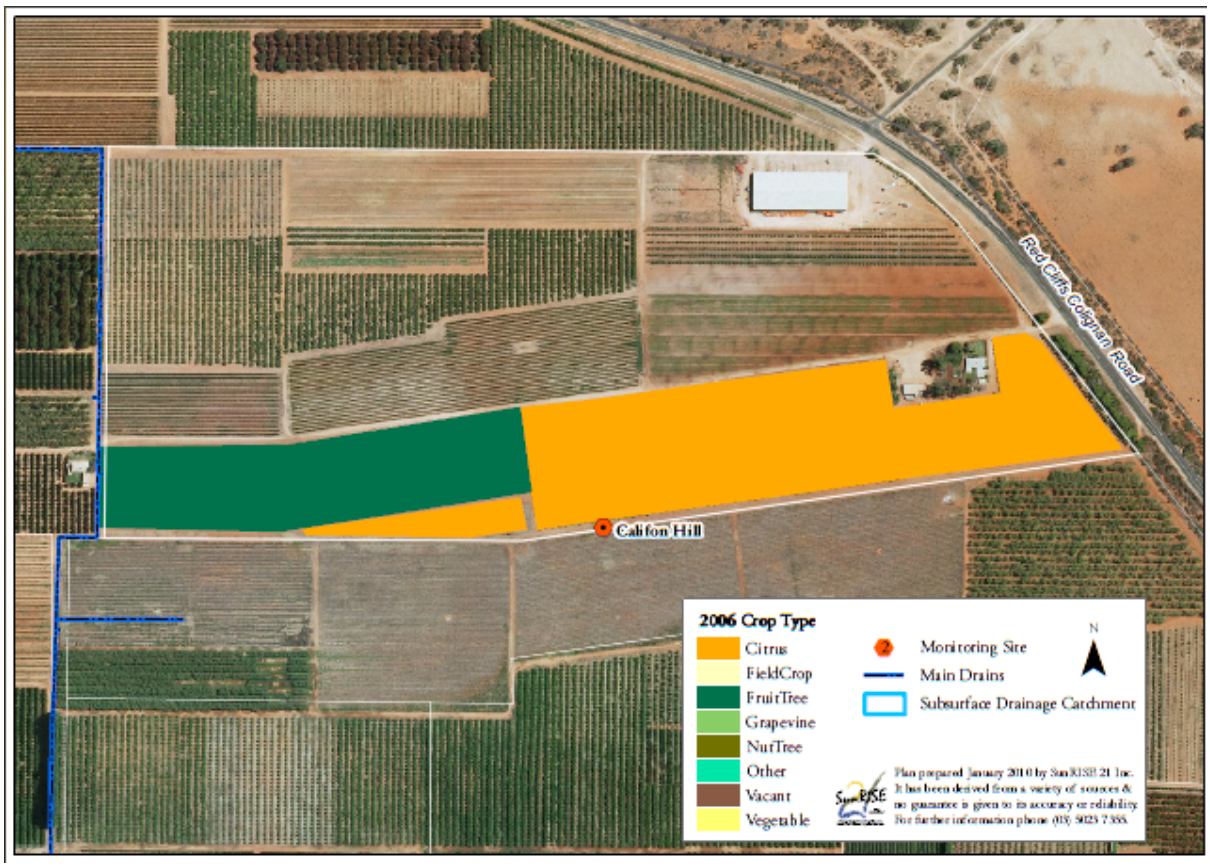


Figure 8.8 Map showing location of Califon Hill monitoring site, which is in the Nangiloc irrigation area, together with local land use.

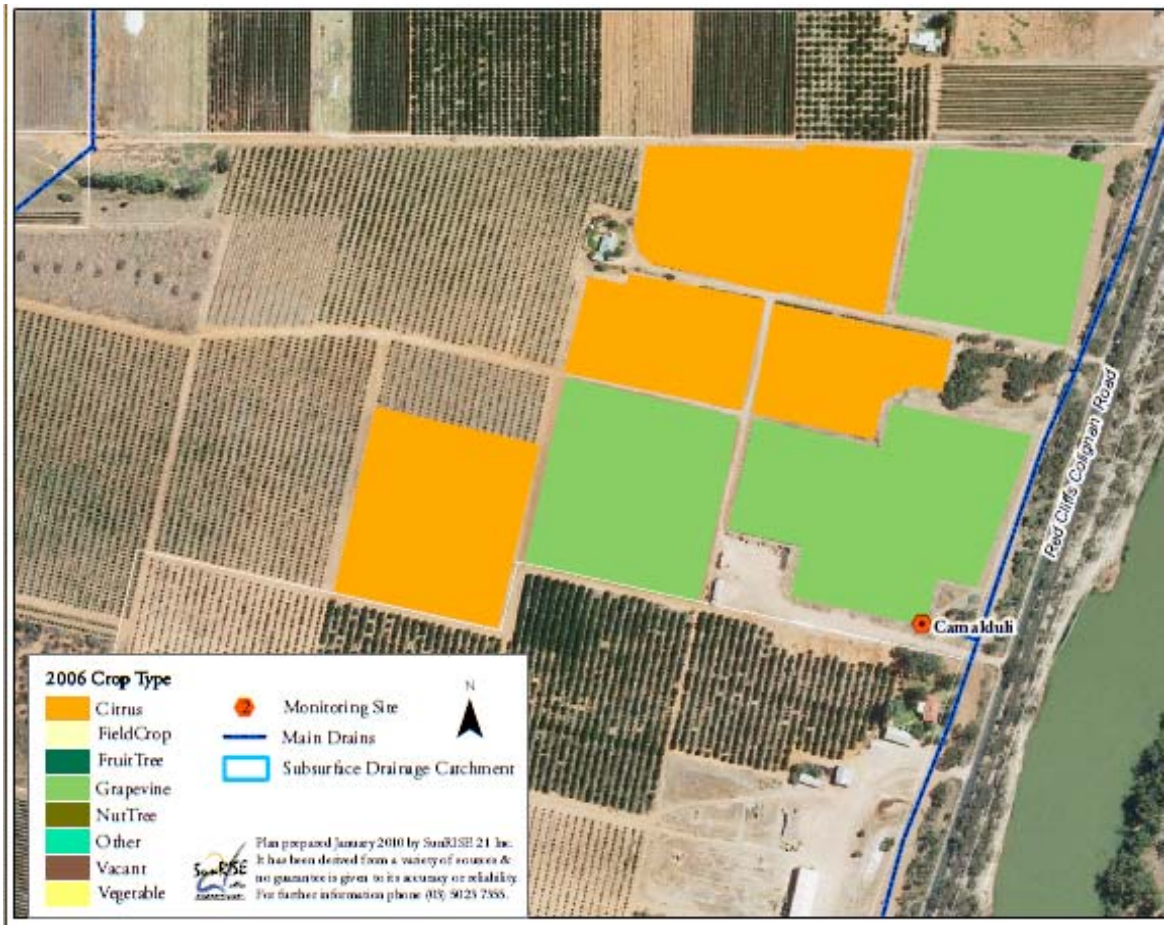


Figure 8.9 Map showing location of Camalduli monitoring site, which is in the Nangiloc irrigation area, together with local land use.



Figure 8.10 Map showing location of Iraak Road monitoring site, which is in the Nangiloc irrigation area, together with local land use.



Figure 8.11 Map showing location of Keens monitoring site, which is in the Nangiloc irrigation area, together with local land use

Table 8.8 Catchment area and land use at each monitoring point.

Monitoring Site	Catchment (ha)	Crop	Irrigation district
414702	1,090	88% Vines	FMIT
414703	1,496	92% Vines	Redcliff
414705	1,249	82% Vines	Redcliff
414712	352	88% Vines	Redcliff
414714	171	71% Vines	Redcliff
414723	543	73% Citrus	Nangiloc/Colignan
414728	1067	73% Citrus	Nangiloc/Colignan
Iraak Road	22	51% Citrus	Nangiloc/Colignan
Califon Hill	12	70% Citrus	Nangiloc/Colignan
Camalduli	17	50% Vines/50% Citrus	Nangiloc/Colignan
Keens	52	66% NutTree	Nangiloc/Colignan
Holland Lake	1159	79% Vines	Coomealla
Risbeys Pump Stn	791	72% Vines	Coomealla

8.3.1. Salinity in caisson samples

Figure 8.12 shows a plot of the nitrate-N against chloride. There is a wide range of chloride concentrations among the sites, but much less variation within a site. The lowest chloride levels were at Califon Hill where all the values were less than 100 mg/L whereas all the samples from Iraak Road exceeded 300 mg/L.

8.3.2. Nutrients in caisson samples

The distribution of the concentration of nutrients is shown as box plots in Figure 8.13 and Figure 8.14. Relationships between the nutrients are shown in Table 8.9 – note that in that table all the caisson data have been included, so there is a mixture of 'within' caisson effects and 'among' caisson effects. The correlations coefficients are therefore only indicative and should not be used for testing.

Nitrate

The nitrate-N values (Figure 8.12) were clustered for each site and ranged from less than 5 mg/L at Califon Hill to over 20 mg/L at Camalduli. The relatively low values at Califon Hill may be associated with the low chloride levels, perhaps suggesting dilution or a high leaching fraction. Overall there was no relationship between chloride and nitrate-N. If chloride concentration can be used as a measure of the leaching fraction, the current data would infer that the nitrate levels are not affected by the leaching fraction.

Phosphate

Phosphate values were mainly in the range 0 – 1 mg/L, but there was one value of 1.4 mg/L at Califon Hill. The distribution was similar across all four sites, but there was no relationship between nitrate-N and P.

Calcium

There was a strong negative relationship between calcium and sodium. An inspection of a plot of those data (Figure 8.16) indicates that the correlation is driven by among site differences rather that within site effects.

Boron

There was a strong positive relationship between boron and sodium (Table 8.9). Unlike the relationship between Na and Ca (which was mainly driven by among site differences) Figure 8.16 shows relationships within sites for Califon Hill and at Keens.

Table 8.9 Correlations between nutrients in the caisson data.

	Cl	NO3	NH4	B	Ca	Mg	Na	K	P	S
Cl	1.00									
NO3	-0.17	1.00								
NH4	-0.33	-0.24	1.00							
B	0.89	0.13	-0.53	1.00						
Ca	-0.81	-0.05	0.53	-0.78	1.00					
Mg	0.11	-0.29	0.20	-0.09	-0.02	1.00				
Na	0.94	-0.08	-0.49	0.90	-0.91	-0.06	1.00			
K	0.17	0.21	0.06	0.20	0.13	0.46	-0.04	1.00		
P	-0.27	-0.19	0.38	-0.28	0.47	-0.04	-0.32	0.17	1.00	
S	0.34	-0.07	0.24	0.32	-0.02	0.01	0.21	0.36	-0.28	1.00

Correlations greater than 0.9 are highlighted in red and those between 0.75 and 0.90 are highlighted in yellow.

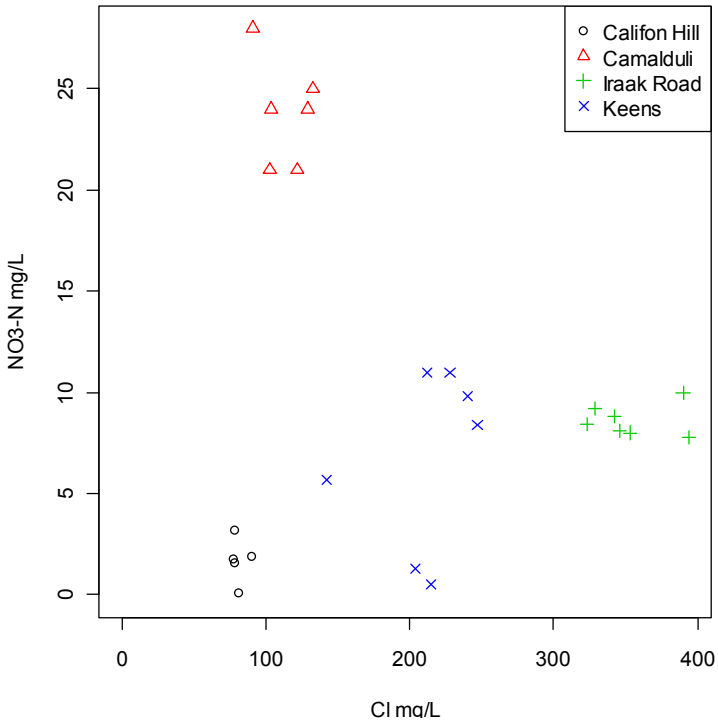


Figure 8.12 Relationship between chloride concentration and nitrate N concentration in samples taken from 4 sites.

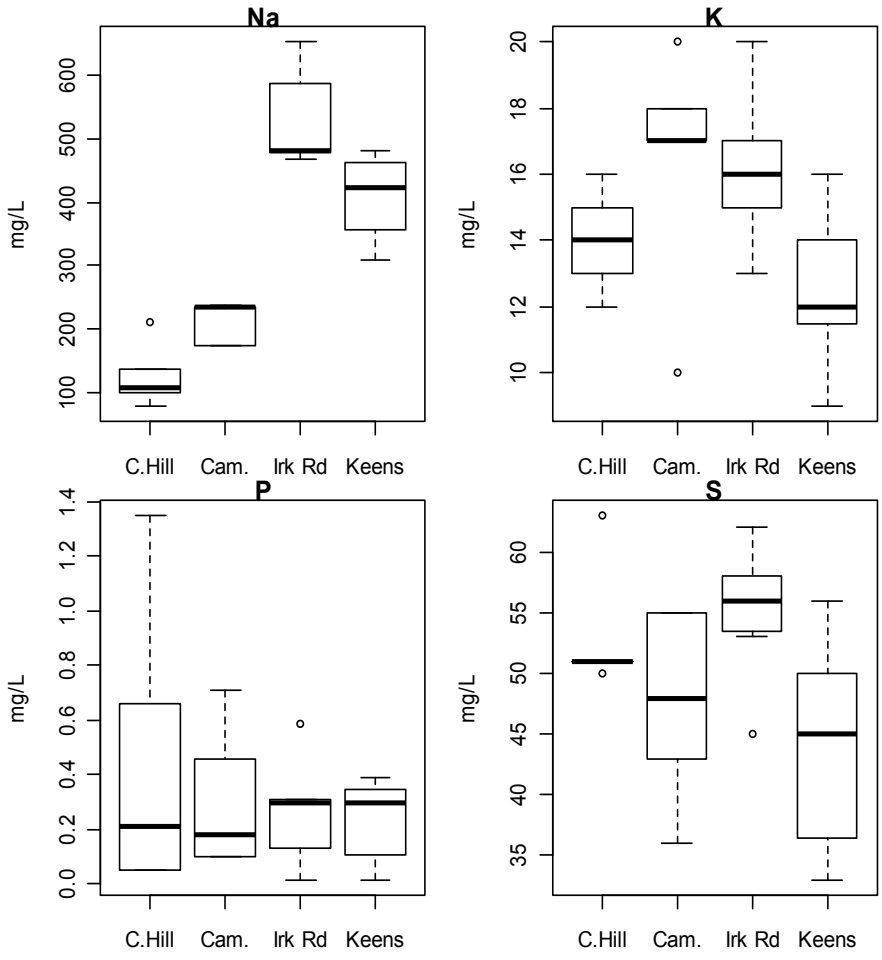


Figure 8.13 Distribution of concentrations of Na, K, P and S in caisson samples.

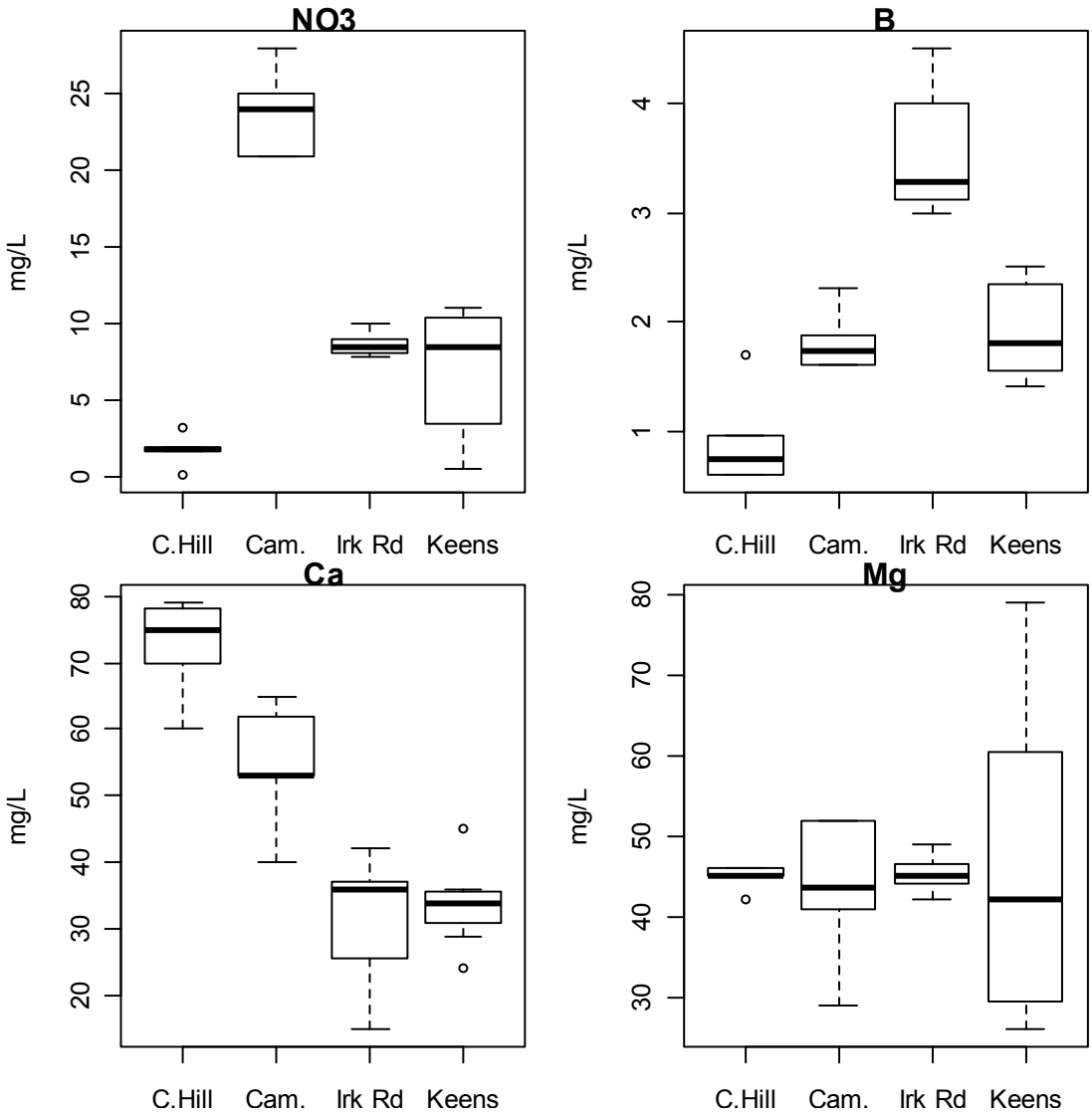


Figure 8.14 Distribution of concentrations of nitrate-N, B, Ca and Mg in caisson samples.

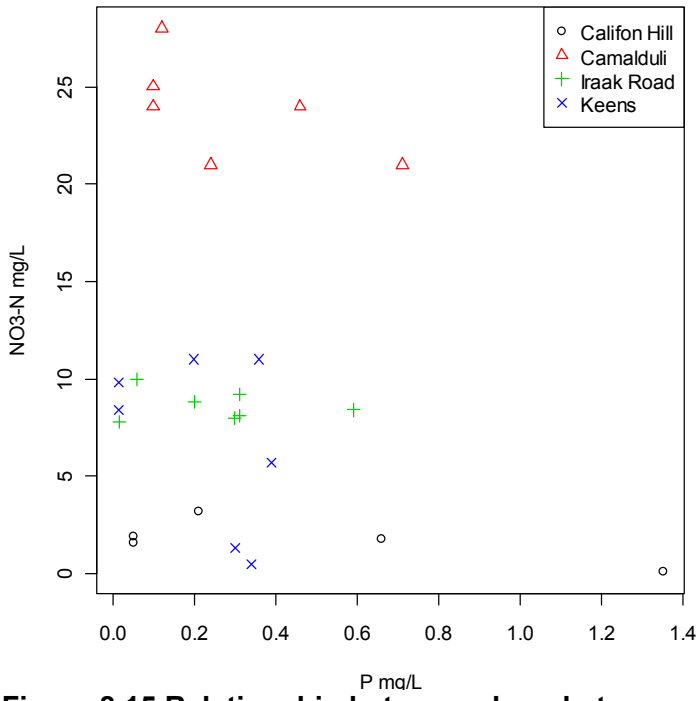


Figure 8.15 Relationship between phosphate concentration and nitrate N concentration in samples taken from 4 sites.

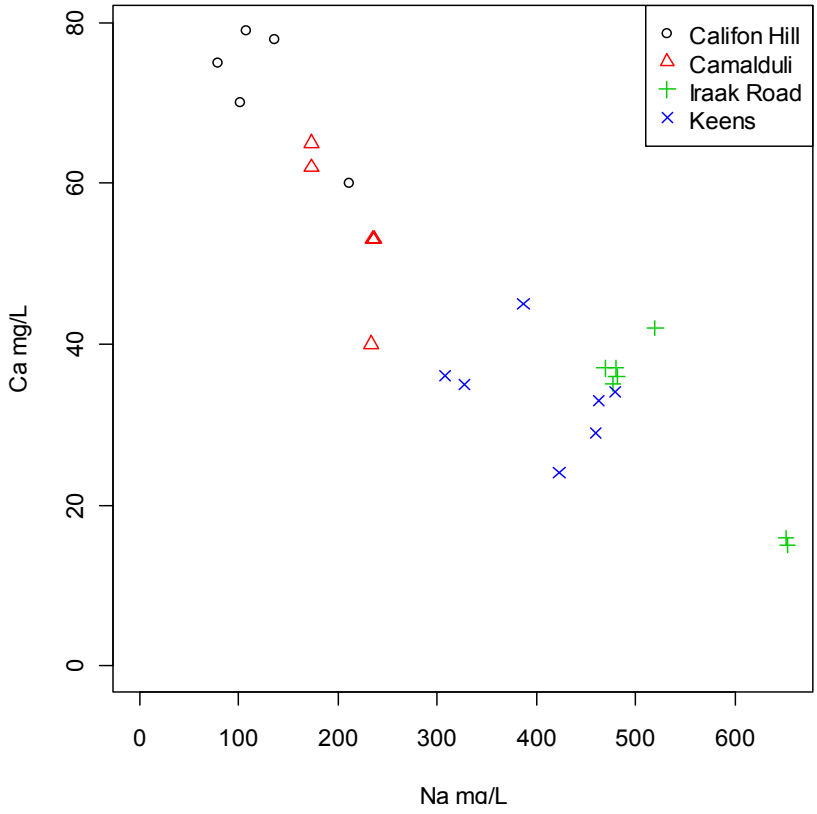


Figure 8.16 Relationship between Na and Ca in the caisson data.

