Improving soil management on irrigated soils in the South-east of South Australia

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2 INTRODUCTION

This report presents the results of a series of comparisons between soils under irrigation and analogous nearby dry land soils. The irrigated soils can be considered the treatment being tested, with the dry land (non-irrigated) sites being the control. Ten properties were investigated as a part of the comparisons, with each property having up to 5 soil pits under an irrigation treatment and 5 soil pits under a dry land control.

The aim of this report is to provide an interpretation of the medium and long term effects of irrigation on soils. The soils were described using conventional soil description techniques, and were tested for a range of soil chemistry attributes deemed relevant to the irrigation treatments. A large amount of data was developed from the descriptions and chemistry testing, and these were compared for the purposes of better understanding how the soils have responded to irrigation, and how best to manage the soils into the future.

3 METHODOLOGY

3.1 FIELD DATA COLLECTION:
Two main treatments were of interest to the study, that of soils under irrigation, and that of dry land soils. Within each treatment five replications were made in order to make some distinction between treatment effects and natural site variability. The methodology for the field data collection involved selecting five sites within each pivot being assessed. An additional five sites were located approximately 100m outside the pivot area to act as control dry land (non-irrigated) comparisons.

The physical descriptions of the soils included:
- Surface condition,
- Horizon identification and depth,
- Field texture,
- Coarse fragments,
- Soil colour and mottling,
- Aggregate structure,
- Soil strength and moisture content,
- Segregations,
- Root abundance,
- Abundance of visible pores,
- Photographs of the cleaned pits and close ups of each horizon,
- Landscape photos.

3.2 IRRIGATION WATER
Refer to Appendix 1 for more detail:
Bore water quality measured from the 10 sites ranged from:
- 1.15 mS/cm; 850 ppm; 3.5 SAR (red clay in Coonawarra).
- 7.15 mS/cm; 4340 ppm; 15.4 SAR (shallow sand on brown clay near Keith).
The scientific literature suggests SARs greater than 3 or 6 may cause reduction in drainage.
Bore water quality measured from the 10 sites ranged from:

- $\text{HCO}_3^-$  170 to 430 ppm
- $\text{Na}^+$  145 to 1040 ppm
- $\text{Cl}^-$  340 to 2460 ppm
- $\text{Ca}^{1+}$  24 to 180 ppm
- $\text{Mg}^+$  12 to 110 ppm
- $\text{pH}$ - 7.7 - 8.5.

**Note:** $\text{HCO}_3^-$ was not very variable between sites (quite high amounts in all sources). For all water sources, Na and Cl comprised the bulk of the salts.

### 3.3 SOIL CHEMICAL ANALYSIS:

Soil samples were taken from the individual horizons identified within each pit. These were tested for the following:

- Surface horizons- phosphorus, potassium, sulphur, organic carbon, reactive iron, salinity, pH, chloride, calcium carbonate, saturated cations and anions, copper, zinc, manganese, iron, aluminium, boron and nitrogen.
- Non- surface horizons- phosphorus, potassium, sulphur, organic carbon, reactive iron, salinity, pH, chloride, calcium carbonate, and saturated cations and anions.

Most soils had measurements of exchangeable cations also. In some soils that overlay calcrete, the calcrete layers were tested for salinity, chloride and pH only.

Simple statistical interpretations were used to indicate the significance of the results, with standard deviations being used to measure variability within the treatments, and the level of variability compared to the size of the difference between the mean values.

### 3.4 ASSUMPTIONS:

- That the 100m distance from the irrigated area will provide soils that are themselves unaffected by the irrigation.
- That the soils from the two treatments will represent each other closely and that any different measurements made will relate more to the treatments than to differences in the soil type.
- That the irrigation bore data approximates long term water quality.

**Note:** The measurements made during this study were aimed at comparing the influence of irrigation on soil properties over a number of years. They do not reflect seasonal fluctuations in salinity and other shorter term impacts.

This study investigates a small number of soils over a single period in time. As a consequence the results and recommendations found in this report are indicative only, and should be viewed in that light.

### 3.5 RESULTS FORMAT

The sites and systems investigated during this study were quite varied, and made direct comparisons between properties difficult. Consequently, the results have been written up as a series of case studies.

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1 The water from the 3 Neuarpurr and Bool Lagoon sites were all sampled and tested separately from the other sites. It is possible the lower Ca found in these samples is a result of delays in processing and testing.
4 CASE STUDIES

4.1 NW NEUARPURR PIVOT- LOAM ON CLAY

4.1.1 Background:
- Date soil sampled- 30th August 2007 (prior to irrigation season commencing)
- Number of years of irrigation- 7 yrs
- Approximate water applied- ~3.5M per yr
- Gypsum- 5 - 7.5 t/ha of gypsum applied to irrigation since commencing.
- Water quality- pH of 8.5; ECe of 2.0 mS/cm; TDS ~1250 ppm; SAR of 7.6.
4.1.2 Soil physical properties:

Most of the soils measured were thin, structureless sandy clay loams (A1-10cm), occasionally with a thin bleached horizon (A2-15cm). This loam was generally around 10-15cm thick. Underneath the loam was a medium to heavy red or brown mottled clay with very poor structure (B21-40cm; B22-75cm), extending to an average depth of 75cm. This depth was generally the extent of the main root zone. Below 75cm, a layer of highly calcareous (limey) clay occurred (B23-100cm; B3-150cm).

