Know-how for Horticulture™

Sustainable use of recycled water for horticultural irrigation on the Northern Adelaide Plains

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The University of Adelaide

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VG97081

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HAL Project - VG 97081

Sustainable use of reclaimed water for Horticultural Irrigation on the Northern Adelaide Plains

FINAL REPORT

March 2004

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The purpose of this report is to communicate the final outcomes and impacts to the Horticulture and reclaimed water industry of the HAL project VG 97081 including research, communication resources and publications. We wish to acknowledge and thank our primary funding source, Horticulture Australia Limited, and our additional funding sources - Northern Adelaide and Barossa Catchment Water Management Board and Water Reticulation Services Virginia Adelaide and Barossa Catchment Water Management Board which supported add-on projects

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CONTENTS

1 Abbreviations

NAP – Northern Adelaide Plains
RCW – reclaimed water
CARW – Class A Reclaimed Water
EC – Electrical Conductivity
SAR – Sodium Adsorption Ratio
NABCWMB – Northern Adelaide Plains and Barossa Catchment Water Management Board

2 Media Summary

Project VG79081: Sustainable use of reclaimed water for Horticultural Irrigation on the Northern Adelaide Plains

This Horticultural Australia Limited project has played a pivotal role in helping the ground-breaking development of a sustainable reclaimed water scheme in the Virginia Triangle, South Australia (One of the largest Class A reclamation and reuse schemes in the world). It has secured a safe, environmentally friendly, and guaranteed water source for a diverse range of horticulture in SA. Australia now has some of the world leaders in water reclamation and reuse industry. Recently the knowledge acquired during this project has been captured in a new project funded by Horticultural Australia Limited, that will help coordinate reclaimed water development in horticulture across Australia; maximising the potential benefits to Australian horticulture.

3 Technical summary

In 1998, for the first time in Australia, water reclaimed from sewage wastewater treatment plants was going to be used for the production of vegetables and a range of other horticultural products (eg. almonds, grapevines). The SA Department of Human Services completed extensive research and verification programs to ensure the treatment process was capable of guaranteeing a supply of Class A water to the Northern Adelaide Plain horticultural precinct. They set standards for this Class A water would ensure any health risks were extremely low (eg. effectively zero). However, growers were still concerned about the sustainability of irrigation with reclaimed water from an agronomic and environmental aspect. This project aimed to ensure the practice would be sustainable and, if not, assess if management techniques could be adopted to cope with the different water sources. The broad objectives of this research project were to:

- monitor the effects of reclaimed water on soil fertility and degradation of soil physical properties in the NAP;
- determine any short or long-term detrimental/beneficial effects on soil fertility due to the use of reclaimed water; and
- develop and communicate management techniques appropriate for the soils on the NAP to ensure that use of reclaimed water will increase productivity and economic return, while not degrading the environment.

Research activities identified and monitored key indicators for sustainability. This included soil boron concentrations, salinity and sodium adsorption ratios. A range of extension projects culminated in the development of user manual for growers, a text book on reclaimed water use in Australian agriculture, and the maintenance of the quality of produce grown with reclaimed water.

Specific outcomes from the research project have been:

- Awareness that SAR of the irrigation water may need to be decreased and/or appropriate farming methods developed and practised with the use of RCW to protect these soils for future horticultural activities (Stevens et al 2003).

- A low cost soil test, using a simple 1:5 soil:water extract was compared to accepted soil extracts (for assessing detrimental physico-chemical soil changes) and has been proposed as a grower management tool to assist in monitoring the physico-chemical changes (boron, salinity and sodicity) of the NAP soils(see Stevens et al 2003).
- Recommendations to manage the regional water table.
- A grower awareness of problems with algae when using reclaimed water and methods to manage potential issues.
- Confirmation that produce grown with reclaimed water is as safe as any produce grown with any other water source. Improving grower confidence in reclaimed water.
- Production of a grower manual for use of reclaimed water in horticulture on the Northern Adelaide Plains. Identifying soil types, land capabilities and relevant management techniques for growing particular horticultural crops with reclaimed water from the Bolivar Wastewater Treatment Plant.
- Extensive communication to the water industry across Australia regarding the possibilities of developing reclaimed water schemes with a range of horticultural commodities.
- Exposure of the Australian general public, through ABC's Landline program, to positive stories involving horticultural use of reclaimed water in Australia, United States of America and Israel.

Future work suggested includes:

- Hydroponic or soil-less culture production using reclaimed water
- Management of the surface water-table on the Northern Adelaide Plains
- A coordinator of reclaimed water development in Australian Horticulture
- Irrigation development officers for some horticultural areas

Research project which have developed from these recommends are:

- Sustainable Salinity and Water Management on the Northern Adelaide Plains. Stage 1 – Identification of actions to provide a sustainable water balance and prevent salinity damage. Funded (2002) by the National Action Plans for Salinity and the Northern Adelaide and Barossa Catchment Management Board
- Drainage Fluxes to the Water Table beneath Irrigated Crops on the Northern Adelaide Plains: Comparison of Existing and Alternative Irrigation Management Systems. Funded (2003) by the Northern Adelaide Plains and Barossa Catchment Water Management Board (NABCWMB).
- Coordinator Reclaimed Water Development Horticulture. Funded by Horticulture Australia Limited (2003), with a voluntary contribution from the horticultural and water industries, and state government departments.
- Reclaimed water use in Australian Horticulture. Developing an environmental and economically sustainable approach for Australia. Funded by Land and Water Australia (2003).

4 Introduction

While the earth's population grows, there is increasing demand on fresh water supplies, for a variety of needs. Now, and in the future, water resources will need to be better managed. One option available for better management of water is reclamation of sewage effluent (reclaimed water). Already, reclaimed water is often used for irrigating parklands and golf courses, there are also some domestic non-potable reuse applications (Law 1996; Mujeriego et al 1996; Shelef, Azov 1996). Planned water reuse requires adequate treatment to meet the quality requirements of the intended reuse. In the near future, agricultural and urban irrigation will play an important role in water reuse, especially in dry climates (Bouwer 1994).

A good supply of underground water for irrigation has developed the Virginia area of the Northern Adelaide Plains (NAP) into a major producer of horticultural crops in South Australia. However, the long-term supply of this water was threatened. Total pumping volumes from aquifers have been estimated to be much greater than the total recharge (Anon 1995).

Reclaimed water may be a relatively simple solution to water scarcity problems. However, it could have potential adverse long-term effects on sustainable use of agricultural soils and ground water quality. Several recent studies, involving the application of reclaimed water, have shown declines in soil fertility related to degradation of soil structure and increases in salinity and sodicity. Others issues which have been flagged by these studies are: increasing soil boron levels; contamination of ground waters; bacterial and pathogenic contamination of produce; clogging of irrigation equipment and enhanced transport of some pesticides (Wienhold, Trooien 1995; Curtin et al 1995; Myers et al 1995; Armon et al 1994; Muszkat et al 1993; Juanico et al 1995; Graber et al 1995). The majority of these studies have been completed on soils with different hydrological and physico-chemical properties to soils of the NAP and many used for intense horticulture throughout Australia.

From the limited data available, the short and long-term detrimental effects of reclaimed water use in the NAP are unknown. Possible management techniques to overcome potentially detrimental effects must be explored to ensure the short-term gains of a guaranteed water supply are not offset by the deterioration of soil fertility. Changes in irrigation management may also be required to ensure reclaimed water, which has much higher salinity than the aquifer water currently used, is used correctly.

At the beginning of the project there was no such research being conducted on the NAP. With the imminent release of reclaimed water for irrigation purposes, research in this area was vital to ensure best management practices were adopted for the district and to verify that large-scale reclamation schemes were viable for the horticultural industry in Australia. Instigated correctly, reclaimed water used for horticultural purposes on the NAP could set the example for similar horticultural uses across Australia and provide a sustainable, guaranteed, renewable water resource for the horticultural industry, whilst relieving pressures on potable water resources. If successful, such a scheme could also provide the horticultural industry with the confidence to embrace this renewable water resource for the foreseeable future; providing a valuable resource for a range of horticultural enterprises.

The broad objectives of this research project were to:

- monitor the effects of reclaimed water on soil fertility and degradation of soil physical properties in the NAP;
- determine any short or long-term detrimental/beneficial effects on soil fertility due to the use of reclaimed water; and
- develop and communicate management techniques appropriate for the soils on the NAP to ensure that use of reclaimed water will increase productivity and economic return, while not degrading the environment.

The specific objectives were to:

1. Develop and communicate management strategies for reclaimed water use on the NAP, tailored to meet the needs of local growers.
2. Assess the indirect toxic effects of sodium and chloride on plants, decline in soil structure and nutrient availability due to increases in soil salinity and sodicity, leaching of contaminants into ground water, indirect effects of associated anions on uptake of cadmium and heavy metals in food crops, soils and reclaimed water.
3. Produce a Reference Manual for the use of reclaimed water in horticulture on the NAP.
4. Conduct several field days and produce information brochures to enhance adoption by the industry. Publication of a public awareness manual/brochure on the benefit/limitation of irrigating with reclaimed water.
5. Publication of a manual (Growers Manual) to identify soil types, land capabilities and relevant management techniques for growing particular horticultural crops with reclaimed water.
6. Establishment of research and development priorities regarding the management of reclaimed water to ensure productivity and quality of produce.

5 Methods

5.1 Soils Research

5.1.1 Historical comparison – Effect of water type on key soil properties.

5.1.1.1 Site

The NAPs are approximately 30 km north of central Adelaide, South Australia. A diverse range of vegetables (grown in glass or shade houses or broad acre), pastures, fruits and ornamental crops are grown and there are 5 major soils types used for growing these crops (Table 1).

Table 1. Description of soils on the Northern Adelaide Plains used in this study and the irrigation history of selected sites.

Soil type[A]	Characteristics[A]	Soil classification[B]	Texture[C] 0-15 cm	Irrigation history
1	More than 35cm sandy topsoil over permeable clay or clay loam	Lithocalcic, Mesonatric, Red Sodosol	Loamy sand	25 years RCW[D], some bore water for last 3 years.
2	Between 25 and 35cm sandy topsoil over permeable clay or clay loam	Sodic, Eutrophic, Red Kandosol	Loamy sand	18 years RCW/bore
2	As above	Mesonatric, Hypercalcic, Red Sodosol	Loamy sand	≥12 years RCW/bore
3	Between 15 and 25cm sandy topsoil over permeable clay or clay loam	Calcic, Subnatric, Red Sodosol	Sandy loam	25 years RCW, some bore water for the last 3 years.
4	Between 10 and 15cm sandy topsoil over impermeable clay or dense nodular calcrete	Sodic, Calcic, Red Dermosol	Sandy clay loam	≥14 years RCW only
5	About 50cm friable clay loam over permeable clay and clay loam	Episodic, Epipedal, Black Vertosol.	Medium clay	≥15 years RCW/bore

[A] Matheson (1975)
[B] described by McDonald (1990) and classified according Isbell(1996).
[C] hand textural analysis
[D] RCW = reclaimed water

5.1.1.2 Selection of soil sampling locations

Soil sampling locations were determined using three criteria:

1. Historically, soils were either: virgin (not used agriculturally for at least the last 20 years); bore-irrigated (i.e. irrigated with bore water for agricultural purposes for at least 10 years); or RCW-irrigated (i.e. irrigated with reclaimed water (RCW) for agricultural purposes for between 10-28 years).
2. Sampling sites should provide a cross-section of the 5 main soil types of the NAP (Table 1) and within each soil type contain soils that meet criteria 1.
3. Within each soil type (Criteria 2) and irrigation history (Criteria 1) agricultural practices were similar.

Not all criteria could always be met due to the large number of possible criteria combinations and the diverse range of horticultural crops and practices on the NAP. In total, soil cores were taken from 46 sites from across the NAP.

5.1.1.3 Soil coring

All soil cores were taken using 50 mm diameter steel push tube to 1.0 m deep. In some cases rocks or dense dry clay was encountered preventing sampling to 1.0 m. To assess seasonal variation in soil, chemical properties samples were cored after winter and after summer. For the first sampling (after summer, 1998), paired soil cores were taken 1 m apart at 10 cm depth intervals and bulked for analysis (n = 11 for bore, 19 for RCW and 16 for virgin). Occasionally, duplicate paired cores were taken 15 m from the first pair, to assess site variability. To reduce sampling and analysis costs and allow some assessment of site variability, for the second sampling (after winter, 1999), two soil cores were taken 5 m apart, and sections of 3 soil horizons sampled (A, B and C), at each location (n = 11 for bore, 14 for RCW, and 2 for virgin). Depth of the A, B and C horizons varied with respect to soil type and in some soils the true C horizon was not attained, but the 90-100 cm depth sampled. Cores at each location were not bulked, but analysed separately.

5.1.1.4 Chemical analysis, characterisation and classification of soil types

Matheson developed an intensive ‘agricultural-use’ soil map of the area in 1975. To relate soil classification to the agricultural-use definitions of Matheson (1975; Table 1), seven soil pits were dug, where core sampling indicated soils typical to those described by Matheson 1975). Soil profiles within each soil type were described according to the Australian Soil and Land Survey Handbook (McDonald et al 1990) and classified according to the Australian Soil Classification (Isbell 1996).
The major soil horizons were sampled and chemically analysed for pH and electrical conductivity (EC) (1:5 soil:water; Rayment and Higginson 1992), exchangeable cations by leaching with 1M NH4Cl (Rayment and Higginson 1992), and particle-size distribution (percent by weight of sand, silt, clay; Allen 1981).

5.1.1.5 Measurement of soil core chemical properties

Soil core sections were dried at 40°C and ground to pass through a 2 mm sieve. Soil extracts were analysed for pH and EC in a 1:5 soil:water extract ($EC_{1:5}$; Rayment, Higginson 1992). A subsample, diluted with $Ba(NO_3)_2$ to a final concentration of 0.01M was used for Cl analysis (automated ferricyanide method; Rayment, Higginson 1992). A 15 mL subsample of the 1:5 soil:water extract was then centrifuged (10,000 rpm for 10 min), passed through a 0.45 µm cellulose nitrate filter, acidified with one drop of 10 M HCl, and stored at 4°C prior to analysis by inductively coupled plasma atomic emission spectrophotometry (ICP-AES) for Ca, Mg, Na and B. Concentrations of Ca, Mg and Na in the 1:5 soil:water extracts determined by ICP-AES were used to calculate the SAR ($SAR_{1:5}$; Rengasamy et al 1984).

5.1.1.6 Comparison of methods for soil chemical and physical analyses

Due to the large number of analyses required, it was impractical to complete commonly used chemical analysis (e.g. saturation extracts) on all samples to allow comparison with literature values. However, the more commonly used soil chemical analytical procedures were completed on several cores (> 10, depending on analysis) selected to represent all soil types and soil horizons of the NAP. This allowed correlation of data to literature values. The more commonly used methods which were correlated with our 1:5 soil:water method on selected soil cores were:

1. The original $SAR_{1:5}$ method of Rengasamy et al 1984) using atomic adsorption spectrophotometry (AAS). We used a universal flaming solution (UFS; derived from Varian 1989) to suppress elemental ionisation during the

determination of Ca, Mg and Na, although Rengasamy *et al.* (1984) did not record if they used UFS. $SAR_{1:5}$ values determined by AAS were compared to those determined by ICP. This comparison was made as the higher ionisation temperatures of the ICP compared to AAS could potentially measure some colloidal (< 0.45 µm) cations (Spiers *et al*. 1983). All $SAR_{1:5}$ values quoted in this paper were determined using ICP unless stated otherwise.

2. Hot-water soluble extractable B (B_{hws}; Cartwright et al 1983) was compared to room temperature 1:5 soil:water B ($B_{1:5}$), and saturation paste extract B (B_{se}; Rayment, Higginson 1992).
3. Soil exchangeable sodium percentage (ESP; Rayment, Higginson 1992) was compared to $SAR_{1:5}$.
4. Saturation paste electrical conductivity ($EC_{se;}$ Rayment, Higginson 1992) was compared to $EC_{1:5}$.
5. Soil sodicity rankings were determined, using a simple field test sodicity meter (Rengasamy, Bourne 1998). These rankings (non sodic, sodic and highly sodic) were then related to $EC_{1:5}$ and $SAR_{1:5}$.

5.1.1.7 Determination of water chemistry

To compare water quality parameters for reclaimed and bore water used at sites where soil cores were taken, water chemical data were sourced from several publications and databases (Table 2), as well as analysis of current site irrigation water quality (APHA 1998).

5.1.1.8 Statistical analysis

Genstat (Anon 1998) was used for regression analysis. Because of the unbalanced nature of core sampling, Residual Maximum Likelihood (Anon 1998) methods were used for estimation of variance components when comparing results for soil history, type and depth. The analyses were performed using REML in Genstat, where the cores were considered random and the depths and irrigation types were considered as fixed. The inclusion of the random core term ensured that the testing of the main effects of the irrigation water was against an appropriate error. The normality assumption was investigated using residual plots.

5.1.2 Glasshouse study – Effect of irrigation water and practice on cadmium uptake by lettuce.

As highlighted in Milestone Report 2, variability in previous management of potential paired sites (matched soils, one irrigated with bore water, one irrigated with reclaimed water) hindered the development of this experimental approach. With 11 sites irrigated for >10 years with reclaimed water (some for 24 years), we hoped to match farming practices (crop, fertiliser rates, soil additives, irrigation method) and soil type with one grower using reclaimed water and another using bore water.

However, most of the farms which used reclaimed water for >10 years were located near the Sewage Treatment Plant's ocean out-fall channel, from where the reclaimed water is pumped to keep pumping and capital costs to a minimum. As a result, these farms were therefore on the poorer quality soils, typical to the western side of the NAP.

Table 2. Chemical properties of irrigation water used historically.

Property	units	mean	Median	range	sd
Bore water					
TDS	mg/L	844[A]	820[A]	570-1127[A]	187[A]
EC	dS/m	1.59[B]	1.55[B]	1.13-2.06[B]	0.31[B]
SAR	$(mmol_c/L)^{0.5}$	6.13[B]	5.85[B]	5.02-7.93[B]	1.09[B]
pH		7.73[C]	7.70[C]	7.60-8.10[C]	0.11[C]
Reclaimed water					
TDS[E]	mg/L	1446	-	1195-1814	-
EC[D]	dS/m	2.6	-	2.1-3.1	-
EC[F]	dS/m	2.4	-	1.8-3.1	-
SAR[E]	$(mmol_c/L)^{0.5}$	11.3	-	8.0-12.2	-
pH[E]		8.0	-	6.8-9.3	-

[A] Historical data (1978-97) from Primary Industries and Resources South Australia, Groundwater Section (n=7).
[B] Calculated from [A] using data from Stevens et al 2000a).
[C] From Stevens et al 2000a).
[D] Calculated from [E] using data from Anon 1995).
[E] Historical data (1967-70) from Matheson, Lobban 1974).
[F] Historical data (1967-95) from Anon 1996b).
- Insufficient data provided to determine median and standard deviations from the mean.

These factors made pairing of sites for field experiments and glasshouse cores impractical. However, as field soil-coring studies progressed, we gradually began to understand the changes in physicochemical properties of the soil due to irrigation with reclaimed water, and the influences of farm management. These changes were also complicated by a large number of variables (e.g. soil type, irrigation method, fertiliser management, soil additive management, crop type and tillage method), which contributed to changes in soil physicochemical properties.

Due to the difficulties in matching soils for the intact-core study, (outlined above) we replaced the intact-core study with re-packed pot experiments, using similar soil types with different management practices. Because of the intensive cultivation practices used in vegetable growing, large packed pots represent conditions similar to those in the field.

A glasshouse pot experiment was completed using three of the soils identified in the preliminary soil corings. The pot experiment was designed to investigate the effect of irrigation rates, irrigation water type (bore water, RCW) and soil type (long-term RCW-irrigated soil, long-term bore-irrigated soil and virgin soil) on lettuce growth and Cd uptake. Lettuce was selected for this experiment for two reasons:

1) A recent survey, conducted by CSIRO for PIRSA, found 4 samples exceeding the maximum permitted concentrations (MPC) of cadmium on a fresh weight basis (Zarcinas et al 1997),

2) It is one of the most susceptible crops to pathogenic contamination as there is no kill step from farm to plate and could therefore be valuable for future experimentation.

Single plants of lettuce (Lactuca sativa cv. Iceberg) were grown for 112 days in pots containing 12 kg of soil in a glasshouse (temperature range 16 – 26°C). The experiment was arranged in a randomised block design with three soils (one only presented in this paper), two water treatments (recycled water (RW) and bore water (BW)) and three irrigation scheduling treatments. Selected soil and irrigation water properties are listed in Table 3.

Table 3: Initial soil and irrigation water properties

Soil		Irrigation water		
Property	Value	Property	Bore Water	*Reclaimed water*
$pH_{1:5\ water}$	8.5	pH	7.5	*8.1*
$EC^{A}_{1:5\ water}$ (mS cm^{-1})	0.13	EC^{A} (mS cm^{-1})	1.1	*1.8*
Cl (mg kg^{-1})	20	Cl (mg L^{-1})	230	*410*
EDTA-extractable Cd (mg kg^{-1})	0.09	SAR^{B}	3.5	*8.7*
Organic Carbon (%)	0.5			

^{A}Electrical Conductivity; ^{B}Sodium Adsorption Ratio

Irrigation scheduling was defined as: minimal (soil water potential) -0.8 to -0.18 bar; optimal -0.18 to -0.07 bar; and leaching < -0.04 bar with a 20% leaching fraction. When soil water for two or more pots per treatment reached predefined lower potentials, appropriate volumes of water were applied to increase potentials to the upper predefined value for that treatment.

5.1.3 Field experiment – Assessment of soil additives on managing sodicity.

Due to the difficulties in obtaining truly paired sites (i.e. variability in previous soil, water and crop management, and soil type (discussed above)), the paired site approach for field experiments was replaced with four field sites. The sites were chosen on the basis that they represented some of the longest use of reclaimed water on vegetables and included the 4 major soil types used for growing vegetables on the NAP.

The aim of the field experiment was to identify a cost effective soil additive to maintain/improve soil fertility when irrigating with reclaimed water and to identify any changes in soil fertility related to long-term use of recycled water. The experiment was a randomised block design with a control and 5 (Sites 1 and 2) or 7 (Sites 3 and 4) treatment plots replicated 5 times. Treatments included: sewage sludge, water treatment sludge, gypsum, aglime and composted green waste at all sites, and for sites 3 and 4 two extra treatments of flue dust and kiln dust.

5.1.3.1 Sites

Sites were chosen on the basis that they represent some of the longest-term use of reclaimed water and that they included the range of soil types that are currently used for growing vegetable on the NAP (Table 4).

5.1.3.2 Experimental Design and treatments

At each site, the experiment was a completely randomised design with a control and 8 treatment plots replicated 5 times. Each plot was 4 m^2 with a 1 m buffer strip surrounding it. Treatments (soil additives) were applied approximately 1-10 days before sowing and incorporated by a rotary hoe to a depth of 15-20 cm. Treatments included: Sewage sludge; Water treatment sludge; Gypsum; Aglime; Composted green waste; Flue dust; Kiln dust-A; and Kiln dust-B. The primary beneficial components of the additives were either calcium (Ca), organic carbon (OC) or iron. Rates of additive application were determined by four criteria:

1. Annual loadings of impurities in additives (heavy metals) should be kept below the guideline value for each impurity Anon 1997, whilst beneficial component loadings were maintained at similar rates.
2. Total Ca added to the soil should be sufficient to replace 3 year Ca losses through irrigation and counteract the sodic effects of irrigation water.
3. Changes in soil pH should not effect plant growth.
4. Continual annual addition should increase soil organic carbon to 2.0 % over a ten-year period.

Table 4. Field experiment sites

Site Number	Soil type as per [A]	Plant	Soil	Texture 0-15 cm	pH	Water history
1	1	Carrots	Sodic Eutrophic Red Kandosol	Loamy sand	5.9	Reclaimed water 25 years
2	5	Tomato	Episodic, Epipedal, Black Vertosol.	Medium Clay	8.3	Reclaimed water 25 years
3	4	Potato	Sodic, Calcic, Red Dermosol	Sandy clay loam	8.0	≥14 years RCW only
4	2	Potato	Calcic, Subnatric, Red Sodosol	Sandy loam	8.3	25 years RCW, some bore water for the last 3 years.

[A]Matheson (1975)

Only Kiln-dust A, Kiln-dust B, Gypsum and Lime treatments, and the control plots are presented in this report as responses to the organic amendments were not measurable and at the rates required to obtain a measurable affect, their application in a broadacre horticultural sense were not considered to be economical viable. Calcium additives were applied at a calculated rate of 1751 kg Ca/ha. Calculation was based on the analysis supplied by the additive supplier, however, actual rates applied where sightly different due to different moisture contents and more precise analysis completed in our laboratories. Chemical properties of the additives are shown below (Table 5).

Table 5. Chemical properties of Kiln-dusts, Gypsum and Aglime additives.

			Additive			
Property	Analysis	Unit	Kiln-dust A	Kiln-dust B	Gypsum	Aglime
Ca	Extracted	mg/kg	8107	4181	4064	6967
	Total	%	46.2	34.4	18.2	41.2
	Total Quoted[A]	%	26-40	30-50	20.8	34
Na	Extracted	mg/kg	104	1552	447	412
	Total	mg/kg	715	3085	1084	1028
	Total Quoted[A]	mg/kg	<740	<7000	105	<740
Mg	Extracted	mg/kg	0.4	0.3	117.0	1.1
	Total	mg/kg	3434.0	5299.0	2454.7	3801.0
	Total Quoted[A]	mg/kg	2500	6000	.5	5380
pH	1:5 soil:water		13.00	12.70	8.10	12.51
EC		mS/cm	42.2	10.8	2.6	8.5
Arsenic	Total	mg/kg	<10	13.9	<10	<10
	Total Quoted[A]		2-60	80	Na	na
Cadmium	Total	mg/kg	<0.06	5.380	<0.06	<0.06
	Total Quoted[A]		<0.5-2	<5	Na	na
Copper	Total	mg/kg	9.2	9.7	4.0	7.6
	Total Quoted[A]		10-20	10	0.5	na
Lead	Total	mg/kg	<20	52.9	<20	<20
	Total Quoted[A]		10-130	40	Na	na
Zinc	Total	mg/kg	11.9	45.1	24.9	16.7
	Total Quoted[A]		5-15	60	2.4	na

[A]Quoted by suppliers as typical of their quality.
< indicates less than the defined detection limit for that metal
na = not available

Table 6. Loadings of metals applied to soils with additives

		Max[A]	Kiln-dust A		Kiln-dust B		Gypsum		Aglime	
	CCL	Loading	Loading	Soil inc.[B]	Loading	Soil inc.[B]	Loading	Soil inc.[B]	Loading	Soil inc.[B]
Metal	kg/ha	kg/ha/a	kg/ha/a	mg/kg	kg/ha/a	mg/kg	kg/ha/a	mg/kg	kg/ha/a	mg/kg
Ca			2697	887	2008	660	1532	504	2091	687
Na			4.2	1.4	18.0	5.9	9.1	3.0	3.6	1.2
Mg			20.0	6.6	30.9	10.2	20.7	6.8	17.4	5.7
As	20	0.7	0.06	0.02	0.08	0.03	<0.08	0.03	0.05	0.02
Cd	2	0.15	0.00	0.00	0.03	0.01	0.00	0.00	0.00	0.00
Cu	140	12	0.05	0.02	0.06	0.02	0.03	0.01	0.04	0.01
Pb	260	15	0.12	0.04	0.31	0.10	0.17	0.06	0.10	0.03
Hg	2	0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ni	85	3	0.05	0.02	0.05	0.02	0.07	0.02	0.04	0.01
Zn	300	30	0.07	0.02	0.26	0.09	0.21	0.07	0.08	0.03
Additive applied			5836.8		5836.8		8418.5		5075.5	

[A]Maximum permitted annual loading (Anon 1997)
[B]Soil inc. = calculated soil increase in metal assuming a soil bulk density of 1500 kg/m^3 and an incorporation depth of 0.20 m.
CCL = Cumulative Contaminant Loading limit. The maximum contaminant loading from irrigation water in soil before site specific risk assessment is recommended if irrigation and contaminant addition is continued ANZECC, ARMCANZ 2000.

5.1.3.3 Soils

Soil samples on all plots at both sites were sampled 1 month after application/incorporation of additives and at harvest. Data presented in this report was from soils sampled at harvest. Four cores (50mm diameter) to a depth of 15 cm were taken randomly from within the central 2 m^2 of the plot and combined for each plot. Soil samples were dried at 40°C and ground to pass through a 2mm sieve and stored in sealed plastic container prior to analysis.

Soil chemical analysis of all samples included: pH, electrical conductivity (Rayment, Higginson 1992), extractable chloride and extractable sodium absorption ratio (SAR) using 1:5 soil:water extracts (Rayment, Higginson 1992; Rengasamy et al 1984 and Inductively Couple Plasma Atomic Emission Spectrometry (ICP) analysis of cations; aqua regia soluble (Zarcinas et al 1996) Al, As, B, Ca, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, and Zn; plant available Colwell P and K (Rayment, Higginson 1992). Cadmium in soil digests was determined using Electro-thermal Atomic Adsorption Spectrometry.

5.1.3.4 Plants

Carrots were grown at Site 1, tomatoes at Site 2, and potatoes at Sites 3 and 4. Carrots were grown in soil beds and irrigation was via impact sprinklers. Tomatoes were grown in trellised rows approximately 2 m apart and were drip irrigated under plastic sheets 1 m wide that covered the complete row. Potatoes where grown in single row mounds and irrigated with impact sprinklers. Fertilisation at all sites was as per grower normal practice.

At both sites plants were harvested approximately 5 days prior to growers commencing their first harvest (approximately 3 months from planting). Two 2 metre rows (central to the plot) of plants were removed from each plot and divided into edible portion and vegetative growth. Total fresh weights were recorded and subsamples taken from each plot for analysis. Plant materials were washed (1% Decon detergent, followed by 3 rinses with deionised water), dried (moisture contents determined) and ground to pass through a 1 mm sieve.

Ground plant material was digested with acid (concentrated HNO_3 acid; Zarcinas et al 1987) and digested material analysed for major metals (Al, B, Ca, Cu, Fe, K, Mg, Mn, Na, Ni, P, S and Zn) using ICP. Cadmium (Cd) in plant digests was determined using Graphite Furnace Atomic Adsorption Spectrometry (McLaughlin et al 1997).

5.1.3.5 Statistical analysis

All statistical analysis was completed using Genstat (Anon 1998) unless stated otherwise. Significant differences and least significant differences (LSD) were calculated at $p \leq 0.05$ using analysis of variance (ANOVA). If large residuals identified in the initial ANOVA could be explained they were removed and a second ANOVA determined. Additional spatial analysis was completed at Site 2 where there were obvious differences in one row of the randomised design (Gilmour et al 1997).