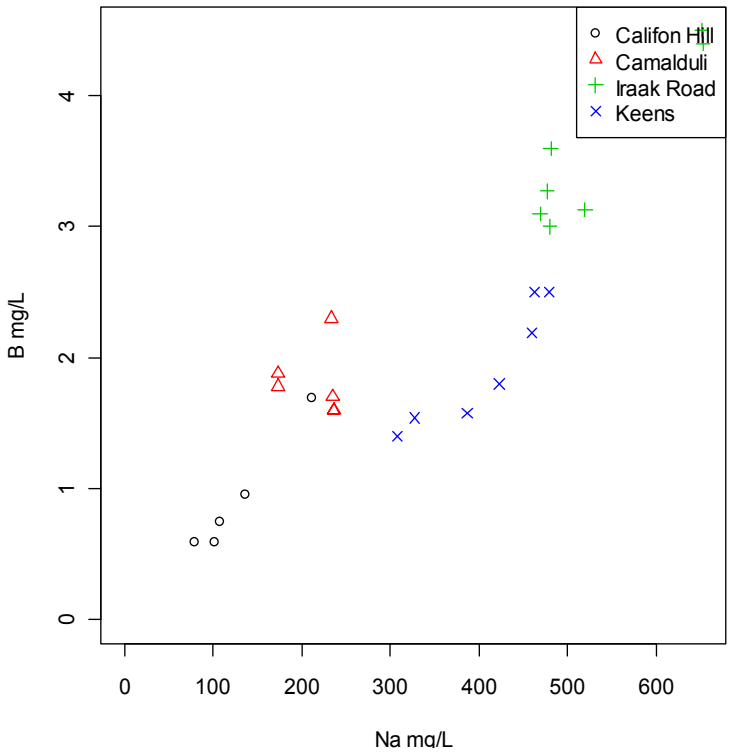


Figure 8.17 Relationship between Na and B in the caisson data

8.3.3. Pesticide residues in caisson samples

Details of the pesticide analyses are given in Table 8.10. Chlorpyrifos was found in 4 samples out of 17 analysed. There was only one detections of the other 16 pesticides investigated, Diuron. The presence of chlorpyrifos was confirmed using GC-MS. Details of the method are given in Section 6.5.1.

Chlorpyrifos is a very toxic pesticide with a tolerance level of 0.01 µg/L (Allinson 2007), This figure is less than the detection limit for the method/analyzer used for this project. Any detection of chlorpyrifos is therefore a cause for concern. An occurrence of a value of 7.4µg/L would therefore require approximately 1000 times dilution to meet environmental requirements.

Table 8.10 Summary of pesticide analyses from Sunraysia samples.

Sample Location	Chlorpyrifos (µg/L)	Diuron (µg/L)	Other 16 pesticides
Number of detections	4	1	0
Maximum concentration	7.4 µg/L	0.06 µg/L	NA

Details of detection limit for each chlorpyrifos, diuron and the other 16 pesticide are given in Table 6.1.

8.4. Spatial sampling survey

A spatial sample of sampling points was undertaken in December 2009. Twelve drainage sites were sampled in Sunraysia and an additional two sites were included from NSW (Risbeys and Holland Lake, Western Murray Irrigation monitoring sites). Two additional samples of channel water were included in the survey. The samples were analysed at CSIRO Urrbrae for EC, nutrients and heavy metals.

The average EC of the drainage samples was 1.5 dS/m, which was 17 times higher than the EC of the channel water. Average chloride concentrations were 160 mg/L in the drains and 9 mg/L in the channel, suggesting a concentration factor of 18. Concentration factors were 16 for Mg and 24 for Na. Some concentration factors that were much less – K increased from 1.7 to 9.2 which was a factor of 5; this lower value may reflect nutrient removal. By contrast, nitrate values were less than the QL of 0.01 mg/L in the channel water but averaged 12.7 mg/L in the drains and sulphur concentration increased from 1.1 mg/L in the channel to 49 mg/L in the drains – a factor of 44; these cases may reflect applied fertiliser being leached into the drains.

8.4.1. Salinity

A summary of eight analytes is given in Table 8.11 and displayed as box plots in Figure 8.18. The salinity in the drains is moderate with a maximum observed EC of 2.5 dS/m and a maximum Cl of 390 mg/L and a mean of 158 mg/L.

8.4.2. SAR

The mean SAR value observed was 8 with a median value of 4.5. The majority of the samples therefore present only a minor risk to soil structure but some would present a moderate risk (Table 6.2).

Table 8.11 Summary of concentrations of 8 analytes in channels and drains.

	EC (dS/m)	Cl (mg/L)	NOx-.N (mg/L)	Ca (mg/L)	K (mg/L)	Mg (mg/L)	Na (mg/L)	S (mg/L)
Mean channels	0.09	9	0.05	4	2	3	9	1
Mean drains	1.5	158	12.6	58	9	46	210	49
Max drains	2.5	390	36	82	16	88	382	106

8.4.3. Nutrients

The mean concentration of NO_x-N in the drains was 12.6 mg/L with all the samples from the drains >3 mg/L. The mean value exceeds the guidelines for protecting 95% or 90% of species. The maximum value of 38 mg/L and two values of 20 mg/L exceed the guidelines for protecting 80% of species. The maximum value occurred in the Iraak area, with the two values of 20 mg/L, (one in Red Cliff and one in Coomealla (NSW).

Phosphate levels in all but two cases were below the quantifiable limit.

Sulphur levels were much higher in the drains than in the channels with a mean value of 49 and a maximum of 106 mg/L.
Heavy metals (copper, lead and zinc) were all below the quantifiable limit.

Table 8.12 shows the correlations between analytes that were above the QL. The high correlation between EC and Na was to be expected as was a correlation between Na and Cl. The strength of the correlation (0.90) between EC and Mg was not expected.

There was some correlation between S and Mg and Ca, which may suggest that some gypsum has been mobilised by the irrigation water.

In contrast to the caisson data, there was a weak positive relationship between Na and Ca (Figure 8.16). It is unclear why the relationship between Na and Ca should differ between the two surveys.

The relationship between Na and B that was found in the caisson data was also found in this spatial survey. The correlation was 0.86 (Table 8.12 and Figure 8.17).

Table 8.12 Correlations between selected analytes from the spatial survey.

	EC	Cl	NOx-N	Ca	K	Mg	Na	S	B
EC	1.00								
Cl	0.93	1.00							
NOx-N	0.62	0.53	1.00						
Ca	0.63	0.56	0.07	1.00					
K	0.58	0.36	0.25	0.43	1.00				
Mg	0.90	0.82	0.60	0.66	0.60	1.00			
Na	0.96	0.86	0.66	0.42	0.58	0.78	1.00		
S	0.77	0.74	0.41	0.75	0.30	0.77	0.63	1.00	
B	0.87	0.84	0.47	0.40	0.49	0.82	0.86	0.58	1.00

Correlation exceeding 0.9 are highlighted in red and those between 0.75 and 0.9 are highlighted in yellow.

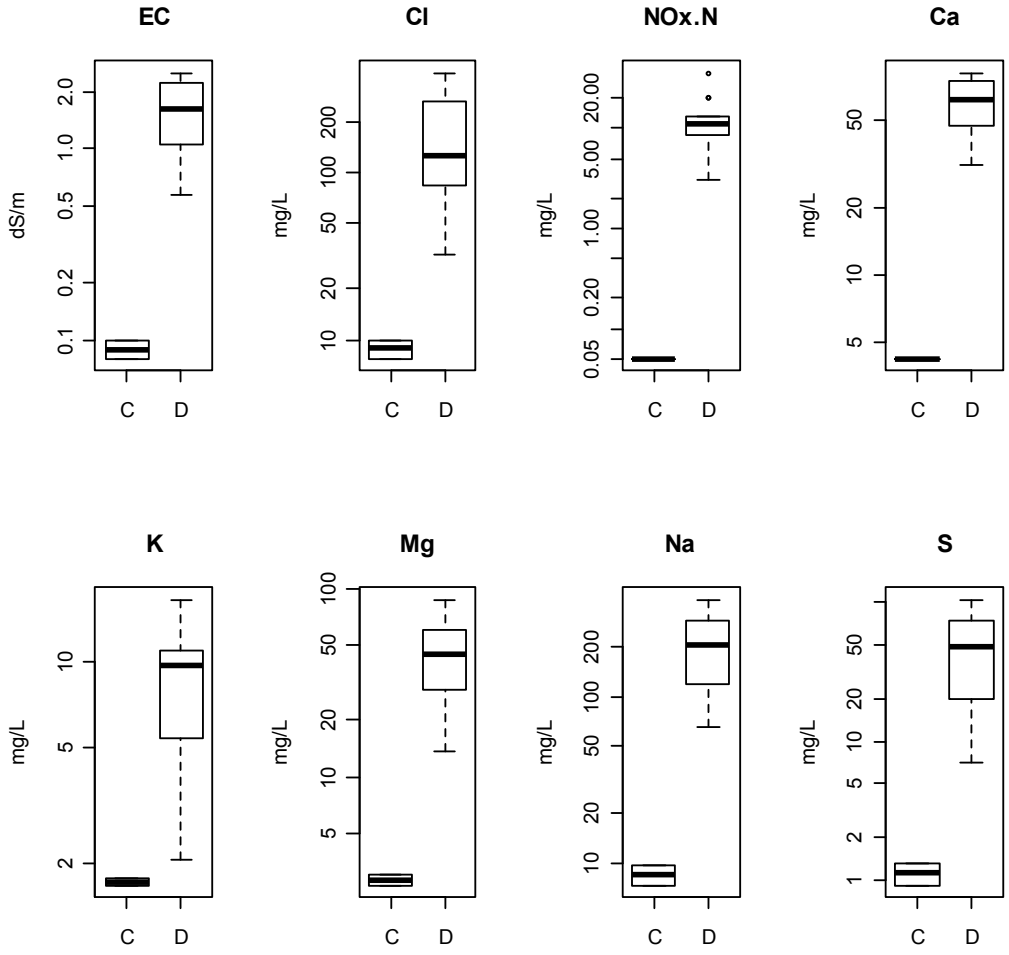


Figure 8.18 Box plot comparison of 8 analytes in channels (2 replicates) and drains (14 replicates).

9. MURRUMBIDGEE IRRIGATION AREA

9.1. Background

The Murrumbidgee Irrigation Area (MIA) lies between latitudes 34^0-35^0 S and longitudes 145^0-147^0 E and lies to the north of the Murrumbidgee River. The MIA is irrigated from water diverted from the Murrumbidgee River, supplied by large catchment dams located in the Snowy Mountains.The location of the MIA is shown in the Murray-Darling Basin and is bounded to the east by the Great Dividing Range.

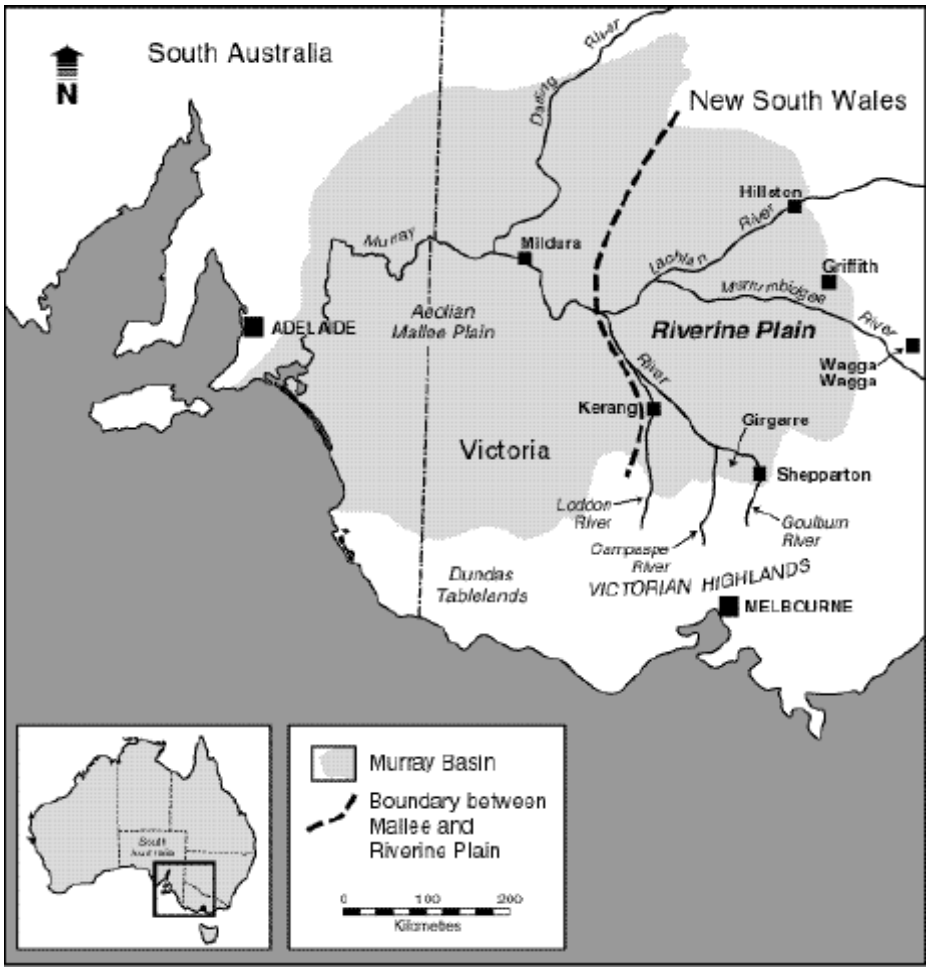


Figure 9.1 Location of the Riverine Plain which includes the Murrumbidgee Irrigation Area (after Herczeg *et al*. 2001)

Rainfall for the area is on average 394 mm/year (see Figure 9.2). The mean monthly rainfall is almost uniformly spread across the year. Mean maximum temperature ranges from 14^o C in July to 33^o C in January with a mean minimum temperature of 4^oC (July).

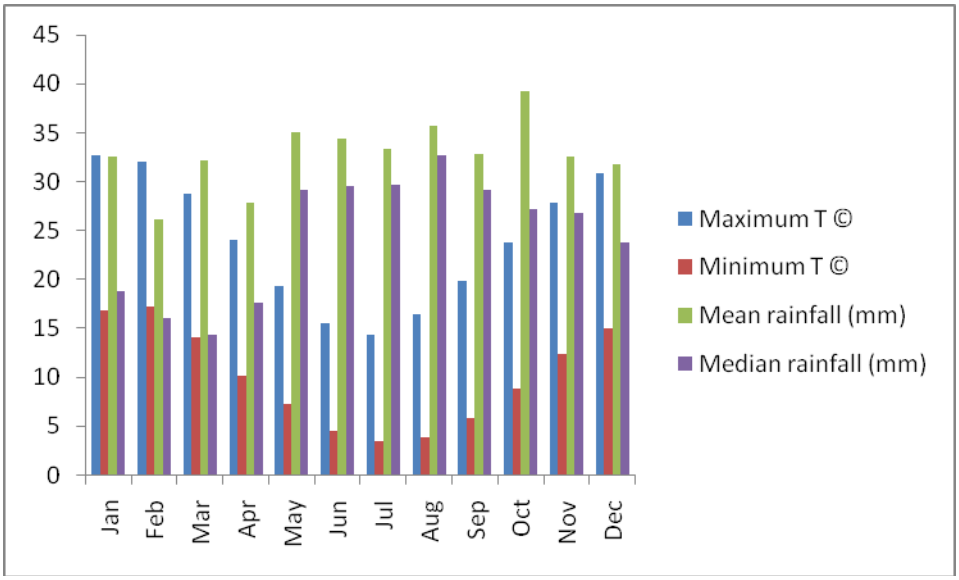


Figure 9.2 Temperature and rainfall for each month at Griffith Airport.

Rainfall for the area is on average 394 mm/year (see Figure 9.2). The mean monthly rainfall is almost uniformly spread across the year. Mean maximum temperature ranges from 14^{o} C in July to 33^{o} C in January with a mean minimum temperature of 4^{o}C (July).

The soils of the area are variable, with at least 94 soil types. These can be classified into the following five broad soil groups (Hornbuckle and Christen 1999):

1. Clays (Both self-mulching and hard setting)
2. Red Brown Earths
3. Transitional Red Brown Earths
4. Sands over Clay
5. Deep Sands

9.2. Parameters of potential concern

The parameters of potential concern to the environment in the drainage water in the MIA are the same as in the other study areas, namely

- Salinity;
- Sodicity or SAR;
- Nutrients; and
- Agricultural chemicals (pesticides)

These contaminants are discussed in the following sections.

9.2.1. Salinity

Most soils in the MIA have considerable stores of geologic salt. For example Christen and Skehan (2001) showed soil profiles with 4 to 16 tonnes/ha of chloride to a depth of 2 m.The origin of the salt in the soil has been studied by Herczeg *et al*. (2001) and they concluded that the origin of the salt in the MDB was from rainfall. Another study by Ladanay-Bell and Acworth (2002) attributed the origin of salt in the upper Shepparton formation to Quaternary dust transport processes. Due to this large store of geologic salt subsurface drains tend to remove more salt than that applied in the irrigation water. This was shown to be true in the MIA and for subsurface drainage systems across Australia by Christen *et al*. 2001. They showed that the amount of salt removed in drains was approximately 10 times more than the amount of salt being applied with irrigation (Figure

9.3) indicating that most of the salt entering the drainage system has come from that stored in the soil rather than the applied water.

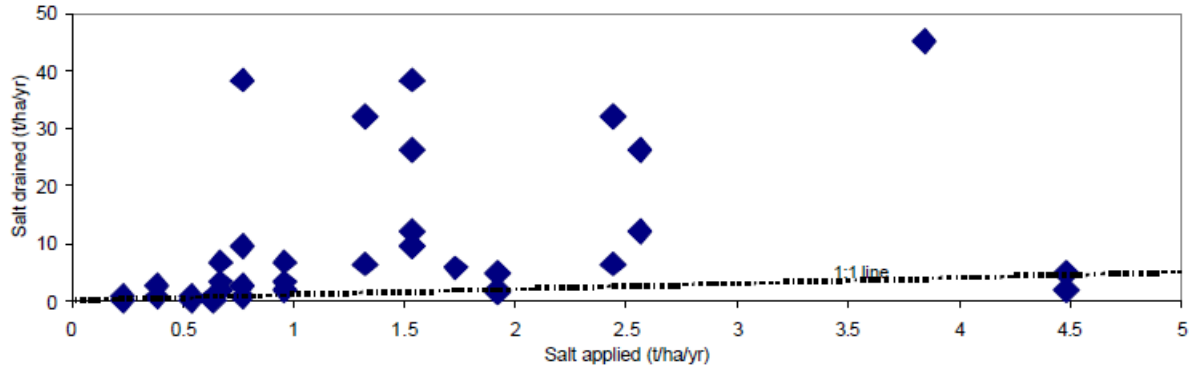


Figure 9.3 Comparison of the amount of salt applied in irrigation water with the amount of salt removed by drainage (Christen *et al*. 2001.).

For this reason subsurface drainage is a large mobiliser of salt. As demonstrated by Duncan *et al* (2008) where there is subsurface drainage it tends to be a large component of the salt balance, despite the drained area usually being relatively small. The salt load from subsurface drainage can represents up to 50% of salt export from an area, e.g. the MIA. For this reason the management of salinity form subsurface drainage has been of high importance. Salt loads from drained areas have been modelled to assess the impacts downstream as shown in Figure 9.4.

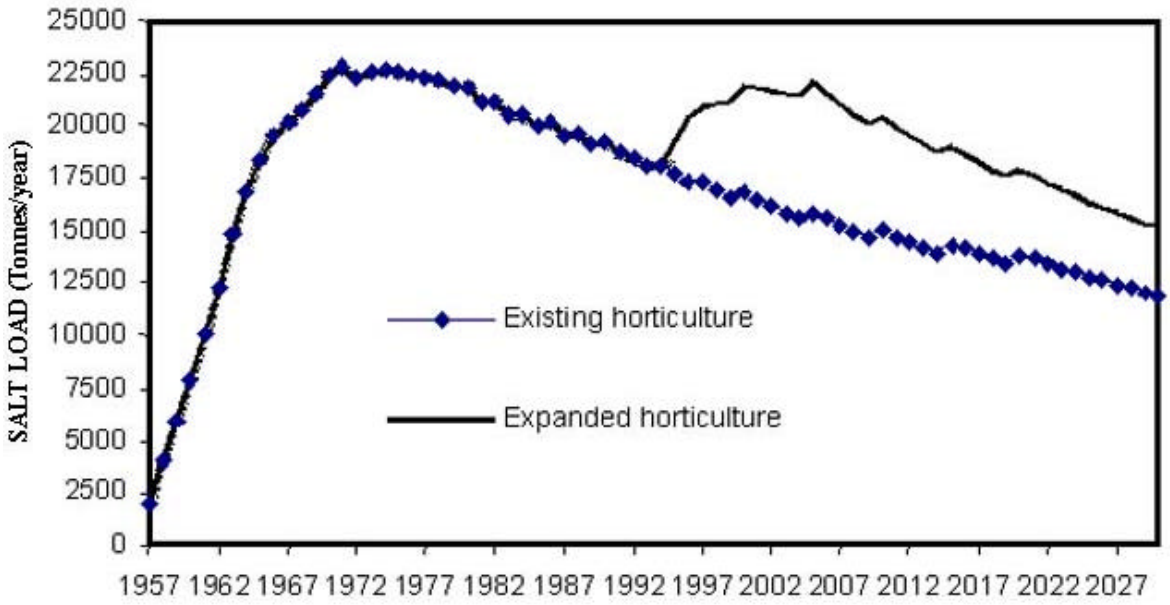


Figure 9.4 Estimated salt load over time from the subsurface drainage systems of the Murrumbidgee Irrigation Area (Hornbuckle 2003).

Although the irrigation supply water is of high quality (~0.1dS/m) about 20-30,000 tonnes of salt are imported into the Murrumbidgee Irrigation Area in full irrigation allocation years. The equivalent of about one quarter of this amount of salt is exported to the Wah Wah Irrigation District, which indicates a gradual accumulation of salt in the area. However, this is negligible compared to the salt already stored in the soil profile. Due to the drop in groundwater levels over the past seven years, the soils are no longer considered to be under immediate threat of salinisation.