The exception to this was Pit 1. This soil was a cracking clay soil, and presented features in the mid and lower profile that indicated a high degree of shrink/swell of the clays. This, in combination with the greater water holding of the upper profile compared to the loamy soils, appears to have reduced leaching of salts, and has resulted in higher salt loadings in the mid and lower profile (up to 8mS/cm compared to 4mS/cm in the other irrigated pits). The natural condition of the soil at Pit 1 is significantly better than that of the other soils in terms of having higher inherent fertility and far superior soil structure.

The natural soil condition of this property has many inherent constraints, particularly poor structure in the B horizon. Poor structure usually relates to low abundance of roots, and impeded drainage of water. Most of the significant soil features portrayed a high level of variability that was unrelated to the irrigation treatment. The soils were all medium clays in the subsoil, with very coarse structure and low porosity.

4.1.3 Physical effects of irrigation:

Colour- There was considerable overlap between the colour of the soils under the two treatments due to the inherent variability of the soils. The strong mottling of the soil, generally related to poor water drainage and inefficient soil water holding, seemed to be very similar between treatments.

Structure- Significant differences in the inherent structural properties of the soils were not observable by the field assessment methods used. Both treatments were generally poorly structured and were likely to drain water and leach salts at slow rates.

Soil strength- Soil strength seemed to be similar between treatments. Penetrometer measurements were made, and these indicated lower resistance to penetration in the irrigated soils. However, differences in the moisture content of the treatments may have contributed to this result.

Surface condition- The surface of the irrigated soil appeared to be significantly harder than the unirrigated soil. This could be observed visually in the soil surface, with surface sealing and compaction being evident, as shown in the following picture. It is possible the surface condition could be due to traffic by stock and equipment while the soil was wet, rather than the direct effects of irrigation on soil salinity.
4.1.4 Chemistry effects of irrigation:
The effects of the irrigation water on the irrigated soils when compared to the control have been summarised below:

**pH**

pH appears to have been made significantly more neutral in the surface under irrigation, with the dryland site being moderately to strongly acidic. This is generally a positive change, however, it may reduce the availability of some nutrients such as manganese, and it may impact of plant specifies that are more adapted to acidic conditions (such as some clover species).

![pH graph](image)

One of the impacts of raised pH has been the affect on extractable aluminium in the soil surface. No aluminium was extracted on the irrigated soils, however, 3mg/kg of aluminium was extracted from the controls. This level of aluminium is approaching toxic levels, and indicates that the soil is becoming strongly acidic.
**Sodicity**   Sodicity, as measured using Sodium Adsorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP), is one indicator of a soil's tendency to become more poorly structured, and develop reduced porosity. In this instance, the soil water had an SAR that was similar for both treatments, with both attaining high sodium levels in the subsoil that can usually be related to poor physical condition. Pre-washed exchangeable cations showed ESP was higher throughout the profile in the control, and again the subsoil of both treatments was likely to reflect sodicity levels that are usually related to low permeability.

**Calcium**   An estimated 2 tonnes per hectare of calcium has been applied to the irrigated soil, with around 1.3 tonnes applied as gypsum and another 0.7 tonnes applied with the water. This is equivalent to around 8.5 tonnes per hectare of gypsum.

**Salinity**   The salinity of the soils was measured as a total of the range of different dissolved salts present in the soil, mainly sodium, potassium, calcium, magnesium, sulphate, nitrate and bicarbonate. Total salinity can be used to indicate the impacts on plants through osmotic affects, and measures of chloride and sodium can give indications of direct toxic impacts on plants.

The salinity of the irrigated soils was higher throughout the profile. It should be noted that salinity in the surface soil is probably highly transient, and may build up to significantly higher levels during the irrigation season.
Over the approximately 7 year period of the site having been irrigated, approximately 30 tonnes per hectare of salt has been applied. The salinity of the irrigation water is around 2 mS/cm, however, below around 40cm the soil salinity is far more concentrated (2 to 3 times).

In order to estimate salt build up over time, chloride was measured as a proportion of the total soil mass. Chloride is a very soluble salt, and as it is not prone to interacting with soil exchange reactions, it is a good indicator of the soils leaching potential. Based on the water chemistry, the years of irrigation and the annual water applications, a rough estimate of the chloride applied with irrigation water is 11 tonnes per hectare. Using the soil chemistry as a rough estimate of chloride retention (based on the differences in chloride content between the control pits and the irrigated pits), the chloride build up over the 7 year period has been around 6 tonnes per hectare. This indicates that while salts are being leached, salts are building at a higher rate than they are being removed through leaching. The main root zone (above 75cm), however, has only built up around 2 tonnes per hectare of chloride, with the majority of the salts building up in the layers between 40-150cm.

Note that salt build ups in the lower profile are likely to reflect natural low permeability, and perhaps insufficient leaching fraction. Significant structural changes induced by irrigation were not observed.