5.2 Produce quality

When this proposal was first submitted to HRDC (now Horticulture Australia Limited), SQF2000 was thought to be the preferred quality assurance program. Now there are a range of quality assurance procedures, some driven through national accreditation and others from the purchaser.

Several growers using reclaimed water have met specific quality assurance accreditation for their market. Consequently, we did not develop further the SQF2000 accreditation concept. However, many growers are still reluctant to advertise the fact that they use reclaimed water. The following research on produce quality was undertaken to provide growers, retailers and the public, on ground information as to the quality of produce grown with reclaimed water.

5.2.1 Heavy metals in vegetables on the NAP – a baseline study

On a broad scale, a collaborative approach was taken when monitoring heavy metals in vegetables from the NAP. Primary Industries and Resources South Australia (PIRSA) were running a Pooraka Foodcare Project (PFCP) that focused on pesticide residuals in vegetables. This project was overseen by Dr Chris Etherton and managed by Mr Dennis Heanes. Due to cost restraints, the PFCP had initially decided not to test for heavy metals in vegetables, although they were keen to do so.

We arranged for the remaining unused samples of vegetables from the NAP to be delivered to our laboratories, where we analysed them for Cd (the heavy metal most likely to increase in vegetables due to the use of recycled water) as an indicator of heavy metal contamination. Samples were transported on ice from WA to our laboratories in SA and total fresh weights were recorded, as received, samples dried at 70^{o}C and ground to pass through a 1 mm sieve. Ground plant material was digested with acid (concentrated HNO3 acid; (Zarcinas et al 1987) and digested material analysed for major metals (Al, B, Ca, Cu, Fe, K, Mg, Mn, Na, Ni, P, S and Zn) using ICP. Cadmium (Cd) in plant digests was determined using Graphite Furnace Atomic Adsorption Spectrometry (McLaughlin et al 1997).

Vegetables analysed included: Bean -french, Bean - Broad, Beans - not specified, Beetroot, Broccoli, Cabbage, Capsicum - Green, Capsicum - Red, Carrot, Cauliflower, Celery, Coriander, Cucumber, Lettuce – not specified, Lettuce - Radiccio, Lettuce - Green Oak, Lettuce - Iceberg, Mushroom, Onion, Parsley, Parsnip, Pea, Potato - red, Potato - white, Radish, Snow peas, Spinach, Spring Onion, Swede, Tomato, Turnip and Zucchini (n=90).

Increases above half the Maximum Permitted Concentration (MPC) were brought to the attention of the PFCP and action taken to determine if the changes were due to the implementation of irrigation with reclaimed water, or other factors.

5.2.2 Heavy metals in produce grown in field trials

Field trials were grown as outlined in Section 5.1.3. All field trial additives were applied at Ca (2 ton/ha) and C rates (2.5 ton/ha) while C rates were limited by heavy metal contaminants in some additives (Table 5). Guideline values for annual application of metals to soils were not exceeded (Anon 1996a). All plant samples (potatoes, carrots, tomatoes, brocolli) from the first and second year of field trial harvests were analysed for metals. Samples were prepared and analysed as outline in Section 5.2.1.

5.2.3 *Microbial or algal contamination of vegetables by irrigation with reclaimed water*

Following the summer of 1999-2000, reclaimed water users of the Northern Adelaide Plains (NAP) were questioning the use of Class A Reclaimed Water (CARW) for growing vegetables. There were concerns that excessive algae growth in reclaimed water on-farm storage facilities, or microbial contamination from reclaimed water, could degrade the quality of their produce, leading to consumer and/or wholesaler rejection. Already some growers using reclaimed water did not want to be publicly associated with it because of concerns of possible market place repercussions. This grower perception was still prevalent despite the community, grower and wholesaler (buyer) education undertaken prior to the commissioning of the Virginia Pipeline Scheme (VPS).

Concerns have also been raised regarding toxic blue-green algae blooms (cyanobacteria) in storage facilities and transfer of toxins to vegetables irrigated with this water (Codd et al 1999; Cooper et al 1996). However, research assessing these concerns is limited. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality while discussing the issue conclude, "No trigger values for cyanobacteria in irrigation waters are recommended at this time" (ANZECC, ARMCANZ 2000). Research is required to assess the level of risk associated with toxin transfer to vegetables and associated health effects.

Pathogen contamination of vegetables grown with the high-class reclaimed water (i.e. Class A) is generally not significantly different to vegetables grown on traditional high quality water sources (e.g. surface runoff or groundwater) (Sheikh et al 1999; Asano 1998; Sheikh et al 1990; Smith 1985). However, the ultimate test of a reclamation and reuse scheme is the assessment of the final product.

Previous studies suggest the risk of infection from eating vegetables irrigated with water of containing <1,000 thermotolerant coliforms/100mL is of the order of 1:100,000 to 1:1,000,000 (Shuval et al 1997). The microbiological quality of Class A reclaimed water that is supplied through the VPS is <10 thermotolerant coliforms /100mL (DHS, EPA SA 1999) and so the risk of infection will be much lower. CARW quality is guaranteed to meet standards for unrestricted irrigation method for application (DHS, EPA SA 1999). If the quality of produce grown with CARW meets that of produce grown using other acceptable water sources, users should also be confident in production of highest quality produce.

One of the major concerns with reclaimed water use in the vegetable industry is the pathogenic contamination of produce. The concurrent PIRSA NHT project completed a small-scale test of microbial contamination of produce grown with reclaimed water and found no levels above normal background.

Extra funding was sought to complete a more definitive study on pathogenic contamination of vegetables grown with reclaimed water on the NAP. This funding was necessary due to the high cost of testing for pathogenic contamination and algal related toxins present in vegetables. We obtained collaborative funding for the project (Increasing the acceptance of reclaimed water on the NAP for vegetable production), which is described below, from the Northern Adelaide & Barossa Water Catchment Management Board and Water Reticulation Services Virginia.

The main aims of this research were to determine if:

- Algae found in reclaimed water and bore water on-farm storages were the same species;
- Algae density varied between on-farm storage methods and water sources on the NAP;
- Algae present in water storages on the NAP were toxin producing, and
- Differences in microbial contamination of vegetables grown on the NAP and irrigated with reclaimed or bore water, or purchased from the market place were detectable.

5.2.3.1 Sample sites for algae in on-farm storage

Eight Class A Reclaimed Water (CARW) on-farm water storage facilities and eight groundwater on-farm water storage facilities were randomly selected across the NAP. All sites were sampled twice, once following at least 5 days of moderate temperature (five day average <25^{o}C, 06/11/00) and once following at least 5 days of hot weather (five day average > 35^{o}C, 05/01/01) (Table 15). Water storage conditions were recorded to allow comparison of algae growth with on-farm storage types. When tanks were sampled they were either covered or uncovered. All dams sampled, except for one, were uncovered as there are few dam storages which are covered presently on the NAP.

5.2.3.2 Water analysis for algae in on-farm storage

All water analysis was completed by the Australian Water Quality Centre; Bolivar South Australia, using NATA accredited methodologies. Algae species were identified and quantified (visibly identified by microscopic inspection) and chlorophyll-a and -b in all samples were also determined by spectrophotometric methods, giving an approximation of the total algal abundance or biomass.

5.2.3.3 Sampling for pathogen contamination of vegetables

Sampling conditions were selected to represent the worst-case scenario for pathogen transfer from water to produce. Overhead spray irrigated vegetables were sampled as they have the greatest risk of pathogen contamination and transfer to consumers (i.e. pooling of CARW on harvestable portions (DHS, EPA SA 1999) and because they can be eaten raw without further processing or cooking).

Four vegetable crops commonly grown on the NAP with reclaimed water were sampled from fields irrigated with Class A reclaimed water and the same crops were sampled from fields irrigated with groundwater on the NAP (Table 7). The same crops were also sampled from a retail market place.

Table 7. Sampling protocol for assessing vegetable contamination.

	Crops sampled			
Vegetable source	Leafy		Flower	
Field reclaimed water irrigated	Lettuce	Silverbeet	Broccoli	Cauliflower[A]
Field bore water irrigated	Lettuce	Silverbeet	Broccoli	Cauliflower[A]
Market place	Lettuce	Silverbeet	Broccoli	Cauliflower

[A]Cauliflower were replaced with Broccoli crops where cauliflowers were unavailable at sampling.

Field sampling was undertaken within one week prior to crop harvesting and within 24 hours of the last irrigation. Harvestable portions of crops were sampled in triplicate at 30 m intervals on a linear transect. Sterile plastic gloves and knives were used for sampling. Individual samples were taken early in the morning and immediately sealed in sterile bags and stored at 4^{o} C prior to analysis. At all sites visual assessments were made to ensure that there were no foreign external sources of contamination, other than normal agricultural practice for these crops (e.g. bird soiling or excessive soil contamination).

All plant samples were tested for *E.coli*, Coliforms, thermotolerant Coliforms and *Salmonella*. Coliforms and *E.coli* were used as indicators of faecal contamination and hence the possible presence of enteric pathogens. *Salmonella* was used as an example of an enteric pathogen associated with food borne illness. Bacterial analysis was undertaken using the Most Probable Number (MPN) method of Australian Standard AS1766.2.3-1992 by the Institute of Medical and Veterinary Science, Adelaide, South Australia. Analysis was initiated on the day of sampling.

5.2.3.4 Statistical analysis

Genstat (Anon 1998) was used to analyse data variance. Significant differences were determined at $p \leq 0.05$ unless otherwise stated.

5.3 Water & Nutrient Mass balance

5.3.1 Water quality

Water samples from all field sites and coring sites were taken and analysed for a range of inorganic parameters. This was an ongoing process during the implementation of the use of recycled water as an independent monitoring program and to provide water quality data for field experiments and soil core data. Comparison where also made with analysis supplied from Water Reticulation Services Virginia.

5.3.2 Nutrient balances

A complete (leaf, tuber and fruit) nutrient analysis of field-grown potatoes, onions, carrots and tomatoes was completed for developing nutrient budgets for using recycled water. Tomato, onions, carrots and potatoes were sampled and analysed fortnightly through their growth cycle to determine nutrient budgets for these crops, accumulating site-specific data for the NAP. Analysis began early in 1999.

Nutrient budgets were completed and meteorological data used to assimilate the wettest and driest year and appropriate irrigation regimes (given the reclaimed water salinity) for these years. From these irrigation regimes, the contribution of N, P, K and B from reclaimed water was assessed.

5.4 Groundwater

5.4.1 Groundwater monitoring

With the introduction of reclaimed water use on the NAP, not only will the quality of water used for irrigation change, but also the quantity of water applied in the NAP area could approximately double. Such an increased hydraulic loading and a change in water management to cope with different water qualities could lead to increases in N, P and salts leaching through soils and into the upper quaternary aquifer underlying the NAP horticultural areas. Changes in soil chemistry may also increase movement of inorganic and organic pollutants. Decreases in aquifer water demand may also lead to changes in aquifer water levels and pressures.

As part of the Virginia Pipeline Scheme Irrigation Management Plan (IMP) it is proposed that several observation bores be dug to the Q1 quaternary aquifer (upper most aquifer) in an area predicted to receive a high hydraulic loading of reclaimed water. Such a scheme would act as an early warning system to potential problems with movement of contaminants through the soil into the groundwater of the NAP.

However, there still remains insufficient baseline data on the water quality in the quaternary and Tertiary aquifers of the NAP against which changes in quality can be benchmarked. At present, only one water parameter (electrical conductivity (EC)) is being monitored on a scale representative of the NAP. There are little data that can provide a representative baseline for the water quality of the NAP aquifers with respect to nutrients, heavy metals, and selected pesticides.

Using data from EPA-SA and the Groundwater Program of PIRSA we identified 71 bores that have reasonable historic EC data, suggesting bore lining is reasonable quality and there is little leakage from nearby abandoned bores. These bores will also provide a good representative sampling from the four main aquifers of the NAP and the area used for horticulture on the NAP. Before sampling begins, these bores will be cross-checked with a report from the Groundwater Program of PIRSA identifying leaky or contaminated bores. Correct bore water height measurement, sampling and analysis of the bores before and after the irrigation season will provide an extensive baseline data set of aquifer water quality prior to the widespread use of reclaimed water on the NAP.

The aim of this research was to ensure that a comprehensive baseline for water quality of the six major aquifers under the Northern Adelaide Plains was determined before extensive reclaimed water use began in the district.

5.4.1.1 Bore selection criteria

The main aquifers underlying the NAP and used for irrigation are derived from Quaternary and Tertiary deposits. In the Quaternary series there are four aquifers (Q1-Q4) with Q1 being the uppermost aquifer. In the Tertiary series there are two main aquifers used (T1, T2) (Table 1).

Table 8. Aquifer depths on the North Adelaide Plain

Aquifer	Approximate Depth[A] (m)
Q1	3-10
Q2	10-20
Q3	20-35
Q4	30-70
T1	50-80
T2	40-190

[A]Pers. comm. Nabil Gerges, PIRSA.

Using data from EPA-SA and the Groundwater Program of PIRSA, 71 bores were identified that had reasonable historical EC data (suggesting bore lining was of a reasonable quality and there was little leakage from nearby abandoned bores) and/or good bore casing data. These bores were also selected to provide a good representative sampling from the six main aquifers of the NAP and the area used for horticulture on the NAP. Bores were cross-checked with a report from the Groundwater Program of PIRSA which identified leaky or contaminated bores, and any leaky or contaminated bores avoided. In an attempt to ensure samples were taken from areas where there may be the large increases in the hydraulic loading due to reclaimed water use, the sampling strategy was weighted to areas where irrigation with reclaimed water is likely to be greatest (Figure 1).

5.4.1.2 Sampling and sample preparation

Four subsamples were taken from each bore. Two subsamples were filtered using standard methods (Method 3030 B[1]; Anon, 1992). Of the two filtered subsamples and the two unfiltered subsamples, one of each was acidified with 1ml concentrated, high purity, nitric acid (HNO_3) per 500ml of sample to pH <2 immediately after sampling and stored at 4^oC (Method 3010 B[1],).

Heights of water in bores were not measured, as PIRSA (Nabil Gerges) indicated they already have a good on going monitoring program on the NAP for this parameter.

5.4.1.3 Inorganics analysis

pH, EC and carbonate/bicarbonate were determined at 25^oC on the unfiltered and unacidified subsample within 24 hours of sampling using methods 4500-H^+ B, 2510 B and 2320 B titration, respectively (Anon 1992).

Dissolved metals were determined by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP AES), method 3120 B (Anon 1992) on the filtered acidified subsample. For the first sampling period only, total metals were determined by ICP following high purity nitric acid digestion as per method 3030 E (Anon 1992). These extra analyses were completed to determine what proportion of the metals present in the sample existed in solution and in colloidal form. A laboratory performance check, ICP multi-element standard from EM Science, Item No. ICPM0143-1, was included in each batch in triplicate. As in all methods used, sample duplicates and reagent blanks were included every 10 samples.

Concentrations of Cd were too low to be determined by the above method. Hence, Cd concentrations in unfiltered/acidified samples were determined using Graphite Furnace Atomic Absorption Spectrometry (GF-AAS) as per method 3113 (Anon 1992).

Similarly, low concentrations of soluble PO_4 in filtered/unacidified subsamples were determined using a colorimetric procedure (molybdate reactive P) , 4500-P F (Anon 1992). A laboratory performance check, multi-component anion standard from EM Science, Item No. ICAM014-1, was included in each batch in triplicate.

Total N (Persulfate method) was determined colorimetrically on filtered/unacidified subsamples using method 4500-N C (APHA 1998). This method was modified by digesting the samples in a dry oven at 105^oC for two hours. Recovery of nitrogen was checked using glutamic and nicotinic acid standards in triplicate as per 4500-N C (APHA 1998) and (Adrian Beech, pers. com.) respectively.

Concentrations of NO_3-N, SO_4, Cl, F were determined using Ion Chromatography (IC) on filtered/unacidified subsamples as per method 4110B (Anon 1992) (Modifications: AS9 HC column was used, eluent 9 mmol $NaCO_3$). A laboratory performance check, multi-component anion standard from EM Science, Item No. ICAM014-1, was included in each batch in triplicate

Soluble reactive silica was determined colorimetrically on filtered/unacidified samples as per method 4500-Si F (Anon 1992).

5.4.1.4 Pesticides analysis

Pesticides tested for were determined from those known to be used extensively on the NAP (Table 9) and/or those considered to be relatively mobile. The mobility of the pesticides was assessed using Pesticide Impact Ranking Index (PIRI; Kookana et al. 1998) on the basis of sorption and persistence parameters. Eight pesticides were analysed for in water samples (Table 10).

Water samples were analysed using on-line trace enrichment High Performance Liquid Chromotography (HPLC) and Diode Array Detector (DAD). The procedures are described below.

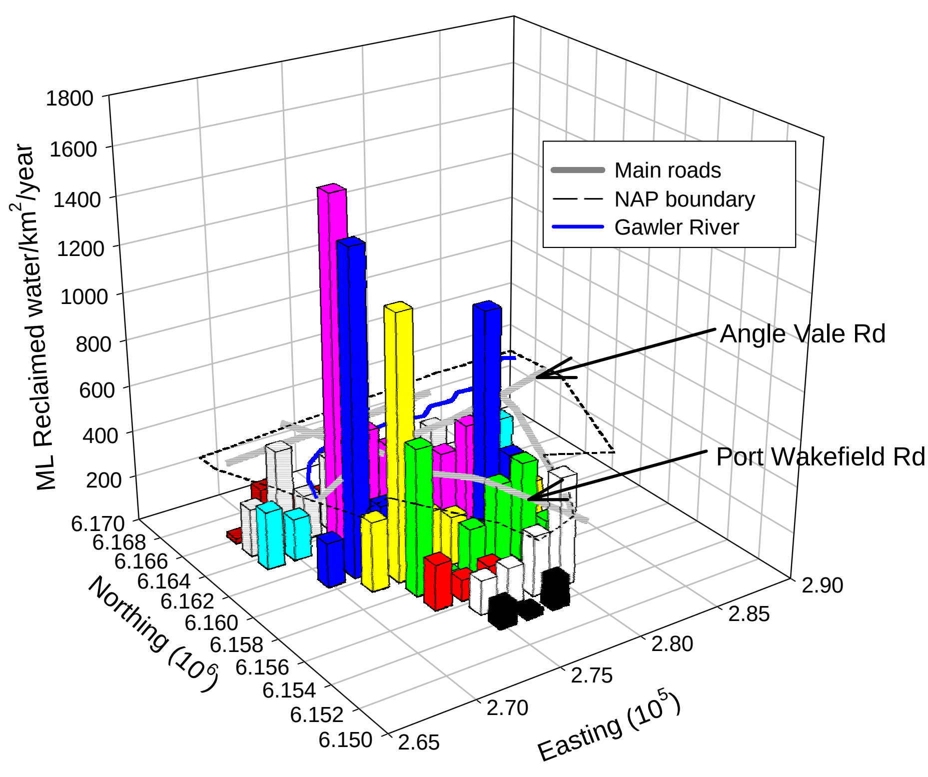

Figure 1. Licensed annual hydraulic loadings of reclaimed water on the Northern Adelaide Plains (1999).

On-line enrichment of pesticide residues in water sample was performed on a Varian 9200 Prospekt automated solid phase extraction system. Bondesil C_{18} cartridges (10mm x ID 8mm) were used for the preconcentration of pesticide residues. The conditioning of C_{18} cartridges was performed sequentially with 10 ml of methanol (5 ml/min) and 10 ml of Mili-Q water (5 ml/min). 250 ml of water sample was percolated through C_{18} cartridge at 5 ml/min. Finally, the retained pesticides were directly eluted using an acetonitrile-water mobile phase to the HPLC system for the separation and DAD detection.

The operating conditions were: Injection volume - 50 µl; Mobile phase - A:Water, B: Acetonitrile; 80% A for 15 min; 70% A for 20 min; 50% A for 30 min; 35% A for 40 min; Column: C18 (Waters, 5NVC C18-4um); UV - 220 nm for test pesticides (Scanning from 200-280nm); and Calibration: 5, 12.5, 25, 50 (ng).

Table 9. Pesticides used on the Northern Adelaide Plains (Dillard, *et al*. 1994; Stephen West, PIRSA, pers. com.).

Active Ingredients	Trade Name
Chlorothalonil	Bravo
Copper products	
Mancozeb	Dithane M45 Mancozol
Metalaxyl	Ridomil, Ridomil plus
Azinphos methyl	Gusathion
Diazinon	Diazinon, Gesapon 800
Dimethoate	Rogor, Dimethoate, Perfekthion, Roxion
Endosulfan	Thiodan, Endosan, Cucumber dust
Methamidophos*	Nitofol, Monitor
Monocrotophos*	Azodrin 400, Cronofos, Nuvacron
Omethaote	Folimat
Parathion	Parathion, Folidol, Methyl Parathion
Permethrin	Ambush, Pounce
Primicarb	Pirimor
DCPA	
Diquat	Reglone, Spray seed, Tryquat
Paraquat	Gramoxone, Nuquat, Spray seed, Tryquat
Fluazifop butyl	Fusilade
Glyphosate	Roundup, Glyphos, Glyphosphate
Metribuzin	Lexone DF, Sencor 480

* most commonly used

Table 10. Pesticides analysed, retention time and detection limits

Pesticide	Retention (min)	Detection limit[A] (ng)
simazine	18.1	2.0
atrazine	25.7	2.0
carbaryl	26.7	3.0
diuron	28.3	4.0
propazine	30.8	4.0
prometryn	33.6	2.0
mathalion	34.1	4.0
chlopyrifos	37.7	8.0

[A]Detection limits were estimated by signal/noise=3

Pesticides were identified by spiking water sample 10986 with the tested pesticides (pesticide selected from Table 9) at 10 ppb level, the spiked water sample was analysed based on the conditions as described above. The retention time and peak area obtained from the spiked sample was used for the identification of the pesticides in other water samples.

5.4.1.5 Statistical analysis

Regression analysis were performed using Genstat 5.0 release 4.1 (Anon 1998).

5.4.2 District water balances

High water tables on the Northern Adelaide Plains have lead to major concerns of horticulture in the area being sustainable in the long-term. This research was funded by the NABCWMB, but has been included in this report as much of the data generated from the HAL VG97081 project contributed to the water balance study, and it provides an example of the benefit obtained from data produced in HAL projects and the skills developed in, and for, the industry.

The scope of the research was to identify the major inflow and outflow component of the water table, or shallow aquifer, on the Northern Adelaide Plains. Once identified, the volumes of these components where then calculated, using the best data available. For some components data was limited and of poor quality (Gerges, Kelly 2002).

The scope of the research was to:

1. Identify inflows and outflow to the water table, or shallow aquifer, on the Northern Adelaide Plains (NAP).
2. Calculate sensitivity of components (first approximation).
3. Report to Research Steering Committee with possible ranges of component inputs into the water balance for the region.

The following data is an assessment of the shallow aquifer water balance, in the area defined by this report, on the NAP. The research also identifies gaps in our knowledge and further data required to improve our understanding and estimates of this water balance.

5.4.2.1 Method

To develop a first approximation of the water balance components influencing the shallow aquifer on the NAP, the following calculations and assumptions were made to provide an estimate with the limited data currently available.

The hydrogeological equation to describe water balance was based on the law of conservation of matter. This implies that at a specific time any water entering a hydrogeological system must either go into storage within the system boundaries or be exported in the form of extraction or flow out of the system. The water balance equation for an aquifer was expressed as:

$$\pm \text{Change In Storage} = \text{Inflow} - \text{Outflow}$$

Potential inflow components identified were:

(a) Rivers (Para, Gawler) – direct recharge
(b) Irrigation infiltration (domestic water)
(c) Irrigation infiltration (groundwater)
(d) Irrigation infiltration (reclaimed water)
(e) Rainfall
(f) Irrigation dams leakage (leaky storage)
(g) Wetlands (leakage)
(h) Drainage from well and/or trenches
(i) Upward leakage from Q1 Aquifer
(j) Upward leakage from other aquifers (leaky wells)
(k) Stormwater drainage (shadehouse structures)
(l) Stormwater drainage (Urban runoff)
(m) Lateral inflow
(n) Domestic water (sewage/septic)
(o) Wastewater dumping (hydroponics and nursery industry)
(p) Sewage lagoons and channel at Bolivar
(q) Salt pans

Potential outflow components identified were:

(r) Pumping of perched water tables
(s) Evapotranspiration
(t) Soil moisture deficient (soil storage)
(u) Downward leakage into Q1 aquifer and beyond
(v) Downward leakage into other aquifers (leaky bores)
(w) Stormwater drainage (Urban runoff)
(x) Stormwater drainage (Shadehouse structures)
(y) Surface runoff (rainfall)
(z) Lateral outflow (Barriers at sea/aquifer interface, seepage into creeks and rivers)
(aa) Rivers (Para, Gawler) summer drains back into rivers

Where possible, each component was estimated, with the best available data, to assess their respective contribution to the water balance. A summary of the logic used for calculating water balance components follows.

5.4.2.2 Study Area

The area investigated was based on the extent of extraction from T2 aquifer on the NAP. This area measured 13.18 km by 7.95 km or approximately 110 km^2 (Gerges, Kelly 2002). Information from this area would be typical of that found on the Northern Adelaide Plains irrigation areas. Total area that could be used for agricultural purposes was estimated to be 10,500 ha with 3,160 ha within the 10,500 identified as being cropped (Hogan, West 1999).

5.4.2.3 Surface components

Rivers (Para, Gawler)
Net contributions from rivers were considered to be nil, as inflow during winter would be compensated by outflow during summer.

Irrigation (Mains water)
Using GIS, SA Water was able to estimate the mains water applied to the study area (5000 ML). 50% of this was estimated to be used for irrigation and 50% for household and industries uses.
Irrigation (groundwater)
Information provided by Department of Water Resources. Estimated to be 14,185 ML for the study area.

Irrigation (reclaimed water)
Estimation based on reclaimed water use for the year 2000-2001 provide by Water Reticulation Services Virginia. Estimated to be 6000 ML for the study area.

Rainfall
Hydraulic modelling showed that the net input to the water table from rainfall to be insignificant. However, this figure is based on monthly averages and a soil water deficit of approximately 5500 ML. This coupled with calculated monthly evapotranspiration figures, demonstrated that soil deficit would on average not be exceed (Table 25). Rainfall on irrigated land was considered in evapotranspiration.

Surface runoff (rainfall)
Average rainfall data negated any contribution of rainfall from vacant land to the water table due the soil water deficit. However, in practice intense rainfall events will contribute to runoff which can potentially contribute directly to percolation in recharge areas. The assumption used to calculate runoff events was that, in any one day, if the rainfall was greater than 15 mm, the rainfall greater than 15 mm would contribute to runoff volumes; A worse-case scenario.

Irrigation dams (leaky storage)
Assumptions used for calculating the contribution of leaky dams to the water table are listed in Table 11.

Table 11. Assumptions used for calculating leakage from dams

Parameter	Value	Unit
Average Dam	2.5	ML/dam
Number of dams	500	
Bottom area	1250	m^2/dam
K	1.23×10^{-4}	m/day
Volume	0.14	m^3/day
Volume/year	25.6	ML/year for 500 dams

Wetlands (leakage)
Andrews Farm was identified as the only wetland that could influence the water balance in the study area. A recent study by the City of Playford estimated the area of the wetlands to be 1.8 ha with an average leakage of 15mm/day.

Stormwater drainage (shadehouse/glasshouse structures)
Shadehouse/Glasshouse structures were estimated to cover 357 ha in the study area with an average rainfall of 440mm. Water inflows into the groundwater were calculated using field factor of 50% assuming that some shadehouse structures did not have storm water runoff.

Stormwater drainage (Urban runoff)
The areas considered for storm water drainage were Virginia, Munno Para West and Angle Vale. The calculation was based on 440 mm of rain falling on a combined area of 3.18 km^2 with 40% estimated to drain to the water table

Domestic water (sewage/septic)
Using GIS, SA Water was able to calculate the mains water applied to the study area (~5000 ML). 50% of this was estimated to be used for irrigation and 50% for household and industries uses. 80% household and industry used water was estimated to percolate to the water table, through septic tanks and drains (i.e. 2000 ML).

Wastewater dumping (hydroponics and nursery industry)
The area of hydroponic/nursery industry was estimated to be 20 ha, with an annual rainfall of 440 mm. It was assumed that there would also be irrigation excess or runoff from within these industries and not all water would percolate. Therefore, an irrigation factor of 2.4 was used for estimating excess watering and a 0.8 field factor was used to estimate percolation.

Sewage lagoons and outfall channel at Bolivar
No information was available for leakage from sewage lagoons at Bolivar and they were considered outside the influence of the study area. It is our understanding that the Bolivar outfall channel is concrete lined and should therefore have no impact on the water balance.

Salt pans
No information was available on their influence of nearby saltpans to the water balance and they were considered to be outside the range of the study area.

Evapotranspiration

Evapotranspiration calculations were based on average crop factors for crops grown on the NAP (NSW-Agriculture 1991). Soil factors were supplied by John Hutson (pers com, Flinders Uni.). The area under crop within the region being examined was calculated as a percentage of the 10,500 ha and the relative percentages were determined from the land-use map as described in Hogan, West 1999 and tabled in Table 12. These areas are the basis for the calculation of evapotranspiration and hence the amount of water that potentially percolates below the root zone of crops. The seasonal land-use was also required and given in Table 13, this estimated area of land use was based on personal communication with Agricultural advisors Howard Hollow (PIRSA Rural Solutions) and Dominic Cavallaro (Horticultural Consultant). 3160 ha were estimated to be cropped annually.

Table 12 Land-use in the region considered for the determination of the water balance

Land-use	% of total area	Area (ha)
Broadacre vegetables	25.1	2636
Glass & Shadehouses	3.4	357
Almonds	4.9	5145
Grapes	3.0	315
Vacant Land	63.6	6678

Table 13 Seasonal land-use. Sourced from a workshop on the Northern Adelaide Plains involving growers and advisors

Land-use	% land-use in a season	Approximate % of crop grown in Winter	Summer
Broadacre vegetables	75	70	30
Glass & Shadehouses	100	50	50
Almonds	100	100	100
Grapes	100	100	100
Vacant Land	100	100	100

5.4.2.4 Groundwater components

Lateral inflow and out flow

In analysing lateral throughflow, flow nets were constructed and Darcy's equation was applied to each flow path:

$Q_F = (Tiw).t/1000$

Where:

Q_F = lateral throughflow (ML/year)

T = aquifer transmissivity (m^2/day) = 50 m^2/d

i = hydraulic gradients, ie. potentiometric surface slope =$1.78 * 10^{-3}$ m/m

w = width of flow path (m) =$8.2 * 10^3$m

t = time (days) =365 days

In calculating the lateral throughflow and because of the paucity of the data and the insignificant head differences between both aquifers, information from both aquifers were used to construct potentiometric surface to calculate the hydraulic gradients. Using the upper limits of transmissivity of 50 m^2/day (K_h= 25), which is considered very high, the lateral throughflow value of 266 ML/year was calculated.