It is no longer considered sustainable or acceptable to dispose of saline drainage water without regard to the consequences associated with its disposal. Therefore, the major problem challenging the sustainability of irrigated agriculture in many arid and semi-arid regions of the world today is the disposal of saline water. A very common practice now is to divert the saline water to evaporation basins to prevent it returning to the river system (Christen *et al*. 2001).

9.2.2. SAR

Groundwater SAR for the MIA was found by William and Ward (1987) to typically exceed 10. According to the data presented in Table 6.2, values of SAR exceeding 9 present a severed risk of causing structural damage to soil. The irrigation methods and hydrology of the region has since changed so the data of William and Ward is unlikely to refect the current situation.

9.2.3. Nutrient levels

Details of nutrient application have been obtained by Hutton *et al*. (2008). Their study recorded the amounts of N and P applied to the vineyards over two seasons (2004/05, 2005/06), for 7 vineyards from which conclusions were drawn between supply of and nutrient status of the vines and nutrient removal from the vineyard with the crop. For the majority of cases, plant tissue analysis was not used routinely by growers for determining vine nutritional status. For furrow irrigated vineyards, nitrogen fertilizer was applied as a split application between flowering and post-harvest, or as a single large post-harvest application. In all cases the fertilizers were broadcast or ripped into the furrow. For drip irrigated vineyards, a split application between flowering and post-harvest was the most common practice. This was usually applied as soluble N via the drip system. The rates of N application varied three fold across vineyards in all seasons, with the average annual amounts applied ranging from 43.0 to 88.5 kg/ha. These differences were reflected in the N status commonly measured as N concentration in the petioles at flowering, ranging from 0.75% to 1.76% DW. Application rates of P fertilizers ranged from 7.5 to 32.7 kg/ha. These fertilizers, most commonly superphosphate, CROPLIFT 400®, or DAP, were broadcast at all vineyards in their study sites. They concluded that the N supply in nearly all vineyards was more than sufficient. Application rates of 40-50 kg N/ha would appear sufficient for both optimal vegetative growth and juice N concentrations.

All sites studied by Hutton *et al.* (2008) underwent from two to five deep drainage events in each season. The first drainage event usually occurred in late spring, whilst the last drainage event, though considerably smaller, was frequently recorded the following autumn. During these periods when saturated soil moisture conditions were frequently observed, drainage was likely and the soil solution contained salt and nitrate as the leachate was transported below the root-zone.

However, for the three drip irrigated farms studied by Hutton *et al.* (2008), the average nitrate concentration below the root-zone was < 25 mg/L which is less than the WHO limit for drinking water of 50 mg /L. There may be some environmental risk as the environmental standards are much lower, with a requirement of less than 17 mg/L to protect 80% of species or 0.7 mg/L to protect 95% of species WQG (2000). Best practice drip irrigation does not appear to present a significant health risk but there may be an environmental risk. Conversely, there was a high likelihood that deep drainage and concomitant nutrient pollution frequently occurred throughout the irrigation season on the furrow irrigated farms. This occurred under the furrows where the soil was always close to saturation, and on a number of occasions the recorded nitrate concentrations exceeded the WHO limit.

In general, the soil solution samples by Hutton *et al.* (2008) showed low levels of ammonium and phosphate, predominantly less than 0.5 mg/L. The nitrate levels were much higher, 10-100 mg/L, with a larger variability.

On average Hutton *et al.* (2008) found that deep drainage from drip irrigated vineyards was minimal (0.64 ML/ha) during the irrigation period of either season, so the potential for N loss was low. Furthermore, from surface runoff measurements, less than 5% of irrigation water applied to furrow irrigated vines left the vineyard. On this basis, in the worst case scenario annual N loss was less than 0.3 kg N/ha, indicating surface and deep drainage N loss was minor relative to the fertilizer inputs.

Monitoring of drainage water by MIL (2009) found only traces of nitrate in the drainage water (Table 9.1) values were generally less than 1 mg/L. Phosphate values as monitored by MIL were also very low.

Table 9.1 Nutrient levels in drainage water monitored by MIL (2009).

Site	EMR	NARREG	STUR	BYD	BARDENS	3WAYS	PENFOLDS
			Nitrite + Nitrate as N (QL 0.01 mg/L)				
Sep	<0.01	<0.01	<0.01	<0.01	0.2	<0.01	<0.01
Jan	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
May	1.08	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
			Total Kjeldahl Nitrogen as N (QL 0.1mg/L)				
Sep	0.4	0.3	<0.1	0.6	0.8	0.3	0.7
Jan	0.4	0.3	0.9	0.7	0.7	0.3	0.6
May	0.5	0.8	0.7	1.4	0.7	0.5	0.4
			Total Nitrogen as N (QL 0.1mg/L)				
Sep	0.4	0.3	<0.1	0.6	1	0.3	0.7
Jan	0.4	0.3	0.9	0.7	0.7	0.3	0.6
May	1.6	0.8	0.7	1.4	0.7	0.5	0.4
			Total Phosphorus as P (QL 0.01mg/L)				
Sep	<0.01	<0.01	0.04	0.02	0.21	<0.01	<0.01
Jan	0.02	0.05	0.01	0.01	0.05	<0.01	<0.01
May	0.02	0.05	<0.01	0.13	0.07	0.01	0.03

9.2.4. Pesticides

The ability to detect pesticides has increased in recent years, with some detection limits being as low as 0.005 µg/L. At the same time there has been a decreased community tolerance to contamination from pesticides so that the concentrations that must be reported have decreased. An example is molinate: in 2004 the notification level was lowered from 12.5 to 4 µg/L and the action level lowered from 25 to 14 µg/L by NSW Department of Environment and Climate Change.

A survey of agricultural chemicals was included as part of a study by McCaffery (1999) of subsurface drainage. That study considered a range of pesticides as listed in Appendix 5, Table 13.3 No details of the methods used for analysis were given in that report. That survey detected diuron and /or bromacil in 8 out of 36 samples in 1998 and 10 out of 36 samples in 1999 but provided no data on the concentration of those two pesticides other than stating that all detection limits were less than the notifiable limits of 8 µg/L for diuron and 750 µg/L for bromacil.

Murrumbidgee Irrigation Limited provides annual reports of the pesticide contaminants at 7 monitoring points in its surface drainage network with monthly sampling, making 84 samples per year. Data from those samplings is presented both as concentrations and frequency of the DECCW guideline values, notification levels or action levels being exceeded. Typically the notification level and action levels correspond to WQG (2000) water quality guidelines corresponding to levels that protect 95% or 90% of species. There are exceptions: e.g .for endosulfan the ANZ-WQG 95% and 90% guidelines are 0.01 and 0.02 µg/L respectively, whereas the notification and action levels are 0.03 and 0.2 µg/L respectively. Metolachlor has no WQG (2000) values but there are notification and action levels of 0.02 and 0.1 µg/L respectively.

MIL reported trace levels for atrazine and simazine in the supply and notification level of diuron (at MIL stations BYD and Bardens). The monitoring stations were NARREG, EMR, Penfold's Bridge, 3 WAYS, STUR, BYD and Barden's. The data for simazine given in their Table M3 are shown in Table 9.2. From that table it can be seen that 17 of 21 intake samples had a detectable level of simazine. Similarly, Table 9.3 shows simazine data for the drainage monitoring data, where 23 of 24 samples were positive for simazine. Lower frequencies were found for other pesticides – a summary is given in Table 9.3. It is noted that atrazine and simazine are rarely if ever used in viticulture in the MIA, but there would be traces of these input via the irrigation water.

The samples taken by MIL were directed at minimising risk and sampling was focused on where there was considered to be an increased chance of contamination being detected. As a result the sampling should not be considered as a random but rather biased toward areas of concern.

Table 9.2 Levels of Simazine in intake water for MIA 2008-9.

Site	EMR	NARREG	STUR	BYD	BARDENS	3WAYS	PENFOLDS
Sep	0.106	0.060	0.038	2.63	0.544	0.059	0.058
Jan	<0.005	0.080	<0.005	0.090	0.192	<0.005	<0.005
May	0.074	0.010	0.071	0.175	0.060	0.093	0.065

Units are µg/L.
After MIL 2009 Table M3.

Table 9.3 Simazine monitoring data for 9 MIA monitoring sites in 2008-9.

	BARDENS	MIRMCN	MDJWE	LMC	BYD	LW6	BBOW	WWO	GRI
Jul	NT	NT	NT	NT	NT	NT	NT	NT	NT
Aug	NT	NT	NT	NT	NT	NT	NT	NT	NT
Sep	0.755	0.817	3.21	1.62	2.11	NT	NT	NT	NT
Oct	NT	NT	NT	NT	NT	NT	NT	NT	NT
Nov	NT	0.252	0.598	0.394	NT	NT	NT	0.117	NT
Dec	NT	0.106	0.087	0.141	0.159	0.05	0.168	NT	<0.020
Jan	NT	NT	NT	NT	NT	NT	NT	NT	NT
Feb	NT	0.061	0.060	0.009	0.023	NT	NT	NT	NT
Mar	NT	NT	NT	NT	NT	NT	NT	NT	NT
Apr	NT	NT	NT	NT	NT	NT	NT	NT	NT
May	NT	NT	NT	NT	NT	NT	NT	NT	NT
Jun	NT	0.695	0.323	NT	0.464	0.07	NT	NT	NT

Units are ug/L.
After MIL 2009 Table M4.

Table 9.4 Frequency of detection of selected pesticides in intake water and drainage water averaged over 7 stations.

Pesticide	QL	Intake data				Averaged Outfall data					Increase
		-ve	+ve	Note	%+ve	-ve	+ve	Note	Action	% +ve	
α-Endosulfan	0.01	7	0		0%	9				0%	0%
β-Endosulfan	0.01	7	0		0%	9				0%	0%
Simazine	0.005	4	17		81%	1	22	1		96%	15%
Diuron	0.005	17	3	1	19%	1	21	2		96%	77%
Atrazine	0.005	9	12		57%	4	20			83%	26%
Molinate	0.005	21			0%	18	6			25%	25%
Metolachlor	0.005	19	2		10%	21	2	1		13%	3%
Malathion	0.005	21			0%	18	1	2	3	25%	25%
Diazinon	0.005	21			0%	21	1	2		13%	13%
Thiobencarb	0.005	19	2		10%	22	1			4%	-6%
Chlorpyrifos	0.005	21	0		0%	20		4		17%	17%
Trifluralin	0.005	21	0		0%	18	6			25%	25%

For intake data 3 times were considered and for outfall data 12 times were considered (MIL 2009). –ve = number of negatives; +ve = number of positives samples; Note = number exceeding notification level; Action = number exceeding action level.

A plot of the frequency of exceedance (as provided by MIL 2008) is shown in Figure 9.5. There were more stringent requirements introduced in July 2004 and these increased the number of reportable detections. The water quality sampling strategy by MIL has changed recently and now a risk based approach is being used to target chemicals and sites.

An interesting point made in MIL (2009) is the degree of contamination of the intake water, The data in Table 9.2 shows that traces of traces of simazine is frequently detected in supply water, which is beyond the control of MIL. A comparison of the frequency of detections in intake and outfall water, given in Table 9.4, shows that in some cases (e.g.

simazine, metolachlor) the frequency of detection in intake and drainage water are comparable. The concentrations however would be very different in intake and drainage water samples.

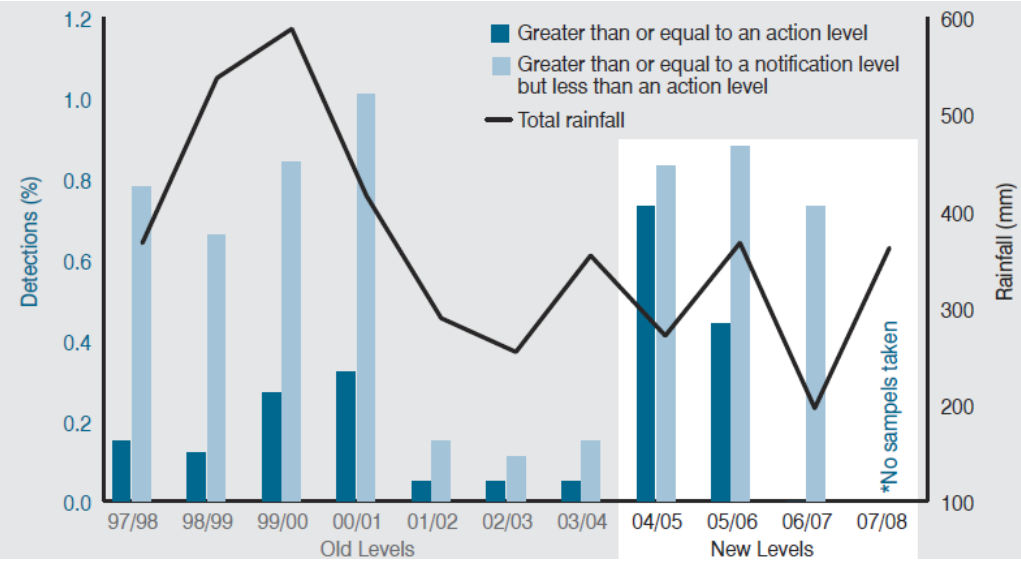


Figure 9.5 Pesticide detections levels (%) for all DECC sites (Source MIL 2008).

9.3. Spatial survey

A survey of drainage water from subsurface drains was conducted in the Griffith area in November. The sites were visited once, when samples were collected for both pesticide and inorganic analyses. These sites were aligned where possible with sites previously sampled in 1989 and 1999 by McCaffery (1999).

Table 9.5 shows a summary of the 33 samples collected at that time. The frequency distribution of the analytes was symmetric for same analytes (e.g. boron and potassium) but in many cases (e.g. magnesium) there are some very high values. A summary of the analyses is given in Table 9.5. The mean values exceeded the WQG (2000) values, where they were available.

Table 9.5 Mean minimum and maximum of 9 analytes from samples collected from tile drains in the Griffith area.

Analyte	Mean	Minimum	Maximum	WQG(2000) for 95% protection
NO_x-N	8.9	0.2	33	0.7
Cl	270	9.0	1322	NA
Na	385	10.5	1300	NA
Ca	43.9	10.1	143	NA
Mg	55.3	8.9	272	NA
K	14.1	3.8	30.4	NA
S	101	4.5	503	NA
B	1.6	0.0	3.5	0.37
P	0.4	0.0	2.3	NA
Al	0.0	0.0	0.3	NA
Fe	0.0	0.0	0.2	NA
Mn	0.1	0.0	0.4	1.9
Zn	0.0	0.0	0.1	0.008

Units are mg/L.

9.3.1. Salinity

A principal component analysis of the data showed that the first component was approximately an average of all the analytes and that a single component contributed to 67% of the total variance. The loadings of all the analytes had the same sign (Table 9.6). This is illustrated in Figure 9.7, where all the arrows (which indicate the loadings) point to the left, indicating that they all contributed to that component in a similar manner. The first component, being an average of all the ions present, therefore represents the amount of salt present.

The second component is largely a contrast between the concentration of P and NO_x-N in the samples, with the arrow pointing up for P but down for NO_x-N.

Table 9.6 Loadings of the principal component analysis, which was based on the spatial survey. Blank values indicate very low loadings.

Loading	Component 1	Component 2
NO_x-N	-0.295	-0.555
Cl	-0.429	0.122
Na	-0.385	
Ca	-0.183	0.137
Mg	-0.309	
K	-0.169	
S	-0.48	
B	-0.337	-0.239
P	-0.283	0.771

9.3.2. SAR

The summary guidelines for interpreting water SAR values are shown in Table 6.2. A box plot of the SAR values is given in Figure 9.6, which shows that 13 of the 33 SAR values exceed 9 and so present a serious risk to soil structure and a further 11 had an SAR in the range 6 -9 which is likely to create moderate to severe harm. Over 2/3 of the samples would be expected to do moderate or severe harm to soil structure. There is no clear geographic pattern to the high SAR values.

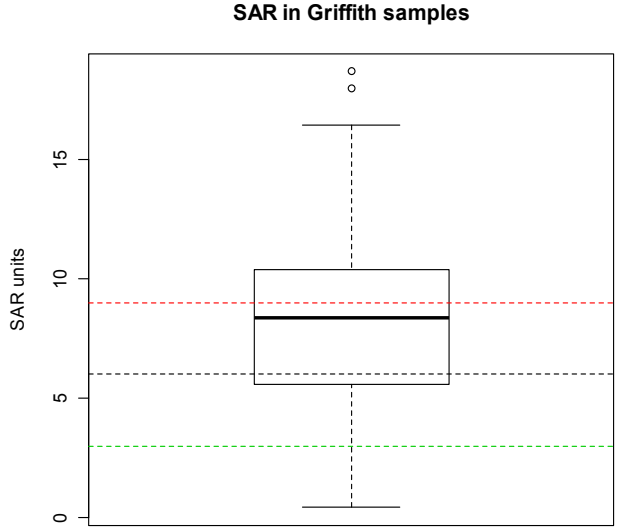


Figure 9.6 Boxplot of SAR values from tile drain samples collected in the Griffith area. Values between the green and black lines could have slight deleterious effect on soil structure, those between the black and red lines moderate effect and those above the red line would be expected to have a serious deleterious effect on soil structure.

9.3.3. Nutrients

The second component of the principal component analysis was largely a contrast between the concentration of P and NO_x-N in the samples, with the arrow pointing up for P but down for NO_x-N.

The principal component analyses highlights that in some sites P and NO_x-N were both high, whereas in other samples only one of these nutrients was high. This highlights different behaviour of P and NO_3-N, suggesting that contamination from P and NO_x has arisen from different sources.

Summaries of other analytes are given as boxplots in Appendix 5, Figure 13.4.

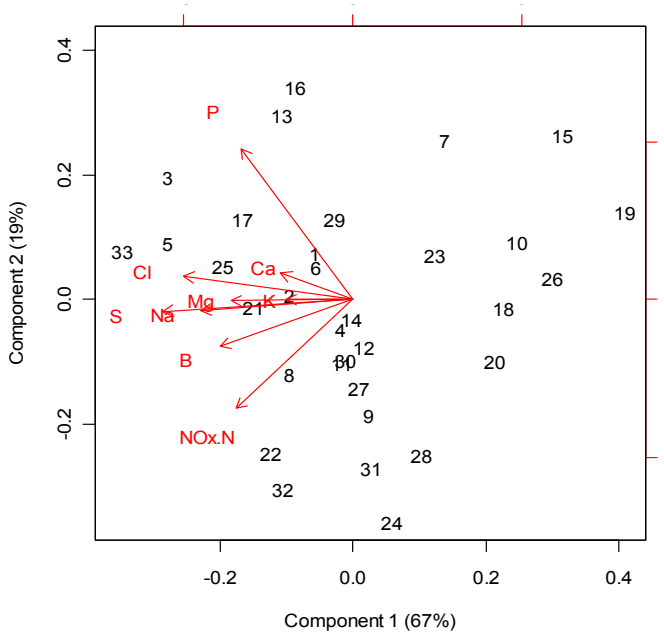


Figure 9.7 Biplot of principal component analysis based on log transformed soil water analyses of inorganic ions.

9.3.4. Pesticides

There were three detections of diuron in the samples from the spatial survey. There were no detections of any of the other 17 monitored pesticides in samples collected from the 33 sites in the spatial survey of the drainage water.

9.4. Detailed study of 4 farms

9.4.1. Scope of temporal monitoring

Temporal monitoring was conducted at 4 sites Details of those sites are given in Table 9.7.

Suction cup data were collected by Dr Ron Hutton from locations spread across 3 farms. The suctions cups were installed at 0.25, 0.5, 0.75 and 1.0 m depths, but this report considers only the lowest three depths. Samples were collected during the interval May 2007 to July 2009 and analysed for TDN, TDP, NH4, NO_x and EC. These data are presented as box plots below. The location of the suction cup sites are shown in Figure 9.8 to 9.11.

Table 9.7 Details of monitoring sites used in the MIA

Farm	A	B	C	D
Hutton et al. (2008)	FL*	DL*		FS*
Hornbuckle (2003)	–	–	MLD*	–
Soil	Hanwood Loam	Hanwood Loam	Bilbul loam	Banna sand
Irrigation	Twin furrow	Drip	Furrow	Furrow
Planting date	2002	2002	2000	2001
Suction cup	Yes	Yes	No	Yes
Flow data	Zero flow recorded as drainage pump was kept turned off	Insufficient flow to quantify	Several drainage events	Insufficient flow to quantify
Area (ha)	2.9	2.9	1.5	3.4

Data for Farm C from Hornbuckle (2003), other data from Hutton *et al.* (2008).

*FL, flood furrow on loam
*DL, drip on loam
*FS, flood furrow on sand
*MLD, Multi level drains



Figure 9.8 Farm A Furrow irrigation on loam



Figure 9.9 Farm B Drip irrigation on loam



Figure 9.10 Farm C, furrow irrigation on loam



Figure 9.11 Farm D Furrow irrigation on sand

9.4.2. Farm A

Farm A was chosen by Hutton *et al.* (2008) as representative of farms using furrow irrigation on a loam soil. Suction cup data were available for locations MH and MT, which are shown in Figure 9.12.

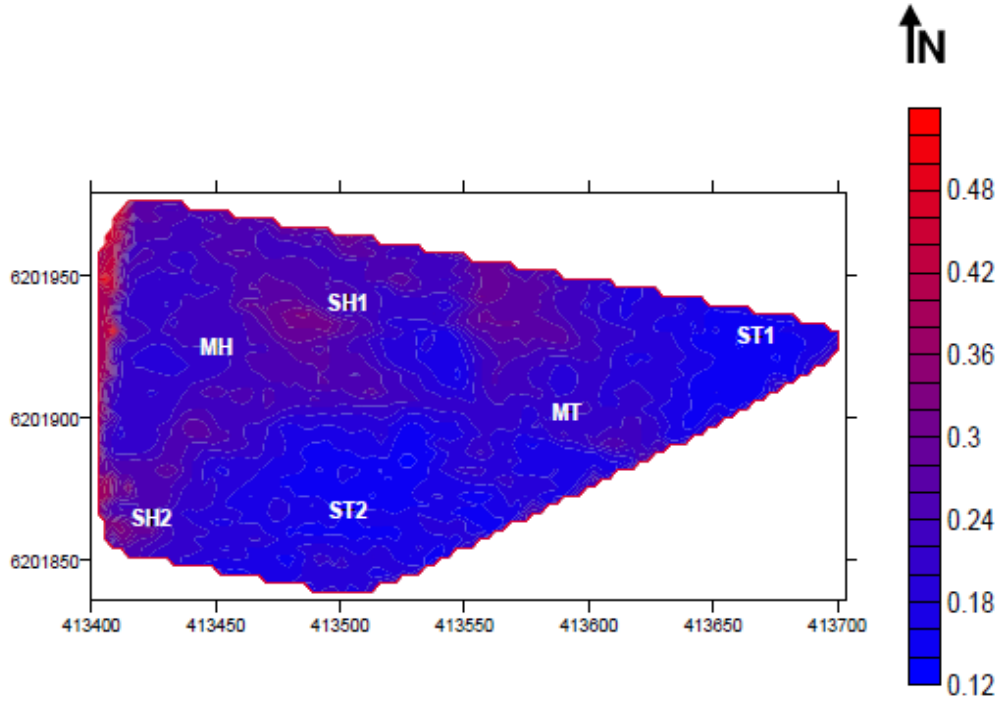


Figure 9.12 EM38 survey showing average profile EC [dS/m] to 1.5m of Farm A, showing suction cup locations MH and MT (after Hutton *et al*. 2008).