Nutrition  ETDA extractable Fe presented significantly lower levels under irrigation. This can be expected as iron tends to be less available under wetter, more alkaline conditions. However, the wetter, more alkaline conditions are more likely to have significant impacts on yields than the direct impacts of the reduced iron availability.
Other nutrients, including extractable phosphorus, potassium, nitrogen, manganese, zinc and copper were all higher in the irrigated soils, probably simply reflecting greater fertiliser inputs.

**Organic carbon**  Organic carbon tended to be higher in the irrigated soils than the unirrigated ones. This probably reflects the higher nutrition inputs and greater organic matter production of the irrigated sites. Also, the moister conditions of the irrigated soils may have promoted greater biological activity in the soil.
4.2 CENTRAL NEUARPURR PIVOT- LOAM ON CLAY

Background-
- **Date soil sampled**- 28\textsuperscript{th} August 2007 (prior to irrigation season commencing)
- **Number of years of irrigation**- 4yrs
- **Approximate water applied**- ~3 M per yr
- **Gypsum**- 1.25 t/ha of gypsum applied to irrigation since commencing.
- **Water quality**- pH of 8.5; ECe of 1.7mS/cm; TDS ~1050ppm; SAR of 7.0.
4.2.1 Soil physical properties:
Most of the soils measured were thin, structureless sandy loams (A1- 10cm), occasionally
with a thin bleached horizon A2- 15cm). This loam was generally around 10-15cm thick.
Underneath the loam was a light to medium red or brown mottled clay with moderate to
poor structure, extending to an average depth of 70cm (B21- 35cm; B22- 70cm). This
depth was generally the extent of the main root zone. Below 70cm, a layer of calcareous
(limey) clay occurred (B23- 105cm; B3- 150cm).

The natural soil condition presented moderate to low permeability in the B horizon (below
15cm). Most of the significant soil features portrayed a high level of variability that was
unrelated to the irrigation treatment. In other words, the natural condition of the soil is
already at a state of moderately low water drainage potential.

4.2.2 Physical effects of irrigation:
Colour- The strong mottling present in all of the sub-soils indicates imperfect to poor water
drainage. This feature seemed to be very similar between the 2 treatments. However, the
dominance of brighter red colours in the subsoil indicate that the soil is unlikely to
experience long term waterlogging in the upper half of the soil profile.

Structure- Significant differences in the inherent structural properties of the soils were not
observable by the field assessment methods used. Both treatments were generally
moderately to poorly structured and were likely to drain water and leach salts at slow rates.

Soil strength- Most of the differences between the treatments were unlikely to be
significant

Soil strength seemed to be similar between treatments. Penetrometer measurements were
made, and these indicated lower resistance to penetration in the dry land soils. Differences
in the moisture content of the treatments may have contributed to this result. However, the
higher average strength of the irrigated soils in the layer between 8 and 12cm was greater
than one standard deviation, indicating that the irrigation may have lead to significant
increases in soil hardness in the upper profile (bear in mind that moist soils are more
prone to compaction from stock and other traffic).

4.2.3 Chemistry effects of irrigation:
The effects of the irrigation water on the irrigated soils when compared to the control have
been summarised below:

pH  pH appears to have been made significantly more neutral in the surface under
irrigation, with the dryland site being moderately to strongly acidic.

The sub-soil pH was generally lower than the control, and this mirrors the lower sodicity of
the irrigated sub-soil. Where this difference may not be significant, it could relate to
the leaching of some sodium out of the profile.
No aluminium was extractable on the irrigated soils, however, 3.6mg/kg of aluminium was extracted from the controls.

**Sodicity**  The sodicity of the soil water in the surface 3 horizons was very similar for both treatments. It should be noted that all the SAR measurements of the sub-soil (below around 15cm) are high enough to reflect sodicity levels that are usually related to low permeability.

1.25 tonnes per hectare of gypsum have been spread on the irrigated paddock. The equivalent calcium of 1.3 tonnes per hectare of gypsum has also been added with the irrigation water. This has resulted in higher soluble calcium in the upper 70cm of the profile compared to the control. Free lime levels were not significantly different.

**Salinity**  Approximately 12 tonnes of salt have been applied over the 4 years of irrigation. The salinity of the irrigation water was around 1.7 mS/cm, and the soil salinity is higher than this below 15cm. The salinity of the irrigated soils was slightly higher throughout the root zone (to 70 cm). However, it tended to be significantly lower in the profile below the rootzone. This may indicate that salts have been concentrated over the past season, however, over the longer term, it is likely that salts are being effectively flushed from the profile.
Approximately 5 tonnes of chloride have been applied in the irrigation water. The chloride measured in the soils under the irrigation indicate that the total mass of soil chloride has actually been reduced by irrigating. Most of this relates to lower chloride levels in the lower profile, showing that water applied may be making its way out of the system at an appreciable rate, and that the long term accumulation of salt is not occurring. The slight build up of chloride in the upper sub-soil indicates that leaching during the last season has not been enough to remove the more recently deposited soluble salts.