The hydraulic gradients were calculated using a manually contoured map. A contouring package was utilized to contour the NAP area using all available of Q1 aquifer and perched water table observation wells (Gerges, Kelly 2002). The same package was used to contour the small area where dense water level information is available (recently drilled area), using Q1 aquifer data only and the perched water table data only (Gerges, Kelly 2002). All figures show a reasonable agreement in hydraulic gradient and the general flow direction.

In calculating the lateral throughflow of the perched water table and Q1 aquifers, transmissivities were estimated from lithological logs and aquifer thickness

Leakage between aquifers

Vertical leakage can be defined as the enhanced flow through the confining beds due to the head differences between the aquifers. Leakage occurs over the whole area and it forms part of the inflow and outflow mechanisms. Knowing the head difference between the aquifers and the vertical hydraulic conductivity and thickness of the confining beds, it is possible to calculate the leakage between aquifers using Darcy's law from the following equation:

$Q_L = K_v\ (\Delta h/b).(A/1000).t$

Where:

Q_L	= rate of leakage through confining bed (ML/day)
K_v	= vertical hydraulic conductivity of confining bed (m/day)
Δh	= head difference between aquifers (m)
b	= thickness of confining bed (m)
$\Delta h/b$	= hydraulic gradient across confining bed (m)
A	= area over which leakage is calculated (km^2)
T	= time (days)

Information from observation wells indicates a mainly downward hydraulic gradient between all Quaternary aquifers and the Tertiary aquifers. The greatest head difference occurs near Virginia and Angle Vale areas.

During summer, the hydraulic gradient is downward from the Q1 to the Tertiary aquifer(s). This gradient is generally maintained during winter due to extraction from the Tertiary aquifer(s) pumping centres. The large head difference will induce downward leakage from the Q1 through to the Tertiary aquifer(s).

In the area of concern (high water tables), where there is insignificant head difference between the perched water table and the Q1 aquifer, these aquifers are probably hydraulically connected in this area. However the average head difference between aquifers was estimated at 0.2 m and an average thickness of confining bed separating the perched water table from Q1 aquifer was estimated at 2 m. The vertical hydraulic conductivity of confining bed from Virginia site of 1.2×10^{-4} m/d was used in this calculation. Using this information over 110 km^2 area leakage was calculated as follows:

During the 155 days of winter period, leakage was calculated at 204 ML/155 days. Based on the assumption that one third of the leakage is upward from the Q1 aquifer to the perched water table, there is 68 ML inflow into the aquifer. The other 66 % or 137 ML occurs as downward leakage from perched water table to the Q1 aquifer.

During the 210 days of summer it is expected that most of leakage is downward from perched water table to the Q1 aquifer and was calculated to be 277 ML. Therefore, total downward leakage of 414 ML was regarded as outflow from the perched water table aquifer. However, it is expected that the vertical hydraulic conductivity is not uniform over the area and consequently leakage will change significantly.

Change in storage

Head change and the volume of water released from a confined aquifer was related by the storage coefficient which, according to Bear (1979), is defined as:

$S = bS_s$

Where:

S_s	= specific storage = $\text{Ø}\beta + [(1- \text{Ø})\alpha]$
b	= thickness of confining bed (m)
Ø	= porosity
β	= compressibility of water
α	= compressibility aquifer matrix

The average annual change in storage can be calculated from the following equation.

$\Delta S_t = S. (\Delta h. A)$

Where:

ΔS_t	= average annual change in storage (ML/yr^{-1})
S	= storage coefficient or specific yield (dimensionless)
Δh	= change in head during the period of study- (mm)
A	= area (km^2)

A hydrograph from the Q1 aquifer shows that a general decline in the water level occurs up to 1999 (Gerges, Kelly 2002). The loss from storage is related to several factors including a reduction in the rate of recharge, extraction from the aquifer, evapotranspiration, downward leakage, natural discharge and leakage via corroded bore casings.

As there is virtually no pumping from these aquifers, this loss from storage is believed to be due to downward leakage in response to pumping from the underlying Tertiary aquifer or downward leakage via corroded casing. This is in contrast to more recent hydrographs (Gerges, Kelly 2002) from the perched water table and the Q1 aquifer (summer 2000 and 2001 and winters 2000 and 2001) which suggest that:

- The average rise in head between winter 2000 and winter 2001 was approximately 0.46 m for Q1 aquifer and 0.4 m for the perched aquifer.
- The average rise in head between summer 2000 and summer 2001 was approximately 0.21 m for Q1 aquifer and 0.33.m for perched water table aquifer.

Therefore, considering that:

S	= storage coefficient or specific yield (dimensionless) = 0.1
Δh	= change in head during the period of study- (mm) =0.5m =500mm
A	= area (km2) =110 Km

Then
ΔSt = average annual change in storage can be calculated at 5500 ML/yr^{-1}

Leakage from corroded casing
Calculating the anticipated amount of leakage from a corroded casing was based on the assumption that leakage from a shallow saline Quaternary aquifer(s) averages 0.15 l/s per well into the deep Tertiary aquifer. Based on the assumption that 100 wells are leaking within the area at the lowest rate of 0.15 l/s, total leakage was calculated at approximately 500 ML/year

6 Results and related discussion

6.1 Soils Research

6.1.1 Historical comparison – Effect of water type on key soil properties.

6.1.1.1 Development and verification of low cost soil analysis methods

Soil SAR values were not significantly different between AAS and ICP methods (Figure 2). These data suggest that the filtering and acidification steps in the sample preparation for ICP analysis removed colloidal particles by settling or precipitation and hence were not sampled, aspirated and analysed (Spiers *et al.*, 1983). Comparison of soil B measurements indicated a significant relationship between B_{hws} and $B_{1:5}$ (Figure 3). Using this relationship, B_{hws} was converted to mannitol extractable B (Cartwright et al 1983) and then to saturation extract B (B_{se}; Rayment, Higginson 1992), and the relationship between $B_{1:5}$ and B_{se} modelled (Equation 1).

$$B_{se} = 0.021 + 1.459B_{1:5} + 0.472B_{1:5}{}^{2} + 0.033B_{1:5}{}^{3} \qquad \text{(Equation 1).}$$

The model (Equation 1) was verified using samples taken from the 5 main soil types (Table 1) of the NAP at 3 sampling depths (0-10, 40-50 and 90-100 cm, n = 30). There were no significant differences ($p > 0.05$) between B_{se} and that calculated from $B_{1:5}$ ($r^2 = 0.92$, n = 28). These data confirmed that for the soils of the NAP, $B_{1:5}$ can be converted to B_{se} with a high degree of confidence using Equation 1 above. This conversion allowed a low cost measure of plant available soil B for the NAP that was easily related to critical published values for crops (Maas 1986).

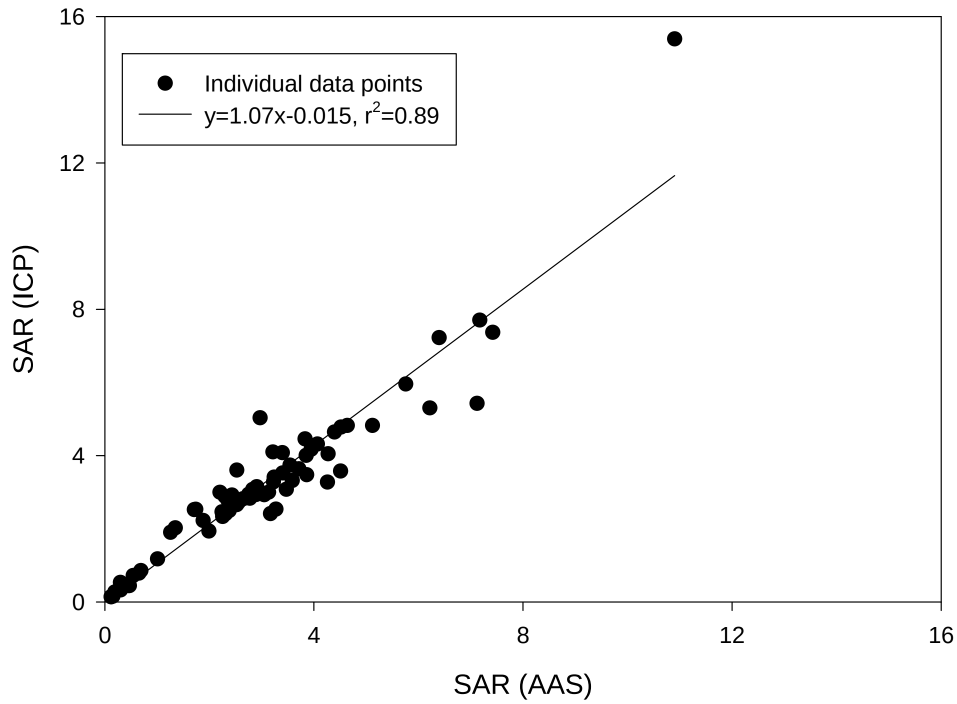

Figure 2. **Relationship between sodium adsorption ratios (SAR) calculated from cations measured in 1:5 soil water solutions using inductively coupled plasma (ICP) and atomic adsorption spectrophotometry (AAS). Slope not significantly different ($p > 0.05$) from 1, and x and y intercept not significantly different ($p > 0.05$) to 0. Soil types 1 to 5 (Table 1) and a range of depths (0-100 cm), n=70.**

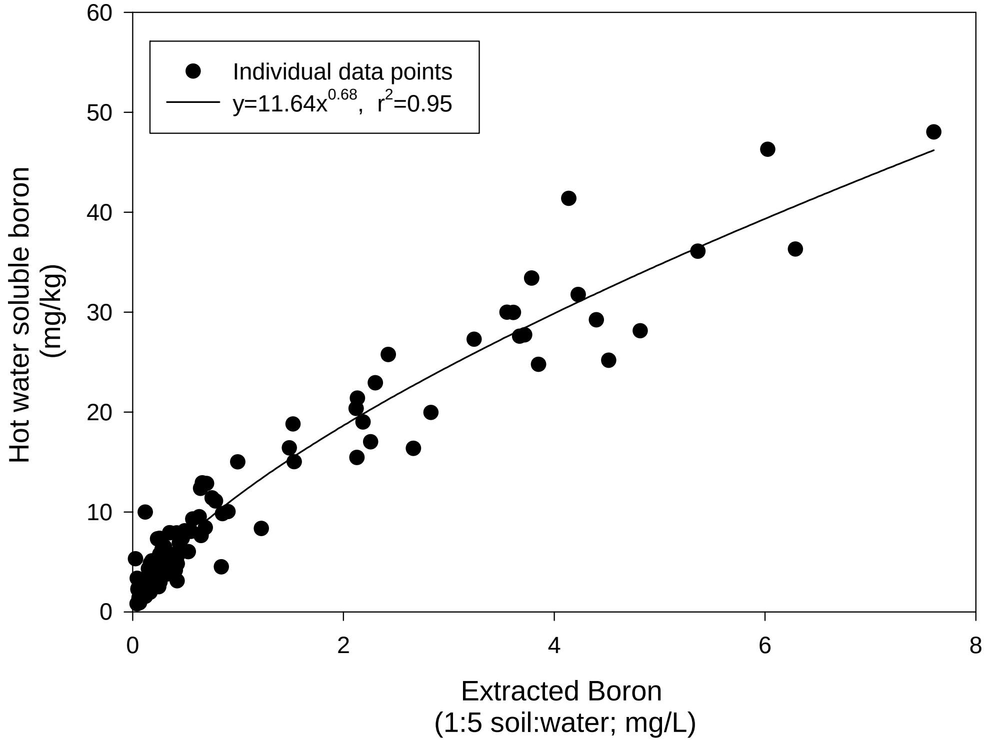

Figure 3. **Relationship between hot water soluble Boron (B_{hws}) and 1:5 soil:water extractable boron ($B_{1:5}$). Soils included the 5 main soil types of the Northern Adelaide Plains, ranging in texture from sand to clay at 3 depths 0-10, 40-50 and 90-100 cm, n=129.**

There was a significant correlation of $SAR_{1:5}$ with ESP (Figure 4). This relationship was similar to that found by Rengasamy et al (1984) on similar soils using similar methods. However, the data of Rengasamy et al (1984) was linear (r^2=0.47) and data presented in this paper curvilinear (r^2 = 0.83; Figure 4). These differences were because $SAR_{1:5}$ data from the present study ranged from approximately 0-100 compared with 0.1 –12.4 in the study of Rengasamy et al (1984). In the $SAR_{1:5}$ range of 0 – 20 (ESP < 40) differences between the two studies were insignificant (Figure 4). $SAR_{1:5}$, a more cost-effective analysis than ESP, can therefore be confidently used as a surrogate measurement of ESP on these soils. It should be noted that even though there is commonly a close relationship between SAR and ESP (ANZECC, ARMCANZ 2000), they measure two distinct soil parameters. ESP measures the proportion of Na ions on the soil exchange phase (after soil solution cations are removed) while SAR measures the proportions of Na, Ca and Mg in the soil solution, where the divalent cations would be preferentially adsorbed onto the exchange surfaces of the soil.

Regression analysis between ESP and $SAR_{1:5}$ indicated that coefficients of determination were not significantly improved if grouped by irrigation water history (r^2=0.86, standard error 0.09). This analysis indicated that there was little effect of soil irrigation history on the relationship between ESP and SAR, and therefore the effects of water quality on soil cation exchange properties were minimal.

The good correlation between $EC_{1:5}$ and EC_{se} for the NAP soils (Figure 5) suggests that for any soil type on the NAP a soil $EC_{1:5}$ multiplied by 8.2 gives a good estimate of EC_{se}, allowing direct comparison with critical values found in the literature (Maas 1986). This relationship allows comparison with salinity toxicity EC_{se} data used in the literature using the simpler $EC_{1:5}$ measurements. There was no significant difference in the relationship when data (n=30) were grouped and regressed in soil textural classes (n=5). This analysis suggests that the use of different conversion factors for different soil textures, as suggested by Shaw (1988), is not required for the soils of the NAP.

When we arbitrarily divided data from the field test sodicity meter into 3 divisions (Figure 6), 64, 67 and 55% of the non-sodic, sodic and highly sodic rankings (respectively) related directly to $EC_{1:5}$ and $SAR_{1:5}$ data. Much of the variation between these arbitrary divisions was between sodic and highly sodic categories. By combining sodic and highly sodic rankings the relationship between the field test sodicity ranking and $EC_{1:5}$ and SAR was 91% accurate. These data suggest that for the soils of the NAP, $EC_{1:5}$ and $SAR_{1:5}$ give a good first approximation of soil sodicity (ie. sodic or non-sodic) and the potential of NAP soils to disperse. However, the field sodicity meter uses rainwater or deionised water in the dispersion test. Low EC water may be inappropriate for assessing dispersion below the soil surface. Under normal conditions these soils would be exposed to water that accumulated salts from the upper soil profile when the wetting front moved through the soil profile. Therefore interpretation of the field sodicity meter's results at depth, in comparison with what may actually occur in the field, is limited.

These data verify that a 1:5 soil:water extract, which is currently a routine extraction method for determining soil pH, can offer a low cost method for determining several key soil chemico-physical parameters (as discussed above). These parameters can then be confidently converted to critical soil values reported in the literature, providing a tool for monitoring and managing soils when irrigating with RCW on the NAP.

6.1.1.2 Properties of the Northern Adelaide Plain soils and irrigation water

Many of the subsoils of the NAP are naturally sodic because of the shallow (1.5 m), saline water table on the western side of the NAP (Matheson, Lobban 1974). There are several main orders of soil types on the NAP; Sodosols, Dermosols, Vertosols and Kandosols (Table 1). Others have also reported on the heterogeneity of the NAP soils (Matheson 1975).
Some typical water quality properties of bore and RCW used for irrigation at the sites where soil cores were taken are listed in Table 2. Mean TDS, EC and SAR values of bore water were approximately half that of RCW over the study period (1978-1998). Such differences in water quality should be reflected in changes in soil chemical properties given similar farming practices. For example, the ESP of the soil surface would be expected to equilibrate with the SAR of the irrigation water (Oster 1994).

6.1.1.3 Changes in soil chemical properties with the use of reclaimed water

The calculated means for the after-summer samples, where saline and sodic effects would be expected to be greatest, for irrigation history and soil depth changes (Figure 7, Figure 9 and Figure 10) were typical of data from both sampling times. For simplicity, data discussed below refer to the after-summer sampling.

6.1.2 Electrical conductivity

Electrical conductivity of irrigated soils (bore and RCW) were significantly different from virgin soils (Figure 7). The EC bore and RCW irrigated soils were not significantly different and were approximately 2.8 dS/m (EC_{se} or 0.4 dS/m $EC_{1:5}$) in the top 20 cm of soil. On average, the EC of borewater-irrigated soils was lower than RCW-irrigated soils and did not change significantly until depth in both irrigated soils (Figure 5 and Figure 7). In contrast, the EC of the virgin soils was low in the upper soil profile (EC_{se} 1.1 dS/m; Figure 5 and Figure 7) and increased significantly ($p \leq 0.05$) down the profile to an EC_{se} of 6.9 dS/m.

Crop salinity responses are influenced by climate, irrigation and agronomic management (Rhoades, Loveday 1990). However, most vegetable crops (except zucchini) suffer a 10% yield reduction at an EC_{se} of 2.7 ± 0.8 dS/m (ANZECC and ARMCANZ 2000). Topsoil salinities measured in these soils were near these thresholds and careful management of soil salinity is required.

It is generally accepted that a soil with EC_{se} > 4 dS/m is a saline soil (Richards, 1954; Sumner *et al*., 1998). However, this arbitrary value of soil salinity should reflect the crops grown. Given the salinity threshold of most vegetable crops, we suggest that a critical EC_{se} > 3.0 dS/m would be appropriate in soils where vegetable crops are grown on the NAP. On average, at the end of the growing season (after summer sampling; Figure 7) the top 30 cm of the irrigated soils (reclaimed or bore water) and virgin soils did not exceed the critical EC_{se} of 3 dS/m. These data suggest that current and past irrigation scheduling has included a leaching fraction adequate to maintain soil salinity at acceptable levels for most crops grown on the NAP. For example, a leaching fraction of 20 – 50% would be considered an ideal leaching fraction for

RCW use (Rhoades, Loveday 1990). However, below 30 cm, RCW-irrigated soils are nearing the proposed salinity threshold (EC_{se} 3 dS/m), which could have detrimental consequences for deep-rooted crops in the future. The salinity changes in virgin soils are a consequence of rainfall leaching the topsoil, but rainfall has been insufficient to leach the lower depths and prevent upward migration of shallow saline groundwater on the western side of the NAP (Matheson, Lobban 1974).

6.1.2.1 Soil pH

The pH of the NAP soils were generally greater than 7. Differences in soil pH due to irrigation with RCW and bore water were not significant ($p > 0.05$; Figure 8). The use of soil amendments (e.g. gypsum and lime) as part of normal horticultural practice, will have a much greater effect on soil pH than the use of the two water sources studied here (Stevens et al., 2000b).

6.1.2.2 Sodium absorption ratio

Sodium absorption ratio is calculated using the cation concentrations (expressed as equivalents/L) in water or soil extracts (Equation 2)

$$SAR = \frac{[Na^+]}{\sqrt{\frac{([Ca^{2+}]+[Mg^{2+}])}{2}}} \qquad \textbf{(Equation 2)}$$

(Cation concentrations are expressed as equivalents/L)

There were significant differences in SAR between irrigation history, soil depth, and soil type ($p \leq 0.05$). Irrigation water history had a greater influence on soil $SAR_{1:5}$ than $EC_{1:5}$ (Figure 9 and Figure 7). Mean $SAR_{1:5}$ values of RCW-irrigated soils were generally three times greater than bore water irrigated soils at all depths down the soil profile (Figure 9). $SAR_{1:5}$ values in virgin soils were low in the topsoil (< 0.7) but higher than bore and RCW-irrigated soils at depth (> 7.0), this was likely to be a consequence of the upward migration of saline, Na-dominant, groundwater (i.e. SAR = 44).

There is still considerable debate on the functional definition of a sodic soil (reviewed by Sumner et al., 1998). One definition of a sodic soil is a soil with an ESP > 6 (Northcote, Skene 1972). For the soils of the NAP this would equate to a $SAR_{1:5}$ of 1.2 (Figure 4), and all soils except for the 0-20/30cm depth of the bore/virgin irrigated soils would be considered sodic (Figure 9). However, if a scheme for prediction of the dispersive behaviour of soils, similar to Rengasamy et al 1984) is adopted, and SAR and EC values are set to define sodicity in relation to soil dispersivity and sodicity-induced problems (e.g. restrictive drainage, surface crusting and high soil strength); a $SAR_{1:5}$ of 2 at low $EC_{1:5}$ (<0.5) and 3 at higher $EC_{1:5}$ (0.5-1.0) would give a more practical definition for sodic soils on the NAP (calculated from Figure 6). Using this practical definition, on average the bore water irrigated soils would not be classified as sodic at any depth (Figure 9). Below 20 cm RCW-irrigated and virgin soils would be consider sodic, and the upper 20 cm of the RCW-irrigated soil would be marginally sodic.

Detrimental soil chemical changes, due to the sodic nature of RCW used for irrigation on the NAP for the last 10 to 28 years, can lead directly to changes in soil physical properties. Current farming practices on the NAP do not address these potential detrimental effects, as sodicity has increased in soils with RCW use. If these sodicity-induced effects are not managed correctly now, soil permeability could be reduced to a level that will not sustain adequate leaching fractions. However, the functional implications of these SAR changes are difficult to interpret, given the discussion above on the functional definitions of sodicity. If leach fraction are decreased due to lower soil permeability, this may lead to increased salinity or the formation of perched water tables necessitating mechanical drainage. Others have reported significant decreases in soil infiltration rates or hydraulic conductivities as the soil ESP or SAR increased (Oster 1994; McIntyre 1979) on a range of soils. Matheson, Lobban 1974) speculated that higher salinity at one site was from a perched water table on the NAP.

As an indication of possible soil saturated hydraulic conductivity changes, data from McIntyre 1979) and (Figure 9) were used to estimate decreases in soil permeability. Using SAR values for a soil depth of 0-10 and 90-100 cm (Figure 9), we calculated that 2.75 and 10 cm/day (respectively) decrease in permeability of the RCW-irrigated soil compared to the bore-irrigated soil could occur. Permeability data collected in 1975 (Anon 1976) from the NAP suggests, even though many of the NAP soils had high permeability, for some subsoils (below 30 cm depth) a decrease in permeability of 10 cm/day would impact significantly on soil drainage. However, the fact that soil salinity has remained at acceptable levels after 10-28 years of RCW use, suggests that leaching fractions have been maintained and soil permeability has not been sufficiently restricted by SAR changes. Decreases in SAR of bore-water-irrigated soils relative to virgin soils suggest that these soils, which are highly sodic at depth (80-100 cm), maintain sufficient permeability to allow leaching when irrigated with good quality water. These observations contradict the permeability calculation above. This apparent contradiction could be due to: (1) heterogeneity of NAP soils and sodic soils which are not sufficient to develop a continuous barrier to vertical water permeability, (2) permeable surface soils that can allow drainage water to flow horizontally if vertical movement is restricted, (3) the sodicity effects are not yet extensive and severe enough to be physically significant, or (4) the data reported by McIntyre (1979) used to estimated soil permeability was obtained using low salinity water (EC = 0.09 dS/m). Therefore our permeability calculations would not take into account effects arising from the increase in soil-water salinity, from salts in the soil, as water passes through the soil profile. Increases in soil-solution salinity would suppress soil dispersion and increase permeability (Rengasamy et al 1984).

Further research is required to quantify the effects of RCW-induced soil sodicity changes, relative to bore water irrigated and virgin sites (Figure 9), on the changes in permeability (hydraulic conductivity) of NAP soils. The variability in soils, water and crop management has made it difficult to determine if changes in SAR are at equilibrium or are on an upward trend. However, there were no significant ($p \leq 0.05$) correlations between soil SAR and period of RCW irrigation at any depth, suggesting that a new equilibrium may have been reached within a 10 year period of RCW use. Data presented in this paper and the literature suggests a potential problem with soil SAR in the future if management strategies are not devised and implemented. Further work is required to assess any correlation between SAR values and soil permeability in order to obtain a functionally-defined critical SAR value for the soils of the NAP. Once defined, a functional SAR value for the soils of the NAP will allow more rational assessment of shifts in soil SAR values from use of RCW.

6.1.2.3 Boron

The minimum B_{se} concentration found in soil cores taken from the NAP was equivalent to 0.07 mg/kg. Non-limiting concentrations of B_{hws} in soils, from a deficiency perspective, are generally in the 0.15 to 0.5 mg/kg soil (Bell 1999). This equates to approximately 0.02-0.04 mg B_{se}/L, suggesting B deficiency would not be an issue on these soils.

There were significant ($p \leq 0.05$) interactions for irrigation history and depth (Figure 10), but not for soil type. Data suggest that long-term irrigation with bore water has led to leaching of some B down the soil profile, while long-term RCW use has increased B concentrations in the topsoil (0-20 cm), but maintained similar B concentrations to virgin soils in the subsoils (Figure 10). Others have found that irrigation of sandy soils with sewage water containing similar concentrations of B (0.4 mg/L) increased B concentrations in the lower soil profile, but after 67 years of irrigation they had not reached toxic levels (El-Hassanin et al 1993).

Use of RCW has increased B concentrations in topsoils (0-20 cm) to a level where according to Maas (1986), B-sensitive plants could suffer yield decreases, i.e. $B_{1:5}$ > 0.3 mg/L or B_{se} > 0.5 mg/L (we assumed that soil water B ~ B_{se}). At lower depths (e.g. 50-100 cm), B concentrations in RCW-irrigated soils are similar to virgin soils and levels are such that root penetration of moderately tolerant plants (Maas 1986) could be restricted, i.e. $B_{1:5}$ > 1.2 mg/L or B_{se} 2.0 – 4.0 mg/L.

The fact that most of the data for critical B toxicity values quoted by Maas (1986) were derived from sand culture experiments, led us to conclude that for most soils and plants grown on the NAP, the B concentrations reported here would not cause yield reductions. However, further soil and crop monitoring studies should be undertaken to determine if B levels increase in the future.

Although RCW use has led to a significant increase in soil B concentrations in the topsoils, these changes should not be detrimental to plant growth. However, caution in the use of fertilisers containing B should be practised as B concentrations for all soils were close to critical toxicity thresholds.

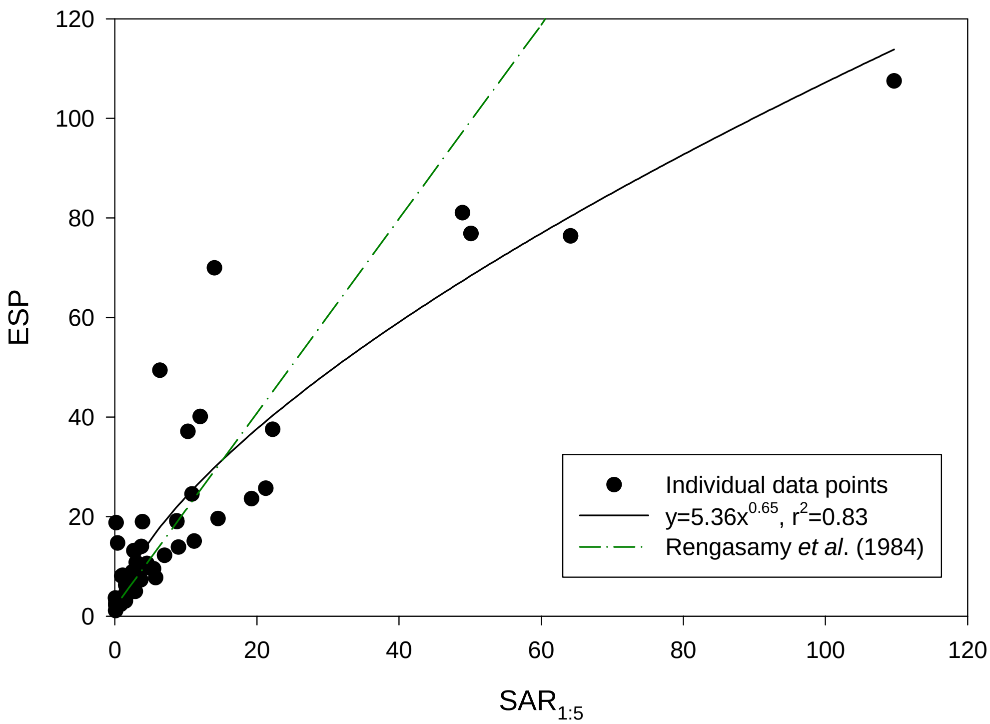

Figure 4. Relationship between soil exchangeable sodium percentage (ESP) and sodium absorption ratios ($SAR_{1:5}$). Soils include the 5 main soil types of the Northern Adelaide Plains (Table 1), ranging in texture from sand to clay at 3 depths 0-10, 40-50 and 90-100 cm, n=66.