Fertiliser history

At Farm A, the annual total nitrogen applied ranged from 0 kg N/ha in 2006/07 and up to 198.8 kg N/ha in 2007/08. Over the same period the range in applied P was from 0 kg P/ha in 2006/07 and 2007/08 and up to 27.9 kg P/ha in 2004/05. N and P fertilizers were applied as mixed applications in autumn (May 04, April 05). Additional N was applied as Nitram in November 2004 and as urea in March and September 2007 (Hutton *et al.* 2008). A summary of the fertiliser history is given in Table 9.8.

Table 9.8 Irrigation, rainfall and fertiliser application at Farm A (after Hutton et al. 2008).

	2004/05	2005/06	2006/07	2007/08	2008/09
Irrigation (mm)	600	550	550	692	634
Rainfall (mm)	252	367	165	345	304
Total water (mm)	852	917	715	1037	938
Fertiliser N (kg/ha)	88	30	0	200	53
Fertiliser P (kg/ha)	28	13	0	0	13

Salinity

The EC values in the suction cup sample from 1 m depth had an EC that ranged from 5000-10000 µS/cm, with an average of 5900 µS/cm. Using the NSW DPI approximation that 1000 µS/cm is equivalent to 640 mg/L, and assuming that that is in the form of NaCl, the equivalent Cl concentration would be approximately 2300 mg/L.

The samples collected from the drains had Cl concentrations ranging from 40 – 165 mg/L. The Cl concentration in the suction cup samples was therefore approximately 20 times as concentrated as the Cl in the drains.

SAR

SAR in the drainage water was relatively low with a mean of 5.9 but ranging between 4.1 and 7.8.

Nitrates

There was a sharp peak in the nitrate concentration in the 50 cm suction cup following the application of 200 kg/ha of N fertiliser with a maximum of 470 mg/L. Concentrations at 50 cm exceeded 100 mg/L for 6 months after the fertiliser event. The peak was less apparent at 75 cm with no values exceeding 100 mg/L. Values at 100 cm were lower and much more stable at about 10 mg/L.

Nitrate levels in the drain were fairly stable with an average concentration of just below 10 mg/L. The concentration in the drains was therefore comparable to the concentrations at 100 cm. This concentration meets WQG for drinking water but it exceeds the environmental WQG of 0.7 mg/L.

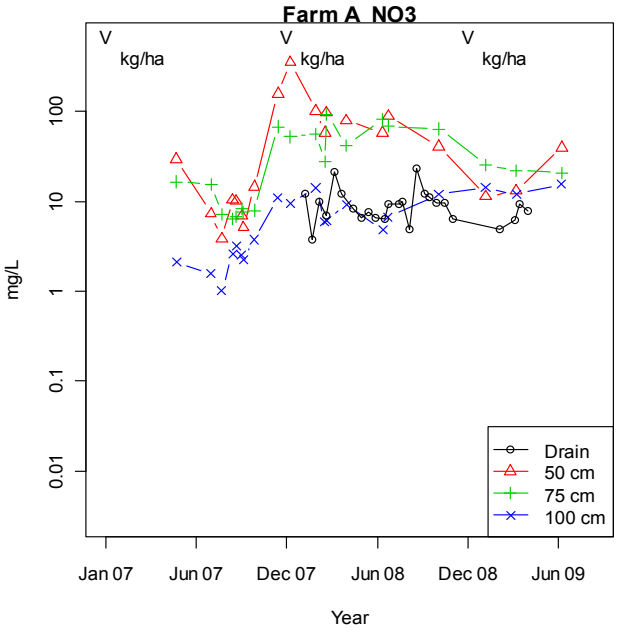


Figure 9.13 Changes in suction cup NO_x and nitrate in the tile drains over the study period at Farm A

Phosphate

Phosphate levels were less than1 mg/L in the 50 cm suction cup samples, and the concentration decreased with depth. The concentration in the tile drains were typically below the quantifiable limit, and as such do not pose an environmental risk.

Figure 9.14 Changes in suction cup P and P in the tile drains over the study period at Farm A.

9.4.3. Farm B

Farm B was chosen by Hutton *et al.* (2008) as a site to represent vineyards that were irrigated by a drip system and with a loam soil type. Suction cup samples were taken from the three locations marked in Figure 9.15.

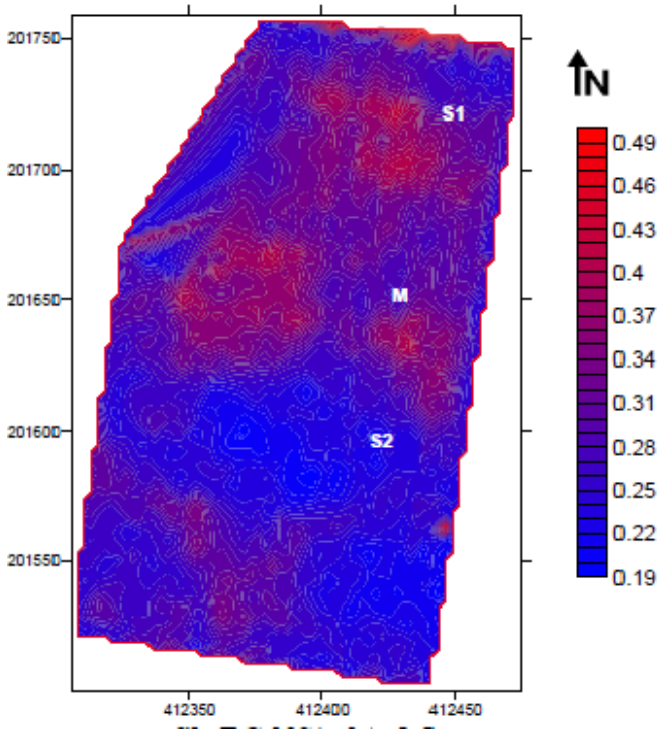


Figure 9.15 EM38 survey showing average profile EC [dS/m] to 1.5m of Farm B, showing suction cup locations S1, M and S2 (after Hutton et al. 2008).

Fertiliser history

The annual total nitrogen applied ranged from 12.0 kg N/ha in 2008/09 to 91.0 kg N/ha in 2007/08. Over the same period the range in P application varied from no P applied in 2004/05 up to 25.0 kg P/ha in 2006/07.

Table 9.9 Irrigation, rainfall and fertiliser application at Farm B (after Hutton et al. 2008).

	2004/05	2005/06	2006/07	2007/08	2008/09
Irrigation (mm)	220	210	265	447	289
Rainfall (mm)	252	367	165	345	304
Total water (mm)	472	577	430	792	593
Fertiliser N (kg/ha)	55	45	65	91	12
Fertiliser P (kg/ha)	0	15	25	13	5

There was sufficient flow to enable drainage water samples to be collected manually in two short intervals (one in June and one in November 2008) but the flow could not be quantified.

Salinity

The suction cup EC data ranged from 450 – 5200 µS/cm, with an average of 1900 µS/cm. The samples collected from the drain in June – July 2008 had an average Cl of 62 mg/L but this increased in the second series to 180 mg/L Cl when drainage occurred in November 2008.

NSW Department of Agriculture suggest that 1000 µS/cm is equivalent to 640 mg/L, and if this is all in the form of NaCl, 1900 µS/cm would be equivalent to 700 mg/L Cl. The

concentrations being observed in the suction cups are therefore much higher than the values found in the drainage water.

SAR

There were insufficient drainage samples to give an accurate estimate of SAR.

Nitrate

Nitrate data were available from manually collected subsurface drain samples when the drain was flowing. Suction cup data from 50 cm and 100 cm were available for a longer period and NO_x (assumed to be predominantly nitrate) was recorded for those samples from the locations shown in Figure 9.15. The suction cup data were averaged across the sites within that vineyard.

A summary of the nitrate data is given in Figure 9.16. The suction cup data showed a peak in late 2007, and this presumably corresponds with the application of fertiliser at the rate of 91 kg/ha. The concentration at 50 cm had a maximum level of 180 mg/L and then rapidly declined. The maximum concentration found at 100 cm was 70 mg/L.

Nitrate levels in the drain samples were more stable, initially having a mean of 24 mg/L rising to 33 mg/L. There is some evidence from Figure 9.16 that the initial 100 cm data was lagged behind the 50 cm peak – this lagging could be a result of slow leaching associated with the lack of leaching (and hence drainage) at that Farm B.

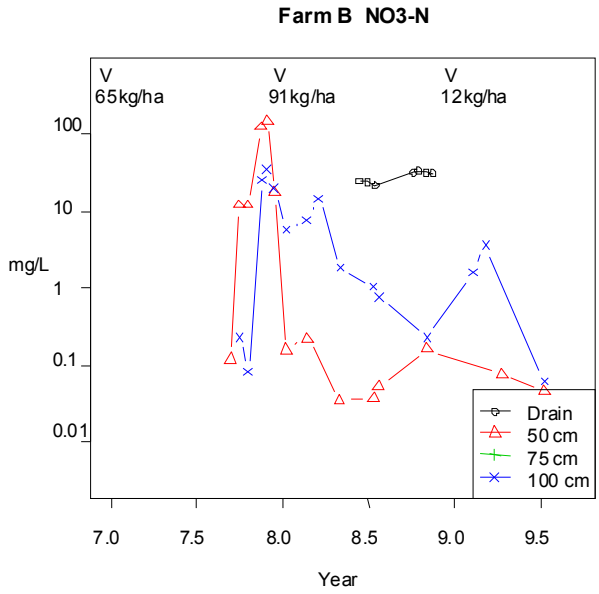


Figure 9.16 Changes in suction cup NO_x and nitrate in the tile drains over the study period at Farm B.

Phosphate

The phosphate levels were low (< 1 mg/L) in the 50 cm samples, and were less in the 100 cm samples. The concentration in the drains was typically lower than the concentration in the suction cups, so the amount of phosphate coming from the drain would be low.

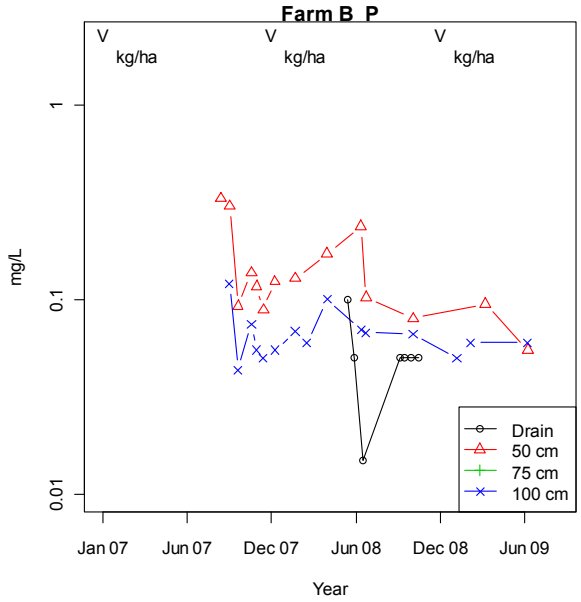


Figure 9.17 Changes in P for suction cup and tile drains over the study period at Farm B

9.4.4. Farm C

Farm C was included in this study as the site had been extensively studied by Hornbuckle (2003). It was known to have very effective drainage. Other data including EM38 data were also available (Figure 9.18). Farm C is representative of furrow irrigation on a loam soil.

Flow measurement data were available for this farm and some results were obtained that could be matched to irrigation events (Figure 9.19). Further analyses of these data are required before quantitative conclusions can be drawn. However using a provisional calibration (Section 6.5), the associate volumes associated with the peaks shown in Figure 9.19 were estimated. The results of those calculations are shown in Table 9.10. The amount of drainage was estimated at 0.58 ML or 0.39 ML/ha.

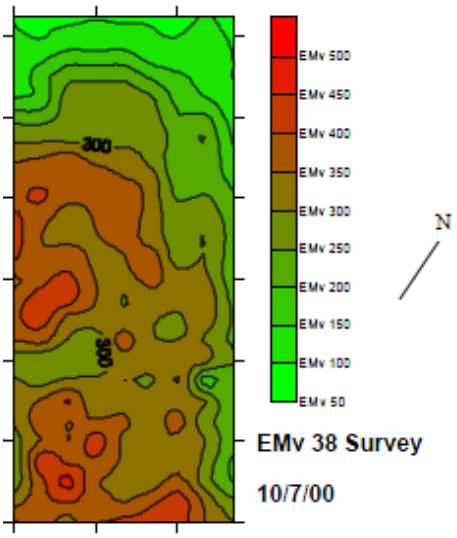


Figure 9.18 Map of EM38 v at Farm C. There were no suction cups at this site (Hornbuckle 2003)

Fertiliser history

At Farm C, fertiliser is applied in the first week of November and at the end of March (approximately). The application rate per fertiliser event is 90 kg N/ha and 34 kg P/ha.

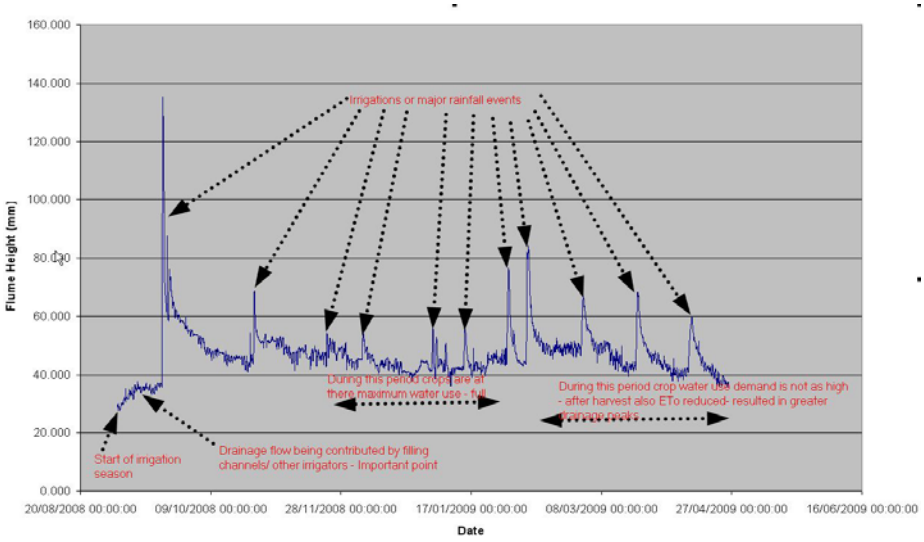


Figure 9.19 Height of water in flume at Farm C

Salinity

Chloride levels in the drainage water from Farm C range from 620 – 3400 mg/L. The EC values varied during the study and were related in part to the height measures in the plume. Figure 9.20 shows a plot of the height in the plume and EC levels for the centre month of the data shown in Figure 9.19. Associated with the rise in the plume is a sharp increase in the EC levels followed by a rapid decline in the EC. The relationship between plume height and EC is therefore not a direct correlation. One interpretation of the rise in EC may be associated with a first flush removing deposits on the surface of the drain, while the sharp decline may be interpreted as preferential flow from the irrigation to the tile drains. The response is rapid – occurring over a period of less than a day.

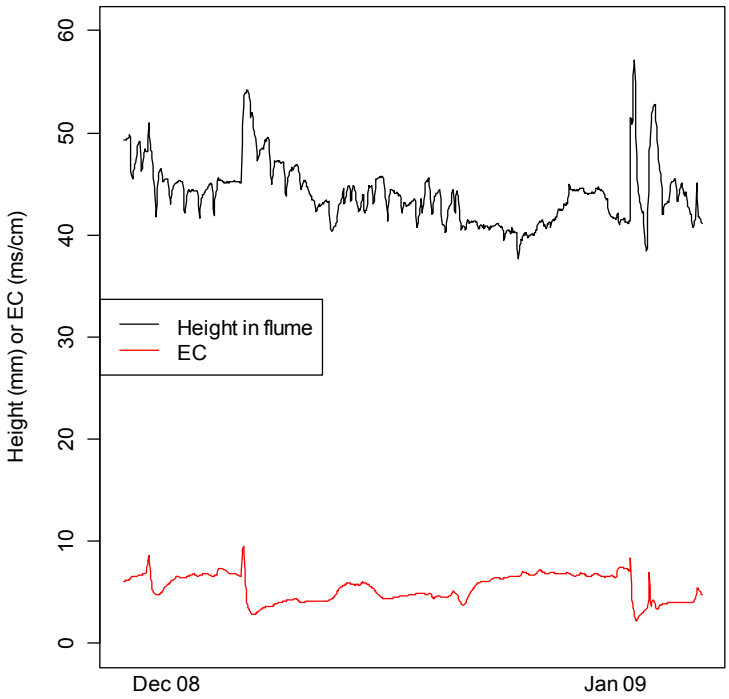


Figure 9.20 Relationship between height of water in plume and EC.

SAR

The SAR values in the drainage water from Farm C were much higher than those from Farm A and ranged from 7.7 to 16.7 with a mean of 13.7. Based on the data in Table 6.2, SAR values as high as this pose a threat to soil structure.

Nitrate

Changes in the nitrate concentration that were observed during the monitoring are shown in Figure 9.21. The highest concentration was almost 60 mg/L with an average of 30 mg/L of nitrate N. The high values of nitrate correspond with the times of fertiliser application. Farm C had the highest levels of N fertiliser of the four farms and the highest level of nitrate in the drains from those farms where drainage water could be sampled.

The nitrate concentrations were estimated from manual samplings, and the timing of these did not match exactly with the identified times of flow. The concentrations at those times were estimated using a smoothing spline as shown in Figure 9.22. This enabled the calculation of a load, (as described in Section 6.2). The resultant calculations indicated a loss of 20.2 kg N or 13.4 kg N/ha.

The calculations involved several approximations and should be considered as indicative rather than definitive.

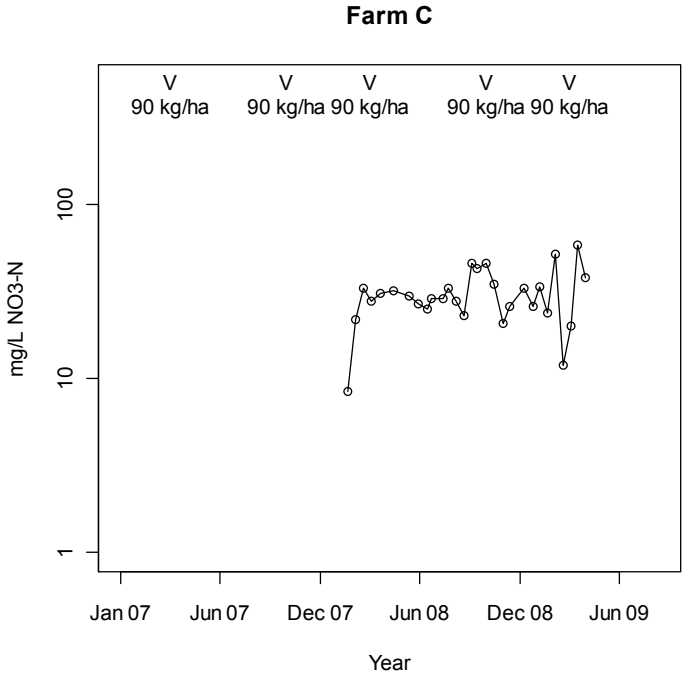


Figure 9.21 Changes in nitrate concentrations in drain at Farm C.

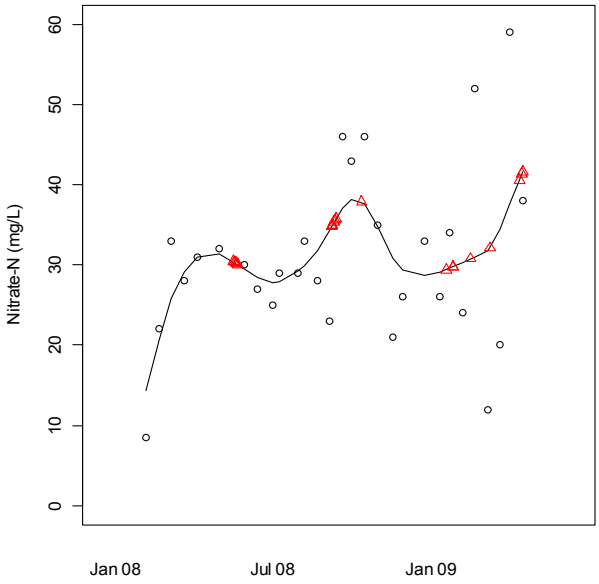


Figure 9.22 Interpolation of intermediate nitrate values. Using a smoothing spline with 7 degrees of freedom. Red triangles are interpolated values used for estimation of nitrate load.

Table 9.10 Estimation of flow and load using flow measurement data

Day	Flow (ML)	Concentration of nitrate-N (mg/L)	Load (kg)
20/09/08	0.322	34.8	11.2
21/09/08	0.027	35.0	0.9
22/09/08	0.023	35.0	0.8
23/09/08	0.028	35.4	1.0
24/09/08	0.015	35.6	0.5
25/09/08	0.011	35.8	0.4
26/10/08	0.007	37.9	0.3
31/01/09	0.023	29.4	0.7
7/02/09	0.032	29.7	0.9
9/02/09	0.030	29.8	0.9
28/02/09	0.005	30.8	0.2
22/03/09	0.016	32.1	0.5
26/04/09	0.045	40.6	1.8
Total	0.585	(34.0, mean)	20.2

Phosphate

Changes in phosphate concentration that were observed during the monitoring are shown in Figure 9.23. Most of the values were less than 1 mg/L but there were peaks of 4.8 and 3.6 in the autumns of 2008 and 2009.