**Nutrition**  
ETDA extractable Fe presented significantly lower levels under irrigation. This can be expected as iron tends to be less available under wetter, more alkaline conditions. However, the wetter, more alkaline conditions are more likely to have significant impacts on yields than the direct impacts of the reduced iron availability.

Other nutrients did not generally reflect significant differences.

**Organic carbon**  
Organic carbon did not show significant differences.
4.3 E NEUARPURR PIVOT- LOAM ON CLAY
- **Date soil sampled:** 24\textsuperscript{th} August 2007 (prior to irrigation season commencing)
- **Number of years of irrigation:** 6yrs
- **Approximate water applied:** ~3.5M per yr
- **Gypsum:** 5 t/ha of gypsum applied to irrigation since commencing.
- **Water quality:** pH of 8.2; ECe of 1.4mS/cm; TDS ~880ppm; SAR of 5.9.
- **Soil in the pivot paddock has been ripped to around 30cm.**
4.3.1 Soil physical properties:
Pits 1-6 were soils with thin, weakly structured sandy clay loams (A1-8cm), occasionally with a thin bleached horizon (A2-10cm). This loam was generally around 10cm thick. Underneath the loam was a weakly structured light clay (B1-25cm). This was followed by a light to medium red or brown mottled clay with moderate to poor structure (B21-50cm; B22-70cm), extending to an average depth of 70cm. This depth was generally the extent of the main root zone. Below 70cm, a layer of slightly calcareous (limey) clay occurred (B23-110cm; B3-150cm). There was very little observable difference between the irrigated and dry land treatments. These soils are likely to be naturally slow draining.

Pits 7-10 were black cracking clays. The soils were clayey throughout. Their structure was moderate to coarse in the top 60 cm, with very coarse lower profile (with indications of strong shrink/swell properties). The irrigated soils were limey at shallower depths to the dry land soils, however, this may simply be natural variation.

These two main soil types were different enough to warrant separate analysis and comparison.

4.3.2 Physical effects of irrigation:
Colour- The dominant colours and mottles for the loamy surfaced soils were similar for both treatments. The cracking soils seemed to be greyer and paler in the irrigated soils, perhaps indicating longer durations of saturation. This may just reflect the higher lime content. The irrigated soils had a slight brown mottle that was absent in the dry land soil.
Structure- Significant changes have been produced to the structure of the soils that have been ripped. The ripping process has reduced the contrast of the surface-subsoil interface, and is likely to significantly improve surface soil drainage.

There were little other observable structural differences between the treatments.

Soil strength- The penetrometer readings for the loamy surfaced soils showed little difference. The readings for the cracking clays showed the root zone of the dry land controls was significantly harder than the irrigated soils. This was due to the much dryer condition of the dry land soil.

Surface condition- The surface of the irrigated soil was significantly altered by the ripping. This had placed lumps of clay on the surface. The strength of the soil surface was similar to the dry land.

4.3.3 Chemistry effects of irrigation:
The effects of the irrigation water on the irrigated soils when compared to the control have been summarised below:

**pH**
For the loam surfaced soils, pH appears to have been made significantly more neutral in the surface under irrigation, with the dryland site being moderately acidic.

Neither soil treatment presented appreciable extractable aluminium.

![Graph showing pH for loam soils](image)

For the cracking clay soils, pH appears to be little changed by irrigation.

![Graph showing pH for cracking clay soils](image)
**Sodicity** The sodicity of the irrigated loamy soils, as indicated by the SAR of the soil water, was higher than the control throughout the profile. Both treatments attained high levels in the subsoil that can usually be related to poor physical condition in the soil.

The sodicity of the cracking clay soils, as indicated by the SAR of the soil water, was similar between treatments in the surface horizons. However, the irrigated soil showed much lower SAR results in the sub-soil. This probably relates somewhat to natural soil variability, with the irrigated soils being significantly more calcareous in the subsoil. Both treatments attained high levels in the subsoil that can usually be related to poor physical condition.

**Calcium** The irrigated soils generally had higher soluble calcium throughout the profile than the control. Approximately 5 tonnes of gypsum had been spread per hectare, with the water applied contributing the equivalent of a further 3 tonnes per hectare of gypsum.
Salinity  Over the 6 years of irrigation, a total of around 20 tonnes per hectare of salt have been applied to the irrigated soils. The salinity of the water applied was around 1.4 mS/cm, and the soil salinity of the irrigated sites is much higher than this throughout. This indicates a lack of leaching, and requires further investigation (particularly given the time of year when this was sampled). It could reflect insufficient volumes of water applied per application for adequate leaching.

The salinity of the irrigated soils was significantly higher throughout the rootzone on both soil types. The salinity of the irrigated loams at the time of measurement was significant, and likely to impact yields in sensitive species.

Approximately 7 tonnes per hectare of chloride has been applied to the irrigated soils. This appears to have built up in the irrigated profiles (when compared to the dryland sites). The additional chloride remaining in the soil equated to approximately 3 tonnes per hectare (1.5t/ha in the rootzone) for the both soil types.
**Nutrition**  ETDA extractable Fe presented significantly lower levels under irrigation on the loamy soils. The cracking clay soils were similar to each other in iron content.