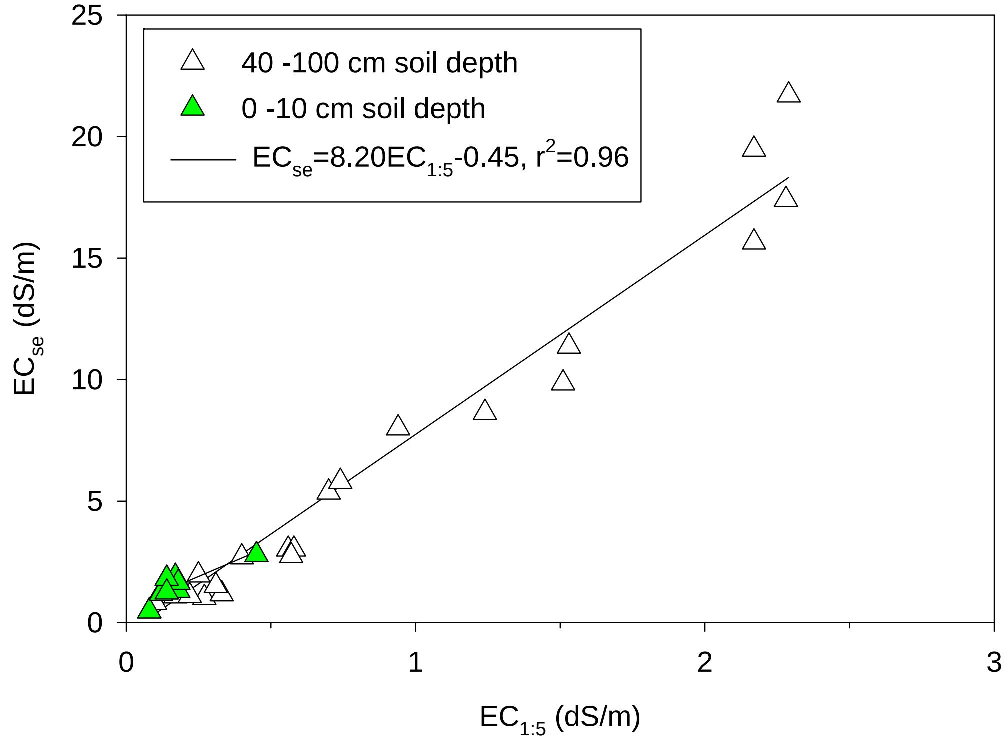

Figure 5. **Comparison between electrical conductivities in saturation paste extracts (EC_{se}) and 1:5 soil:water extracts ($EC_{1:5}$) from soils types 1 to 5 (Table 1) on the Northern Adelaide Plains. (n = 30, 10 sites, 3 depths). Cores sampled in 1998. Clay content of samples ranged from 5 to 47 %.**

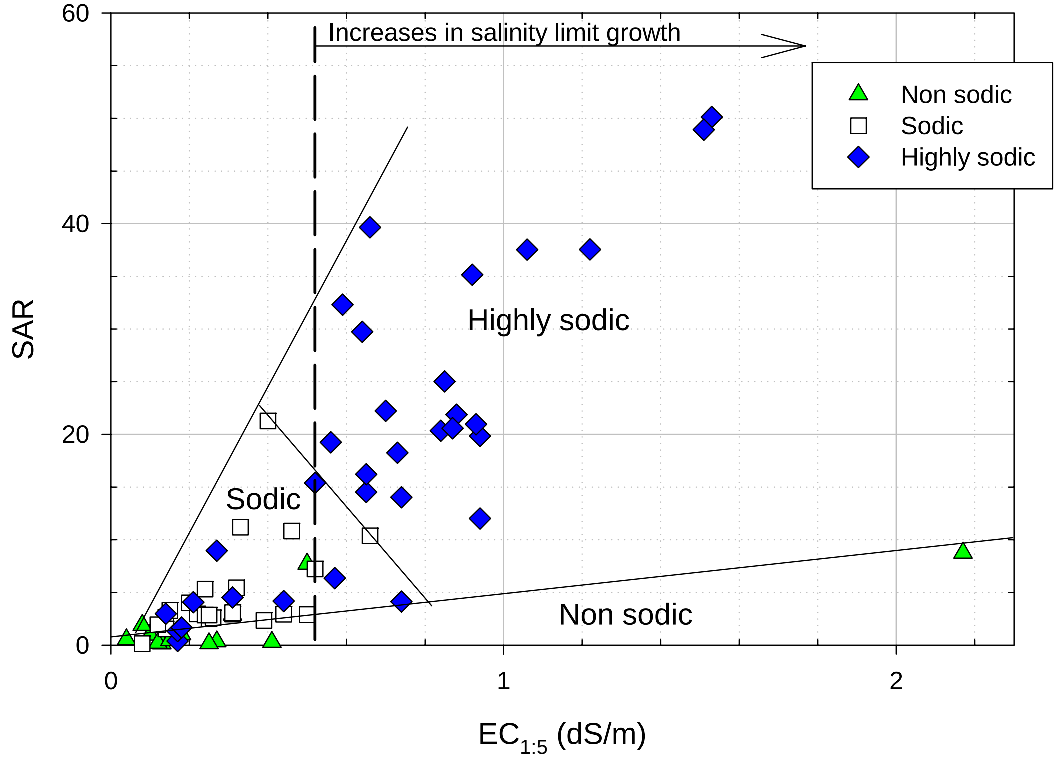

Figure 6. **Effects of sodium adsorption ratio (SAR) and electrical conductivity ($EC_{1:5}$) measured in 1:5 soil:water extract on soil sodicity/dispersitivity determined by a simple sodicity field test. (Symbols are measured single data points). Soils included the 5 main soil types of the NAP, after winter and summer samplings, ranging in texture from sand to clay at 3 depths (0-10, 40-50 and 90-100 cm), n = 71. Lines were drawn in arbitrarily to define an area containing the highest number of points for a sodicity field test ranking.**

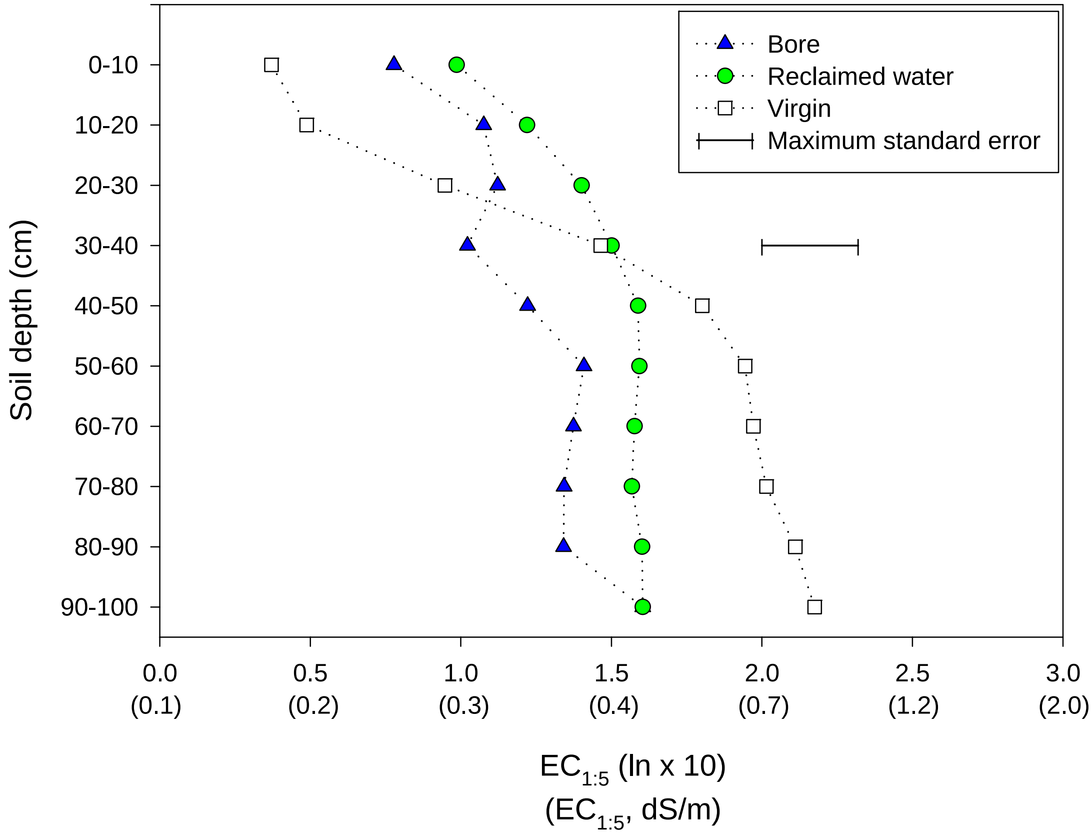

Figure 7. Changes in soil electrical conductivity ($EC_{1:5}$) with depth related to historical water use. After summer sampling. Number of observations = 113 (bore), 193 (reclaimed water) and 161 (virgin). $EC_{1:5}$ scale is natural log, transformed because data was not normally distributed.

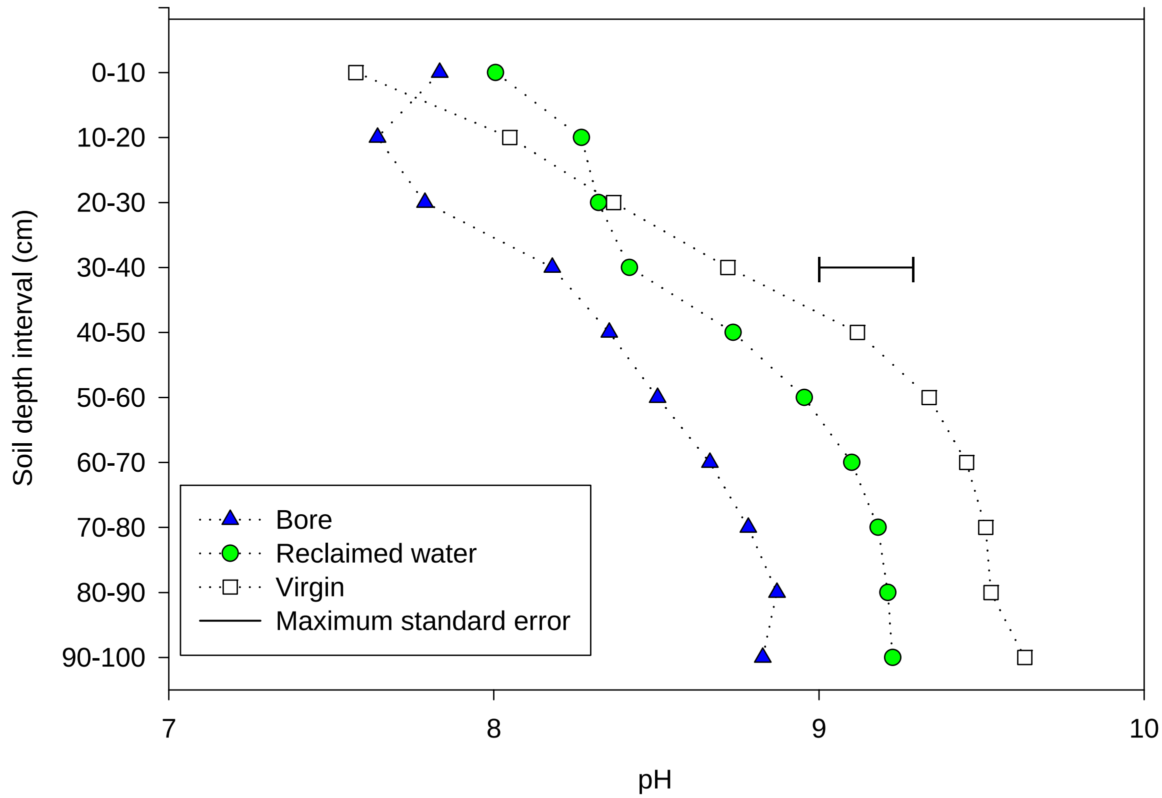

Figure 8. **Effect of soil irrigation history on soil $pH_{1:5}$. After summer sampling. Number of observations = 113 (bore), 193 (reclaimed water) and 161 (virgin).**

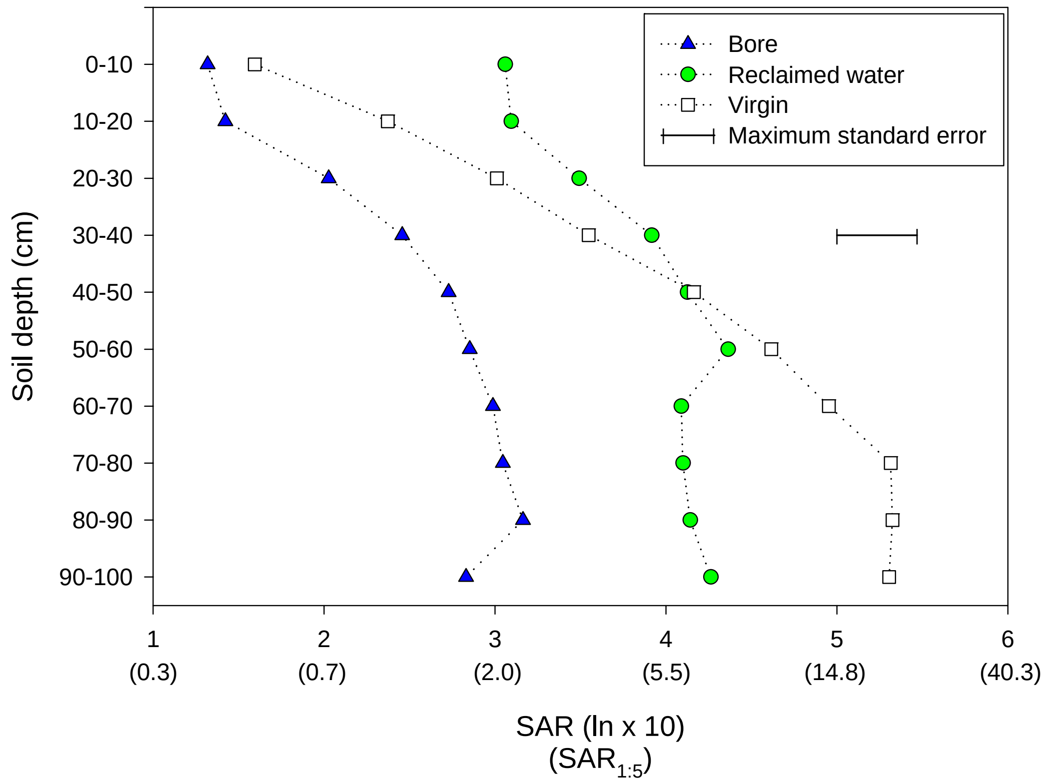

Figure 9. **Changes in soil sodium adsorption ratio (SAR) with depth related to historical water use. After summer sampling. Number of observations = 105 (bore), 131 (reclaimed water) and 102 (virgin). $SAR_{1:5}$ scale is natural log, transformed because data was not normally distributed.**

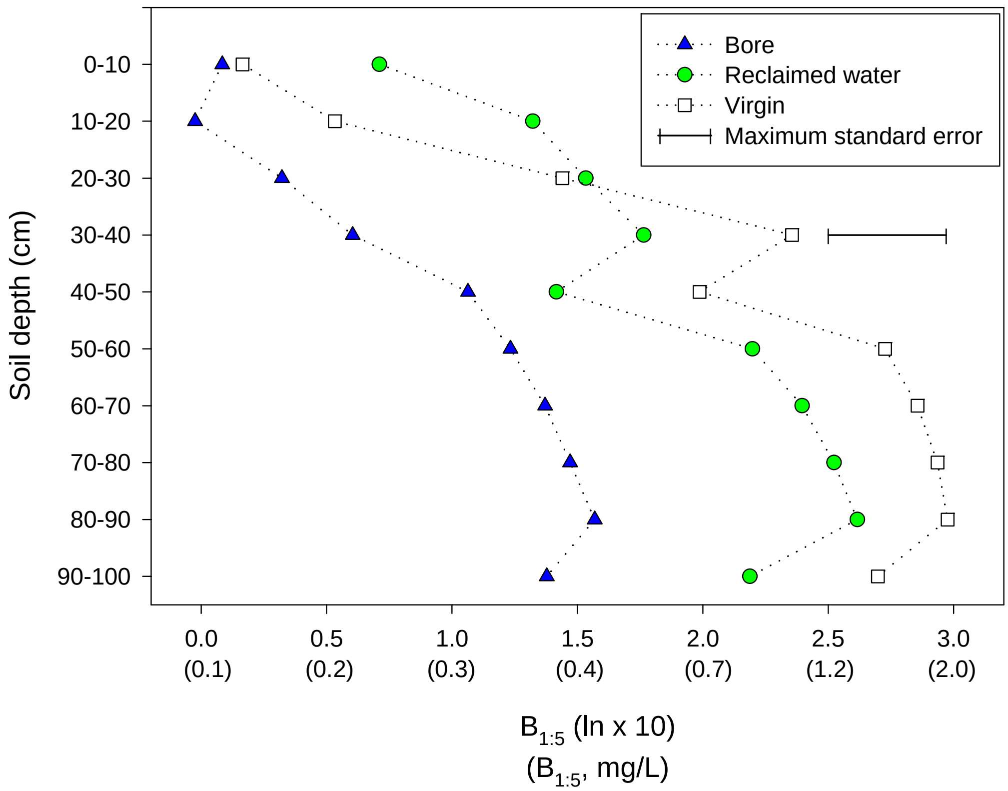

Figure 10. Changes in soil $B_{1:5}$ with depth related to historical water use. After summer samplings. Number of observations = 105 (bore), 131 (reclaimed water) and 106 (virgin). $B_{1:5}$ scale is natural log, transformed because data was not normally distributed

6.1.3 Glasshouse study – Effect of irrigation water and practice on cadmium uptake by lettuce.

There was no relationship between lettuce dry weights and Cd concentration in lettuce (Figure 11) and therefore no effect of growth dilution on Cd concentrations. Irrigation scheduling significantly affected plant Cd concentrations - at low mean soil water potentials concentrations of Cd in lettuce was significantly greater (and equalled the ML) than at high mean potentials for both irrigation waters (bore water $P < 0.05$, recycled water $P < 0.001$). The mechanism for increased Cd uptake by lettuce was likely due to increased soil solution Cl concentrations induced by the different irrigation scheduling regimes (McLaughlin et al 1994). The irrigation scheduling which included leaching prevented soil solution Cl concentrations from increasing, while the treatment having low mean soil water potentials allowed soil solution Cl and Cd concentrations to increase (data not shown). For each irrigation treatment there were no significant ($p<0.05$) differences between water types (Figure 11). These data suggest that although Cl loading in reclaimed water was approximately double (Table 1) that of bore water, irrigation scheduling overrode any effects due to water quality.

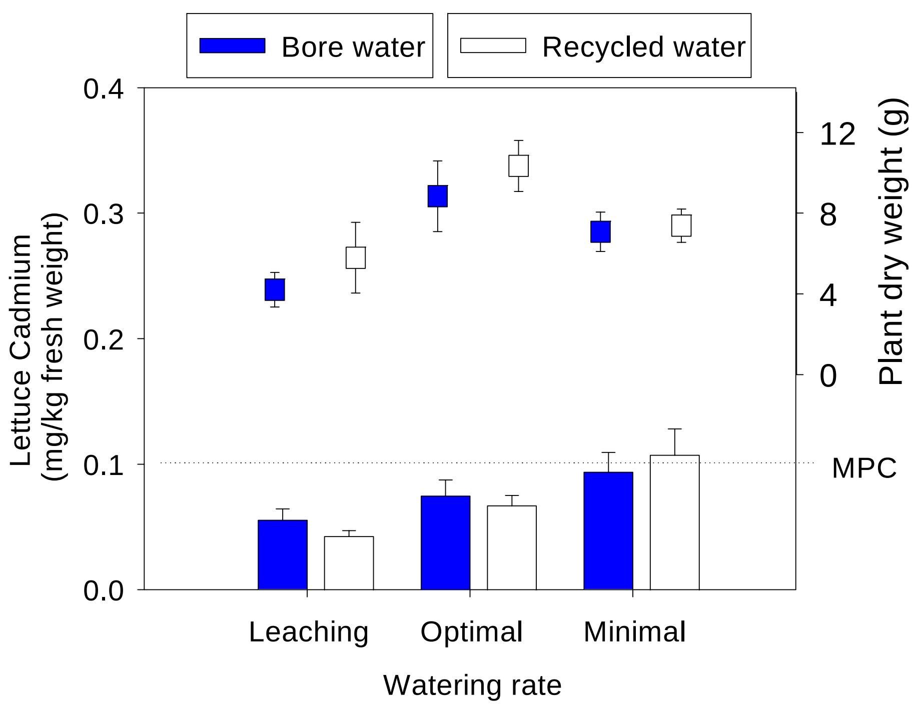

Figure 11. Effect of irrigation scheduling on yield and uptake of cadmium by lettuce. Error bars = one standard deviation from the mean, n = 4. MPC = Maximum Permitted Concentration.

6.1.4 Field experiment – Assessment of soil additives on managing sodicity.

6.1.4.1 Soils

The sodium adsorption ratio (SAR) of soil is a measure used to assess the ratio of exchangeable Na to other major cations (Mg and Ca) in the soil (Equation 2; Rengasamy et al 1984). In soils, SAR is measured by extracting the soil with water (soil:water ratio 1:5), filtering and measuring Ca, Mg and Na in the extract (extracted Ca, Mg and Na). Irrigation with waters of high SAR can increase soil SAR. Simply, increases in SAR indicate a replacement of divalent cations, which hold soil aggregates together, with monovalent cations, which cause soils to become dispersive. Dispersive soils lead to surface crusting and water infiltration problems as the soils structure is degraded. Degraded soil structure limits water and gas transport and root growth, with obvious detrimental effects on plant growth (Rengasamy, Olsson 1993). Soils with SARs above 6 are generally considered sodic and would be expected to display such problems, although other soil characteristics can also contribute to sodicity (Rengasamy et al 1984; Rayment, Higginson 1992). Sodic soils contain higher than desirable amounts of sodium attached to clay particles, and swell and disperse when in contact with water (Rengasamy, Bourne 1998).

All additives in this report were primarily chosen for the beneficial effects of Ca in relation to SAR and soil structural benefits. Although the SAR of the experimental soils was already low (Figure 12), reduction in SAR will be beneficial in the longer term in maintaining good soil structure. Extractable Ca was significantly increased from control plots by Gypsum application at both sites (Figure 13) and Kiln-dust A application at Site 1. Extracted Ca was higher in the Kiln-dust A and higher loading were applied the Kiln-dust B because of the higher Ca concentration in Kiln-dust A (Table 5and Table 6). The extractable Ca in Gypsum was lower and total loading lower, however data suggests that the solubility in soil over the growing season was higher. Gypsum is generally accepted to have a high solubility compared to lime when applied to soil (Rengasamy, Bourne 1998).

Total trial soil Ca concentrations were significantly higher than control soil at both sites where Kiln-dust A, Kiln-dust B or Gypsum had been applied (Figure 14). The low increase in total Ca for the Aglime treatment may be due to lime's insolubility in the digestion procedure, or particulate leaching from the 0-15 cm sample depth. Further investigations are required to confirm this. Even though the same rates of Ca were applied for each treatment to both sites, total soil Ca concentrations in the top 15 cm at Site 2 increased double that of Site 1 due to the higher clay content providing sorption sites for Ca (Figure 14). Differences between calculated and measured increases in total Ca concentrations for Site 2 cannot be fully explained. Total soil Ca increases in the top 15 cm of soil were not consistent across treatments and sites because of difference in Ca solubility and greater leaching on sandy soils compared to clay soils. Changes in soil chemistry (0-15 cm depth) from additives were generally greater at Site 1 (loamy sand soil) compared with Site 2 (medium clay soil).

Changes in SAR reflected extractable Ca levels (Figure 12 and Figure 13). SAR was significantly lower in trials plots than control plots at Site 1 where Gypsum, Kiln-dust A and Aglime was applied. Kiln-dust B had no significant effects on SAR while Aglime did, probably due to the higher solubility of Ca in the Aglime (Table 5). There were no significant differences from control at Site 2 due to the clay soils ability to adsorb significant amounts of the soluble Ca applied (Figure 12) and therefore the higher concentrations of extractable Ca concentrations. At both sites, the greatest benefit (decrease) in SAR was from the Gypsum treatment. This was due to high soluble calcium (not measured in 1:5 additive:water extract, but generally accepted to have a higher solubility in soil). For example, the total amount of Ca in the gypsum may be eventually soluble in soil (in 3 months), however, only the extracted (water soluble) Ca in Aglime may be soluble in soil in this time-frame.

The benefit of Gypsum to SAR is also probably due to the added benefit of Mg (Figure 13; Equation 2; Table 5). Soil extracted Mg in the Gypsum treated soil (8.29) was significantly greater than control soils (3.25 mg/kg). No other treatment significantly increased soil extracted Mg (data not shown). Total loadings of Mg from different treatments were similar (Table 6) suggesting that Mg was more soluble in Gypsum. Table 5 supports this suggestion, where Mg in Gypsum is approximately 100 times more water-soluble that any other treatment. However, in some cases the effects of Mg on the sodic nature of soils is questionable (Rengasamy 1987). These data confirm the influence of additive extractable Ca on SAR values but also highlight that extractable Ca (as defined in this report) does not, in some cases (Gypsum), give a good indication of additive Ca solubility, or rate of solubility, in soil.

At Site 1 and 2, no significant treatment effects were found for extractable Na or Cl, or for bicarbonate extractable (plant available) phosphorus or potassium, and therefore no nutritional or toxic effects from these elements would be expected.

Effects of additives on soil pH were greater on the sandy weakly buffered soil (Site 1) where pH varied from 5.5 to 7.5. At Site 2, a heavy textured and stronger buffered soil, similar trends in pH changes occurred but to a lesser extent were pH varied from 7.5 to 8 (Figure 15). At Site 1, Kiln-dust A and B significantly increased pH compared to control soils and Gypsum significantly decreased pH (Figure 15). However, at Site 2 there were significant increases in soil pH due to application of Kiln-dust A and B, but no significant decreases due to Gypsum. Aglime had no significant effects on soil pH at either site (Figure 15). Changes in pH and effects on nutrient/metal availability are discussed below (6.1.4.2). These data highlight the effectiveness of Kiln-dust to increase soil pH and the obvious benefits on acid soils.

Soil electrical conductivity (EC) was significantly increased from control plots in the Gypsum treatments at Site 1 only (Figure 16). The increased EC in the Gypsum treatment would only affect salt sensitive crops grown on the soil, and yield reduction would probably not be significant (discussed below; ANZECC, ARMCANZ 2000). All other treatments at both sites had no significant effect on soil electrical conductivity.

Total metals added annually were one order of magnitude below those specified by the South Australian Department of Environment and Natural Resources as appropriate (Anon 1996a; Table 14). Total metals added are also orders of magnitude below the cumulative contaminant loading (CCL) limit specified for irrigation water contaminants (Table 6). There were no significant increases compared to control soil in total metals in any treatment soils. Arsenic concentrations were below the detection limit of the ICP (2.5 mg/kg). Long-term annual application of such concentrations should not lead to increases of heavy metal concentrations in soil that would significantly influence plant metal concentrations (discussed below). However, further monitoring in the future is required to confirm this.

6.1.4.2 Plant Yields

At Site 1 additives had no significant effect on yields of carrots (Figure 17). However there was a significant increase in the number of forked carrots (decrease in quality) grown with the Kiln-dust A additive (Figure 17). Other treatments has similar concentrations of calcium (Figure 13 and Figure 14) added suggesting this was not an affect of calcium, however, Kiln-dust A and B both increased soil pH greater than other treatments (Figure 15). There was a significant effect ($p<0.0001$) of soil pH on number of forked carrots (Figure 18). As soil pH increases above approximately 6.5 (Figure 18; Kiln-dust A and B, Site 1) the numbers of forked carrots increased. These data suggest that increases in soil pH above 6.5 will lead to a decrease in carrot quality (number of forked carrots). However, further research is required to confirm this.

At Site 2 additives had no significant effects on total yields (data not shown), however, Kiln-dust A and B delayed tomato ripening and probably maturation of plants (Figure 19). Similar to the forking of carrots, the delay of plant maturation was probably due to the high soil pH of these treatments (Figure 15). Tomatoes were harvested 4 to 5 days before the growers' first picking. The total tomato yield (green and ripe) for plants grown in the Kiln-dust A and B treatments was not significantly different from the control plant yields. However, the lower yield trend of the plants grown with the Kiln-dust A and B treatment is most likely due to the early harvest and delay in maturing from the higher soil pH. It is generally accepted that higher soil pH decreases availability of some nutrients. In this case a pH of 8 (Kiln-dust treatments) compared to 7.5 (controls) has been sufficient to delay maturing. However, there were no significant differences in tomato plant or fruit nutrient concentrations at harvest. Differences may have been greater earlier in the growing season.

6.1.4.3 Metals.

Of the metals analysed in the plant material (Cd, Cu and Zn), in only one case (Cd in carrots) did plant metals exceed the MPC (Table 14). However, mean plant Cd concentrations for edible portions of carrots exceeded the MPC for all treatments. Only one soil additive (Gypsum) increased carrot Cd concentrations significantly from carrots grown on the controls plots (Figure 20). There were no other significant decreases or increases of metals in edible portions of plants (eg. Tomato Cd Figure 20; data not shown for other metals). The Gypsum additive had lower loadings of Cd added as impurities (Table 6), however, this treatment had the greatest effect on soil pH and EC (Figure 15; Figure 16). Further data analysis highlighted a significant relationship between soil pH and concentration of Cd in carrots ($r^2=0.38$; Figure 21). This relationship was not significantly improved if soil electrical conductivity was also considered ($r^2=0.41$; Figure 22). The pH coefficient in the planer plot (Figure 22) significantly affected carrot Cd concentrations ($p<0.0001$), however, the EC coefficient did not ($p=0.06$). Both variables were able to explain 41% of the variation. A higher EC range could have had a significant effect on carrot Cd concentrations (Table 14). Others have found good relationships between irrigation water EC, soil EC, soil pH and Cd uptake by potatoes (McLaughlin 1999; McLaughlin et al 1996).

Table 14. Maximum permitted concentrations of metals in foods (Anon 1993).

Metal	Relevant food category	MPC[A] in food (mg/kg)	Carrot[B] (mg/kg)	Tomato[B] (mg/kg)
Arsenic	All other foods	1.0	nd	nd
Cadmium	Leafy vegetables	0.1		0.008 fw[C]
(Anon 1997)	Root and tuber vegetables	0.1	0.16	
Copper	All other foods	10.0	3 dw[D]	21 dw[D]
Lead	Vegetables	2.0	nd	nd
	Tomato products	2.5		
	All other foods	1.5		
Mercury	All other foods	0.03	nd	nd
Zinc	All other foods	150	20 dw[D]	42 dw[D]

[A] MPC = Maximum permitted concentration
[B] Grand means including all treatments
[C] fw = fresh weight (Carrot mean fresh weight = 84%. Tomato mean fresh weight = 95%)
[D] dw = dry weight
nd = not determined

The above data indicate that at the additive application rates in this study (ie. at or below the metal loading rates for biosolids; (Anon 1996a) potential toxic metals (Cd, Cu and Zn) will not lead to significant increases in plant metal concentrations from increased soil metal concentrations in the short-term. However, changes in soil pH caused by additives had a significant effect on Cd uptake (Figure 21 and Figure 22). The range of soil electrical conductivities experienced in this study, soil electrical conductivity did not significantly affect carrot Cd concentrations (Figure 22). However, higher electrical conductivities could affect Cd uptake.