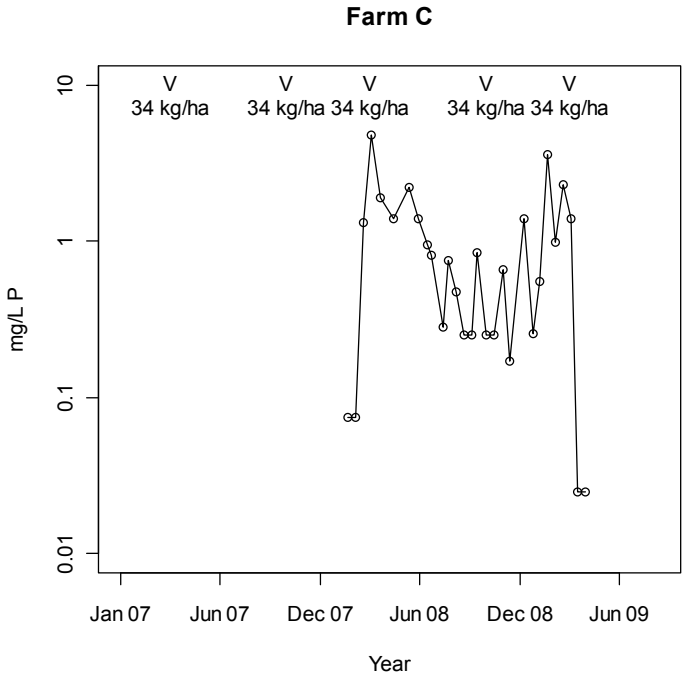


Figure 9.23 Changes in phosphate concentrations in drain at Farm C.

9.4.5. Farm D

Farm D was chosen a by Hutton *et al* (2008) as a representative of flood irrigation on a sandy soil. There were data from suctions cups from locations MH and MT indicated on

the map that is shown in Figure 9.24. There are no data on the subsurface drainage water because there was no flow.

Fertiliser history

At farm D, the annual total nitrogen applied ranged from 53.5 kg N/ha in 2007/08 to 121.7 kg N/ha in 2008/09. Over the same period the annual P applied ranged from 17.4 kg P/ha in 2004/05 up to 31.0 kg P/ha in 2007/08 N and P fertilizer were applied as mixed applications in Autumn (April 04, April 05 and March 06) and as manure (April 07). A summary of the fertiliser applications is given in Table 9.11.

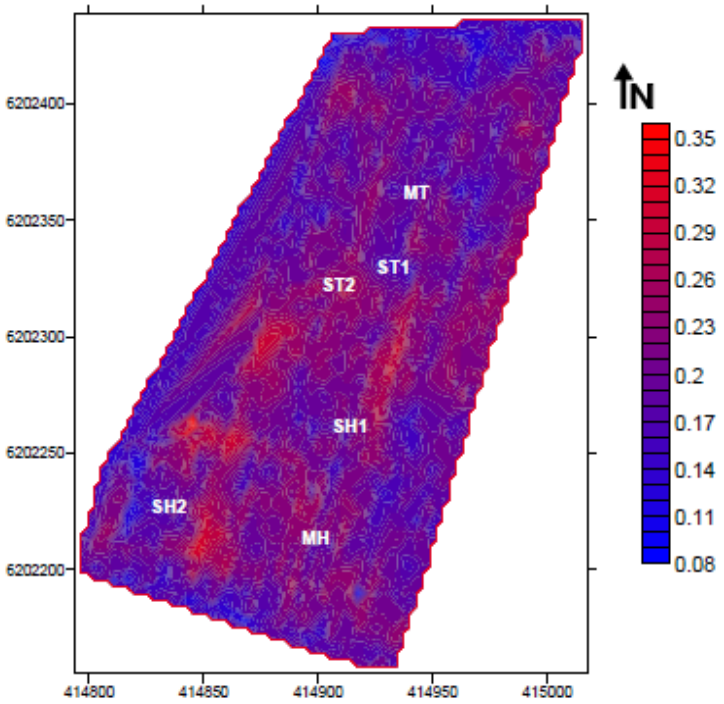


Figure 9.24 EM38 survey showing average profile EC [dS/m] to 1.5m of Farm D showing suction cup locations MH and MT (after Hutton et al. 2008).

Table 9.11 Irrigation, rainfall and fertiliser application at Farm D (after Hutton *et al*. 2008).

	2004/05	2005/06	2006/07	2007/08	2008/09
Irrigation (mm)	500	520	500	637	418
Rainfall (mm)	252	367	165	345	304
Total water (mm)	752	887	665	982	722
Fertiliser N (kg/ha)	81	81	81	54	122
Fertiliser P (kg/ha)	17	28	28	31	23

Salinity

The EC values in the suction cups at 1 m depth ranged from 420 to 6800 µS/cm, with an average of 2800 µS/cm. There was no drainage sample data available.

SAR

No estimate of SAR of the drainage water was possible because there was insufficient flow at that site.

Nitrate

There were moderately high levels of nitrate in late spring of 2008 at both the 50 cm and 75 cm levels. There was poor agreement among the replicate samples with concentrations ranging from 6 to 86 mg/L in October 2008. Concentrations at 100 cm were less than 1 mg/L.

Phosphate

Phosphate levels were generally low, but there was a peak of just over 2 mg/L in autumn 2008. This peak did not occur at the same time as the peak in nitrate at the 50 cm level. Samples from 100 cm depth were consistently lower than those at 50 cm.

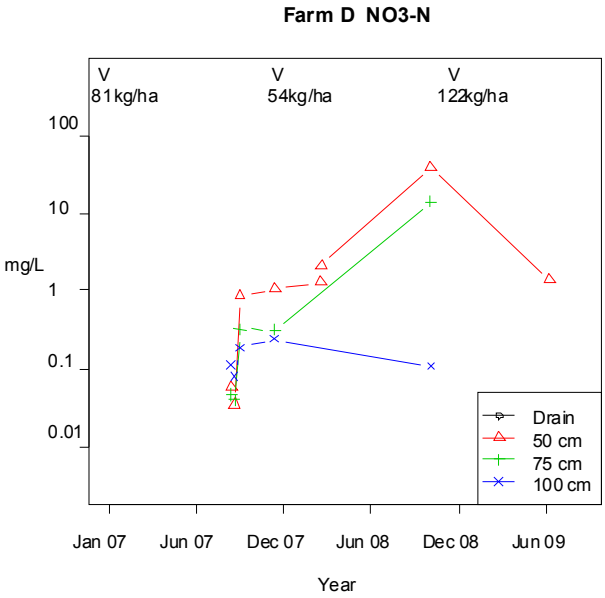


Figure 9.25 Changes in nitrate concentrations in suction cups at Farm D.

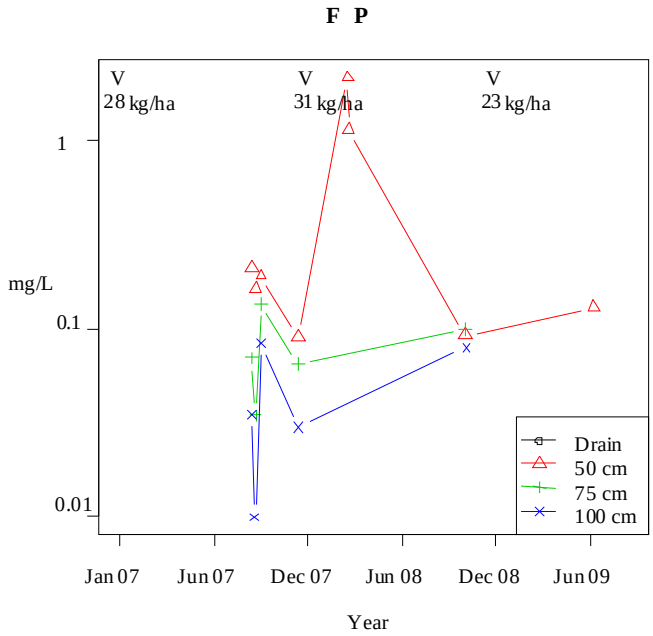


Figure 9.26 Changes in phosphate concentrations in suction cups at Farm D.

9.4.6. Comparison of monitored sites

Comparison of salinity at monitored sites

The salinity as represented by electrical conductivity (EC) values (suction cups) were high, and generally increased with depth (Figure 9.26), with a maximum occurring at 1 m depth at location MT. A log scale was used because of the large range of EC values. The median values at 0.25 m depth were all less than 200 µS/cm.

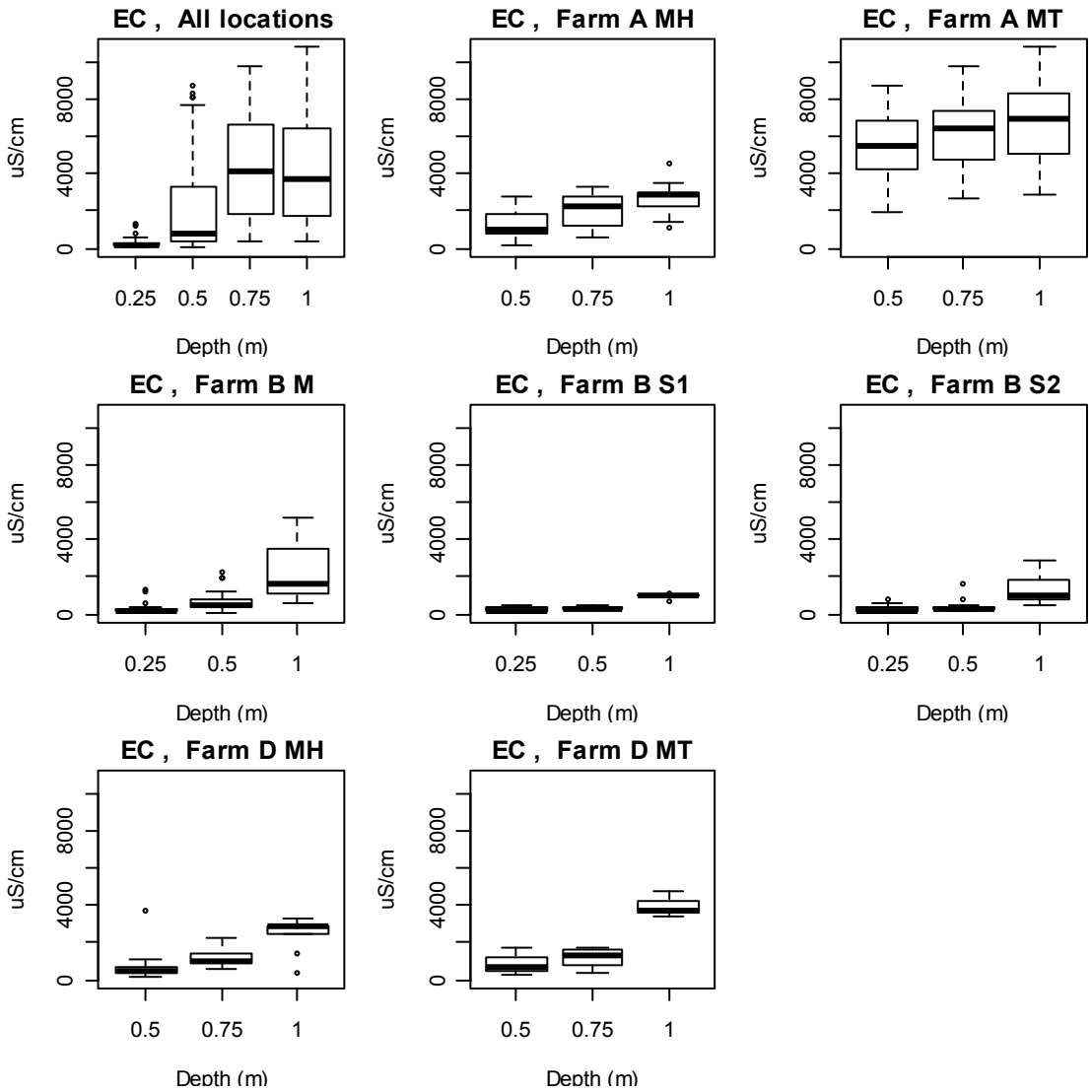


Figure 9.27 Comparison of EC across depths for each suction cup location and for all locations combined.

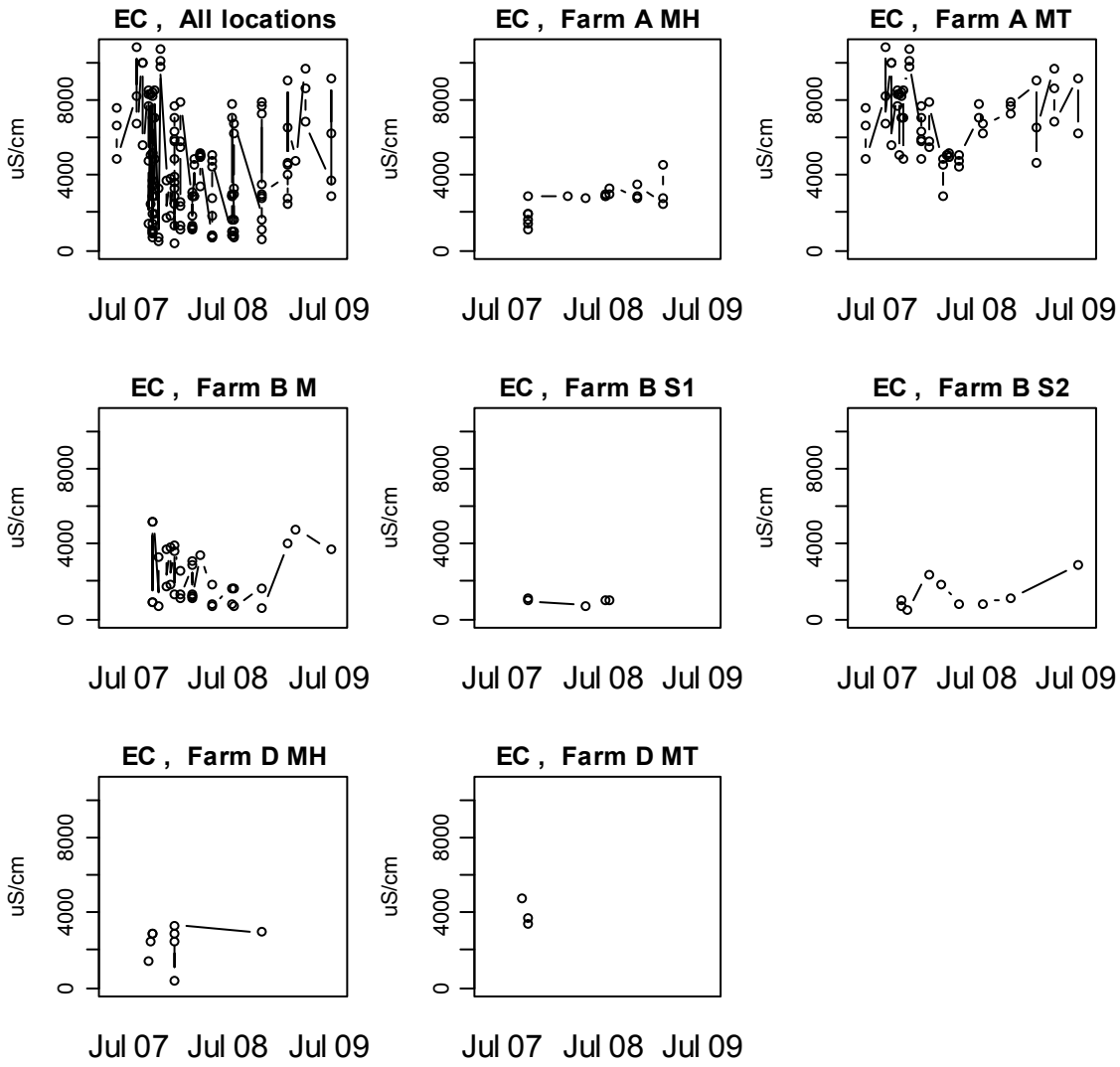


Figure 9.28 Changes in EC over time at 100 cm depth for each suction cup location and all locations combined.

There were large differences between the chloride concentrations at the three sites (sites Figure 9.29), with Farm C having high concentrations that declined over the measurement period. In contrast, Farm A had much lower chloride levels (typically about 150 mg/L), and that concentration stayed more or less constant over the measurement period. There were three very low Cl values in Farm A data but no reason for these low values was found. There were limited observations available for Farm B, but what values were found were in a similar range to these found at Farm A.

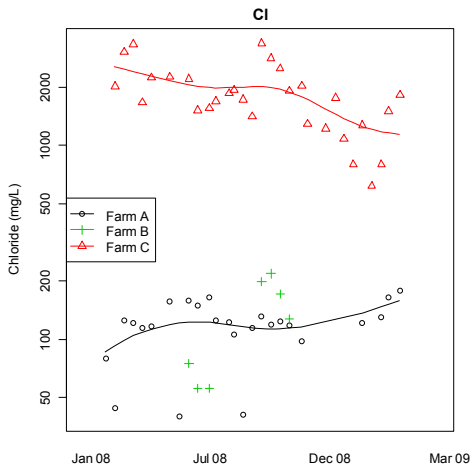


Figure 9.29 Changes in chloride concentration at three monitoring sites. The lines are smoothing splines with 4 degrees of freedom.

Comparison of SAR levels at monitored sites

Sufficient data were available to make a comparison of the SAR values at Farms A and C. The SAR values at Farm A were centred around 6 – the value given in Table 6.2 as giving increased risk. Farm C had higher salinity as discussed above, but the SAR was generally greater than 9. That value, according to the value in Table 6.2, would suggest there would be severe risk to the soil structure.

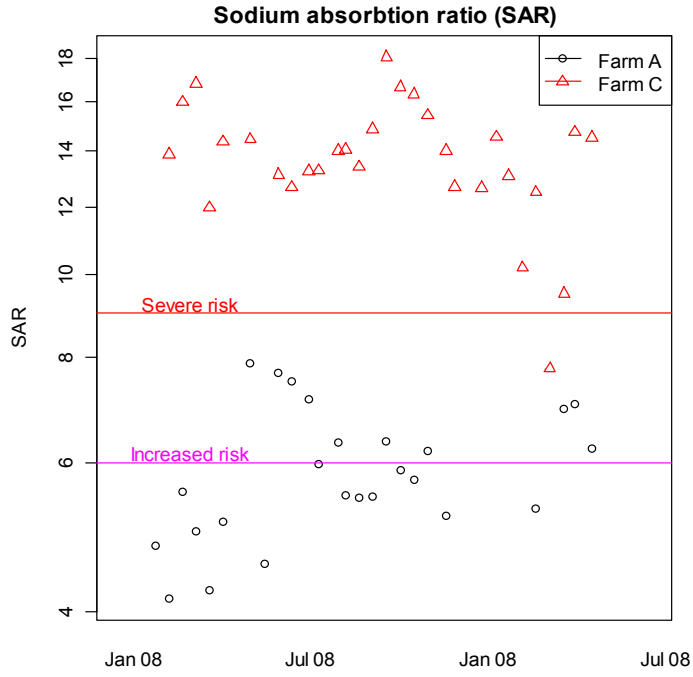


Figure 9.30 Changes in SAR in drainage water of Farms A and C

Comparison of nitrate and other N levels at monitored sites

Generally NH_4 levels were low but there were several outliers, including a value of 20 mg/L at the 0.25 m depth at locations M (Figure 9.31). There were also two values of 4 mg/L at 1 m depth in both the M and MT locations.

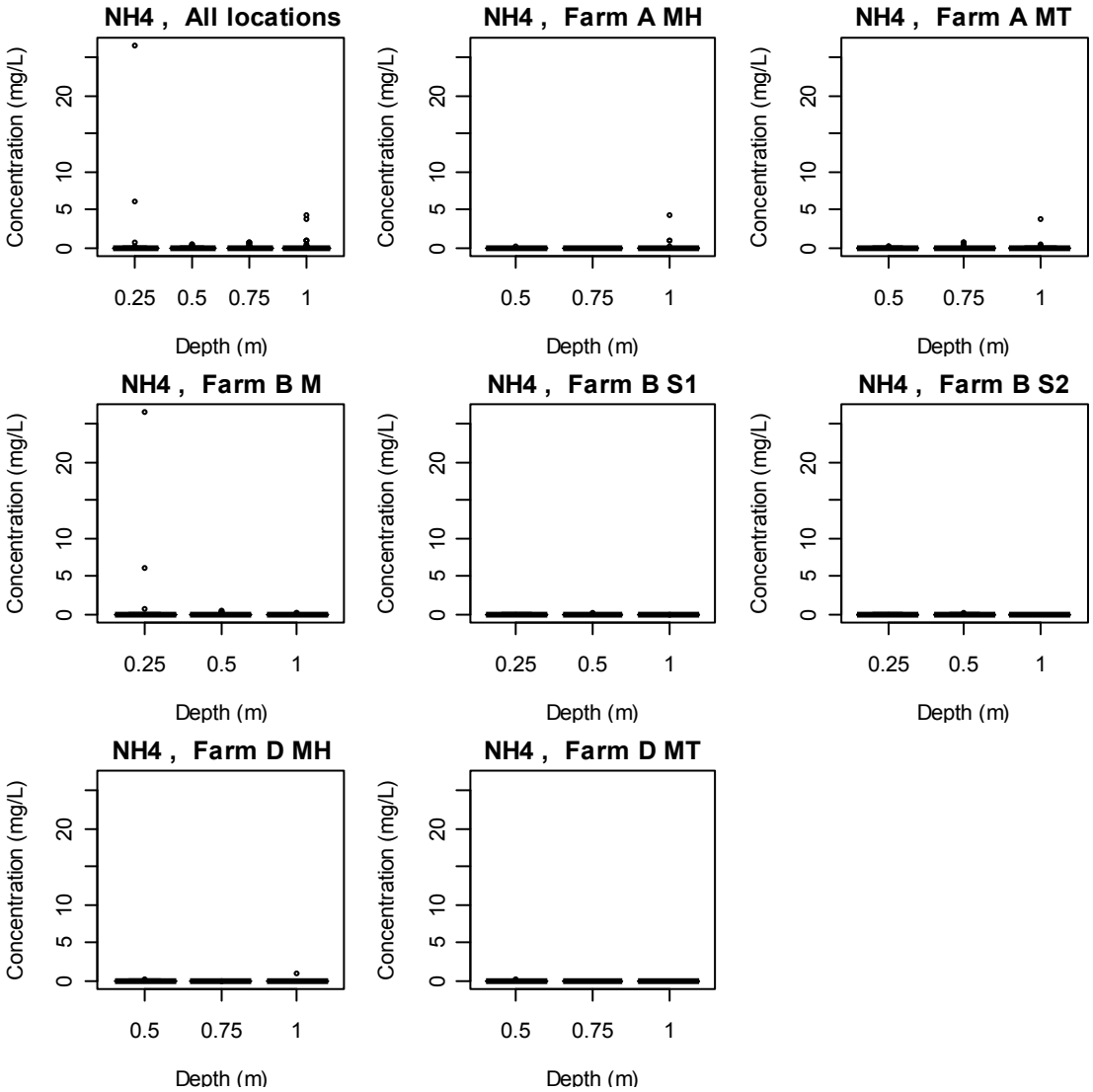


Figure 9.31 Comparison of NH_4 across depths for each location and for all locations combined

The distribution of TDN was skewed and included several very high values. The high values were found to consist mainly of nitrate-N.