Other nutrients and trace elements did not show appreciable relationships to the treatments, although N, P and S were higher under irrigation, probably reflecting higher inputs. Sulfur would be sourced from irrigation water and from the gypsum applied.

**Organic carbon**  Organic carbon tends to drop appreciably when cultivated, and so the recent ripping may have reduced the levels in the irrigated soils. For the irrigated treatment, the levels of organic matter were lower in the loamy soils and slightly higher in the cracking clay soils.
4.4 HYNAM PIVOT- LOAM ON CLAY

4.4.1 Background:
- **Date soil sampled**: 11\(^{th}\) February 2008
- **Number of years of irrigation**: 12 yrs
- **Approximate water applied**: ~5M per yr
- **Gypsum**: 2.5 t/ha of gypsum and 1 t/ha of lime applied to irrigation since commencing.
- **Water quality**: pH of 8.1; ECe of 4.0mS/cm; TDS ~2300ppm; SAR of 9.8.

4.4.2 Soil physical properties:
Most of the soils measured were thin loams (sandy loams through to sandy clay loams), usually with a thin bleached layer (A1- 10cm; A2- 20 to 30cm). The loam ranged from 10cm to 30cm thick, with the thicker loams generally having a more pronounced bleach. Below the loam came a light to medium brown clay with some weak mottling (B21- 45cm;
B22- 70cm). The structure of this clay was very coarse (columnar). This changed at around 60-80cm into a poorly structured limey clay (B23- 110cm; B3- 150cm).

The natural soil condition of the soils measured were poorly structured with low permeability.

4.4.3 Physical effects of irrigation:

Colour- The soils naturally portrayed a range of colours that was more variable within the treatments than between the treatments. The occurrence of mottling was also showed no patterns that could be related to either treatment.

Structure- Significant differences were not apparent, with both treatments having structureless surface loams and very coarsely structured subsoils.

Soil strength- not assessed due to the large difference in soil moisture.

Surface condition- Generally a firm surface- no significant differences observed.

4.4.4 Chemistry effects of irrigation:

The effects of the irrigation water on the irrigated soils when compared to the control have been summarised below:

**pH**  
PH is higher in the surface horizons to a depth of around 50cm, matching the pH of the water applied. Below 50cm the pHs of the different treatments was not significantly different. The higher pH is generally an improvement, and is more suitable for the crop currently being grown (that is, lucerne).

![pH graph](image)

Extractable aluminium in the dry land soils was approaching toxic levels due to the acid conditions (ext. Al of 3 to 4 mg/kg), and these soils require liming to correct this.

**Sodicity**  
The soils are highly sodic, both in the irrigation and the dryland. The irrigated area is more sodic in the upper layers, but both are sodic to the degree that they should have poor drainage capability. Given that this is the natural state, and that the soils are still draining well enough to remove salts, it is probable the soil will not decline in structure any further (apart from perhaps physical compaction of the wet surface soil from stock and other traffic).
**Calcium**  Approximately 2.5 tonnes of gypsum and 1 tonne of lime per hectare have been spread since the soil has been irrigated. However, the equivalent of around 36 tonnes per hectare of gypsum has been applied in the irrigation water. This is reflected in the soluble lime content of the soil.

**Salinity**  Over the approximately 12 year period of the site having been irrigated, approximately 140 tonnes per hectare of salt have been applied. The salinity of the irrigation water is around 4 mS/cm, and the irrigated soil ECE remains below 4 dS/cm throughout, indicating effective leaching of salts.

Almost 70 tonnes per hectare of chloride was applied to the irrigated soil. However, when compared to the dry land soil, only about 4 tonnes per hectare of this chloride is still to be found in the soil.
**Nutrition**  Most macro nutrients reflected the different levels of fertiliser inputs applied to the site. DTPA extractable Fe and Mn were significantly lower on the irrigated site, reflecting the effect of high pH on the availability of these elements. Boron was higher on the irrigated soil, and significant B was measured in the irrigation water.

**Organic carbon**  Organic carbon was not significantly different.
4.5 WIRREGA FLOOD- SAND OVER CLAY OVER CALCRETE

4.5.1 Background:
- **Date soil sampled**: 13th December 2007
- **Number of years of irrigation**: 18yrs
- **Approximate water applied**: ~8M per yr
- **Gypsum**: 5t/ha of gypsum and 5t/ha of lime applied to irrigation since commencing.
- **Water quality**: pH of 7.8; ECe of 6.9mS/cm; TDS ~4300ppm; SAR of 15.
4.5.2 Soil physical properties:
The soils measured were organically darkened, structureless loamy sands (A1- 15cm) over bleached sands. The bleached sand was also structureless (A2- 20 to 50cm), and varied markedly in depth from a few centimetres thick to over 50cm thick. Under the bleached sand was a layer of brown clay (B2- 45cm). This was usually weakly structured to structureless, however it contained abundant pores and was whole coloured. This clay layer was usually fairly thin, usually 10-20cm thick, however, solution holes frequently occurred where the clay was found to much greater depths. The solution hole clay was generally darker and some was strongly structured (SB1- 75cm; SB2- 100cm). Below the clay was fractured calcrete (K1- 65cm; K2- 100cm; K3- 130cm; K4-150cm).