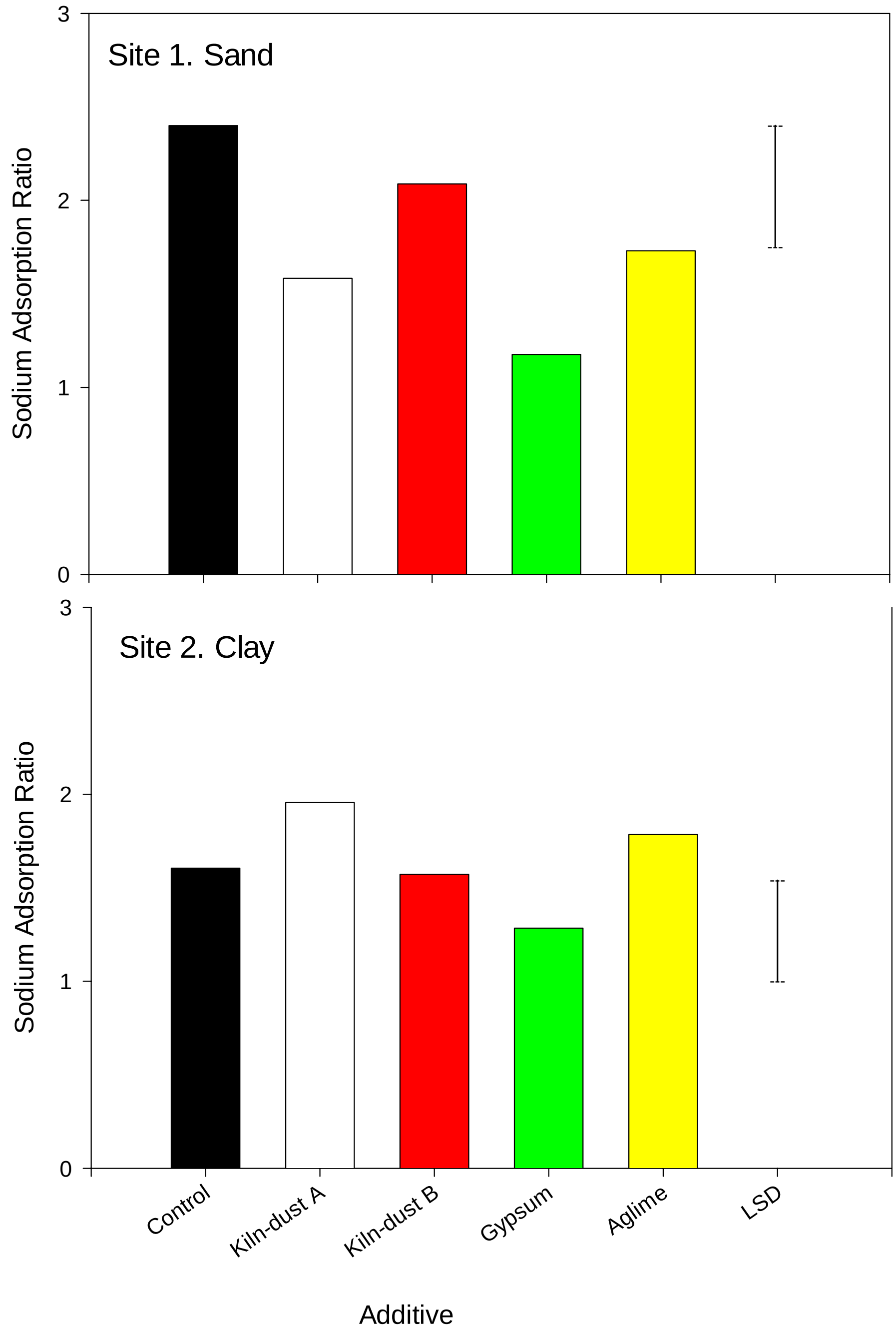

Figure 12. Effect of additives on sodium adsorption ratio (SAR). LSD = Least significant difference determined from ANOVA (Anon 1998) using all treatments.

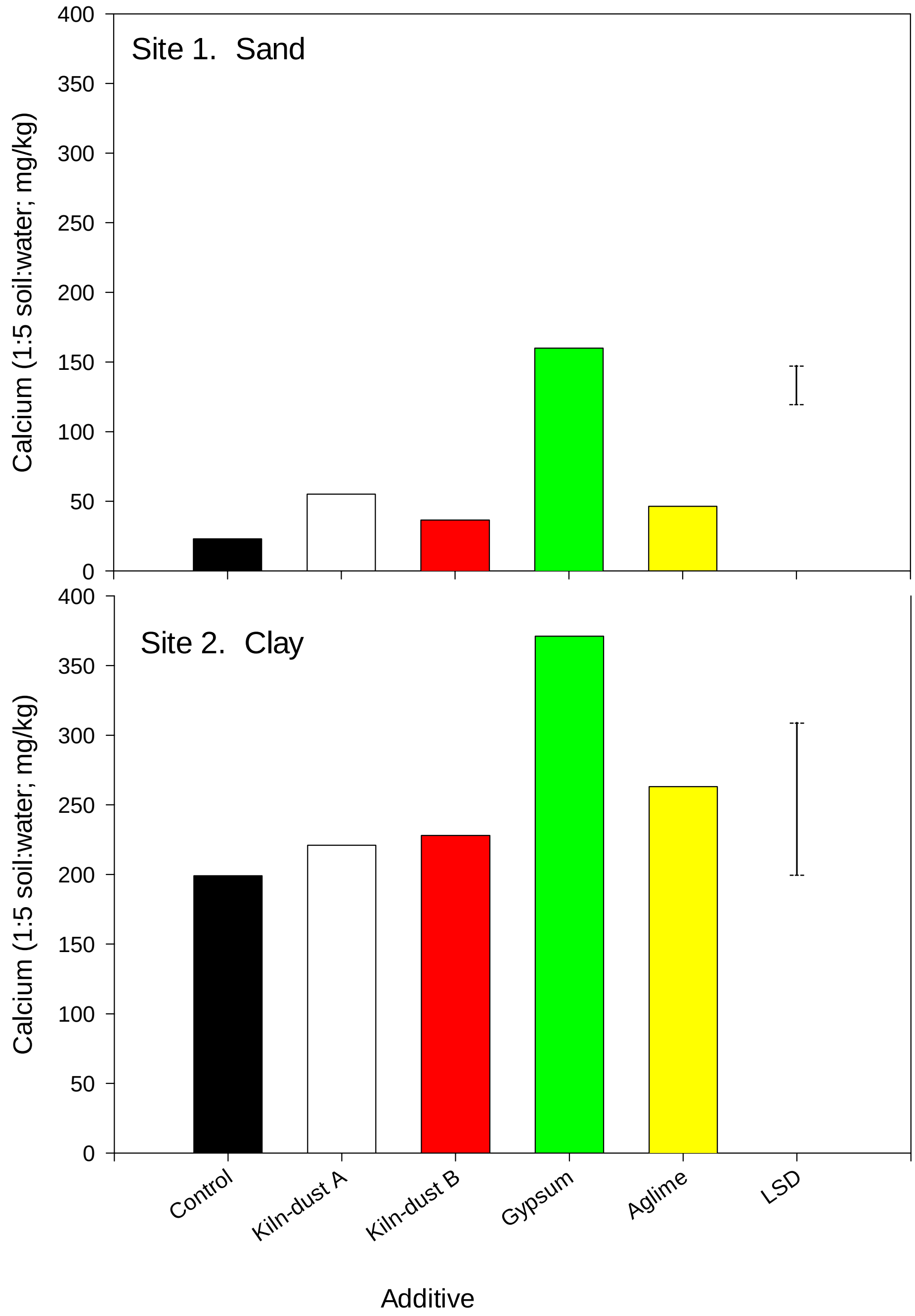

Figure 13. Effect of additives on soil water extractable calcium. LSD = Least significant difference determined from ANOVA (Anon 1998) using all treatments.

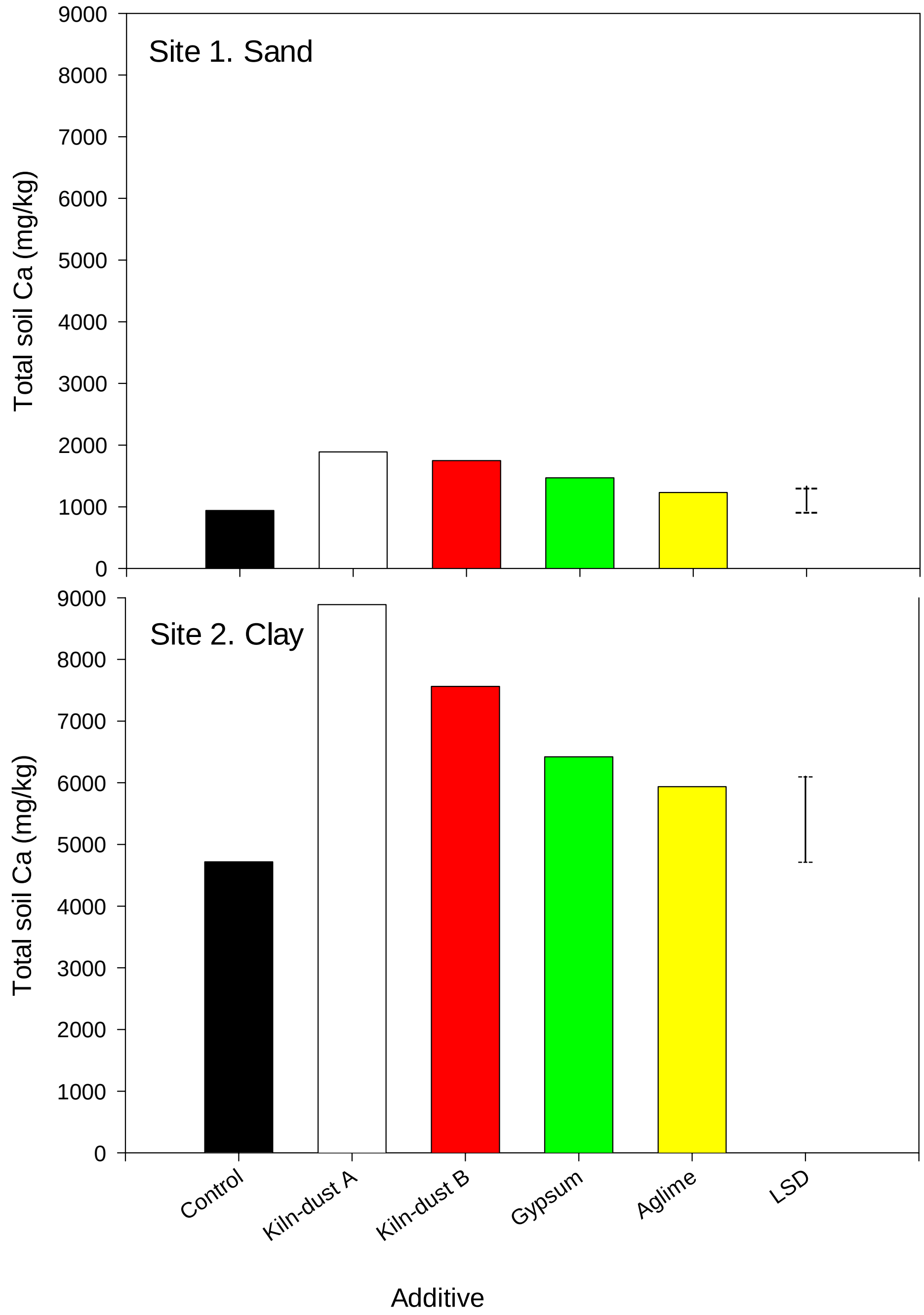

Figure 14. Effect of additives on total soil Calcium. LSD = Least significant difference determined from ANOVA (Anon 1998) using all treatments.

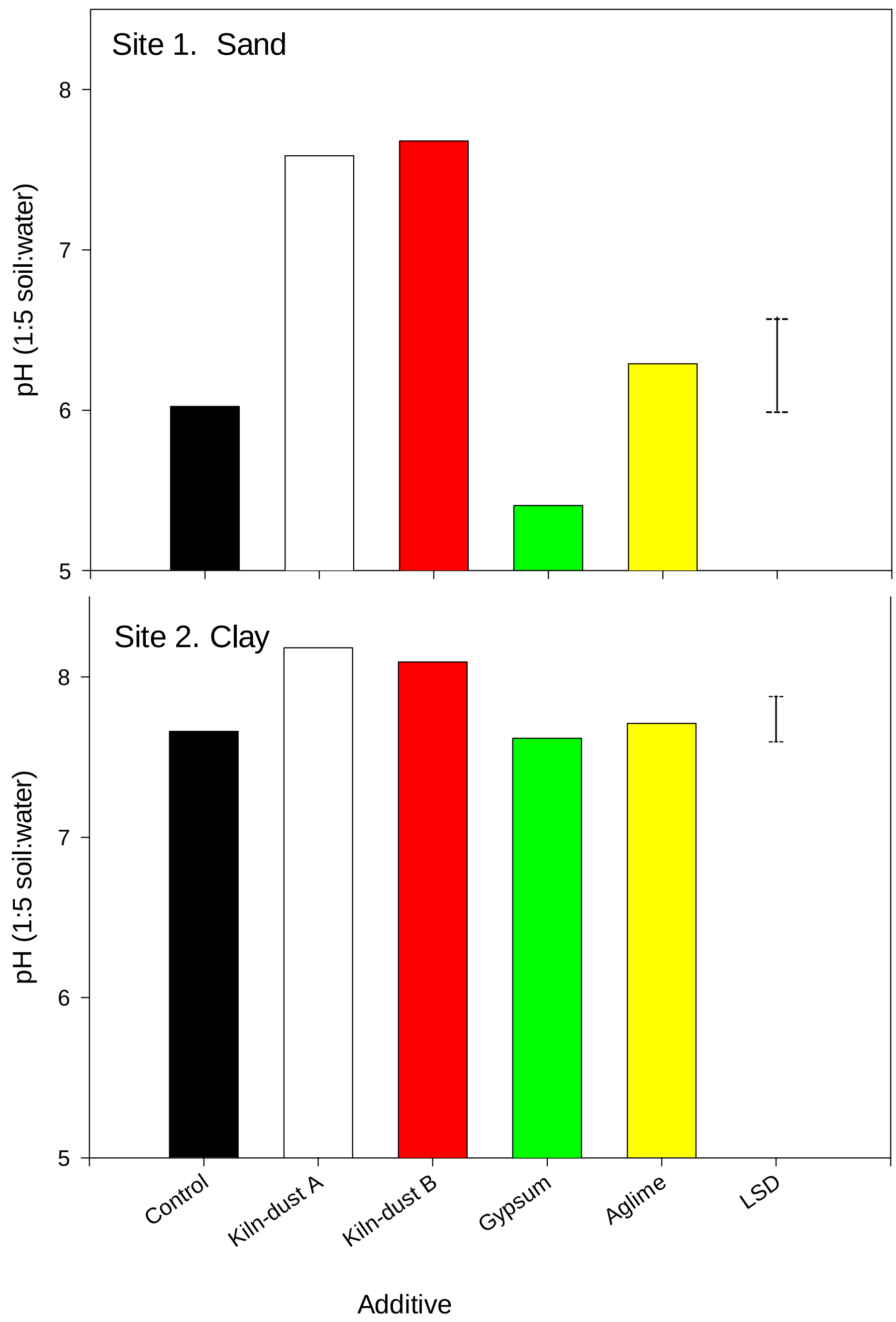

Figure 15. Effect of additives on soil pH. LSD = Least significant difference determined from ANOVA (Anon 1998) using all treatments.

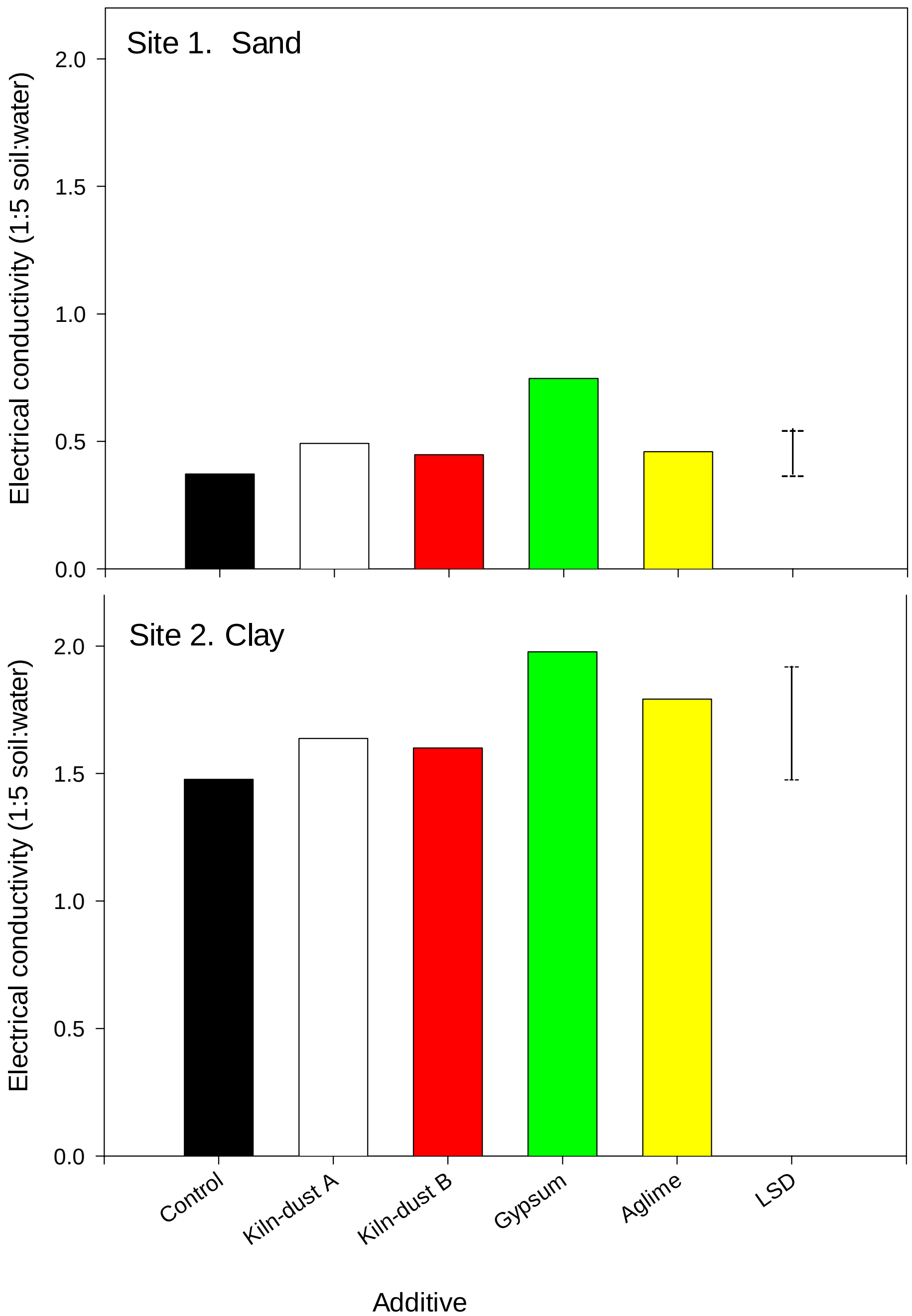

Figure 16. Effect of additive on soil electrical conductivity. LSD = Least significant difference determined from ANOVA (Anon 1998) using all treatments.

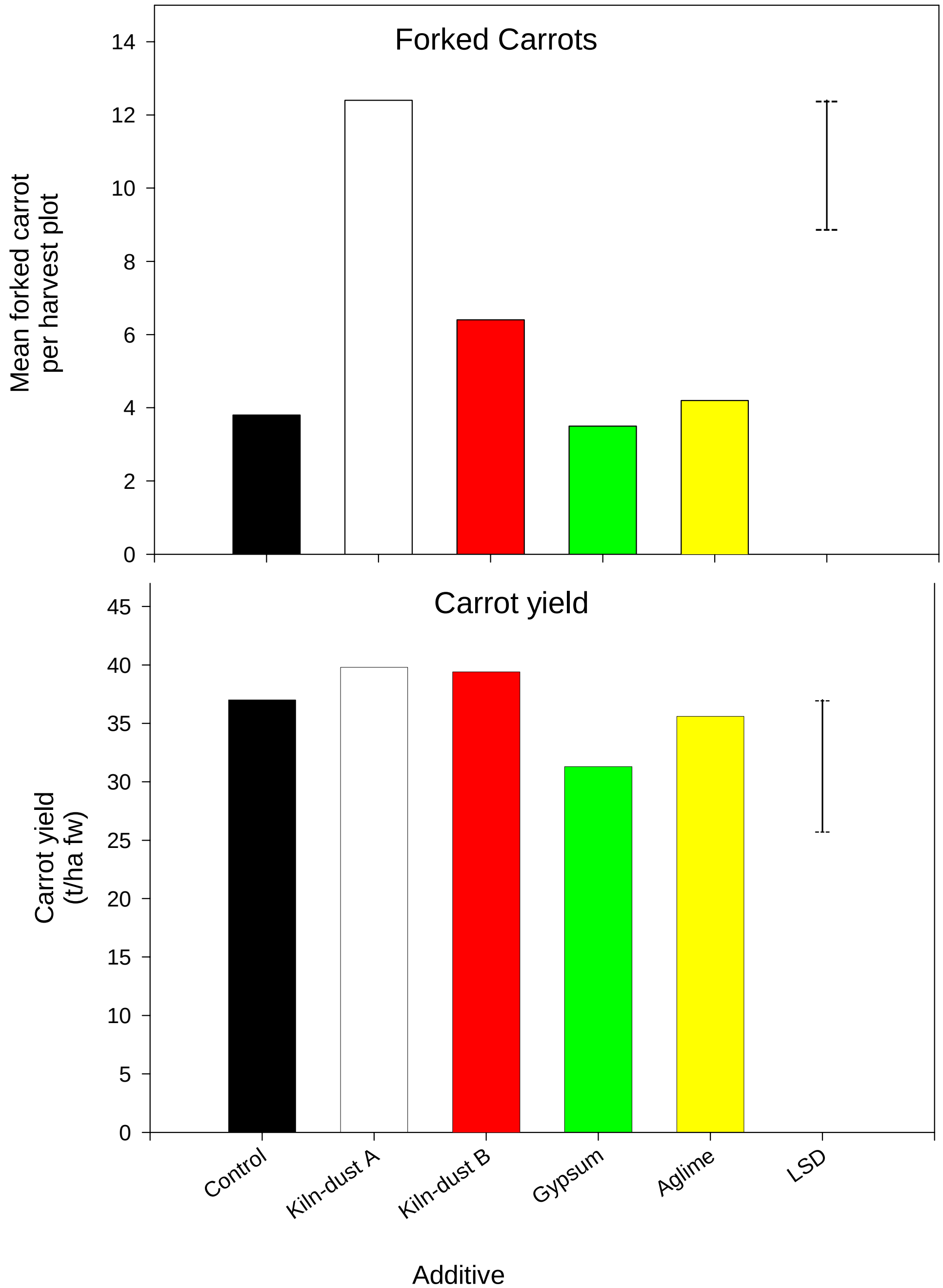

Figure 17. Effect of additive on Carrot yield and quality; Site 1. LSD = Least significant difference determined from ANOVA (Anon 1998) using all treatments.

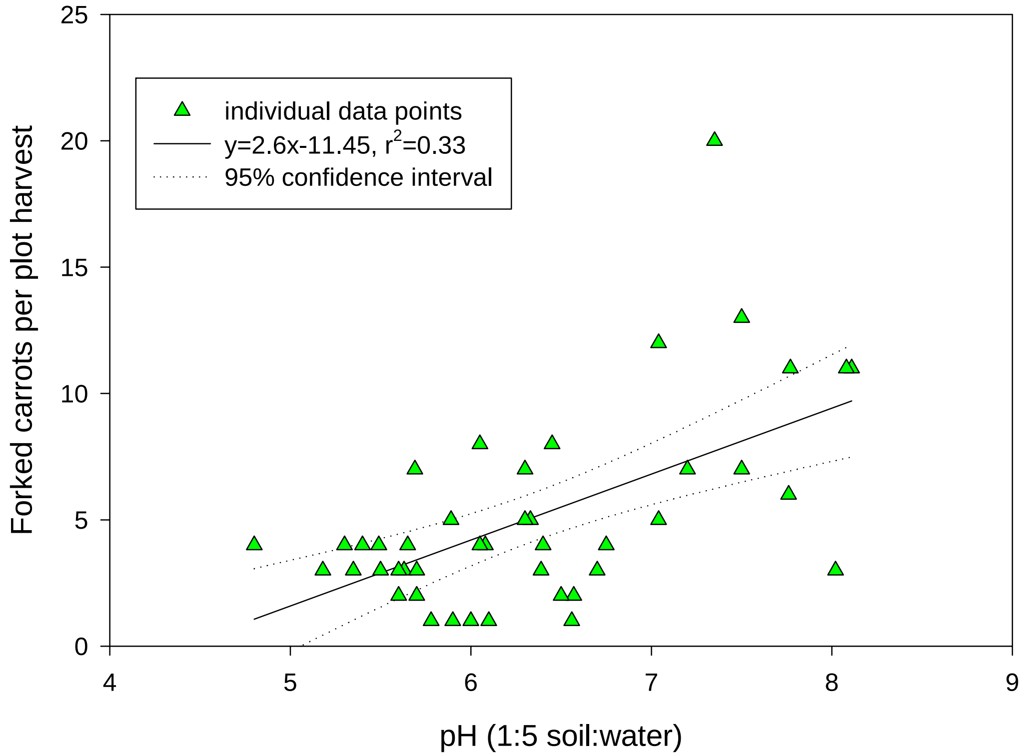

Figure 18. Effect of soil pH on number of forked carrots. All treatments, Site 1.

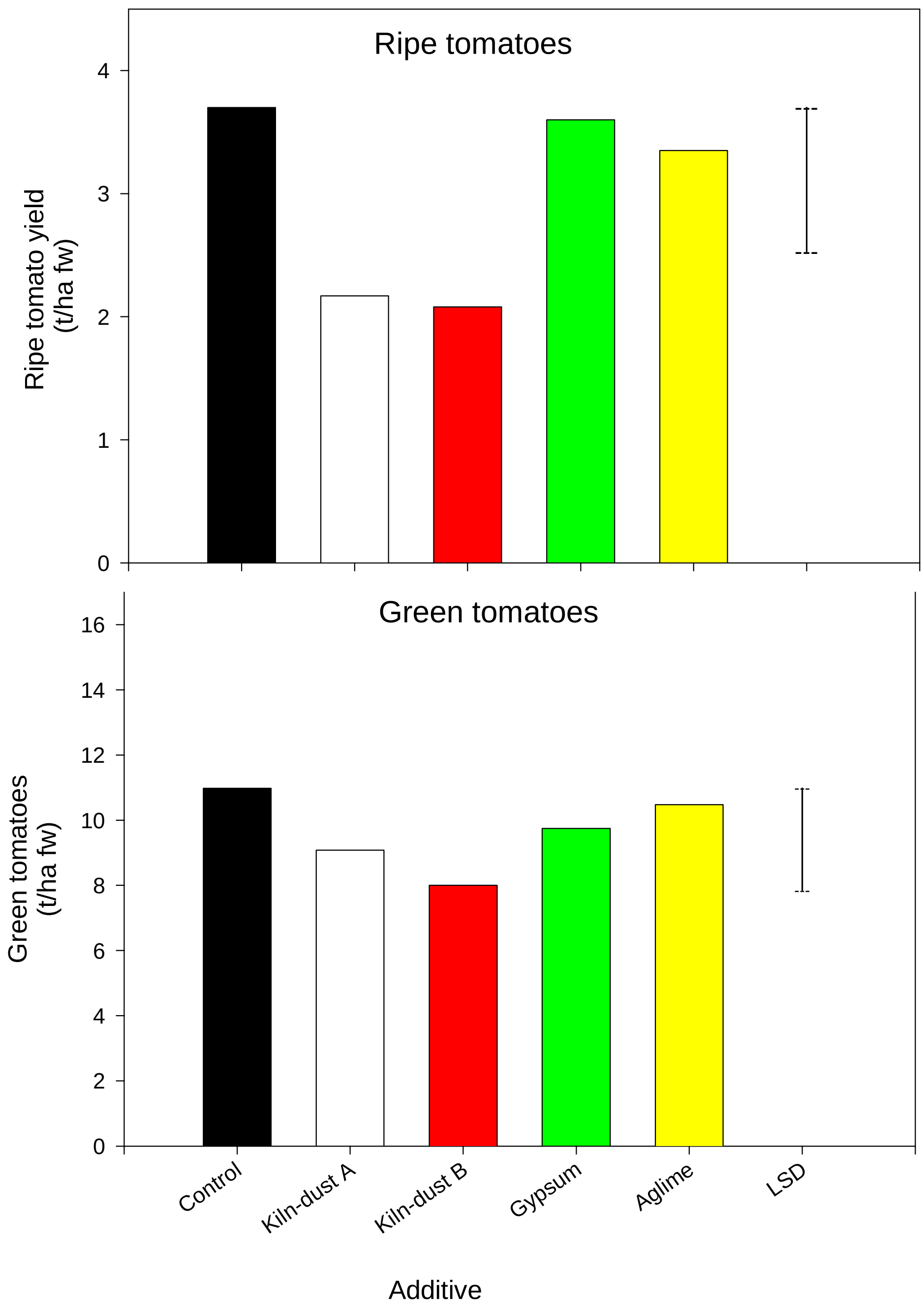

Figure 19. Effect of treatment on tomato yields. LSD = Least significant difference determined from ANOVA (Anon 1998) using all treatments.