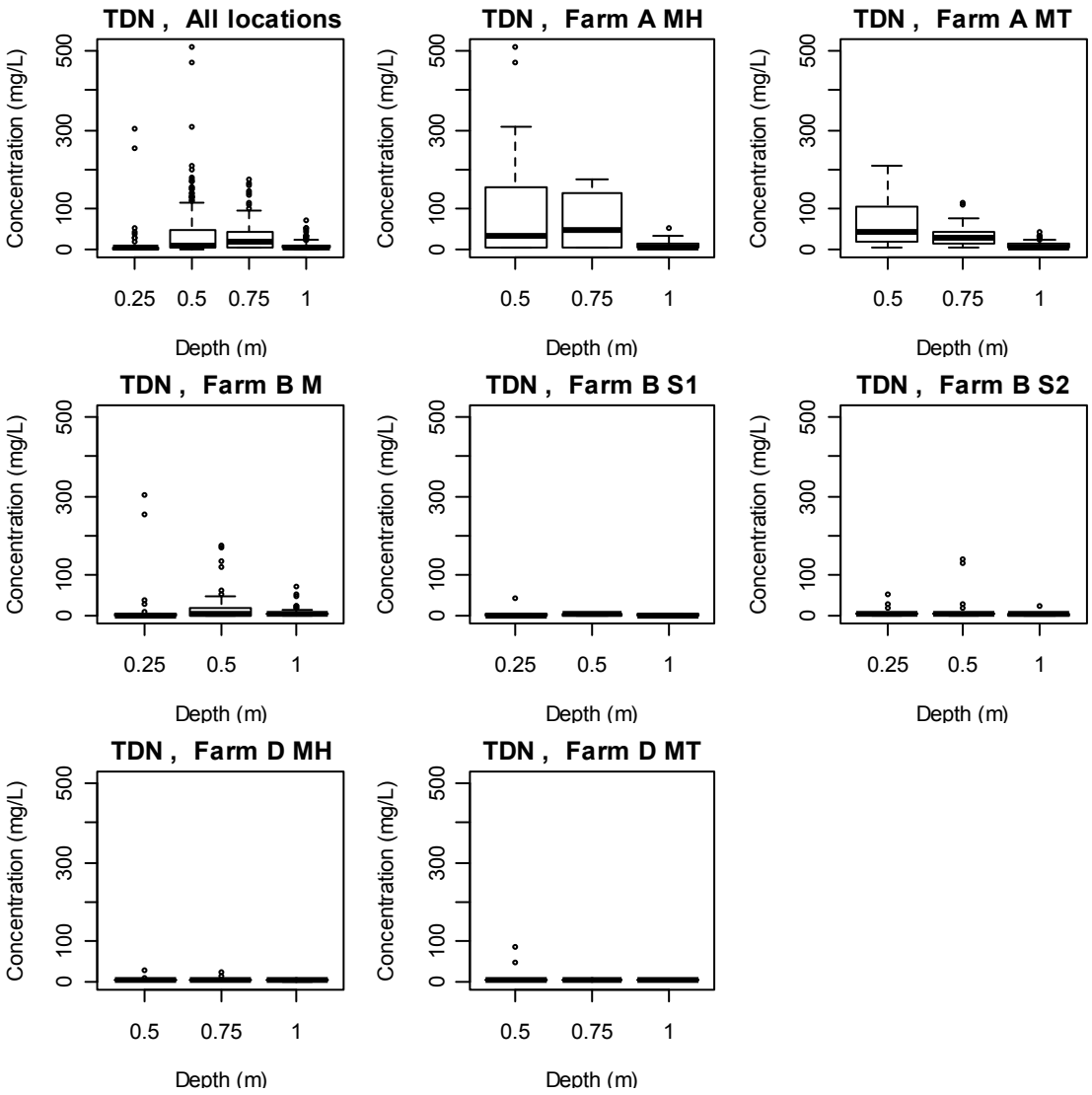


Figure 9.32 Comparison of TDN across depths for each location and for all locations combined.

Most of the NO_x values were low, but there were some marked exceptions, particularly at the 0.5 m depth at the Farm A, MH location, where there were 3 values that exceeded 300 mg/L, including one value of 600 mg/L (Figure 9.33). High values exceeding 100 mg/L occurred at the Farm B, locations M and S2, and at Farm D, location MT.

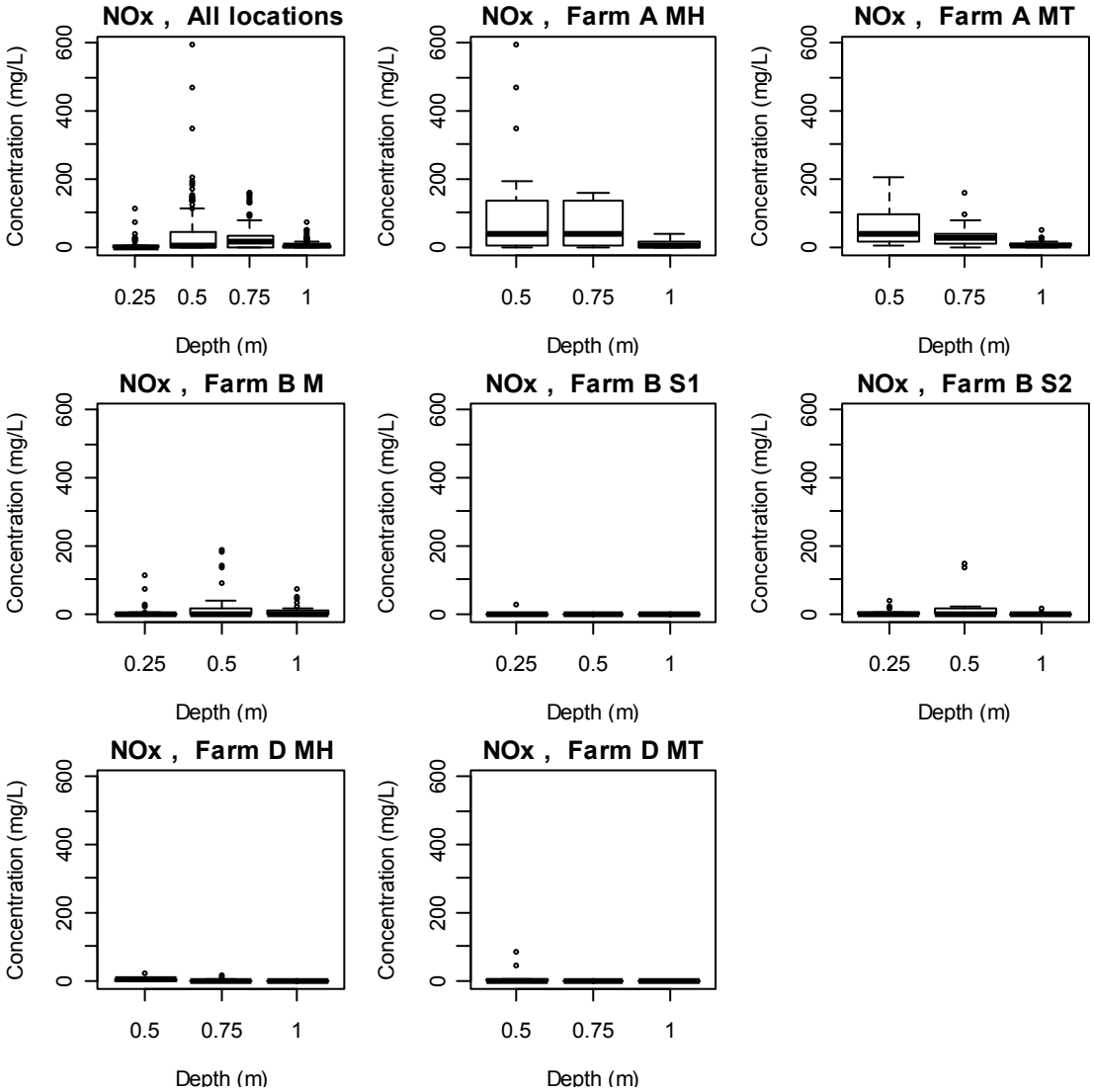


Figure 9.33 Comparison of NO_x across depths for each location and for all locations combined.

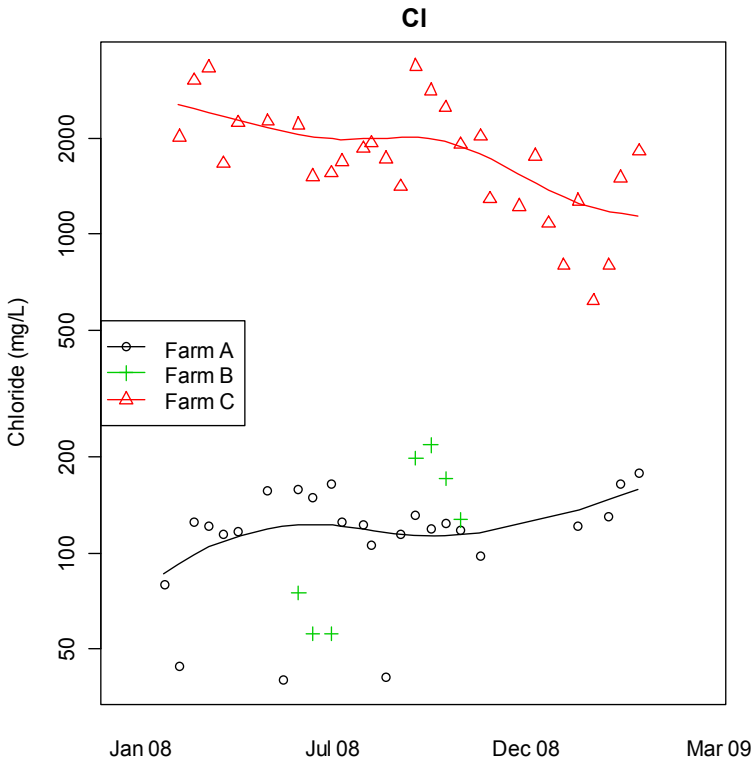


Figure 9.34 Temporal trends in suction cup NO_x at 1.0 m depth.

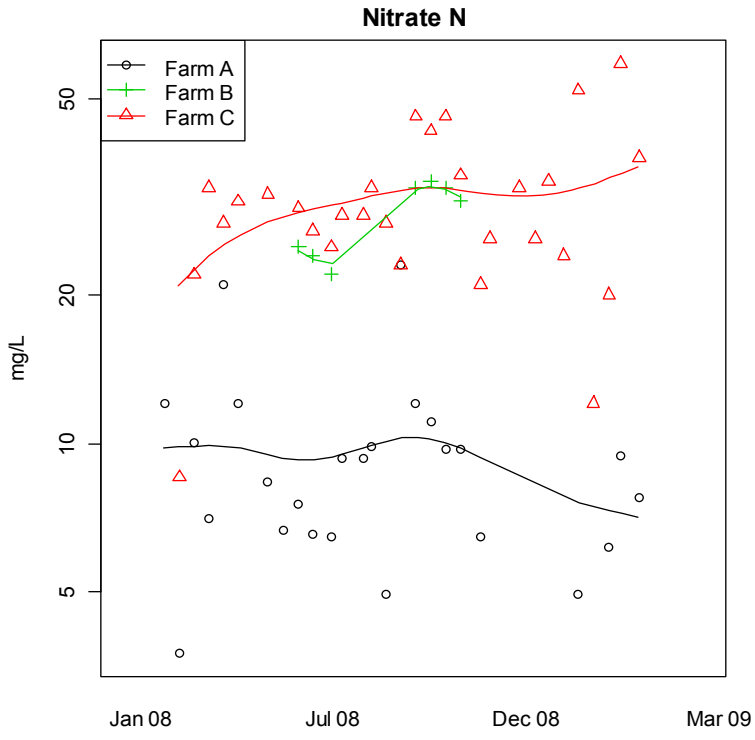


Figure 9.35 Changes in nitrate-N concentration in tile drains at three monitoring sites.

Comparison of phosphate levels at monitoring sites

Most of the phosphate concentrations were less than 0.05 mg/L (Figure 9.36), but there was a scattering of higher values spread over all 4 depths in at Farms 208 and 216.

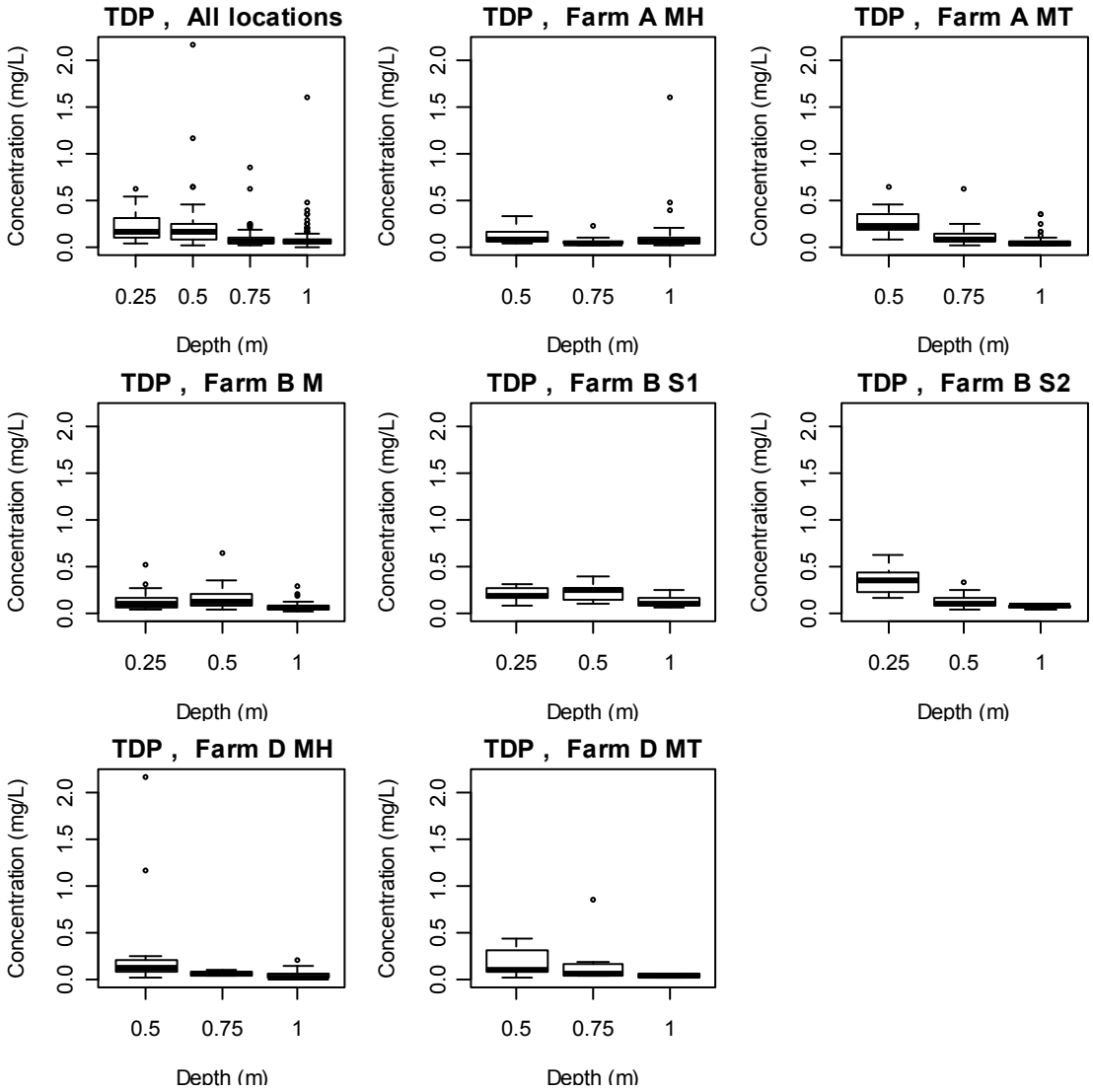


Figure 9.36 Comparison of TDP across depths for each location and for all locations combined.

9.4.7. Temporal pesticide monitoring

A summary of the analyses for pesticides of samples collected at the instrumented sites is given in Section 6.5.1. The only detections were at Farm A where diuron was detected at 0.1 ug/L on 97-2_17-4-208), 0.1 µg/L on 29/5/2008 and again at 1.12 µg/L on 4/9/2008, plus in a composite sample taken from 20/03/2008 to 17/04/2008 from Farm A. There is no WQG for diuron. Details of the detections are given in Table 9.12.

Table 9.12 Summary of pesticide analyses for MIA samples.

Date	Other 17 pesticides			Diuron		
Farm	A	B	C	A	B	C
7/02/2008	BDL	NS	BDL	BDL	NS	BDL
21/02/2008	BDL	NS	BDL	BDL	NS	BDL
6/03/2008	BDL	NS	BDL	BDL	NS	BDL
20/03/2008	BDL	NS	BDL	BDL	NS	BDL
3/04/2008	BDL	NS	BDL	BDL	NS	BDL
17/04/2008	BDL	NS	BDL	**0.10**	NS	BDL
15/05/2008	BDL	NS	BDL	BDL	NS	BDL
29/05/2008	BDL	NS	BDL	**0.10**	NS	BDL
13/06/2008	BDL	BDL	BDL	BDL	BDL	BDL
26/06/2008	BDL	BDL	BDL	BDL	BDL	BDL
14/07/2008	BDL	BDL	BDL	BDL	BDL	BDL
24/07/2008	BDL	NS	BDL	BDL	NS	BDL
13/08/2008	BDL	NS	BDL	BDL	NS	BDL
21/08/2008	BDL	NS	BDL	BDL	NS	BDL
4/09/2008	BDL	NS	BDL	**1.12**	NS	BDL
18/09/2008	BDL	NS	BDL	BDL	NS	BDL
2/10/2008	BDL	BDL	BDL	BDL	BDL	BDL
16/10/2008	BDL	BDL	BDL	BDL	BDL	BDL
30/10/2008	BDL	BDL	BDL	BDL	BDL	BDL
4/11/2008	BDL	BDL	BDL	BDL	BDL	BDL
13/11/2008	BDL	BDL	BDL	BDL	BDL	BDL
2/12/2008	BDL	NS	BDL	BDL	NS	BDL
8/12/2008	BDL	NS	BDL	BDL	NS	BDL
8/01/2009	BDL	NS	BDL	BDL	NS	BDL
23/01/2009	BDL	NS	BDL	BDL	NS	BDL
5/02/2009	BDL	NS	BDL	BDL	NS	BDL
19/02/2009	BDL	NS	BDL	BDL	NS	BDL
5/03/2009	BDL	NS	BDL	BDL	NS	BDL
19/03/2009	BDL	NS	BDL	BDL	NS	BDL
3/04/2009	BDL	NS	BDL	BDL	NS	BDL
14/04/2009	BDL	NS	BDL	BDL	NS	BDL
1/05/2009	BDL	NS	BDL	BDL	NS	BDL

Data are in µg/L.
The other pesticides are listed in Table 6.1
BDL = below detection limit
NS = No sample

10. DISCUSSION

10.1. Salinity

Table 10.1 gives a comparison of the chloride levels found in drains or suction cups across the study regions. The highest values found were in South Australia. The chloride levels in the drainage water at most sites in MIA and in the measured drains at Sunraysia had less chloride than the irrigation water that was being used at Wrattonbully, S.E.,S.A.

Table 10.1 Comparison of Cl contents across study regions.

Location	MIA spatial survey	Sunraysia spatial survey	Suction cups (SA)	Wrattonbully
Source water		9	NA	700
Median drainage water	157	125	560	1100
Range drainage water	9-1320	32-390	130-6300	440-3600

During this project there were several cases where there was evidence of insufficient drainage to maintain a sustainable system. Local observations indicated that two of the four farms studied at MIA had very little drainage. Similarly many of the drainage caissons in Sunraysia have ceased flowing. At Wrattonbully the lysimeters indicated that there is little drainage and also an accumulation of salt in the profile (Figure 7.17). The data on chloride concentrations in drainage water from lysimeters show about a four-fold increase during the period 2003-2009. However, a high concentration of salt was not present in the soil samples that were taken to a depth of 90 cm, indicating that the accumulation must be occurring at a greater depth. Previous studies have indicated that soil moisture is withdrawn from the soil during summer to a depth of at least 1.3 m (Figure 10.1).

Accumulation of salt, even deep in the profile will in time limit access of roots to the deeper soil layers. So just one effect of accumulation of salt will therefore be to limit the effective rooting depth and consequently to reduce the effective water holding capacity of the soil.

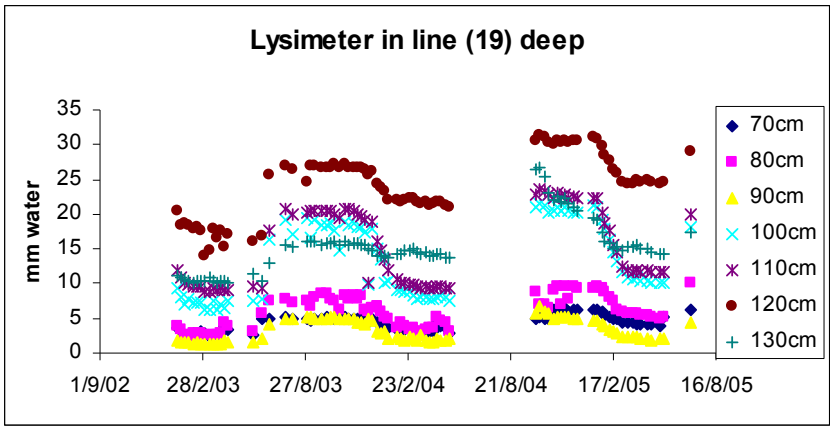


Figure 10.1 Changes in water content of soil in a lysimeter at Wrattonbully. The Diviner access tube was in line with the vines as shown in Figure 7.12.

The detailed information obtained from the lysimeters at Wrattonbully shows a clear pattern of the accumulation of salt in the profile (Figure 7.17). Even in the years of

significant drainage (> 20 mm) there is a net accumulation of Cl in soil profile in the order of 400 kg/ha/yr (Table 7.4).

This quantification of the accumulation of salt has been made possible because of the availability of the excellent lysimeter facility installed by Yalumba. How representative this situation is of predominantly rain-fed vineyards is not known. This question can only be answered accurately by the installation of additional lysimeters in other areas.