The irrigated site had been clay delved, and so significant mixing had occurred between the sand and the clay (and sometimes the calcrete) along the delve lines, and the soil surface contained fine lumps of clay.

The natural condition of the soil was shallow and free draining, with little structure; a low fertility, dense sandy surface, and a porous, massive clay subsoil over a highly permeable calcreted limestone. The soil had strong preferential drainage pathways where the sandy horizons were thicker.

4.5.3 Physical effects of irrigation:
Colour- The treatments portrayed the same range of soil colours, with the clay exhibiting no significant signs of mottling or other colour change.

Structure- Significant differences were not observed.

Soil strength- Differences in soil moisture made assessing soil strength difficult. There did not appear to be significant differences.

Surface condition- The surface of most of the soils was soft, with some loose sand.

4.5.4 Chemistry effects of irrigation:
The effects of the irrigation water on the irrigated soils when compared to the control have been summarised below:

\textbf{pH}\quad pH has risen significantly throughout the profile, reflecting the sodicity of the soil. This is likely to reduce the suitability of the soil for sensitive species, and will reduce the availability of elements such as manganese. Deficiencies in Mn on irrigated sands are common in the SE.
**Sodicity**  The sodicity of the soil is a lot higher than the natural condition of the soil. The sandy surface is unlikely to be altered by sodicity due to its very low clay content. The clay subsoil should respond to such high sodicity by dispersing and losing structure and porosity. This has not in fact been observed in this instance.

**Calcium**  Calcium has been spread on the site as lime at 5 tonnes to the hectare and as gypsum, also at 5 tonnes per hectare. The equivalent of approximately 100 tonnes of gypsum has also been applied in the irrigation water. Free lime is higher in the surface 3 horizons of the irrigated block, as is soluble Ca.
Salinity  Over the approximately 18 year period of the site having been irrigated, approximately 600 tonnes per hectare of salt have been applied. The salinity of the irrigation water is around 6.9 mS/cm, and most of the soil profile is below this concentration, indicating the effective leaching of salts. Some of the calcrete layers had slightly higher salinities than the irrigation water, and this possibly reflects the preferential flow of water through the soil (some soil is being leached more than others- note the solution hole clay is lower in salinity). These higher salinities are below the rootzone.

![Graph showing ECe (DS/m) values for different horizons. The graph compares irrigated and non-irrigated conditions.](image)

Around 350 tonnes per hectare of chloride was applied to the soil in the irrigation, of that an estimated 19 tonnes per hectare has been retained in the soil, and only 6 tonnes per hectare of this is in the rootzone.

Nutrition  Most of the macro nutrients reflect the differences in the inputs of fertiliser. The irrigation has supplied a high amount of sulphur.

Trace elements (EDTA extractable Fe, Mn, Cu, Zn, and extractable B) all appeared to be significantly higher in the irrigated soils. This may reflect applications of fertiliser.

Organic carbon  Organic carbon is lower in the irrigation, probably reflecting the cultivation vs the permanent pasture of the dry land paddock, rather than the irrigation treatment.
4.6 WESTERN FLAT PIVOT- THICK SAND OVER CLAY

4.6.1 Background:
- **Date soil sampled:** 9th November 2007
- **Number of years of irrigation:** 5yrs (with 3 years break after 1st 2 years watering)
- **Approximate water applied:** ~5M per yr
- **Gypsum:** 0t/ha of gypsum applied to irrigation since commencing.
- **Water quality:** pH of 7.7; ECe of 2.8mS/cm; TDS ~1650ppm; SAR of 6.6.

4.6.2 Soil physical properties:
The soils measured were clay spread loamy sands with fragments of clay evident (higher amount of clay evident in irrigated soils). This organically darkened, clay spread layer (A1) was around 20cm thick in the irrigated treatment, and around 15cm thick in the dry land. Beneath the surface layer was a layer of structureless bleached sand, generally becoming more bleached with depth (A21- 40 to 55cm; A22- 50 to 75cm). This layer was thicker in the irrigation due to natural landscape variation, with the average depth being 50cm in the dry land, and 75cm in the irrigation. Two of the irrigated soils had clay lamellae present in the bleached horizon. However, it is unclear whether this relates to irrigation induced clay leaching or a natural feature of the soil.
Below the bleached sand was a very coarsely structured mottled yellow/brown medium clay (B21-70 to 115cm). Coarse sand could be felt in the clay. Vertical pipes of sand were evident in most pits and appear to be a relatively common feature (possibly old root channels). These pipes are likely to have a large impact on preferential drainage of water from the soil. More reduced (lighter and greyer) colours were evident in the clay at depth (B22-100 to 130cm). The lower profile (generally below 100cm in the dryland and 130cm in the irrigated soils) became clay loamy (B3- 150cm).

The natural soil condition is one of excessive drainage and very low fertility. The clayey subsoil is naturally slowly draining, and poorly structured. The clay spreading of the surface has enhanced the potential for the soil retaining fertility.