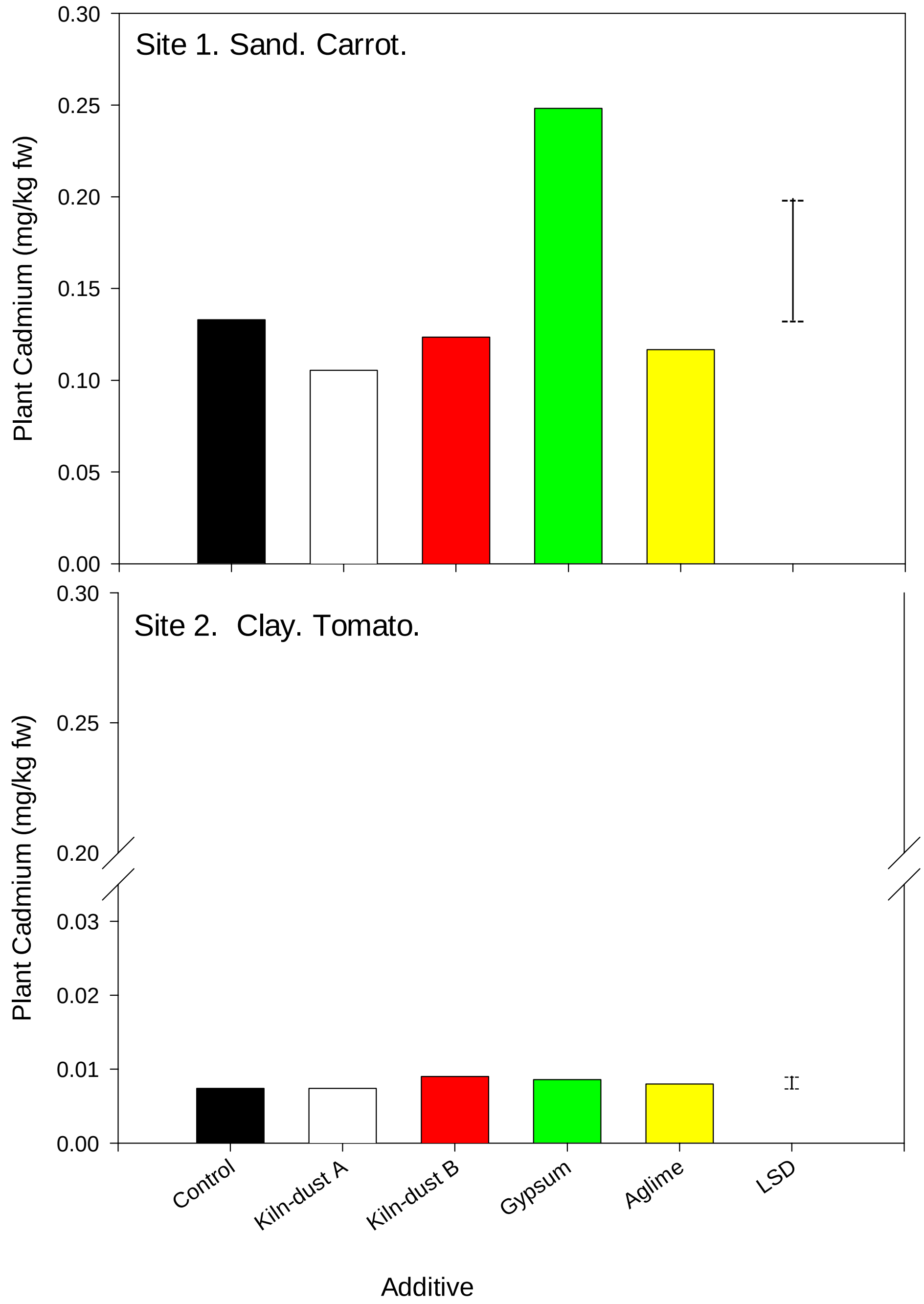

Figure 20. Effect of additives on cadmium concentrations in plant edible portion. LSD = Least significant difference determined from ANOVA (Anon 1998) using all treatments.

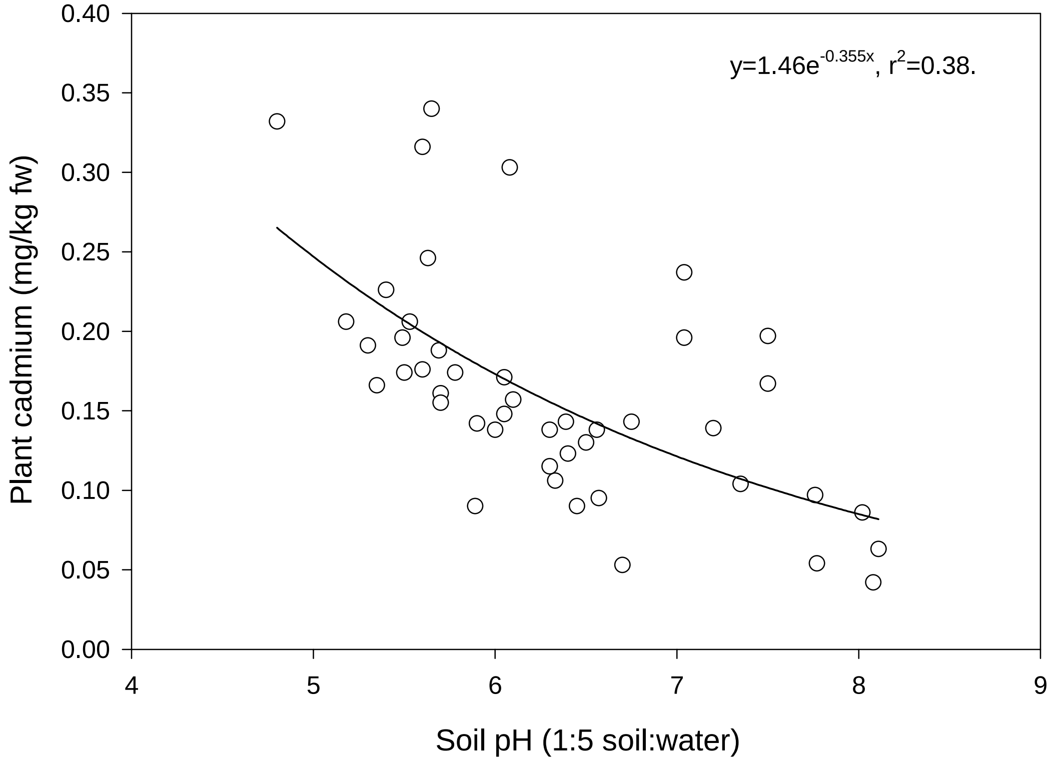

Figure 21. Effect of soil pH on carrot cadmium concentration

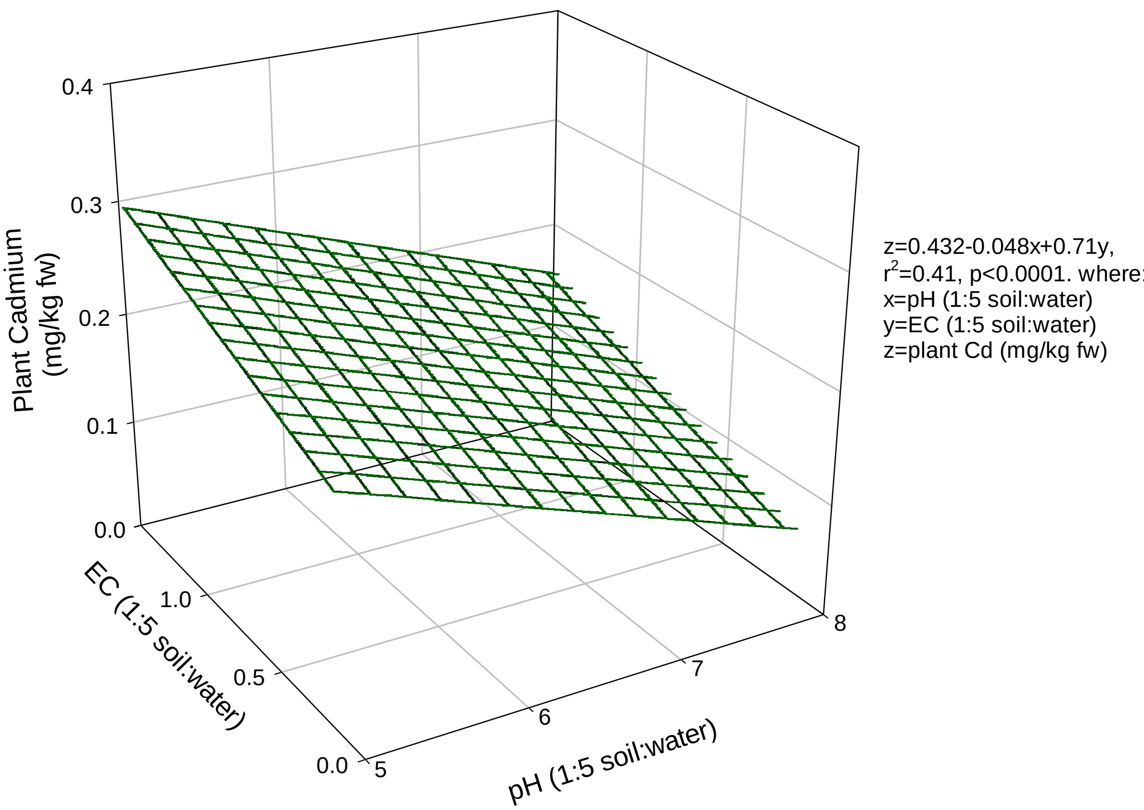

Figure 22. Effect of soil pH and electrical conductivity (EC) on cadmium concentrations in edible portions of carrots.

6.2 Produce quality

6.2.1 Heavy metals in vegetables on the NAP – a baseline study

Final analysis found no vegetables from the Northern Adelaide Plains sampled as part of the Pesticide Residual Surveys exceeded the Maximum Permissible Concentration (MPC) for Cd (FSANZ 2003). For the one sample that did exceed the MPC for Cd, contamination was suspected, and a re-sampling and analysis confirmed contamination. The resampled plant material had less than half the ML for Cd.

The data from these analyses has been incorporated in the National Cadmium Minimisation Strategy database for Cd in Australian produce (HAL Project VX03013).

6.2.2 Heavy metals in produce grown in field trials

Concentrations of cadmium in carrots from the control sites of one field site were 1.5 times the MPC. Field trial data analysis confirmed soil pH to be the major cause of increased carrot cadmium concentrations and appropriate recommendations have been extended to the relevant grower and appropriate brochures (Cadmium in potatoes. Managing the risk from saline irrigation water) displayed at the VHC. See Section 6.1.4.3 for detailed results and discussion.

Recently work from this project has also been used in the development of another industry information brochure on “Cadmium in Vegetables”, published by the National Cadmium Minimisation Strategy (HAL project VX03013: http://www.cadmium-management.org.au).

6.2.3 Microbial or algal contamination of vegetables by irrigation with reclaimed water

6.2.3.1 Algal biomass

For chlorophyll-a concentrations in samples, statistical analysis indicated that there were significant interactions between water source and storage type ($p \leq 0.05$) and water source alone ($p \leq 0.001$). Algae biomass was much greater in CARW compared with bore water in both dams and tanks (Figure 23).

There were lower algae biomass in tank and dam storage facilities when covered compared to open (Figure 23). These data indicate that covering storage facilities can restrict algae growth, possibly due to restricted availability of light. Algae are photosynthetic and require adequate sunlight for growth and are favoured by low turbulence, higher temperatures, abundant nutrients and sufficient sunlight (ANZECC and ARMCANZ, 2000).

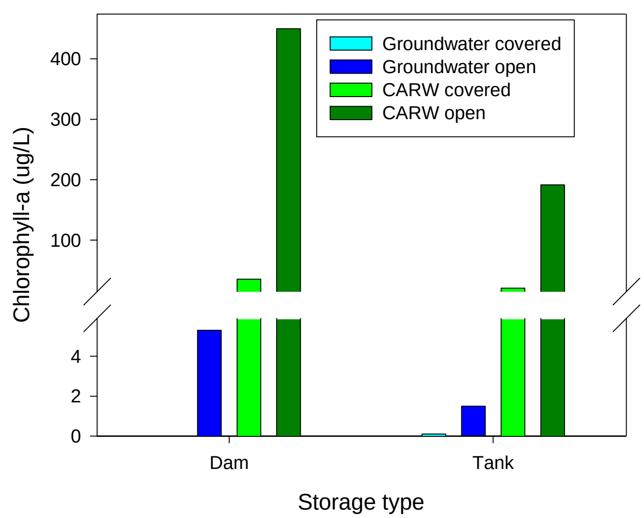

Figure 23. Effect of covered and open dam and tank storage on mean chlorophyll-a concentrations in stored CARW (Class A reclaimed water) and groundwater. Average standard error of difference = 138, n = 32. No sites were identified where bore water was stored in a covered dam.

There were no significant ($p \leq 0.05$) changes in algae population with sampling temperatures, suggesting that the difference between moderate temperatures (22^{o}C) compared with high temperatures (37^{o}C; Table 15) experienced over a 5-day period does not affect algae numbers. This is possibly due to two opposing factors: higher temperatures increase algae growth, but high temperatures also create a higher demand for irrigation water, leading to increased storage water turnover. This may limit algae growth due to reduced time for the development of algal blooms and increased turbulence.

Table 15. Mean maximum daily temperatures for a five-day period for the moderate and high temperature samplings.

Moderate Temperature Sampling		High Temperature Sampling	
Sampled 06/11/00	Max daily temp (^{o}C)	Sampled 05/01/01	Max daily temp (^{o}C)
01/11/00	21	31/12/00	32
02/11/00	22	01/01/01	41
02/11/00	22	02/01/01	39
04/11/00	22	03/01/01	37
05/11/00	22	04/01/01	38
Mean daily max.	22^{o}C	Mean daily max.	37 ^{o}C

Temperature information was gained from the South Australian Bureau of Meteorology from the Edinburgh station.

Lower algal populations in tanks compared with dam storages in this study could also be explained by storage water turnover. Tanks have a higher rate of water turnover due to their relatively lower storage volume, which may limit algae growth.

Observations in the field support this theory regarding the limiting effects of water turnover. Algal problems experienced in the field were observed to be far greater in the summer of 1999-2000 (when irrigation demand was relatively low) when compared with the summer of 2000-01 (when irrigation demand was high). In 2000-01, Adelaide had the warmest mean maximum temperature since 1905-1906 (Bureau of Bureau of Meteorology 2001) and a low summer rainfall that lead to a high irrigation demand in the summer of 2000-01. Consequently when there is high demand, turnover is short and there is generally insufficient time for the development of algal blooms and an increase in turbulence in storage due to receiving and removal of water.

6.2.3.2 Algal species present

Analysis of the water samples showed many species of green, blue-green and golden algae present in the water and large differences in numbers and species of algae present in both water sources (Table 16). Potentially toxic species of algae were found in both CARW and ground water storages. Only one species of blue-green algae that could potentially produce toxins (*Microcystis flos-aquae*) was found in significant numbers. It was detected in CARW but not groundwater. Up to 178,000 cells/mL of *Microcystis flos-aquae* were detected at the point of entry of water from the DAFF plant to the WRSV holding lagoon while the highest concentration found in on-farm storage was 49,000 cells/mL.

It is important to remember that only certain species of blue–green algae are potentially toxin producing. The SA guideline (Fitzgerald, et al., 1999) for acute exposure in drinking water is 50,000 toxin producing *Microcystis* cells/mL (based on consumption of 2 Litres per day). This guideline is for drinking water and is not directly transferable to water for irrigation and the production of vegetables. However, there were no on-farm storages exceeding this guideline value. There is no trigger value for algae in irrigation water (ANZECC and ARMCANZ, 2000).

Table 16. Species list of blue-green algae found in on-farm storage on the Northern Adelaide Plains.

Taxa	Maximum count (cells/mL)	Water source
Anaebaena	19,300	Groundwater, dam
Anabaenopsis	9,800	Groundwater, dam
Aphanizomenon	<1	Groundwater, dam
Arthrospira	42	CARW, dam
Microcystis[A]	178,000	CARW, dam and tank
Lyngbya	<1	CARW, tank
Oscillatoria	1	Groundwater, dam
Phormidium	40	Groundwater & CARW water, dam and tank
Planktothrix	872	Groundwater & CARW water, dam and tank
Pseudanabaena	400	Groundwater & CARW water, dam and tank

[A]The toxicity of *Microcystis flos-aquae* has not been established in the scientific literature. This species is generally considered to be non-toxic, but the potential for some strains to produce toxins cannot be ruled out. Even for "potentially toxic" species of blue-green algae, toxin production can vary both spatially and temporally and will depend on the particular strain of the species that is dominant and/or the prevailing environmental conditions.

The large number (or bloom) of *Microcystis flos-aquae* identified in this report at the high temperature sampling was an unusual event and was not identified in the moderate temperature sampling. This bloom was likely to be due to the extreme environmental conditions experienced during the summer of 2000-01 as discussed earlier. Both raw and treated water for the VPS scheme are monitored continually by United Water for turbidity, a measure which can detect changes in algae populations. The turbidity of filtered water is measured for operational reasons. Turbidity limits are set in Department of Human Services approval conditions and there has always been a notification system. As a result of this study, very high turbidity in raw water, as occurred this summer, will be used to trigger increased surveillance for algal species in the future.

6.2.3.3 Microbial contamination of vegetables.

There were no significant differences in counts of *Salmonella*, thermotolerant coliform or *E.coli* on any of the plants analysed when plants irrigated with CARW were compared to plants irrigated with groundwater, or plants sampled from the market place. There were also no significant differences between plant species when compared between irrigation water type or market samplings. However, coliforms were significantly higher in crops sampled from the market place (Figure 24) compared with crops sampled from the field and grown with reclaimed or bore water. These data suggest that there is a greater risk of pathogen contamination from harvest, transport or market place contamination, than from irrigation with CARW. However, levels for all crops are still very low and there are negligible risks to consumers (Table 17).

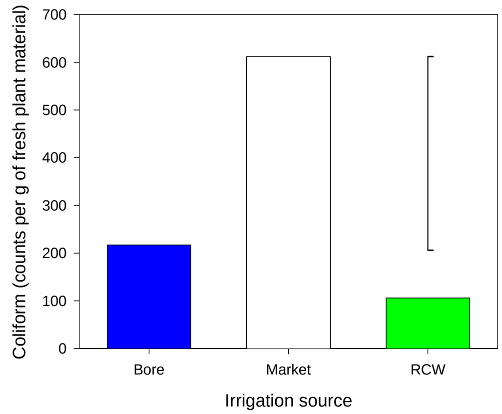

Figure 24. Effect of irrigation water source on mean coliform counts. Error bars represent the least significant difference.

Table 17. Comparison of mean pathogen counts on plant tissue irrigated with reclaimed, groundwater, or from the market place.

	(org./25g)	(Organisms/g)		
Source of Produce	Salmonella	Coliform	Faecal Coliforms	E.coli
Reclaimed Water	0	106	3	1
Groundwater	0	217	101	101
Market Place	0	612	39	38

There are no microbiological food standards for vegetables with the exception of some cultured seeds for example, bean sprouts, which have been identified as causing food borne outbreaks of salmonellosis. Presence of moderate numbers of coliforms and *E.coli* are to be expected given that these vegetables are grown in soil, and not in sterile environments.

Class A Reclaimed Water is required to contain < 10 thermotolerant coliform (or *E.coli*)/100 mL (DHS, EPA SA 1999). At these levels, the risk of contamination of produce from this water which could lead to health concerns is not significantly different to produce grown with more traditional water sources (i.e.very low). Data in this report and the work of others (Sheikh et al 1990; Sheikh et al 1999; Shuval et al 1997) confirm the safety of irrigation of vegetables with CARW. To put these findings into perspective, the standards for CARW are in fact stringent in comparison to other sources of water used for irrigation of horticultural produce (e.g. the Murray River; Table 18).

Table 18. Comparison of *E. coli* in Class A reclaimed water and Lower River Murray water

	E. *coli* (count/100mL)		
Source of Water	Average	Median	Std. Deviation
Class A Reclaimed Water[A]	1.66	0	8.2
Lower River Murray[B]	69.9	33.5	83.1

[A]SA Water (DAFF plant 14 July 00 – 29 March 01)
[B]Modified from Anon 1985-1989 (several sampling site on the Lower River July 1978 to June 1988)

6.3 Water & Nutrient Mass balance

6.3.1 Water quality

Water quality data for field experimental sites and soil cores sites have been reported elsewhere (Stevens et al 2003). Water quality from our independent analysis was similar to those supplied by Water Reticulation Service Virginia, in their Irrigation Management Plan reports (Anon 1999; White 2002; White 2001).

6.3.2 Nutrient balances

Data acquired from continual monitoring of on-farm storage facilities improved nutrient balance models for several horticultural crops. One of the major outcomes was the quantification of nitrogen losses (i.e. 20%) from the Water Treatment Plant storage lagoon to on-farm storages during the irrigation season. Other nutrients remained relatively constant over the experimental period. Fertiliser input from reclaimed water, for tomatoes, potatoes and carrots, was generally less than half of the plants nutritional demands for wet and dry years. These data were verified by comparison with data obtained from other studies and have been incorporated into the user manual (Kelly et al 2001). However, in some cases (eg. dry years and onions), there was a significant excess fertiliser value from irrigation with reclaimed water

Modification of the water treatment plant (addition of biological nutrient removal) led to significant changes in requirements for nutrient management when irrigated with reclaimed water (ie. significant decreases in N and P concentrations). Changes in nutrient concentrations in reclaimed water have been addressed in the Grower Manual (Kelly et al 2001). Standard nutrient concentrations for a range of horticultural crops (Creswell, Huett 1998 and local meteorological data have been used to calculate nutrients supplied through the use of reclaimed water (Table 19).

Table 19. Elements supplied in reclaimed water at different irrigation rates.

	Irrigation Applied (mm)								
Element	300	400	500	600	700	800	900	1000	
$Nitrogen_{(total)}$	14.8	19.7	24.7	29.6	34.5	39.5	44.4	49.4	Nutrient applied kg/ha.
Phosphorus	5.1	6.8	8.5	10.2	11.9	13.6	15.3	17.0	
Potassium	131.7	175.6	219.5	263.4	307.3	351.2	395.1	439.0	
Calcium	122.1	162.8	203.5	244.2	284.9	325.6	366.3	407.0	
Magnesium	120.0	160.0	200.0	240.0	280.0	320.0	360.0	400.0	
Sodium	936.0	1248.0	1560.0	1872.0	2184.0	2496.0	2808.0	3120.0	
Chloride	1377.0	1836.0	2295.0	2754.0	3213.0	3672.0	4131.0	4590.0	
Boron	1.1	1.5	1.8	2.2	2.6	2.9	3.3	3.7	

The success of the grower manual has recognised by the number of reprints required and several schemes across Australia potential using this manual as basis of the development of their own on site specific grower manuals. Collaborative links on irrigation technology and management were also developed through the related PIRSA/NHT/Landcare project managed by Steve West (highlighted in the initial VG97081 proposal). Water samples from soil core sites and field trial sites were analysed and a more comprehensive water sampling took place when the DAFF (Dissolved Air Flocculation and Filtration) treated pipeline water came on line in August 1999.

6.4 Groundwater

6.4.1 Groundwater monitoring

All analysis was within 5% relative standard deviation of certified values and recovery of total N was 101 ± 4.1 %. All chemical data generated from the analysis of water samples are tabulated in the report to the NABCWMB (. These data form the baseline or reference point for aquifer water quality on the NAP. Some difficulties in sample collection and interesting chemical and spatial relationships are highlighted and discussed below.

6.4.1.1 Sampling

Due to the poorly maintained historical data relating to the bores of the NAP only 40% of the first 75 bores selected for sampling and analysis were actually sampled. It was not possible to sample a larger percentage of the bores as many had been backfilled. This information has been supplied to the Department of Mines and Energy to assist in updating their records. A smaller number (approximately 12%) were not locatable, not equipped, or the owners not contactable (Table 20). These sampling difficulties led to the sampling procedure taking longer and being more costly than originally estimated. The first sampling (post summer) was interrupted by the onset of winter, with conditions being too wet to access and Not sure what is meant here pump bores for 30 minutes prior to sampling. None of the bores from the Q1 aquifer were sampled as they were generally abandoned, not equipped or the owners could not be contacted. Fortunately, the Irrigation Management Plan (Anon 1999) has collaborated with the installation of 14 new observation wells, the majority of these new observation bores are located on the western side of the NAP, will monitor the upper (Q1) aquifer, and will therefore act as an early warning indicator of water table rises.

Table 20. Summary of bore sampling (total number of bores = 75)

	Percentage of bores	
Outcome	1st sampling (6/4/99-24/5/99)	2nd sampling (14/9/99-1/10/99)
Sampled	40	69
Not sampled: backfilled	20	3
Not sampled: not locatable	11	9
Not sampled: not equipped	12	10
Not sampled: not contactable	13	7
Not sampled: Refused entry by owner	1	3
Not sampled: Too wet to sample	3	0

6.4.1.2 Comparison of post summer and post winter samplings

When chemical parameters from post summer sampling were regressed against post winter sampling, if the slope of the line was considered to be significantly ($p \leq 0.05$) different from 1, then significant changes in water quality occurred between seasons. For most chemical parameters there were no significant differences between post summer and winter samplings. However, compared with the post winter sampling, B and Na concentrations were significantly higher (7-9%), and Br and N (NO_3 or Total N) were significantly lower (9-17%) in the post summer sampling (Table 21). Simple linear regression using aquifer as groups indicated no significant differences between aquifers (Anon 1998). The interpretation of these findings is difficult. Generally the differences are low and near the expected analytical error of 5%. However, for N the differences were 17% indicating there are inexplicable seasonal changes in aquifer N.

Table 21. **Comparison of chemical parameters between post summer and post winter samplings. If the slope coefficient is significantly less than 1, this indicates that the element was generally present in lower concentrations in the post summer sampling period.**

Chemical Parameter	r^2	Slope Coefficient[A]	LSD[B]	Slope significantly different to 1.00
Br	1.00	0.91	0.019	significant
B	0.99	1.07	0.052	significant
Alkalinity	0.96	0.96	0.105	ns
Ca	0.99	1.02	0.063	ns
Cl	1.00	0.98	0.023	ns
EC	0.99	0.98	0.038	ns
F	0.80	0.98	0.230	ns
Fe	0.80	1.09	0.251	ns
K	0.95	1.08	0.126	ns
Mg	1.00	1.00	0.031	ns
NO_3	1.00	0.90	0.013	significant
N total	1.00	0.83	0.021	significant
Na	0.98	1.09	0.080	significant
S	0.99	0.99	0.048	ns
Si	0.98	0.99	0.063	ns
pH	0.65	0.77	0.272	ns

[A]Post winter sampling x Slope coefficient = post summer sampling
[B]Least significant difference
ns = not significant

6.4.1.3 Electrical Conductivity

For all aquifers, from both sampling times, there was a significant correlation between aquifer electrical conductivity (EC) and measured total dissolved salts (TDS; Figure 25). Approximately, $600 \times EC(dS/m) = TDS(mg/L)$. This is similar to historical data from DEHAA (pers comm. Daryl Harvey).

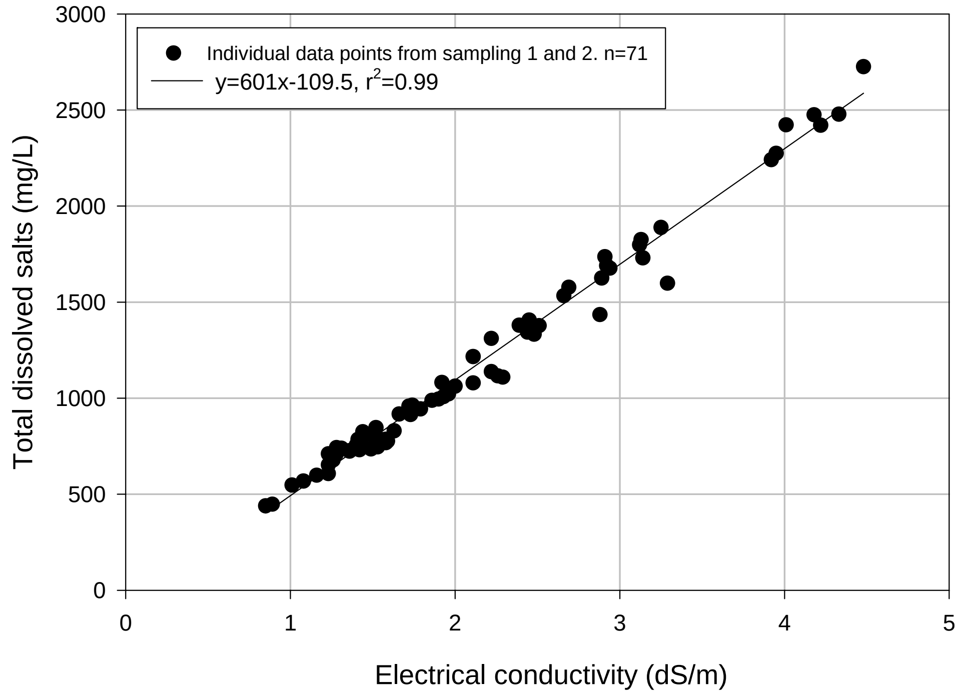

Figure 25. **Relationship between electrical conductivity and total dissolved salts of all aquifers samples from post winter and summer samplings.**

Salinity and sodicity of aquifers varied considerably (Table 22). Salinity was highest in upper Q2 aquifer and lowest in the deepest two aquifers T1 and T2. The sodium absorption ratio (SAR) followed similar trends to salinity (Table 22).

In the upper Quaternary aquifers (Q2, Q3 & Q4), EC of aquifer water varied across aquifer and the NAP (Figure 26). In general, the EC of aquifer water increased the more northerly the bore. However, there were limited samples taken from the south and west portion of the NAP. Samples from the southern region were limited for two reasons. Firstly, it was difficult to find bores which met the bore selection criteria, and secondly, such bores were often abandon or disused, probably due to the poorer quality of this water. As discussed above, the Irrigation Management Plan will allow better monitoring of the Q1 aquifer in this area.

Table 22. Changes in aquifers TDS and SAR (all data).

Aquifer	[A]n	Mean	Minimum	Maximum	Median	SD
Total dissolved salts (TDS)						
Q2	7	1934	917	2725	1730	634
Q3	10	1391	598	1888	1438	420
Q4	10	1493	439	2478	1392	813
T1	17	812	607	1062	785	116
T2	32	972	547	1736	882	325
Sodium absorption ratio (SAR)						
Q2	7	9.4	6.2	13.3	8.9	3
Q3	10	7.7	4.1	11.7	7.2	3
Q4	10	6.7	3.5	10.4	6.2	2
T1	17	5.3	3.8	7.7	5.2	1
T2	32	6.2	2.9	12.6	5.5	2

[A]n = number of observations

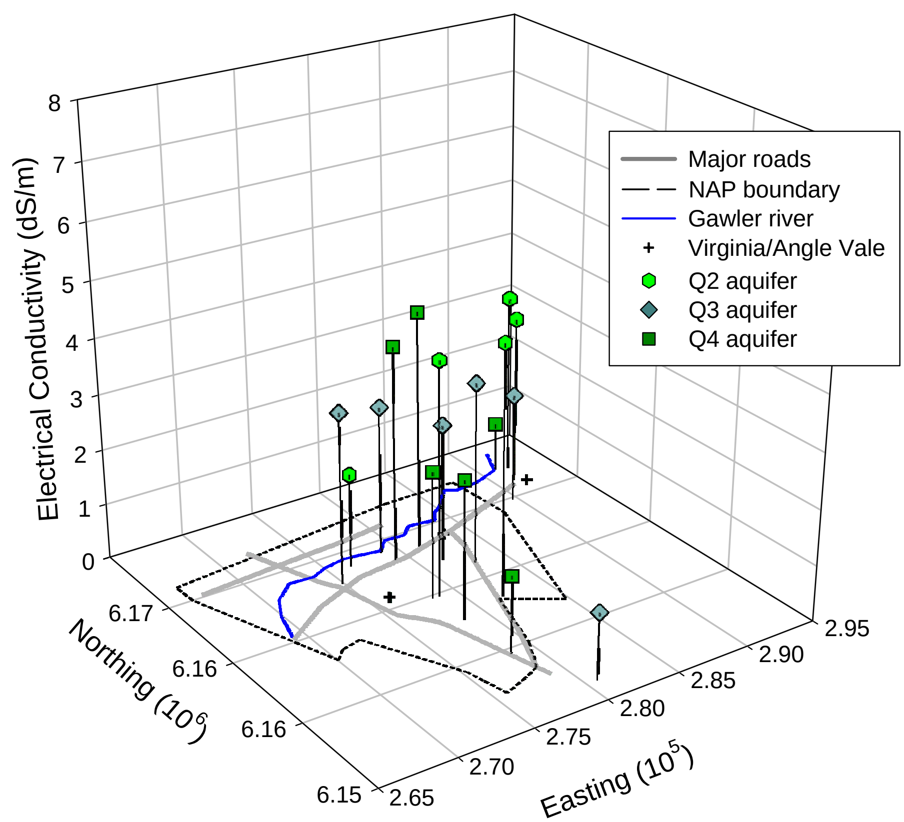

Figure 26. Electrical conductivity of Quaternary aquifers of the Northern Adelaide Plains. Samples from the post winter sampling.