With the reduction in availability of water and the move to more efficient irrigation systems (see for example Table 8.2) there is a need to accurately assess drainage. Where there are tile drains, these should be able to be monitored. The drainage meters are being refined, and current results from them are promising (Ron Hutton pers. comm.) but there remains the question of how well they can represent a vine area. Validation of the drainage meters should be obtained by placing them in suitably constructed lysimeters. It is noted that given the time taken to establish the Wrattonbully lysimeters, those lysimeters should not be further disturbed.

10.2. SAR

The importance of SAR has been recognized widely (see for example NSW 2005) and it is a key indicator of the threat posed to soil structure by water with a high Na content. The SAR data on drainage water from various regions show that in some cases SAR values falls into the moderate risk category. It is not clear if the soil profile has high SAR or the drainage water SAR is high because of selective leaching of Na from the soil profile. In such areas, the measurement of SAR and salinity in the soil profile is recommended to assess the site specific risk and management options.

While SAR will continue to be of importance to grape growers and wine producers (and others), it has limitations. For example, other monovalent ions such as K can also adversely affect soil structure, and it is not considered in the SAR. Furthermore the effect of SAR can be modified by salinity. This makes it unclear what threat would be posed at a site like Farm C that has both high SAR and high salinity.

An alternative measurement of the effect of water on soil structure is the CROSS index that has been proposed by Rengasamy 2010 (*personal communication*). This measure has advantages over SAR as it takes into account the effect of the monovalent ion K and assigns realistic weights to the elements involved. The improvement offered by CROSS over SAR is shown in Figure 10.2. The CROSS index appears to have potential and its use in viticulture especially in relation to drainage water and waste water from wineries should be assessed more widely.

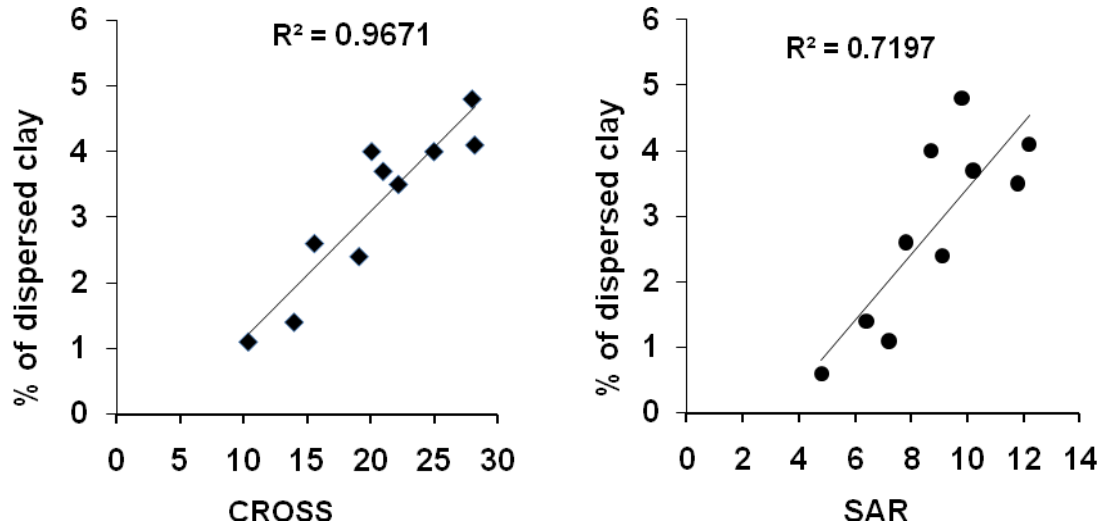


Figure 10.2 Relationships between CROSS, SAR and percentage of dispersed clay (after Rengasamy 2010, *pers comm*).

10.3. Boron

There were numerous occurrences of boron exceeding the WQG – in the MIA spatial survey 25 out of 33 samples exceeded the guideline of 370 µg/L as did all of the Sunraysia samples (Figure 8.14). Our data support the conclusion of GHD (2009) that Zn and B concentrations did exceed guideline values for many samples. Of greater concern is the direct toxicity of boron on plants if it reaches high concentrations in the root-zone. The concentrations of boron in drainage water indicate that it may be reaching toxic levels in the root-zone and may be already affecting productivity on some sites. This is a serious issue to be further investigated for the long term sustainability of viticulture.

10.4. Nutrients

10.4.1. Nitrates

The main nutrient of concern that was found in the drainage water was nitrate. The environmental WQG value for nitrate is very low 0.7 mg/L (ANZECC & ARMCANZ, 2000).). In many cases this value was exceeded in the drainage water. At times very high levels of nitrate were found including values as high as 60 mg/L in drainage water at Farm C. There were also some very high levels (100 mg nitrate N/L) found in suction cups at 50 cm depth at Farm B, but the concentration was much less at depth (Figure 9.16). However, given the low volumes of drainage water at most sites, the total load of nitrate exported from farms is low and has been decreasing in recent years. From a vineyard where flow volumes could be measured, a loss of about 10 kg N/ha was noted during one season. The significant drainage and nitrogen export occurred from a furrow irrigated vineyard.

The findings in this study are consistent with studies reported recently by Barlow et al. 2009. They reported data on N in soil solution in one Rutherglen Shiraz and six Riverina Chardonnay vineyards employing different methods of irrigation (flood, drip). They showed that the average N (nitrate + nitrite) concentrations in soil solution, (at 1m), ranged from 0.64 to 82 mgN/L (Figure 10.3). The highest concentrations in the suction cup samples at 100 cm depth were recorded from the furrow irrigated vineyards. Clearly these concentrations of N are significantly greater than Australian environmental trigger values (e.g. 0.5 mg N/L trigger value for Lowland rivers; WQG 2000).

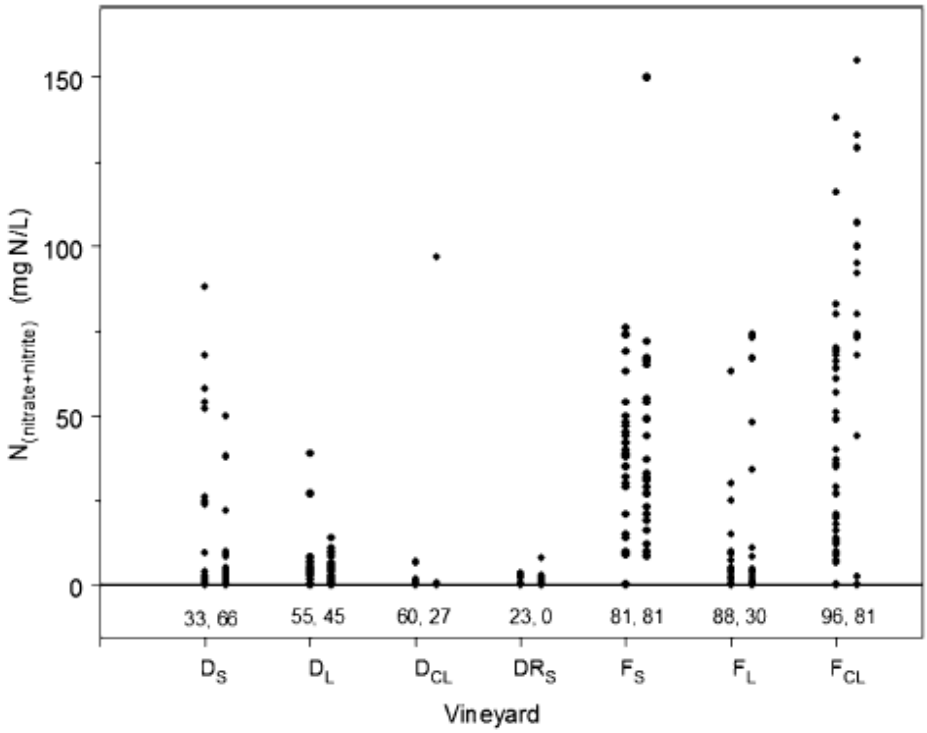


Figure 10.3 Nitrate + Nitrite concentrations at 100 cm depth in vineyards under different methods of irrigation (taken from Barlow et al. 2009).

Excess nitrate in the drainage water is both a waste of fertilizer and harmful to the environment. Hutton et al (2009) have suggested that N applications should be split between pre-bloom and post-harvest to match root growth periods and avoid single large applications that increase N leaching risk. Greater use of standard plant tissue analysis should be encouraged to refine N application rates and allow adjustments from season to season.

There are some data on the nitrogen capital of vines throughout the year. Data from Treeby and Wheatly (2006) showed there was a large increase in the nitrogen capital in the spring, and this would support the recommended pre-bloom application of fertilizer. However there was little, if any, increase in the N capital following harvest, so the efficacy of applying N fertilizer post harvest needs careful consideration.

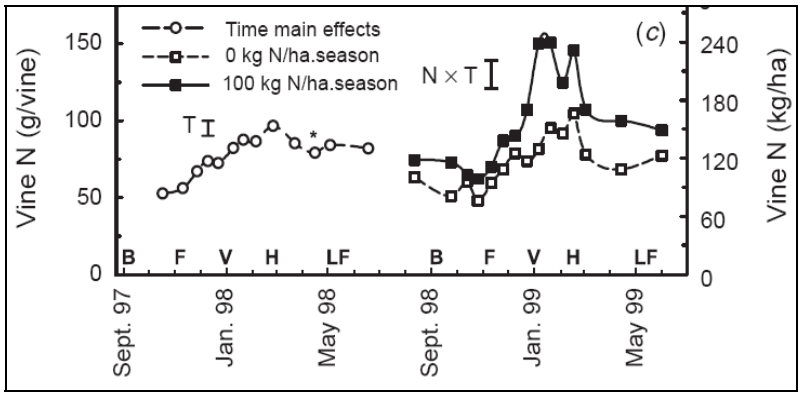


Figure 10.4 Nitrogen capital in vines throughout a season (after Treeby and Wheatley 2006).

10.4.2. Phosphate

Phosphate levels in the drainage water were generally low and often below detection levels. There were however some high values with a value of 1.4 mg/L being found in Sunraysia and a value of 2.3 mg/L in the MIA spatial survey. In both the Sunraysia data and in the MIA there was no significant correlation between nitrate levels and phosphate levels.

10.5. Pesticides

Irrigations or heavy rainfalls apparently results in rapid drainage. If a pesticide application occurred just prior to such an event, there may be potential for that pesticide to be carried into the drainage water. Whether this occurs or not, will depend on factors such as the sorption coefficient K_d (binding ability of the soil for that pesticide) and the fraction of preferential flow. The limited information obtained from the flow rates in this study indicates that, at least in some cases, there is a very rapid drainage following irrigations (Figure 9.19). Similar sharp peaks were also noted in the data from Farm D (MIA). Rapid preferential flow has been linked to the presence of glyphosate in water entering tile drains in other studies (Stone and Wilson 2006).

Chlorpyrifos, although expected to be of low leaching potential, was found in four samples out of 200 samples analysed in this study. Diuron was detected in another four samples and there were no detections of any of the other 16 pesticides investigated (Table 6.5.1). Chlorpyrifos is a very toxic pesticide with a tolerance level of 0.01 µg/L (Allinson 2007, WQG 2000), This figure is less than the detection limit for the method/analyzer used for this project. Any detection of chlorpyrifos is therefore a cause for concern. An occurrence of a value of 7.4 µg/L would therefore require approximately 1000 times dilution to meet environmental requirements. It is however, not clear if viticulture use was the source of chlorpyrifos in the drains as it is used in several other horticultural and other crops.

Recently, chlorpyrifos has come under review by the Australian Pesticide and Veterinary Medicines Authority under the existing chemicals review program (APVMA, 2000). The review identified that chlorpyrifos is currently available for use in Citrus, Pome fruit and Grapes. In grapes it is registered for the control of light brown apple moth 50 g ai/100L or 250 g/ha. The first application is to be made just after berry set and the repeats as required. It can also be used for dormant sprays (25 or 50 g/100 L) to control scale - after pruning (e.g. July). A special permit is available to SA, WA to control African Black Beetle in Grapevines.

It is not clear how much of chlorpyrifos is currently used in grapes, as anecdotal evidence suggests its use has been reduced heavily in the wine grapes. It may however still be used in table grapes. It would be desirable to establish the actual use of chlorpyrifos in vineyards, and if needed measures should be taken to replace it with less toxic pesticides.

The concentration of pesticide in the drainage water will be affected by other factors also. In the extreme case when there is little adsorption and insufficient time for breakdown, there may be pesticides that could be detected. It is noted that there is a high proportion of detections of herbicides in the supply channels (Table 9.4). When pesticide is applied from that source there would very little time for breakdown, and there could be concentration due to evapotranspiration. This may be responsible for some of the detections note by MIL in the drainage water (Table 9.4).

From the above, the quality of the input water needs to be continually assessed (this is currently being done by MIL). It is recommended that that monitoring be maintained. A logical extension of that monitoring would be to identify sources of pesticides entering the system.

Except in very few cases, there was no detection of pesticides in drainage water which suggests the pesticides are not leaking into the drainage water. While this is heartening for the industry, there is no room for complacency, and a program to enhance grower awareness about potential impact of pesticides should be carried out and mechanisms to eliminate toxic compounds such as chlorpyrifos be identified. A risk-based approach can help enhance growers' awareness and the growers should be provided with easy to use "Chemical Reference Charts" as used in the Mt Lofty Ranges.

10.6. Other contaminants

Heavy metals (Copper, Lead and Zinc) were highlighted as chemicals of potential concern by GHD (2009). Our analyses consistently failed to detect copper and lead in the drainage water in South Australian, Sunraysia or in MIA. However the WQG for copper is 1.4 µg/L and 3.4 µg/L for lead, which were below the routine quantification limit of 50 µg/L of the laboratory. There were detections of zinc, but the maximum concentration was 0.140 µg/L in the MIA spatial survey (Section 9.3.3), but this was much higher than the WQG level of 2.4 µg/L. Our data supports the conclusion of GHD (2009) that Zn and B concentrations did exceed guideline values for many samples. Further investigations are required to assess the consequence of exceedance of the guidelines by these contaminants.

11. ACHIEVEMENT OF PROJECT AIMS

The overall aim of the project was to undertake research that would assist the viticultural industry in minimising its environmental footprint through improved root-zone management. During the project there has been limited water available for irrigation in the Murray Darling Basin to the extent where there is little flow from drains. The reduced flow has not been accompanied by increased concentration of contaminants. This in turn means that currently the industry is having little effect on the environment due to the low loads of contaminants in the drainage water. The lack of drainage to some extent limited the study.

In other areas of South Australia there was also evidence of reduced drainage. This was particularly clear in the case of the direct measurements from the lysimeters, but it could also be inferred by the inability to obtain soil water samples at depth in several areas. Together these findings demonstrated that the amount of water that was passing through the rootzone was minimal. An implication of the lack of drainage implies an accumulation of salt, particularly in areas where the irrigation water is of low quality.

In some cases, particularly in the MIA, there was evidence of excess nitrate concentrations in the soil water. This suggests that the amount of applied mineral N fertiliser could be reduced and thus reduce the environmental effect without affecting productivity.

Assays of pesticides were performed on sufficient samples to demonstrate that pesticide contamination of drainage water is rare. Assays for other contaminants were also assessed, thus giving a good coverage of the range of chemicals of potential concern.

The findings of the project have been communicated to key players in the industry through workshops. Further communication of the findings has been limited by the sensitive nature of some of the pesticide data. A factsheet summarising the key findings and their implications for management have been prepared for a wider circulation.

The project has met its objectives, but its foci had to be modified to some extent by the lack of drainage from the rootzone.

12. CONCLUSIONS:

Key conclusions arising from this study are listed below.

- The combination of efficient irrigation methods, general scarcity of water and possibly changing rainfall pattern have resulted in a consistent lack of drainage across all of the studied viticulture regions. The volume of tile drainage has decreased 4-10 folds in many regions and many drains have stopped flowing.
- The salinity of drainage water is increasing with time, especially at sites where poorer quality irrigation water is being used which suggests salt build up in the soil profile, the extent of which depending largely on the salinity of irrigation water.
- The concentrations of boron in drainage water are high and are now reaching levels that may be affecting productivity on some sites.
- Nitrate concentrations in drainage water at some sites exceed environmental guidelines requiring a dilution factor of 10-30 times in the receiving environments. However, their overall load in the drainage water was low due to small total volumes of the drainage water. At some sites with low drainage, the suction cup data shows accumulation of nitrate at depths of 75-100 cm.
- Deep drainage and loss of N is hypothesized to be greater on furrow irrigated farms because larger quantities of water & N are applied at any one time. This could well lead to better management of fertiliser applications to newly established vineyards.
- The analysis of 18 different pesticides in more than 200 samples from various regions showed that pesticides do not appear to be a major concern in drainage water. However a few detections of chlorpyrifos and diuron were noted, which may have arisen from other horticultural use in that particular study area.
- The communication of project findings with stakeholders and especially with the Wine Environment Committee has facilitated the flow of information to the industry in a targeted manner.

13. RECOMMENDATIONS

The study raises several questions that are not only important from the standpoint of the environmental footprint of the industry but also from direct productivity and long term sustainability of viticulture.

Specific recommendations:

- Consistent lack of drainage across all viticulture regions and the evidence of increasing salinity of drainage water are symptomatic of salt build up in the root-zone. Measures should be taken to make allowance for leaching fractions, especially in area with poor quality irrigation water.
- The concentrations of boron in drainage water in some of the study sites indicate boron may be reaching toxic levels in root-zone and may be already affecting productivity on some sites. This is a serious issue that needs to be further investigated for the long term sustainability of viticulture.
- The high SAR in the drainage water is indicative of high salt content in the soil profile. At sites with high SAR in drainage water, the SAR in soil extracts from the upper root-zone need to be established.
- Nitrate concentrations in drainage water at some sites exceeded environmental guidelines and therefore the fertilizer use in vineyards needs to be carefully managed. The fertilizer use efficiency of early season application of N fertilizers on newly established vineyards needs to be better managed.
- Source of nitrate in drainage water may be organic matter in soil. Therefore a dual isotope approach described earlier (Fig. 7.21) in the report should be pursued to quantify the mineral fertilise and organic matter sources of nitrogen in drainage water.
- While pesticides do not seem to be a major concern in drainage water, the industry should establish the current use pattern of pesticides and explore mechanisms to eliminate toxic compounds such as chlorpyrifos. A risk-based approach should be used to enhance growers' awareness and the growers should be provided with easy to use "Chemical Reference Charts" as used in the Mt Lofty Ranges.

General recommendation

- Overall, the industry must develop a strategy to deal with accumulation of chemicals in or below the root-zone and consequent unacceptable concentrations in drainage water that may eventuate during occasional episodic leaching events that may occur in a very wet year. Therefore, investigations on carefully chosen sites (e.g. lysimeters, some tile drain sites) should continue to develop long term trends on water quality, including several dry and wet years.

14. APPENDICES

14.1. Appendix 1: Communication

Communication of the outcomes of research is an important part of the GWRDC's activities.

Activity	Date & Location	Comments
Stakeholders Workshop	January 31st 2007 Loxton (Riverland)	15 attendees, Land Care, Scholefield Robinson, RWIRC, Yalumba, Central Irrigation Trust, GWRDC,CSIRO
Stakeholders Workshop	November 14th 2008 Wrattonbully (SE of SA)	8 attendees, Wine Industry Association from Wrattonbully and Limestone Coast, Yalumba Winery, GWRDC, CSIRO
Stakeholders Workshop	August 6th,2009 Mildura	24 attendees, National Wine and Grape Industry, DPI Victoria, DPI NSW, Western Murray Irrigation, Murray Valley WineG rowers, Zilzie Wines, Wingara Wine Group, Sun Rise 21, RWIRC, Lower Murray Water, Mallee CMA, GWRDC, CSIRO.
Press Article	September 2009 Murray Valley Wine news and Views	
SWI meeting	August 2007	Presented data and findings
SWI meeting	September 2008	Presented data and findings
SWI meeting	August 2009	Presented data and findings
Industry presentation 'Managing root-zone water quality'	February 2010; Wine Centre	
Popular press article	Pesticides -	in press
Popular press article	Winemakers Journal	article withdrawn
Journal article	draft article for Australian Grape and Wine Research	subject to internal review by GWRDC and Yalumba.

14.2. Appendix 2: Intellectual Property:

The valuable information arising from this research has been included in the recommendations.

14.3. Appendix 3: References

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14.4. Appendix 4: Staff

Name	Title	Position	Qualification	Agency	% of time to be spent on the project
1. Rai Kookana	Dr	Research Scientist	PhD	CSIRO	20
2. Ray Correll	Dr	Research Fellow	PhD	Consultant via CSIRO	10
3. Evan Christen	Dr	Research Scientist	PhD	CSIRO	5
4. Lester Smith	Mr	Experimental Scientist	BSc	CSIRO	20
5. Tasha Waller	Ms	Research Support Officer	BSc	CSIRO	20
6. Roy Zandona	Mr	Research Support Officer	BSc	CSIRO	20

14.5. Appendix 5: Additional data

14.5.1. South Australia sites

Table 13.1 Results of pesticide analyses of suction cup data.