4.6.3 Physical effects of irrigation:
Colour- Both treatments exhibited the same range of colours.

Structure- No significant differences were observed, aside from those that could be attributed to natural variation and the effect of clay spreading.

Soil strength- Soil strength appeared to be similar between treatments.

Surface condition- The surface condition of the surface was firm across both treatments.

4.6.4 Chemistry effects of irrigation:
The effects of the irrigation water on the irrigated soils when compared to the control have been summarised below:

**pH**  The irrigation water has lifted the surface soil pH from strongly acid to near neutral, a distinct improvement upon the natural soil condition. The subsoil remains moderately to strongly acidic, and the lower pH of the irrigated site is difficult to explain. It could be related in part to the excessive leaching of nitrate.

![pH Graph]

**Sodicity**  The sodicity of the irrigated soil appears to be strongly elevated compared to the dry land site. However, it is difficult to conceive this affecting the quality of such a sandy and structureless soil. The presence of the subsoil sand pipes are also likely to enhance drainage through the clay horizons.

No gypsum has been spread on this site, however, the equivalent Ca of 12 tonnes of gypsum per hectare has been applied in the irrigation water.
Salinity  Over the approximately 5 year period of the site having been irrigated, approximately 40 tonnes per hectare of salt have been applied. The salinity of the irrigation water is around 2.8 mS/cm, and the soil salinity of the sand is well below this, indicating very efficient leaching. The salts have concentrated slightly in the clay horizons, however, this is generally below the main root zone, and the concentration is not likely to affect the most plant species at this stage.

Of the approximately 20 tonnes per hectare of chloride applied in the irrigation water, approximately 6 tonnes of this could still be measured in the soil profile to 170cm. Only 3.5 tonnes were observed within the profile where roots were growing (above 140cm), and only 0.3 tonnes within the sandy horizons (above 75cm).

Nutrition  Generally the differences in soil nutrients reflect the different inputs of the 2 treatments. The irrigated sites measured higher readings for N, P, S, Mn, Fe, Cu, Zn, B.

However, the higher P recorded (Colwell P of 20ppm) will also relate to the greater ability of the soil to retain P due to its high clay rate. Note the reactive iron content of 280ppm compared to the content of 150ppm on the dry land (iron and aluminium relate to P retention in soils). CEC had also been lifted from around 3 to around 5. K levels were similar between treatments.

Significant B was measured in the irrigation water.

Organic carbon  Organic carbon levels were similar between the treatments, however, the greater disturbance (cultivation) of the irrigated site would reduce the level of OC it could hold.
4.7 PADTHAWAY FLOOD - DARK LOAM ON CLAY ON CALCRETE

Irrigated pits 6-10

Dryland control pits 1-5
4.7.1 Background:
- **Date soil sampled**: 2\textsuperscript{nd} April 2008
- **Number of years of irrigation**: 40yrs
- **Approximate water applied**: ~14M per yr
- **Gypsum**: 2t/ha of gypsum applied to irrigation since commencing.
- **Water quality**: pH ?; EC\textsubscript{e} of 2.6mS/cm; TDS ~1600ppm; SAR of 6.1.

4.7.2 Soil physical properties:
Most of the soils measured were structureless but friable dark grey clay loams. These surfaces (A1) were around 10cm thick on the irrigation, and around 5cm thick on the control (neighbouring holding paddock). The holding paddock had been compacted and eroded. Two profiles on the neighbouring road reserve were also sampled, and these resembled the irrigation paddock more closely.

Below the surface loam was a dark grey light clay with a very coarse prismatic structure (B21- 20cm). This structure appeared to be natural, and was deceiving in that the soil itself was full of large pores, and was very light and soft. This layer extended to a depth of about 20cm. Below this point the soils became quite variable, however, generally hard carbonate nodules and soft lime became common (B22- 30cm), combined with varying depths and quantities of finely structured grey or brown clay. Below this was fractured calcrete (BK).

The natural soil condition was weakly structured but friable, with excellent drainage properties.

4.7.3 Physical effects of irrigation:
Colour- Little difference between treatments in the surface horizons. The variations in the calcareous layers probably relate to natural soil variability.

Structure- No significant differences were found that could be related to the treatments.

Soil strength- Soil strength was quite low, with the soil being friable throughout.

Surface condition- The surface of the irrigation was firm, similar to the road reserve.

4.7.4 Chemistry effects of irrigation:
The effects of the irrigation water on the irrigated soils when compared to the control have been summarised below:

**pH**  
When comparing the comparatively undisturbed road reserve soil with the irrigated soil, there was little difference between the two in pH.
Sodicity

The irrigated soil was significantly more sodic than the unirrigated soils. However, observable deterioration of soil structure was not found, and the soil remains porous and friable.

Calcium

2 tonnes per hectare of gypsum have been spread on the irrigated soil. However, since the irrigation began, the Ca applied in the water will have contributed the equivalent of approximately 300 tonnes per hectare of gypsum.