6.4.1.4 Comparisons between total, dissolved and other forms of inorganic chemicals

For the first sampling period, metals were analysed by ICP on both the dissolved (<0.45µm) and total (unfiltered subsample following nitric acid digestion) fractions. These extra analyses were completed to determine what proportion of the metals present in the sample existed in solution and in colloidal form. For major elements, the correlation between dissolved and total concentrations were significant (Table 23). However for elements of lower concentrations (Fe and B), as the detection limit for the ICP was approached these correlations were poorer (Table 23). Correlations between dissolved and total concentrations for all elements were not significantly different, indicating that most of the elements were present in a dissolved form in the aquifer, rather than in colloidal form (e.g.
Figure **27**). These data suggested that analysis for total concentrations does not provide further useful information. Total concentrations were therefore not determined on the post winter sampling.

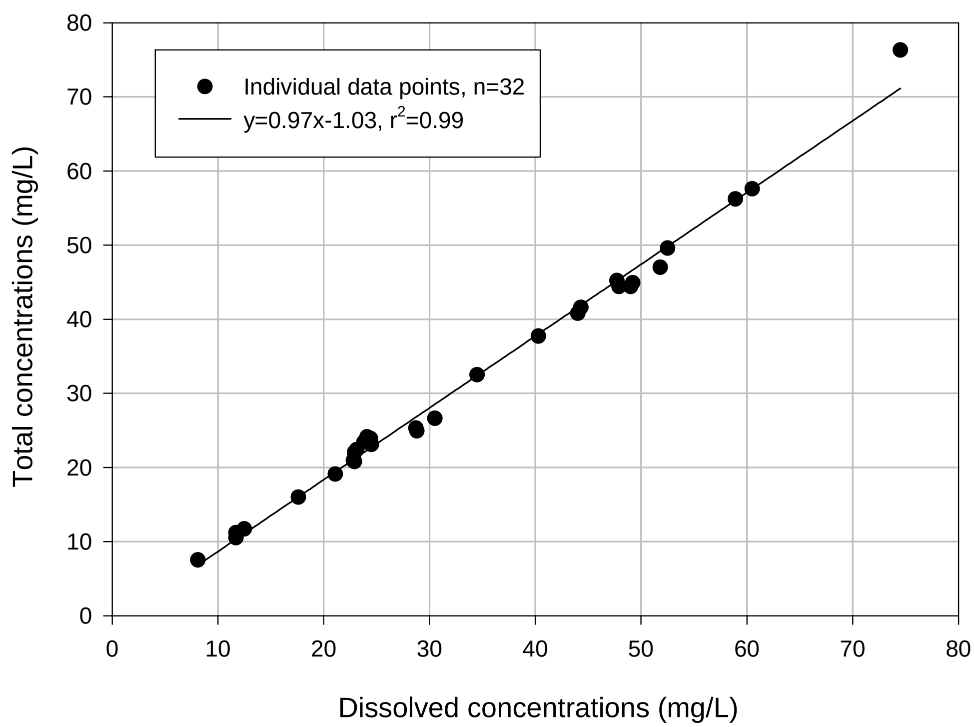

Figure 27. Relationship between dissolved and total concentration of sulfur in all aquifer samples (Q2, Q3, Q4, T1 & T2) from the post summer sampling.

Table 23. Difference between total (acid digest not filtered) and dissolved (0.45 μm filtered) elements in the post summer water samples of bores from all aquifers sampled (n=30).

Element	Coefficient of determination (r^2)	Slope[A]	Slope significantly great than 1.00
Ca	0.99	0.96	ns
K	0.97	0.90	ns
Mg	0.99	0.94	ns
Na	0.99	0.88	ns
S	0.99	0.97	ns
Fe	0.66	0.85	ns
B	0.81	0.88	ns

[A]Slope × total element concentration (mg/L) = dissolved element concentration (mg/L).
ns = not significant.

The major form of nitrogen (N) in the aquifer waters was NO_3-N (Figure 28). Higher N concentrations were generally found in the Quaternary aquifers and concentrations seemed to increase with proximity to the Gawler River (Figure 29). In some cases (one bore each in the Q3 and Q4 aquifer; Figure 29), the concentration of NO_3 exceeded the Australian drinking water guidelines NHMRC, ARMCANZ 1996. However, the salinity of these bore >1500 mg TDS/L would exclude them from use for drinking water purposes. These high NO_3 concentrations indicate aquifer contamination. Possible sources are NO_3-N leaking along corroded bore casings near these bore and/or leaking through the annulus of non-pressure cemented casings, NO_3-N leaking into the aquifer from intensive agriculture along the river, or NO_3-N leaking into the aquifer from the Gawler River. The fact that these deeper aquifers are contaminated with NO_3-N suggests that either these or nearby bores are leaky, or that there is considerable inter-aquifer leakage and short circuiting of the upper aquifers from the Gawler River.

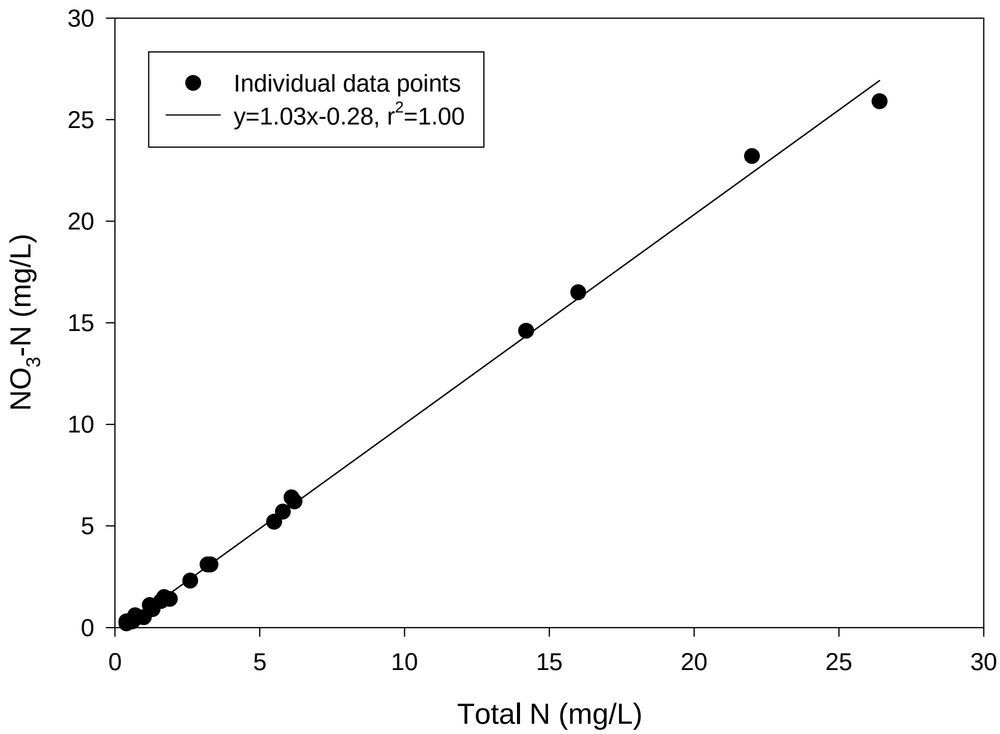

Figure 28. **Relationship between total and nitrate nitrogen forms. Data from all aquifers and post summer and winter sampling, n=25 (i.e. 25 samples with detectable NO_3-N).**

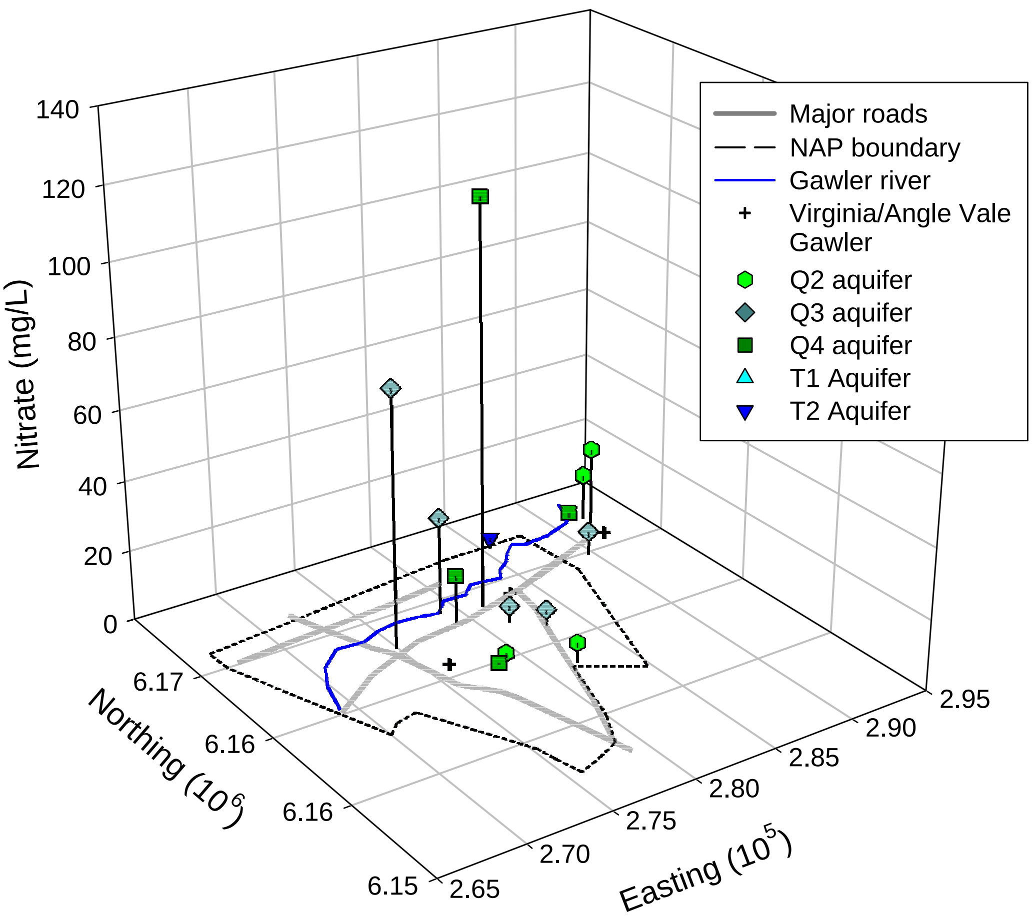

Figure 29. Nitrate concentrations in post winter bore samples. 71% of samples were < 0.05 mg NO_3-N/L.

6.4.1.5 Pesticides

In the first instance eight pesticides were analysed using HPLC-UV system, using on-line enrichment process which gave a preconcentration factor greater than 250 fold. Of the eight pesticides analysed, six pesticides were absent (Table 9 and Table 24). Two pesticides (malathion and chlorpyriphos) which were initially suspected of being present in the samples because well resolved peaks were observed at the retention times of these two pesticides. However, retention times are not a definitive proof of the presence of the pesticides, but only a substance having a similar retention time. We therefore carried out further analyses on the samples, using DAD detector which allows examination of wavelength dependence of the spectral characteristics of the two pesticides and a subsequent matching pesticide standards. This confirmatory test failed to support the presence of both of these compounds. However, there were definitely two compounds present in the samples, which were noted as unidentified compounds with concentrations which are representative of the pesticide know to have similar retention times (Table 24).

We noted that there were some similarities in spectral properties of the unidentified compounds with either malathion or chlorpyriphos. This may only suggest the presence of chemicals with properties similar to these pesticides. The actual identity of these unknown compounds, however, can possibly be established with the help of GC-MS. We have therefore preserved the sample extracts for follow up analysis.

Table 24. The amount (ng) of pesticide detected in 250 ml of water sample.

		Pesticide and concentrations				
Aquifer	Sample Number Sampling 1	simazine, atrazine, carbaryl, diuron, propazine, prometryn. (ng/250ml)	Malathion (needs confirmation)[B]	Unidentifiable compound with some similarity to malathion (Equivalent to ng of malathion)	chlorpyrifos (needs confirmation)[B]	Unidentifiable compound with some similarity to chlorpyrifos (Equivalent to ng of chlorpyrifos)
Q2	2562	nd[A]	nd[A]	23.1	nd[A]	116.5
T2	10986	nd	Nd	53.4	nd	69.3
Q4	12911	nd	Nd	nd	nd	46.9
T1	3816	nd	Nd	nd	nd	63.5
	Sampling 2					
Q2	2562	nd	Nd	20.4	nd	16.5
T2	10986	nd	Nd	nd	nd	45.1
Q4	12911	nd	Nd	nd	nd	39.7
T1	3816	nd	Nd	10.9	nd	34.4
T1	13553	nd	Nd	nd	nd	28.8

[A] nd = not detectable.
[B] Needs confirmation by Gas Chromotograph Mass Spec. (GC-MS) or Liquid Chromotograph Mass Spec. (LC-MS) as comparisons with standard spectral DAD, indicates that function of chemical group is similar to that of standard, however data suggest that these peaks are a derivatives or metabolites of their respective pesticides.

6.4.2 District water balances

6.4.2.1 <u>Inflow components to the water table</u>

The first approximation of surface water percolation to the water table is summarised in Table 25 and Table 26. Given the time frame and complexities of the calculations for leakage of irrigation and rainfall into the water table, these calculations have not been included, but reviewed extensively by Dr Meyer. Table 25 has been calculated assuming the soil water deficit from vacant land, on a monthly average, prevents any rainfall from percolation to the water table.

Table 26 has been calculated assuming more intense rainfalls (assessed on a daily basis) can lead to runoff that will eventually percolate to the water table (a worse case scenario). In both cases the major contribution to surface water percolation to the water table has been identified as excess irrigation water. If there is significant runoff and percolation to ground water, rainfall can also contribute significantly to the inflow into the water table. However, leaky water storage facilities had a relatively low contribution to inflow.

Table 25. Contribution of inflows to water table assuming vacant land soil water deficit.

Source	Amount (ML/yr)	Amount (ML/yr)	% Contribution
Excess Irrigation (leached)	8831		
Appropriate leaching fraction	2154		
Net irrigation contribution to water table		10985	75%
Mains Water Domestic		2000	14%
Glass Houses		785	5%
Virginia, MP and AV Storm Water		559	4%
Water Dumping		170	1.2%
Wetlands		86.7	0.6%
Q1 Aquifer Leakage		68	0.5%
Irrigation Dams		25.6	0.2%
Rainfall (includes soil water deficit for Vacant land)		0	0.0%

Table 26. Contribution of inflows to water table assuming runoff from intense rainfall events contributes to water table.

Source	Amount (ML/yr)	Amount (ML/yr)	% Contribution
Excess Irrigation (leached)	8831		
Appropriate leaching fraction	2154		
Net irrigation contribution to water table		10985	60%
Rainfall (includes intense runoff calc)		3675	20%
Mains Water Domestic		2000	11%
Glass Houses		785	4.3%
Virginia, MP and AV Storm Water		559	3.0%
Water Dumping		170	0.9%
Q1 Aquifer Leakage		124	0.7%
Wetlands		87	0.5%
Irrigation Dams		26	0.1%

6.4.2.2 Water table water balance

The overall water balance has an imbalance of approximately 7700 ML (Table 27). Given the limited data available to estimate the water balance, it is difficult to determine what this imbalance is until further research is completed to refine inflow and outflow components. However, as commented by a reviewer, getting greater refinement in both area and time consideration will change the absolute value of the numbers, but it is highly unlikely that the relative contributions to the water balance will change.

Until better data is available for many ground and surface water components it will be difficult to logically refine the imbalance further. Nevertheless, this first approximation gives an indication of the major and minor contributors to the water balance in the defined study area, which is the intended scope of this report.

6.4.2.3 Regional hydrology

Prior to groundwater development in the NAP area, the historic flow regime was under equilibrium, where the amount of total inflow was equal to the amount of total outflow in order to satisfy the law of conservation of matter.

Historic evidence suggests that most of the deep aquifers had a higher head than the overlying aquifers. This upward hydraulic gradient is characteristic of the discharge side of the groundwater cycle. Consequently there would be an upward flow (leakage) within the Quaternary aquifer, increasing salinity near the surface and discharging from the system either by evaporation from the soil surface or flow from the shallower aquifer to the nearby gulf. This explains the gradual increasing in salinity zone from the Tertiary aquifer towards the Q1 aquifer. As the better quality water leaks upward, evaporation concentrates the salt in the Q1 aquifer and/or the soil profile.

The recent (2001/02) rise in water levels, noted during spring, may be attributed to the fact that toward the end of winter the soil is almost saturated and any excess of irrigation water will infiltrate into the shallow aquifer(s). This infiltration together with reduction in leakage between Q1 and the Tertiary aquifers contribute to adding water into aquifer storage and consequently a rise in the water level.

Recent observations of the Q1 aquifer and the perched water table aquifers show an almost continuous rise, since 1999, in the water level of between 0.3 and 0.5 m/year. The limited available information suggests that the perched water table and Q1 aquifers water levels follow the topography of the area. Examining the topographic contours gradient revealed that it is almost similar to the hydraulic gradient calculated from a potentiometric surface map (Gerges, Kelly 2002). This suggests that the calculated hydraulic gradients may be reasonable. However, the shallow gradients and low transmissivity suggest that lateral throughflow is small.

If the calculated hydraulic gradients is reasonable, then a transmissivity of 730 m^2/day is required to drain the approximately 5000 ML/year (or even greater) added into the aquifer storage. This high transmissivity of 730 m^2/day is considered unrealistic.

When calculating the average annual change in storage, the most sensitive parameter was the specific yield. However, it is obvious from rising water levels that water has been added into aquifer storage, irrelevant to the use of a specific yield of 0.1 or 0.2. In calculating the water balance, the imbalances of approximately 7,700 ML may represent:

- Inaccuracies in the measurement of inflow components
- Inaccuracies in vertical hydraulic conductivity of confining bed separating the perched water table from Q1 aquifer.
- The presence of low laying areas acting as discharge points where evaporation takes place.

Table 27. Summary of all inflows and outflows estimated for the water table of the study area.

Inflow	ML
Rivers (Para, Gawler)	5000
Net irrigation inflow	10985
Irrigation dams (leaky storage)	25.6
Wetlands (leakage)	86.7
Drainage from well and/or trenches	Unknown
Upward leakage from Q1 Aquifer	68
Upward leakage from other aquifers (leaky wells)	Unknown
Stormwater drainage (shadehouse structures)	785
Stormwater drainage (Urban runoff)	559
Lateral inflow	Unknown
Domestic water (sewage/septic)	2000
Wastewater dumping (hydroponics and nursery industry)	170
Sewage lagoons and channel at Bolivar (no leakage?)	0
Salt pans	0
Total inflow	19679
Outflows	
Pumping perched water tables	
Downward leakage into Q1 aquifer and beyond	414
Downward leakage into other aquifers (leaky bores)	500
Stormwater drainage (Urban runoff)	Unknown
Stormwater drainage (Shadehouse structures)	Unknown
Surface runoff (rainfall)	Unknown
Lateral through flow/outflow (Barriers at sea/aquifer interface, seepage into creeks and rivers)	266
Rivers (Para, Gawler) summer drains back into rivers	5000
Total outflow	6180
Water Balance	13499
Change in Storage	5775
Imbalance	7724

Most of the above calculations are based on best-estimates as vital information is not available, viz.:

- Water levels for both aquifers over the 110 km^2 study area. The present network covers only 20% of the study area,
- Hydraulic parameters such as: specific yield; transmissivity; vertical hydraulic conductivity.
- Head relationships between aquifers

Important issues that must be resolved to improve our understanding of the fluctuations in the surface water table of the NAP include:

- Determine the extent of rising water levels in the perched water table, Q1 and Q2 aquifers regionally. This requires installing piezometers into shallow aquifers and conducting aquifer tests.
- Improve our understanding of the hydrogeology of the shallow aquifers on NAP.

7 Discussion

7.1 Soils

7.1.1 Historical comparison - effect of water type on soil quality

Use of RCW on the soils of the NAP has not led to any detrimental changes in the B concentrations in soils or soil salinity. However, the use of RCW has led to significant changes in soil $SAR_{1:5}$ values. This may lead to the development of more sodic, dispersive soils if RCW SAR remains greater than 9. Changes in soil sodicity may result in decreases in soil permeability, which in the long-term could restrict leaching, leading to increases in soil salinity. If good management is adopted now, i.e. correct irrigation scheduling and application of soluble calcium amendments, these detrimental changes should be manageable. The lower SAR of the Class A water and future decreases in this SAR (due to changes in the chemistry of influent into the water treatment plant) should decrease the likelihood of detrimental sodicity developing. However, a functionally-defined critical SAR value for the soils of the NAP needs to be determined to help assess SAR changes rationally.
A low cost soil analysis method for determining several key soil chemico-physical parameters has been verified as a tool for managing soil when irrigating with RCW on the NAP.

7.1.2 Field trials soil amendments

Both Kiln-dusts significantly increase soil pH, total soils Ca concentrations and soil SAR compared to control soils. However, they did not significantly increase, the total heavy metal concentrations in soil or in plants (tomatoes and carrots) grown on these soils in the first year of application. On the lighter textured soil, Cd concentrations in carrots were significantly influenced by soil pH. In acidic soils (pH < 6), the pH and Ca benefits of the Kiln-dusts could provide economical improvements to soil SAR and pH. Decreases in metal availability associated with increased soil pH provide a level of protection against heavy metal contamination of plants grown in soils where the Kiln-dust is applied. However, caution should be practiced in over correcting soil pH or adding to neutral or alkaline soils due to the possible detrimental effects on yield (nutrient imbalances), maturing (delayed) and quality of vegetable (increased forking in carrots).

Yield and quality effects may be overcome through earlier application of Kiln-dust before sowing, allowing equilibration of the additive with the soil, and by maintaining soil pH around 7.0. There are obvious benefits in the use of Kiln-dust for immediate correction of soil pH at low application rates compared to the possible longer-term effect of Aglime on pH.

7.1.3 Glasshouse study – Effect of irrigation water and practice on cadmium uptake by lettuce.

These data suggest that irrigation management could be used by growers to overcome potential problems with Cd concentrations in produce. However, with recycled saline water, there may be a conflict between developing irrigation scheduling to reduce drainage of excess saline water through the profile, and irrigation scheduling designed to minimise Cd accumulation in crops. Further work is required to test this hypothesis in the field.

7.2 Produce quality

7.2.1 Heavy metals in vegetables on the NAP – a baseline study

Irrigation of vegetables with the reclaimed water use on the NAP will has not significantly increased heavy metal concentration in vegetables.

7.2.2 Heavy metals in produce grown in field trials

Produce grown at 3 of the 4 field trial sites (onion, potatoes, tomatoes, broccoli) did no have heavy metal concentrations of concern. However, in the one field trial where heavy metal concentrations were of concern (ie. carrots exceeded the MPC ()), this was not considered a consequence of reclaimed water use (given the low concentration of metals in the reclaimed water), but due to soil acidification, mobilising Cd already in the soil or applied in other soil amendments.

7.2.3 Microbial or algal contamination of vegetables by irrigation with reclaimed water

Results, discussion and outcomes from this section have been included in a:

- Reference manual focused at summarising reclaimed water use and issues on the NAP;
- User manual designed specifically to communicate good management practices for users of reclaimed water, and
- Report to NABCWMB and WRSV (Kelly, Stevens 2002).

7.2.3.1 Algae species present

Although no confirmed toxic species of algae were detected in Class A reclaimed water storage facilities on the Northern Adelaide Plains, this research demonstrates that potentially toxic species of algae may be able to flourish under the right conditions. There is a need for ongoing monitoring of on-farm storage and WRSV equalization lagoon. If potentially toxic species of algae are found, then the presence of toxins should confirmed by chemical analysis.

As blue-green algae growth is favored by warm environmental conditions, a suggested monitoring program would be fortnightly in October and April, and weekly for the warmer months from November to March inclusively.

7.2.3.2 Contamination of vegetables

On-going quality assurance programs must be maintained. However, the data from the report demonstrate that current agronomic practice and the Class A reclaimed water quality on the NAP is sufficient to ensure that produce irrigated with Class A reclaimed water is of the same high quality of that irrigated with other high quality water sources.

7.2.3.3 *Outcomes from microbial and algal contamination of vegetables research*

Improved monitoring practices for reclaimed water, minimising the risk of poor quality produce entering the market and possible consumer backlash damaging the market for reclaimed water grown produce. Pathogen contamination data that support the safety of producing vegetables with Class A Reclaimed Water.

In a more general sense, this research reassures growers of the safety of reclaimed water use. Increased confidence in reclaimed water should lead to increased adoption and use of reclaimed water, which has recently been highlighted at the National Recycle Water Conference in Brisbane (Kelly et al 2003). This has also helped decrease the demand on the already over committed groundwater of the NAP (Gerges 2002).

7.3 Groundwater

7.3.1 Groundwater modelling

The upper aquifers on the NAP (Quaternary 2-4) generally had higher salinities and sodium absorption ratios than lower aquifers (Tertiary 1-2). Within each aquifer, water quality varied across the NAP. The coefficient of variation for salinity was approximately 30% within each aquifer, except for Quaternary 4 which was more variable (>50%). In some cases (one bore each in the Quaternary 3 and 4 aquifer) the concentration of NO_3 exceeded the Australian drinking water guidelines. However, the salinity of these bore waters would exclude them from use for drinking water purposes. These high NO_3 concentrations indicated either bore leakage or aquifer contamination. None of the common pesticides analysed for were definitively detected in the bores sampled. However, some unidentified peaks of pesticide-like chemicals were found in low concentrations in some aquifers

Data from this research provided a definitive reference point of the current NAP aquifer water quality, which will allow assessment of any future changes in water quality due to the widespread use of reclaimed water.

7.3.2 District water balance

Irrigation, rainfall, domestic water use and runoff from shadehouses were identified as the top four major inputs into the water table (Gerges, Kelly 2002).

The solution to rising water tables in the area requires a holistic approach to water management. A range of strategies could be adopted including:

- Construction and improved maintenance of storm water drains servicing the region to drain storm water from the region before it has an opportunity to percolate to the water table.
- Education of glasshouse managers to reuse rainwater that runs from the roof of their structures and is often drained to the ground or roadside. This has the potential to offer significant benefits to the

grower because if it is reused in the glasshouse it could potentially reduce the average salinity of irrigation water.

- Improved irrigation training and management needs to be included into any long-term management strategy.
- Ongoing research into the aquifers on the NAP to improve our understanding of the dynamics of the region's hydrology. This will provide the necessary information to base a long-term management strategy for the region.

In the short-term it will be necessary to identify any areas immediately at risk and develop strategies to ensure their short-term viability.

7.4 The specific outcomes of the research project

7.4.1 Develop a management strategy for irrigating horticultural crops with reclaimed water.

Considering the future scale of RCW use, the SAR of the irrigation water may need to be decreased and/or appropriate farming methods developed and practised with the use of RCW to protect these soils for future horticultural activities (Stevens et al 2003). A low cost soil test, using a simple 1:5 soil:water extract was compared to accepted soil extracts (for assessing detrimental physico-chemical soil changes) and has been proposed as a grower management tool to assist in monitoring the physico-chemical changes (boron, salinity and sodicity) of the NAP soils(see Stevens et al 2003).

7.4.2 Produce a public awareness brochure on the benefits and limitations of irrigating with reclaimed water to ensure its sustainable use

7.4.2.1 Algae

Although no confirmed toxic species of algae were detected in Class A reclaimed water storage facilities on the Northern Adelaide Plains, this report demonstrates that potentially toxic species of algae may be able to flourish under the right conditions. There is a need for ongoing monitoring of on-farm storage and WRSV equalisation lagoon. If potentially toxic species of algae are found, then the presence of toxins should confirmed by chemical analysis.

As blue-green algae growth is favored by warm environmental conditions, a suggested monitoring program would be fortnightly in October and April, and weekly for the warmer months from November to March inclusive.

7.4.2.2 Pathogens

On-going quality assurance programs must be maintained. However, the data from the report demonstrates that current agronomic practice and the Class A reclaimed water quality on the NAP is sufficient to ensure that produce irrigated with Class A reclaimed water is of the same high quality of that irrigated with other high quality water sources.

7.4.3 Produce a grower manual for use of reclaimed water in horticulture on the Northern Adelaide Plains. Identifying soil types, land capabilities and relevant management techniques for growing particular horticultural crops with reclaimed water

Over 200 copies of the manual were originally distributed with the information evening conducted as part of the manuals launch (Kelly et al 2001). Since then an updated edition has been printed and there are continual enquiries from around Australia for copies of the manual.

7.4.4 Establish research and development priorities with respect to the management of reclaimed water to ensure productivity and quality of produce.

On the 28th of November, 2002, a workshop was held to determine the current state of research and communication on the NAP regarding the surface water table and to set the scientific and communication priorities for the region, that will best address these current water table concerns (Stevens 2002).

The participants at the workshop reached consensus that the unequivocal major cause of rising water tables near Virginia was excessive leaching of water beneath irrigation areas. This can be addressed by improving water use efficiency or by decreasing the proportion of area irrigated. Primary information required to assist with management of shallow water tables, that is missing or is not collated in a suitable way, is:

1. Water use patterns -The real-time crop-water table-linked use of bore and reclaimed water on the NAP, monitored through satellite imagery (crop) and a surface ground water piezometer network (water table), to understand water use patterns and identify potential inflows into the surface water table and where improvements in water use efficiency could be made. This was also considered an important part of a communication strategy.
2. Leaching losses beneath irrigated crops with and without management systems – need measurements to identify whether irrigation management alone can prevent salinisation/water table rises.
3. Groundwater monitoring and natural tracer studies to understand the inter aquifer flows and in particular effects on contribution of lower aquifers to the surface water table and rates of downward seepage.