Location ID	Location	Collection Date	Depth	18 Pesticide
10	Loxton	3/03 - 30/06/2006	60-90ml	BDL
10	Loxton	19/09 - 6/11/2006	60-90ml	BDL
10	Loxton	17/11/2006 - 29/10/2007	60-90ml	BDL
11	Loxton	31/08/2007 - 14/09/2007	60-90ml	BDL
1	Barmera	26/09/2007 - 25/06/2007	60-90ml	BDL
15	McLaren Vale	10/07 - 20/08/2007	60-90ml	BDL
15	McLaren Vale	29/08 - 14/09/2007	60-90ml	BDL
15	McLaren Vale	12/10 - 4/12/2007	60-90ml	BDL
16	McLaren Vale	10/07 - 3/08/2007	60-90ml	BDL
16	McLaren Vale	20/08 - 29/08/2007	60-90ml	BDL
16	McLaren Vale	14/09 - 12/10/2007	60-90ml	BDL
16	McLaren Vale	26/10 - 4/12/2007	60-90ml	BDL
9	Langhorne Ck	7/09/2006 - 07/02/2007	60-90ml	BDL
9	Langhorne Ck	13/02 - 23/02/2007	60-90ml	BDL
9	Langhorne Ck	27/02 - 15/06/2007	60-90ml	BDL
9	Langhorne Ck	14/08 - 12/10/2007	60-90ml	BDL
9	Langhorne Ck	26/10/2007 - 09/01/2008	60-90ml	BDL
9	Langhorne Ck	21/01 - 27/02/2008	60-90ml	BDL
8	Currency Ck	25/06 - 10/08/2007	60-90ml	BDL
8	Currency Ck	14/08 - 25/08/2007	60-90ml	BDL
8	Currency Ck	14/09 - 5/10/2007	60-90ml	BDL
15	McLaren Vale	27/8/083	30+60ml	BDL
15	McLaren Vale	2/09/2008	30+60ml	BDL
15	McLaren Vale	17/09/2008	30+60ml	BDL
15	McLaren Vale	24/09/2008	30+60ml	BDL
15	McLaren Vale	1/10/2008	30+60ml	BDL
15	McLaren Vale	8/10/2008	30+60ml	BDL
15	McLaren Vale	15/10/2008	30+60ml	BDL
15	McLaren Vale	22/10/2008	30+60ml	BDL
16	McLaren Vale	27/08/2008	30+60ml	BDL
16	McLaren Vale	2/09/2008	30+60ml	BDL
16	McLaren Vale	11/09/2008	30+60ml	BDL
16	McLaren Vale	17/09/2008	30+60ml	BDL
16	McLaren Vale	24/09/2008	30+60ml	BDL
16	McLaren Vale	1/10/2008	30+60ml	BDL
16	McLaren Vale	15/10/2008	30+60ml	BDL
8	Currency Ck	20/08/2008	30+60ml	BDL
8	Currency Ck	2/09/2008	30+60ml	BDL
8	Currency Ck	23/09/2008	30+60ml	BDL
8	Currency Ck	8/10/2008	30+60ml	BDL
9	Langhorne Ck	12/08/2008	30+60ml	BDL
9	Langhorne Ck	2/09/2008	30+60ml	BDL
9	Langhorne Ck	8/10/2008	30+60ml	BDL
15	McLaren Vale	24/09/2008	90ml	BDL
15	McLaren Vale	1/10/2008	90ml	BDL
15	McLaren Vale	8/10/2008	90ml	BDL
15	McLaren Vale	15/10/2008	90ml	BDL
15	McLaren Vale	22/10+29/10/08	90ml	BDL
8	Currency Ck	8/10+13/11+9/12/08	90ml	BDL
9	Langhorne Ck	8/10+11/11/08	90ml	BDL

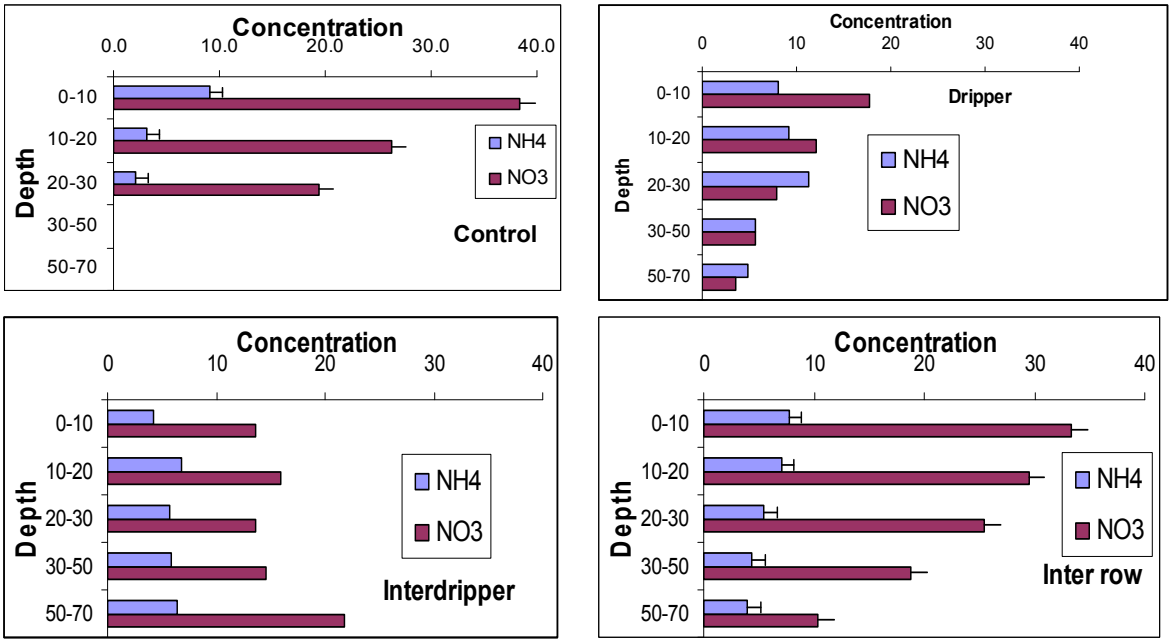


Figure 13.1 Mineral N profiles at 4 locations near the lysimeters taken in 2005.

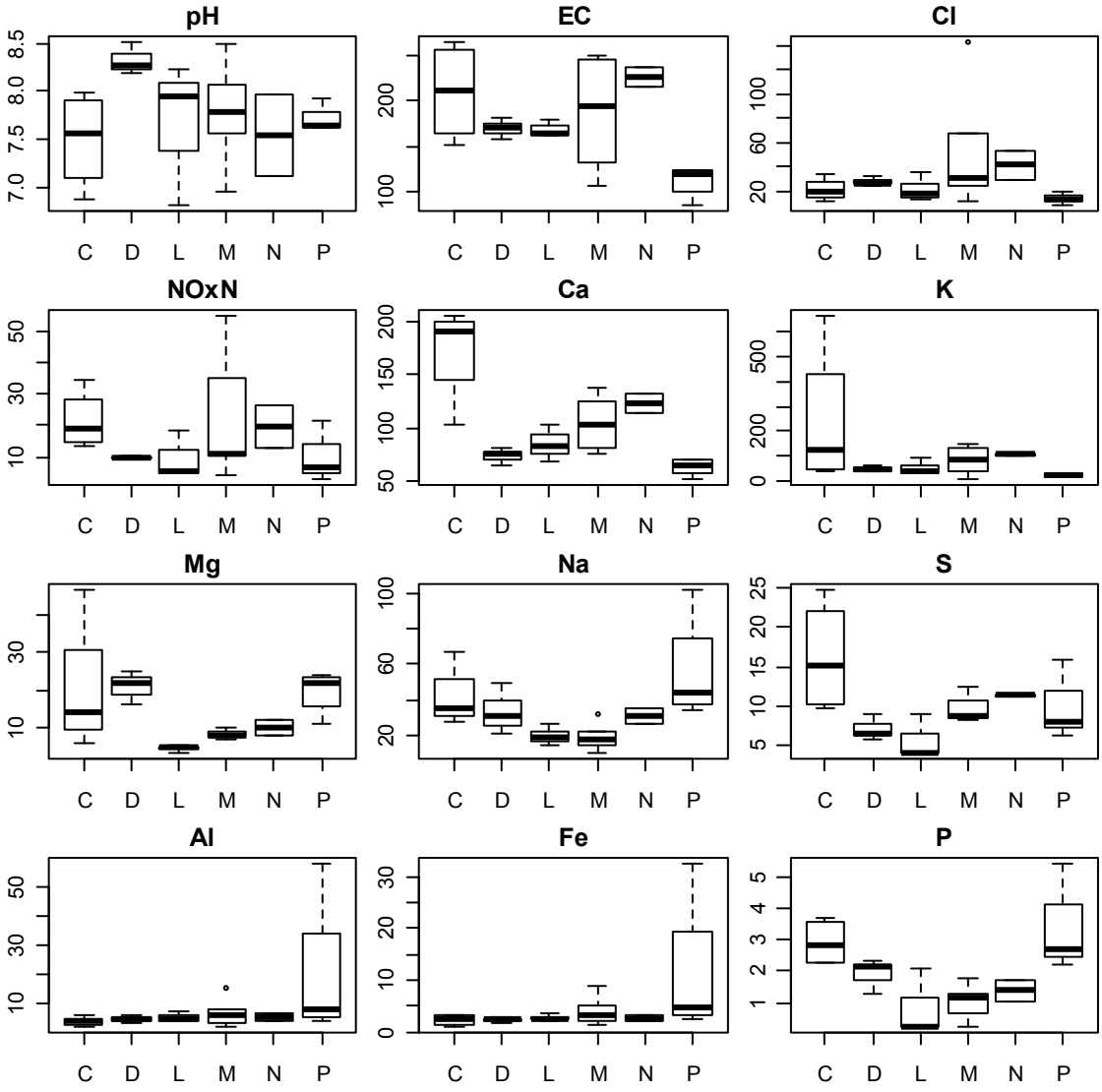


Figure 13.2 Comparison of surface soil (0 – 10 cm) concentrations for different locations near lysimeters. Units are mg/kg except for pH (pH units) and EC (µS/cm). C =controls, D = drip line next to lysimeter, L is adjacent to lysimeter, M and N =e inter row samples on either side of the lysimeter row, P =pseudo-lysimeter.

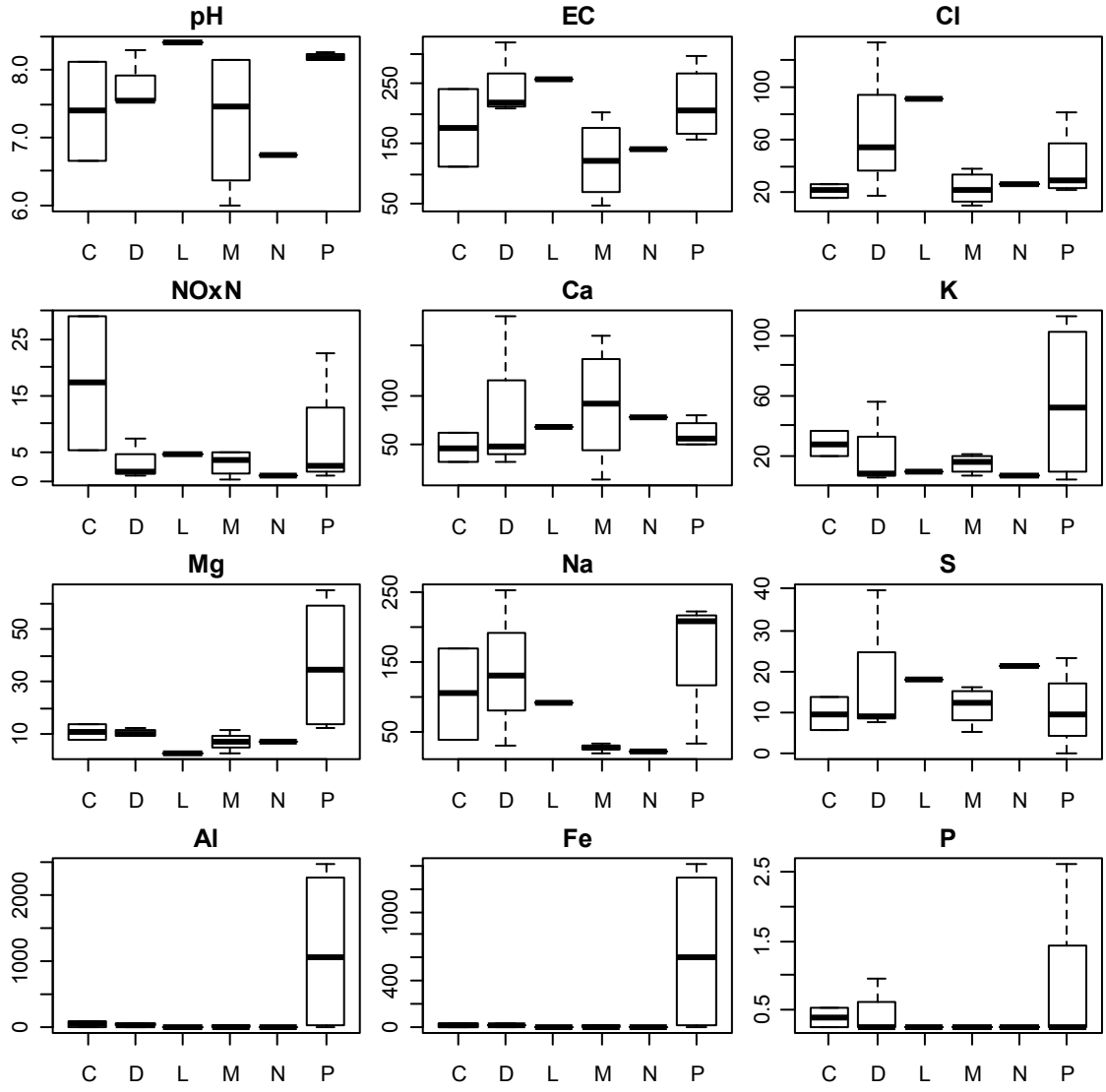


Figure 13.3 Comparison of surface subsoil (70 cm) concentrations for different locations near lysimeters. Units are mg/kg except for pH (pH units) and EC (µS/cm). C =controls, D = drip line next to lysimeter, L is adjacent to lysimeter, M and N =e inter row samples on either side of the lysimeter row, P =pseudo-lysimeter.

14.5.2. Sunraysia sites

Background data

Table 13.2 Percentage of TN that has been discharged in the form of nitrate

Year	Robinvale	Nangiloc-Colignan	Red Cliffs	FMIT	Merbein
1998-1999	96%	95%	96%	86%	80%
1999-2000	97%	96%	96%	90%	83%
2000-2001	96%	96%	95%	84%	80%
2001-2002	95%	96%	99%	79%	73%
2002-2003	95%	97%	95%	78%	65%
2003-2004	94%	95%	95%	80%	64%
2004-2005	95%	96%	95%	58%	68%
2005-2006	94%	96%	93%	83%	74%

14.5.3. MIA Sites

Additional MIA background information

Table 13.3 Pesticides tested in Natural Heritage study (MacAffery 1999).

Test Code	Inclusions	Detection Limit (µg/l)
EN3WGC **Endosulfan Pesticides**	Alpha-Endosulfan Beta-Endosulfan Endosulfan Sulfate	<0.010
PN1WGC **Organophos/Nit Pesticides**	Atrazine Prometryn Trifluralin Pendimethalin Profenofos Chlorpyrifos Molinate Malathion Diazinon Disulfoton Parathion-ethyl Parathion-methyl Sulprofos Thiometon Phorate Dimethoate DemetonSmethyl Metolachlor Alpha-Cypermethrin Cypermethrin Deltamethrin Lambdacyhalothrin Alphamethrin	<0.10 <1.0
MMSWGC **Murrumbidgee misc. pests**	Thiobencarb Bromacil Simazine trichlorfon	<0.1
PX1WGC **Phenoxy Acid Herbicides**	Dicamba MCPA 24D 24DB 245T	<0.50
UR6WLC **Phenyl Urea Herbicides**	Thidiazuron Fluometuron Diuron Metsulfuron-methyl Bensulfuron-methyl Linuron	<0.50

Table 13.4 Data from spatial survey in MIA. EC80/81 and EC91/92 are from McCaffery (1999).

NOx-N	Cl	Na	Ca	Mg	K	S	B	P	Al	Fe	Mn	Zn	Area	EC80/81	EC91/92
10	80	307	27.2	42.5	14.8	75.9	2	0.83	0.07	0.06	0.015	0.019	9.7	2.7	2054
10	130	526	16.8	39.2	18.3	119	3.03	0.53	0.04	0.03	0.02	0.012	15.7	2.92	1756
9	810	1120	70.7	122	30.4	314	3.51	2.29	0.23	0.19	< 0.06	0.14	8.1	3.15	2457
9.8	154	248	19.8	45.4	19.2	36.4	1.85	0.21	0.02	0.02	< 0.006	0.0048			
18	962	1020	92.3	137	17.3	308	3.28	1.16	0.1	0.11	< 0.06	< 0.03	15	6.47	3146
5.1	230	364	24.7	46	17.4	63.8	1.79	0.34	0.04	0.07	< 0.03	< 0.02	19.8	2.7	1775
1.2	152	124	26.6	17.1	15	10.5	0.23	0.42	0.02	0.04	0.048	0.0073	19.8	3.7	1638
16	293	582	20.2	35.8	18.5	94.4	2.35	0.16	0.02	0.03	< 0.03	< 0.02	11.3	2.15	2205
25	77	187	29.8	35.1	10.7	37.1	1.16	0.09	0.01	0	< 0.006	< 0.003	10.5	1.67	1435
1	40	63.1	22.8	15.2	4.77	9.33	0.27	0.09	0.02	0.01	< 0.006	< 0.003	13	2.59	2235
3.1	201	397	36	45.2	13.9	79.3	1.84	0.05	< 0.01	0.02	< 0.03	< 0.02	17	3.27	3402
4	130	262	27.5	37.8	15.4	47.3	1.8	0.08	0.01	0.02	< 0.006	0.0096	6.5	3.39	2926
2.2	437	403	74.1	61.5	12.2	113	0.93	1.4	0.29	0.14	0.039	0.056	9.7	5.79	5403
9.4	157	246	31.5	30.6	8.27	52.7	1.03	0.19	0.02	0.02	< 0.006	0.0045	20.2	6.21	4539
0.2	25	65	13.6	9.52	5.56	4.5	0.3	0.18	0.04	0.03	< 0.006	0.024	18.8	4.49	3315
0.6	474	483	93.5	63.1	13.6	119	1	0.85	0.03	0.04	0.443	< 0.02	32.4	8.83	4630
8.5	325	409	80.3	107	22.3	185	1.61	0.87	0.02	0.04	< 0.03	< 0.02	23.8	4.87	5163
2.2	50	68.7	17.2	10.1	3.76	14.2	0.32	0.06	0.02	0.01	< 0.006	0.034	11.3	2.02	1662
1	9	10.5	32.5	8.86	4.75	5.34	0.04	0.08	0	< 0.004	< 0.006	< 0.003	25.9	1.83	1902
2.5	42	91.5	19.8	23.8	9.71	9.04	0.42	0.03	0	< 0.004	< 0.006	0.0056	13.4	4.99	3435
7.2	672	633	119	94.5	14.8	157	1.39	0.15	< 0.02	< 0.04	< 0.06	< 0.03	9.7		3706
30	275	372	116	84.4	13.4	166	2	0.05	< 0.01	< 0.02	< 0.03	< 0.02	14.6		3937
2.5	61	155	16.1	15.8	9.01	18.8	0.8	0.22	0.02	0.02	< 0.006	0.093	12.5	4.2	3703
18	60	272	10.1	26	9.77	45.5	2.12	0.02	< 0.002	< 0.004	< 0.006	< 0.003	4	1.36	1560
1.6	915	1070	83.2	144	18.7	344	3.49	0.15	< 0.02	< 0.04	< 0.06	< 0.03	16.2		3011
1.5	20	43.3	21.8	9.66	5.07	5.38	0.27	0.07	0.01	< 0.004	< 0.006	0.044	11.3	2.92	2053
5.2	166	302	23.6	42	11.6	56.1	1.61	0.05	< 0.01	< 0.02	< 0.03	< 0.02	9.3	6.51	4575
6.7	52	172	21.9	30.4	17.7	29.1	1.17	0.02	< 0.002	< 0.004	< 0.006	0.0044	10.9	3.07	1945

Units in mg/L

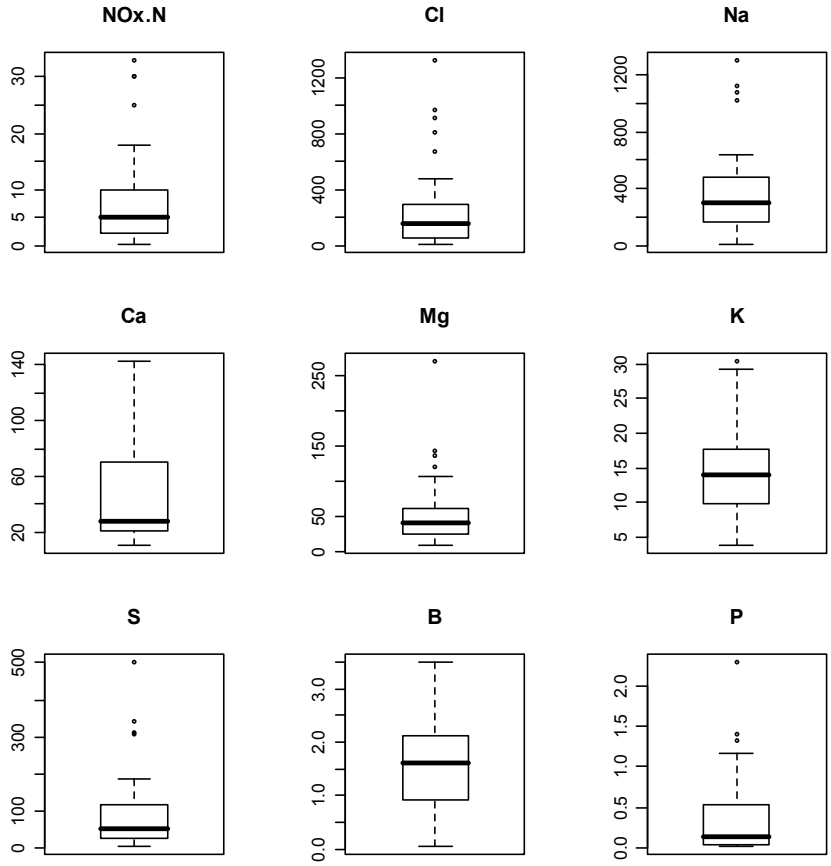


Figure 13.4 Box plots of 9 analytes from tile drain samples collected in the Griffith area.

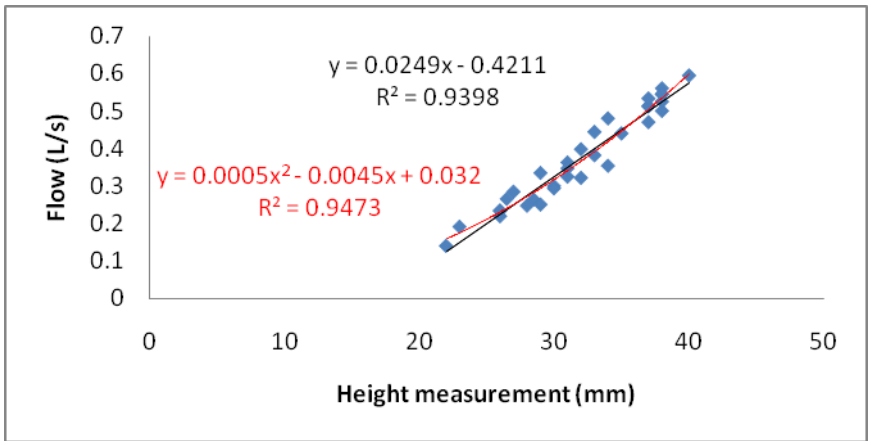


Figure 13.5 Calibration of flume monitoring data.

14.6. Appendix 6: Budget reconciliation

Please use End of Project Financial Statement, downloadable from the GWRDC website at www.gwrdc.com.au.

The financial statement is being submitted separately.