Two other research areas were also identified as high research priorities to refine the modelling of the region's water balances:

1. Understand nutrient and salt fluxes linked with irrigation practices to determine treatment and disposal options necessary for subsurface drainage in future – can be included in (2) above.
2. Quantification of evapotranspiration demand at different times of year for different crops grown in the region and perennial vegetation, to determine water requirements and best management practices.

Participants suggested and agreed that information from the above and a proposed communication workshop should help form, and be part of, a Land and Water Management Plan for the region. It was proposed that the water management strategy should be lead by the EPA and NABCWMB (or the equivalent). The meeting recognised that a combined holistic approach to understanding the water balance in the area, and an extensive communication, training and education program is required to foster the improvement and adoption of best farming practices and surface water management strategies, which should ultimately ensure the NAP is a sustainable irrigation district.

8 Technology transfer

8.1 Award

2000 High Commendation from the AWA South Australian Water Awards. In the category, Protection of the Water Environment: The Virginia Pipeline Scheme for wastewater reuse – an holistic approach to environmental sustainability. Research team – Daryl Stevens, Jim Kelly, Michelle Smart, Mike McLaughlin, Richard Marks, Robert Thomas and Darren Oemcke.

8.2 Growers and industry

8.2.1 Workshops

Stevens DP. 1998. Irrigation with recycled water. Soils in Horticulture: Crop Productivity and Quality Workshop, Virginia Horticultural Centre. (A workshop jointly coordinated by the Australian Soil Science Society and Stevens DP).

8.2.2 Field Days

Two field days were scheduled for February and April. They were discussed with Craig Feutrill (IDO) and he assisted with promotion of these events (ie. Brochures, press releases, etc.). The first field day focused on reclaimed water use and issues that have arisen due to the large-scale use of reclaimed water (Nov. 99').

8.2.3 Reports

Kelly JF, Stevens DP 2001, Virginia Irrigation Scheme: Irrigation Management Plan, Soil Monitoring and User Education. Report. Water Reticulation Services Virginia.

Stevens DP, Kelly J, Feutrill C, McLaughlin M J and Gerges N. 2002 Crops Trials with Recycled Water at the Western Treatment Plant. Melbourne Water File: 995/105/5002. Commercial In confidence.

Stevens DP 1999 Phytoavailability and loadings of nitrogen and phosphorus in reclaimed water used for irrigation on the Northern Adelaide Plains. Commercial in confidence, Seabreeze Farms, Prospect East, Adelaide.

Stevens DP 1999 Field experiments assessing Kiln Dust as a soil additive in irrigated vegetable production on the Northern Adelaide Plains. Commercial in confidence, Bright Cement, Adelaide.

8.2.4 Presentations

Stevens DP. 1998. Methods for managing your soils – Irrigation scheduling using full stop and the SAS Kit. Land Management Group of the NAP (Nick Moccossi, President). Virginia Horticultural Centre.

Stevens DP 1999. Water qualities and effects of irrigation on soils. *In* A workshop on Soil and Water Irrigation. Best Management Practices for the Northern Adelaide

Plains. (D. Stevens, ed.), pp. 5-7. University of Adelaide, Virginia, South Australia. (Workshop coordinated by Stevens DP).

Stevens DP 2000. Reclaimed water on the Northern Adelaide Plains. *In* A workshop on horticultural production on the NAP (fertilisers, pest management, reclaimed water).

Stevens DP 1998. Ensuring soils benefit from long-term use of recycled water. Vegetable Science Forum, Virginia Horticultural Centre. This Forum was organised by Craig Feutrill, Vegetable Technology Transfer Coordinator, HRDC.

Stevens DP 1998. Sustainable use of recycled water for horticultural irrigation on the Northern Adelaide Plains. A workshop run by the Virginia Horticultural Centre (December, 1998).

Stevens DP 2003. What is reclaimed water and what can I do with it? Two Wells Economical Development Board public meeting to determine the community's interest in developing another reclaimed water scheme north of Virginia.

Stevens DP 1999. Guest Lecturing, University of Adelaide, SA. Plant Science. Irrigation with different water qualities. Lectures and field trip.

Stevens DP 2000. Guest Lecturing, University of Adelaide, SA. Plant Science. Postgraduate Short Course. Irrigation with different water qualities and use of reclaimed water. Lectures and field trip.

Stevens DP 1999. Reclaimed water quality and change in on-farm storage. Filtration and sub-surface drip irrigation seminar. White Horse Inn, Bolivar. Philmac Pty. Ltd. and Greene Eden Watering Systems Pty. Ltd.

Stevens DP 2000. Effects of reclaimed water use on soils of the Northern Adelaide Plains. NAP NHT/Landcare funded focus groups.

Stevens DP and Kelly JK 2001. Irrigation with reclaimed water on the Northern Adelaide Plains. Darling Downs, Locker Valley and Brisbane following involvement in the Potatoes 2000 conference and the inaugural AWA Recycling Water Forum. After an invitation from the Queensland Department of Primary Industries, Jim Kelly and Daryl Stevens delivered several seminars to a variety of Qld groups involved in developing water reclamation and reuse schemes. Seminars were focused on knowledge gained from project VG97081, to promote the safe and sustainable use of reclaimed water and to answer questions from concerned groups within the industry and community. A range of audiences were addressed viz. community groups; growers; advisors, consultants, academics; and the Director of the Department of Primary Industries and Regional Officers.

Kelly J 2001 An overview of the Virginia Pipeline scheme. Mineral Nutrition of Plants undergraduate and postgraduate course. Adelaide University. Followed by field trip to the DAFF water reclamation plant, Virginia Horticulture Centre and several growers' properties.

Stevens DP 2000 Reclaimed water on the NAP. A sustainable resource?' Department of Soil and Water Seminar Series, University of Adelaide.

Stevens DP 2000 SARDI Board. Reclaimed water use on the NAP: the current state of play.

Stevens DP 2000. Growing vegetables with reclaimed water. HRDC Sustainability/Whole Farm Management/Biodiversity Research & Development Meeting.

In response to a request from the Department of Plant Science, University of Adelaide, Dr Stevens organised (in conjunction with Dr Rob Reid) a field trip for 3rd and 4th year Plant Science students to the NAP. During this field trip, Dr Stevens presented an overview of this project, increasing student awareness of the issues related to irrigating with RCW. (May 1998)

Kelly JF 2000 Attended Irrigation Association of Australia 2000 National Conference and Exhibition in Melbourne. 23-25 May.

Stevens DP 2000. Attended a grower's trip of greenhouse, irrigation technology and reclaimed water use throughout Israel. Interestingly, Israeli growers can grow better crops using more saline reclaimed water than that on the NAP. The trip highlighted innovative technology that is not yet widely used in Australia and provided some insight into new technology available to assist growers in using poorer quality water.

8.2.5 Promotional and education material

Stevens DP. 1998. Reclaimed water information package. Compiled and edited by Daryl Stevens.

The 2nd edition of the project information brochure was released. A soils map of the NAP and 1 m soil cores of some typical soils of the area were supplied to the VHC. The map and soils were displayed in the foyer of the VHC to increase public awareness of soil types in the district.

Dr Stevens has provided time and literature to Michels Warren (Strategic Communication Solutions Section), a company contracted by the Virginia Horticulture Centre, to produce information sheets on the Virginia Pipeline Project. Final information sheets produced were: Food Quality; Water Quality and The Environment. Fact sheets were produced to coincide with the commissioning of the water reclamation plant (DAFF plant) and commissioning of the reclaimed water pipeline scheme as a pro-active way of handling bad (misinformed) press.

A soils map of the NAP, contour/drainage map and pipeline layout map have been modified as requested and supplied to the Virginia Horticulture Centre.

8.2.6 Study tours

Kennedy R, Feutrill C and Stevens DP 2000. Greenhouse and Irrigation Technology Investigative Tour of Israel. Virginia Horticultural Centre information evening.

Feutrill C, Kelly JF, van der Wielen M, Stevens D. 2001 Investigative tour of reclaimed water use for horticulture in Israel and California, 2001. Horticulture Australia Project VG00089.

8.2.7 Grower Manual – Sustainable use of reclaimed water on the Northern Adelaide Plains

Kelly J, van dar Wielen M, Stevens DP. 2001 Sustainable use of reclaimed water on the Northern Adelaide Plains. Growers Manual. (PIRSA Rural Solutions; Adelaide, South Australia).

8.2.8 Community service

8.2.8.1 <u>Glasshouse Modernisation Project</u>

Mr Kelly has worked in association with Rob Kennedy (IDO Production) of the Virginia Horticulture Centre to identify suitable sites for the location of the Greenhouse Modernisation Project. Data from this project (VG97081) has been beneficial to the Glasshouse Modernisation Project Committee for site selection. Resources and experience accumulated during the project have lead to Mr Kelly assisting with preliminary site inspections.

Mr Kelly assisted the NAP Glasshouse Modernisation Project Committee in the selection of a suitable site for this project and advised on land and irrigation management issues.

8.2.8.2 <u>Potatoes 2000 Conference</u>

Dr Stevens and Mr Kelly prepared a field trip to the NAP for participants of the Potatoes 2000 “Linking Research to Practice” conference held in Adelaide. The field trip included visits to the DAFF Plant, ASR site, Maurice Nicol’s property to see potatoes and carrots grown with reclaimed water and to the VHC where Mr Kelly gave a presentation to the group.

8.2.8.3 <u>Virginia Expo 2000</u>

Mr Kelly hosted three “Chat Room” discussions on reclaimed water at the Virginia Expo 2000. The chat rooms provided an opportunity to discuss issues relating to horticultural production using Class A Reclaimed Water. The chat rooms were well attended with the audiences including local and interstate growers, advisors and industry figures.

8.2.8.4 <u>Visitors to the Northern Adelaide Plains</u>

During this project Dr Stevens and Mr Kelly have assist/shown a countless number of visitors the reclamation and reuse scheme on the Northern Adelaide Plains. Range from student from university courses to international guests. Some of these are listed below.

Representatives from the Shoalhaven Council approached Mr Kelly for information relating to reclaimed water use. Four representatives met with Dr Stevens and Mr Kelly at the Waite Campus where they were given an overview of the research related to water re-use on the NAP. They showed significant interest in the social issues relating to reclaimed water use. Following these discussions, Mr Kelly took the Shoalhaven Council representatives to the NAP to experience first-hand what was being done with reclaimed water in the area.

Marcus Hardie, Land Management Officer – Soils (DPIWE, Tasmania) was assisted with his visit to SA to see reclaimed water being used in South Australia. Several reuse schemes are currently being developed in Tasmanian and knowledge and experience Marcus obtained in SA will be beneficial to development in Tasmania.

After meeting with Mr Kelly and Dr Stevens, Mr Kenna discussed the presentation and tour of the NAP and DAFF plant with Minister Richard Lim of the NT Government, and consequently Mr Kelly has recently taken Minister Lim on a tour of the NAP and the reclamation and reuse scheme.

Mr Kelly and Dr Stevens obtained financial support for Mr Israel to talk to reclaimed water users about his experiences with reclaimed water in California. Keith Israel is the Manager of the Monterey Regional Water Pollution Control Agency, California - the largest tertiary treated reclaimed water scheme in America irrigating vegetables. The underlying theme of the evening was to increase grower confidence in the use of reclaimed water for the production of horticultural crops, and to demonstrate global acceptance of reclaimed water use and produce crops grown with reclaimed water.

Mr Israel has been the driving force behind the Monterey Wastewater Reclamation Scheme, with the pilot treatment plant and field trials established in 1980. His experience is with tertiary-treated and disinfected reclaimed water, similar to that used by growers on the NAP. The project involves the reclamation and reuse of effluent in the irrigation of vegetable crops, some which are eaten raw. The Monterey scheme is one of the largest high quality reclaimed water schemes in the world. In 1999, it used 12 000 ML of reclaimed wastewater which irrigates 4 700 hectares of vegetables.

Fifty growers and advisors attended the information evening, including 4 representatives from the Shoalhaven Council, NSW. There was a tremendous response to Mr Israel's talk with many topical issues relating to reclaimed water discussed with excellent interaction between him and the audience.

Northern Adelaide & Barossa Catchment Management Board and Water Reticulation Services Virginia provided financial support for Mr Israel's visit. Growers were also provided a barbeque tea and refreshments, which provided an excellent opportunity for all participants to interact one-on-one with him.

8.2.8.5 Peterborough Horticultural Project

We have donated a small portion of our time to assist the development of the Peterborough Horticultural Project. The project looks at horticultural production in marginal areas and involves high school students requiring alternative training. The Horticulture Centre was looking to provide students with training opportunities, pathways into employment, and ways of developing their skills to set up their own employment in the horticultural industry.

8.2.8.6 Darling Downs Vision 2000 & Matilda Farms

Jim Kelly and Tony White (WRSV) gave growers from a proposed Qld reuse scheme a guided tour of the NAP horticultural district and its reclamation and reuse scheme. The focus of the tour was on the diversification of production on the NAP and in the research undertaken in project VG97081 to underpin the sustainability and feasibility of a water reuse scheme.

8.2.8.7 Victoria

Jim Kelly and Dr Stevens presented the findings from this project to several executives from Melbourne Water to assist them in assessing the feasibility of similar schemes in Victoria. They also visited several regional water authorities in Victoria to discuss the potential development of reuse schemes for horticultural production.

8.3 Scientific

8.3.1 Papers

Stevens D, Kelly J, Biswas T, Guang-Guo Y. 2003 Assessing the sustainability of schemes that reclaim water and nutrients from effluent for irrigation in Australia. 2nd Australian Recycled Water Conference, Brisbane. AWA. (Invited presentation and paper)

Kelly J, Stevens D, White T. 2003 Achievements of the Virginia Pipeline Scheme: Horticultural production with reclaimed water. 2nd Australian Recycled Water Conference, Brisbane. AWA. (Invited presentation and paper)

Stevens DP, Kelly JK, McLaughlin MJ 2002 Update of current uses for wastewater and biosolids, who is using what and where? 3rd National Food Safety and Quality Assurance Conference, Hobart, Tasmania. (Presentation)

Stevens DP, Kelly JK, McLaughlin MJ 2002 Using reclaimed water and biosolids in agriculture: customers, food and the environment. 3rd National Food Safety and Quality Assurance Conference, Hobart, Tasmania. (Presentation/paper)

Stevens DP, McLaughlin MJ, Smart M 2000 Effects of long-term irrigation with reclaimed water on soils of the Northern Adelaide Plains, SA. Aust. J. Soil Res. 41, 933-948.

Stevens DP, McLaughlin MJ, Owens G, Kelly J, Maier N. 2000 Agronomic issues when using reclaimed water: The Northern Adelaide Plains Experience. Water Recycle Australia, October 19 and 20. Adelaide Australia. p. 55-60. (Presentation/paper)

Stevens DP, McLaughlin M, Owens G, Kelly J and Maier N 2000. Agronomic Issues When Using Reclaimed Water: The Northern Adelaide Plains Experience. Australian Water Association Water Recycling Forum. Adelaide, Australia.

Kelly, J. and Stevens. D.P. (2000). From Problem to Profit. Sewage Effluent Reclamation and Reuse on the Northern Adelaide Plains. Journal Australian Water and Wastewater Association. 27(5) 37-41.

Singh, B., Stevens, D., McLaughlin, M., Zarcinas, B. and Lämmerhirt, M. (2001) Effect of immobilising soil amendments on metal uptake by Swiss chard grown in biosolid-treated soils. (Abstract submitted) Biogeochemistry of Trace Elements, Guelph, Canada.

McLaughlin MJ, Zarcinas BA, Stevens DP, Cook N 2000 Soil Testing for Heavy Metals. Communication in Soil and Plant Analysis. 31, (11-16) 1661-1700.

Stevens DP, McLaughlin MJ. 1999. Effect of irrigation scheduling on cadmium uptake by lettuce. 9th International Conference on the Biogeochemistry of Trace Elements. Vienna, Austria. July 1999. (Poster)

8.3.2 Presentations

Stevens DP, McLaughlin MJ and Smart MK. 2000 Is long-termed reclaimed water use detrimental to soil? South Australia's experience on the Northern Adelaide Plains. Soil 2000: New Horizons for a New Century. Australian and New Zealand Soil Science Society Incorporated Conference. Lincoln University, Lincoln, New Zealand.

D.P. Stevens, M.J. McLaughlin, G. Owens & J. Kelly and N. Maier. 2000. Agronomic issues when using reclaimed water: The Northern Adelaide Plains Experience. Water Recycle Australia 2000 Conference, October 19 and 20. Adelaide, Australia.

Stevens DP 1998 "Sustainable use of reclaimed effluent water for horticultural irrigation on the Northern Adelaide Plains, SA". 4th Australian Horticulture Conference, "Managing Our Future for Innovation Sustainability, Continuity", Melbourne. Organised by the Australian Society of Horticultural Science, October 1998. Poster/paper.

2002 Invited speaker for GWRDC workshop on growing grapes with recycled water.

2002 Invited speaker A Seminar on Environmental and public health risks due to contamination of soils, crops, surface and groundwater from urban, industrial and natural sources in South-East Asia

2002 Invited speaker for Rootzone constraints workshops, Adelaide. Recycled water use in horticulture. Is there a constraint to root growth?

1999 Reclaimed water and cadmium issues. HRDC National Cadmium Coordination Workshop, Adelaide, South Australia.

8.3.3 Reference Manual - Sustainable use of reclaimed water on the Northern Adelaide Plains

To ensure are definitive record is kept of the studies completed on the Northern Adelaide Plains, related to reclaimed water use in the area, the grower manual has been updated with a full list of references related to the area.

8.3.4 Textbook - Growing food crops with reclaimed wastewater: An Australian Perspective.

With Horticulture Australia Limited's support, Dr Stevens and Dr McLaughlin have committed to editing a textbook on 'Water Reuse in Horticulture' from an Australian prospective. The book Chapters are near completion and the book should be published in 2004. The book will benefit readers by providing a definitive Australian reference for teaching water reuse principles (e.g. educational institutions) and for users of reclaimed water (e.g. councils, agriculturalists, the general public).

8.3.5 Advisory roles

McLaughlin MJ, Stevens DP 1998 Maximum Permitted concentrations in food. Canberra, August. A workshop held by the Australian and New Zealand Food Authority (ANZFA) (Attendance at this workshop was not funded though this project.)

8.3.6 Scientific workshops

Mr Kelly and Dr Stevens 2001. The current state of research regarding reclaimed water use on the NAP and identify areas requiring further research effort. Areas identified that require further research were: District hydrology; agronomic field trials; algae control; new technology/niche markets; long-term monitoring of soils and water quality.

Stevens DP. 2002. Groundwater on the Northern Adelaide Plains: Prioritising research and related communication requirements – Workshop summary. Waite Campus, CSIRO Conference Room 1, 28th of November (Stevens 2002).

8.3.7 Field trip - Australian Water Association Water Recycling Forum

Dr Stevens and Mr Kelly were invited by the Water Recycling Forum organisers to lead a half-day tour of the DAFF Plant and of the NAP. There were two buses with 87 participants from the conference. These participants largely comprised of researchers, consultants and council representatives, many of which were involved in horticultural production and interested in the development of water re-use schemes in their own regions. The tour focused on the successful adoption of reclaimed water and associated horticultural production.

8.4 Press Articles.

An article in the Virginia News titled "Sustainable use of reclaimed effluent water for Horticultural Irrigation on the Northern Adelaide Plains", Vol 1, Issue 2. August, 1998.

Project Update printed in Potato Australia, Volume 9, September 1998. p. 8. ISSN 1036 - 8558. Titled, "Sustainable use of reclaimed effluent water for horticultural irrigation on the Northern Adelaide Plains, SA".

The Grower, June 1999. Veglink SA. Irrigation a focus at field day. Supplied by the Virginia Horticultural Centre.

Brief summary update of the project supplied to Nathalie Jarosz, for Potato Australia.

Dr Stevens co-ordinated the writing of an article (Growing Vegetables with Reclaimed Water: Current research, monitoring extension & training to ensure sustainable management of horticulture on the Northern Adelaide Plains) requested by Craig Feutrill for inclusion in the Grower's Veglink SA section.

Dr Stevens was interviewed by Prue Adams (ABC TV Landline) and assisted in some on-site filming as part of a 15 min documentary on the NAP water reclamation scheme. The documentary was screened nationally on the 31/10/99.

Dr Stevens was featured in the Horticultural Forum, Research Profile (Vol. 1 Issue 2). Horticultural Forum is a Northern Adelaide Plains Newsletter produced by the Virginia Horticultural Centre.

Jim Kelly submitted an article for Potatoes Australia titled "Spreading the good word on the sustainable use of reclaimed water for irrigation on the Northern Adelaide Plains, SA".

Dr Stevens, Jim Kelly and Craig Feutrill planed a communication strategy to heighten the awareness of good management of reclaimed water. Reclaimed water use increased with the onset of the irrigation season (September, 2000). This included articles in Horticultural Forum, Good Fruit and Vegetables, and Veglink.

Response to a letter to the Editor of The Advertiser, Adelaide from Stavros Carapetis, North Brighton, published, 04/09/2000. Mr Kelly coordinated a response from himself and Dr Cunliffe (Department of Human Services) to the misinformation contained in the letter regard reclaimed water use on vegetables and heavy metal contamination.
Reclaimed Water Update. Horticultural Forum (Vol. 1 Issue 4. July 2000). Joint release with PIRSA. Horticultural Forum is a Northern Adelaide Plains Newsletter produced by the team at the Virginia Horticultural Centre.

Potatoes Australia, Sept 2000. Sustainable use or reclaimed water in irrigation – Northern Adelaide Plains – SA. Vol 11. p 36.

An article regarding the progress and outcomes from this project was submitted to Potatoes Australia.

8.4.1 Television Media Segments

During the project one Landline documentary on the Virginia Pipeline Scheme was screened by ABC Landline. Dr Stevens assisted this process with an interview discussing this project and some footage of soil sampling at some of the project's field sites.

After the Study tour to Israel and California, 4 Segments on reclaimed water use in agriculture, or related areas, where produced for screening on ABC's Landline program. The segments main themes where reclaimed water use and: salinity, fish, California and Israel.

8.4.2 Horticulture Australia Promotional Videos

As a result of the reclaimed water Study Tour to Israel and California, two promotional videos outlining reclaimed water use in Horticulture were produced for general use in the industry. Video titles were:

- Investigative tour of Israel and California 2001, Horticultural Production with Reclaimed water **(Horticulture)**
- Investigative tour of Israel and California 2001, Horticultural Production with Reclaimed water **(Health Issues)**

9 Recommendations - scientific and industry

Recommendations should relate to the key outcomes of the project. Recommendations should also be made on the need for further research and industry/commercial activities that may be undertaken to enhance adoption of the outcomes of this project.

9.1 Further Research Identified

9.1.1 Hydroponic production using reclaimed water.

The South Australian Reclaimed Water Guidelines (DHS, EPA SA 1999) do not have provision for hydroponic production using reclaimed water. Jim Kelly has had preliminary discussion with researchers in California and Israel to under take a tri-nation research project into hydroponic production using reclaimed water. All groups have identified hydroponic production with reclaimed water as an area requiring further research and are currently sourcing funding.

9.1.2 Surface water table on the NAP

Due to unforeseen changes in the RCW water use pattern on the NAP there is a need to more closely monitor the upper water table fluctuation on the NAP. In an attempt to address this issue a proposal has been submitted to the National Action Plan for Salinity.

Irrigation techniques will become an important part of the future management of horticulture across Australia, particularly with reclaimed water, where the salt loadings are generally higher and leaching fractions critical. Projects for the development of management strategies and developing best management practices are required.

9.1.3 Coordinator of reclaimed water development in horticulture

We recommend the development of a project for the coordination of reclaimed water development across Australia. This project will maximise the benefit from this project (VG97081) by maximising opportunities for reclaim water use in Australian Horticulture and minimise the risks of anyone reuse scheme from being poorly developed, implemented or maintained reflecting negatively on all uses of reclaimed water in horticulture.

9.1.4 Irrigation Development Officer

One of the priorities for sustainable use of reclaimed water, which is generally slightly more saline that other water sources, is good irrigation practice. With the pressures on our limited water supplies, the development of good irrigation practices in the horticultural industry as a whole is essential, and for those that use reclaimed water crucial. The establishment of Irrigation Development Officers could be one initiative taken by the Industry which would assist in assuring water use efficiency and sustainable environmental practice.

9.2 Study Tour

The value of study tour for the industry should not be under estimated and we recommend strongly that support for tours which address important issues for the industry continues.

Between 22nd April and 4th May 2001, 25 participants visited Israel and California on a study tour of reclaimed water use, new reclaimed water technology and alternate crops and farming systems. The tour was led by Jim Kelly, Craig Feutrill and Daryl Stevens and was accompanied by three ABC staff to produce segments for the ABC's Landline program and other industry promotion videos.

The primary purposes of the study tour were to:

1. Observe and discuss technology first hand that might be appropriate for adoption by the Australian reclaimed water industry to improve their businesses;
2. Improve the understanding of overseas R&D and its relevance, encouraging growers to be more active in prioritising research in Australia;

3. Establish and promote linkages between Australian growers and overseas industry members and researchers;
4. Increase grower's knowledge base and understanding so as to reduce the inhibition to the use of reclaimed water and to promote further the demand for use of reclaimed water; and
5. Increase public perception of the benefits and safety of using reclaimed water in agricultural production.

Benefits of the study tour to Australian Horticulture have been at three levels: water industry, grower and consumer.

At the water industry level, seeing the successful operation of a diverse range of reclamation and reuse schemes in Israel and California first hand has given the Australian water industry the confidence and vision to develop and implement schemes in Australia. Interactions between growers and the water industry, during the tour and that seen in Israel and California, will assist the water industry to come to terms with the specific requirements of horticultural water use. This should help to develop more appropriate schemes suited to a range of horticultural enterprises.

At the grower level, use of reclaimed water for horticultural production has been shown to be an internationally accepted method for production of an enormous range of horticultural crops. The study tour and post tour communication highlighted to growers that they are not the first to use reclaimed water, and that tens of thousands of hectares of horticultural crops are grown annually around the world with reclaimed water. Technology used in Australia and the guidelines followed for reclaimed water use were realised are some of the best in the world. Reclaimed water acceptance and adoption of this technology by growers will build confidence in this valuable resource in Australia, which will have substantial benefits to the industry now and in the future. One of the major benefits will be the supply of a sustainable guaranteed water resource.

The tour highlighted to many growers and industry the importance of good targeted research, combined with effective communication and education programs in the adoption of new technologies and their management. If the benefits obtained from research and adoption are better focused and communicated through the collaboration of growers, this can only achieve better outcomes for the industry and better management of our agricultural resources.

Growers found technology rarely seen in Australia, and the combination of reclaimed water with technologies (hydroponic or soil-less cultures) that have not been allowed in Australia. If any of these technologies and management techniques are imported into Australia successfully there will be considerable financial and/or environmental benefits to the industry.

At the consumer level, the post tour television coverage of the tour on ABC's Landline program has highlighted the worldwide use and acceptance of reclaimed water in the production of food crops to the public. This media coverage has also highlighted to the public that if done correctly, reclamation and reuse schemes are environmentally responsible and sustainable. Reclaimed water acceptance by the markets and consumers will assist in building confidence in this valuable resource in

Australia, which will have substantial benefits to the industry now and in the future through optimising the use of Australia's limited water resources.

10 Research projects developed from recommendations.

10.1 Sustainable Salinity and Water Management on the Northern Adelaide Plains. Stage 1 – Identification of actions to provide a sustainable water balance and prevent salinity damage

This project has been funded (2002) by the National Action Plans for Salinity and the Northern Adelaide and Barossa Catchment Management Board. This project is managed through the Virginia Horticulture Centre in collaboration with CSIRO Land and Water, Primary Industries and Resources SA and the Northern Adelaide and Barossa Catchment Water Management Board.

10.2 Drainage Fluxes to the Water Table Beneath Irrigated Crops on the Northern Adelaide Plains: Comparison of Existing and Alternative Irrigation Management Systems

This project has been funded (2003) by the Northern Adelaide Plains and Barossa Catchment Water Management Board (NABCWMB). It was developed by Graham Green and John Hutson (Flinders University), Peter Dillon and Daryl Stevens (CSIRO Land and Water). Principle Scientists are John Hutson and Peter Dillon. The major focus of the project is to quantify and fluxes of irrigation water and help finetune the first approximation of the Northern Adelaide Plains Water Balances (Gerges, Kelly 2002; Section 7.3.2).

10.3 Coordinator of Reclaimed Water Development in Horticulture.

This project was identified as crucial for the ongoing sustainable development of reclaimed water use in Australian Horticultural. Compiled by Jim Kelly (University of Adelaide), Daryl Stevens (CSIRO Land and Water), Craig Feutrill (Horticulture Australia) and Peter Dillon (CSIRO Land and Water), the project has received funding support (2003) from HAL (Project No HG02092), with a voluntary contribution from the industry.

This project aims to help coordinate reclamation and reuse of urban wastewater (reclaimed water) in Australian horticulture. It will provide and facilitate the transfer of knowledge within the reclaimed water industry. Thus, ensuring a consumer accepted and environmentally sustainable reclaimed water industry develops in Australia. On a small scale, the benefits are consolidation of resources put into developing and delivering water reclamation and reuse schemes. On a large scale, the benefits are a sustainable and renewable water resource and an irrigation practice that is considered both acceptable and environmentally friendly by the general public.

10.4 Reclaimed water use in Australian Horticulture. Developing an environmental and economically sustainable approach for Australia.

Land and Water Australia have funded (2003) Stage 1 and 2 of this project, which has the primary aim to assess the requirements of the horticultural reclaimed water industry for the foreseeable future, and ensure any research, communication or training gaps are overcome. Ultimately, ensure that individual reclaimed water schemes developed across Australia are agriculturally, environmentally, economically and socially sustainable for the foreseeable future. The project was compiled by Anne Maree Bolan (Victorian Department of Primary Industries), Bill Ashcroft (Victorian Department of Primary Industries), Nick Turner (WA Water Corporation), Andrew McCrae (Land and Rivers Commission WA), Bob Paulins (Agriculture Western Australia), Daryl Stevens (CSIRO Land and Water) and Peter Dillon (CSIRO Land and Water). Anne Maree is the Project Leader.

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13 Appendix of all publications related to the project

Please see CD posted.