Salinity

Over the approximately 40 year period of the site having been irrigated, approximately 800 tonnes per hectare of salt have been applied. The salinity of the irrigation water is around 2.6 mS/cm, and the soil salinity closely matches this level, indicating that salts are being leached at the same rate they are being applied.
Nutrition  The holding paddock revealed extreme levels of nutrients and other salts as a result of the high stocking rates held on the site. This compromised the comparison somewhat.

When compared to the road reserve, however, the N and P rates were significantly higher on the irrigation, reflecting the inputs of fertiliser. Sulphur was also higher, probably reflecting the S in the water as much as any fertiliser additions. Potassium was similar for both sites, reflecting the high K levels found in SE clay minerals.

Extractable trace elements (Zn Mn, Fe, Cu, B) were all higher on the irrigation. This probably reflects additions from fertiliser. Supply from the irrigation water was not measured.

Organic carbon  Organic carbon was significantly higher in the irrigation than the road reserve.
4.8 REEDY CREEK FLOOD- BLACK CLAY FLATS

4.8.1 Background:

- **Date soil sampled**: 21st February 2008
- **Number of years of irrigation**: Around 36yrs (laser levelled in 1988)
- **Approximate water applied**: ~25M per yr
- **Gypsum**: 0t/ha of gypsum applied to irrigation since commencing.
- **Water quality**: pH of 7.8; ECe of 2.3mS/cm; TDS ~1300ppm; SAR of 5.6.
4.8.2 Soil physical properties:
Despite the appearance of a fairly uniform landscape, the soils of the black flats can be quite varied. Consequently, the first soil profiles described on the irrigated site were quite different in a number of their properties from the soils of the 4th and 5th pits. These latter 2 profiles were more closely aligned with the control profiles, and their chemistry has been separated out in the discussions below.

The soils were all black light to medium clays in the surface (A1-10cm), with pits 1-3 being highly calcareous (limey) in the surface. The other pits were all non-calcareous in the surface. The soils were all very finely structured and friable. The dry land soils presented deep cracks from the surface well into the profile.

Pits 1-3 became grey and limey below about 20cm, with hard nodules of carbonate becoming more common with depth. The soil remained clayey and friable throughout.

The remaining pits were black, finely structured and non calcareous in the top 10cm. They changed very little to a depth of 30cm (A2-30cm), although free lime content increased slightly. Below this point they became greyer and strongly calcareous, with hard carbonate nodules becoming common. The soil remains clayey and friable throughout. Fractured sheet calcrete was found at the base of some profiles.

The natural condition of these soils is finely structured and friable. These soils are formed under wet conditions, with a strong watertable influence, and have high shrink/swell in their clay mineralogy. They are very fertile and very high in organic matter. They are free draining. All of these properties remain true for the irrigated soil.

4.8.3 Physical effects of irrigation:
Colour- The irrigated soils appear to be very similar to the dry land soils in the surface. Most of the subsoil colour variations seem to relate to carbonate content.

Structure- No significant differences were observed. All soils were exceptionally well structured.

Soil strength- Soil strength was not possible to compare due to the very different moisture contents at sampling. The irrigated soils were all friable.

Surface condition- The surface condition of the irrigated soils were soft.

4.8.4 Chemistry effects of irrigation:
The effects of the irrigation water on the irrigated soils when compared to the control have been summarised below:

pH Apart from some slight elevation of surface pH, pHs are very similar between treatments. These generally reflect the limey nature of the soil.
Sodicity    The irrigated surface soil has become slightly more sodic than the control, but probably not to a degree where the soil would disperse and reduce soil quality. The high organic matter and the mineralogy of the soil probably make it very resistant to structural decline in any case. Assuming that the control has not been influenced by subsoil flow, the subsoil sodicity appears to have been greatly reduced through irrigation. Ultimately, regardless of the sodium component of the soil, the soil remains in very good physical condition under both treatments.

Calcium    No gypsum has been applied to the irrigation treatment. However, the equivalent Ca of around 450 tonnes per hectare of gypsum has been applied in the irrigation water.

Salinity    Over the approximately 36 year period of the site having been irrigated, it is estimated that over 1000 tonnes per hectare of salt have been applied. The salinity of the irrigation water is around 2.3 mS/cm, however, the irrigated soil remains well below this level of salinity, indicating how effectively salts are being leached from the profile.
An estimated 500 tonne per hectare of chloride has been applied in the irrigation water. Of this, approximately 0.4 tonnes per hectare can still be found in the upper 30cm of soil. Below 30cm, the Cl levels have been greatly reduced compared to the control.

**Nutrition** Covell phosphorus levels were the same for both treatments. Potassium was significantly lower (300ppm) in the irrigation than in the dry land (550ppm). Sulphur was approximately double in the irrigation, relating to the S supplied in the irrigation water.

Extractible Cu and Zn were both higher under the irrigation.

**Organic carbon** Organic carbon levels for all the treatments were around 5.5% in the surface. Subsoil levels were higher in the irrigation than in the dryland.
4.9 BOOL LAGOON PIVOT- BLACK CLAY FLATS
- Date soil sampled- 21st August 2007 (prior to irrigation season commencing)
- Number of years of irrigation- 12yrs
- Approximate water applied- ~3.1 M per yr
- Gypsum- 5 t/ha of gypsum applied to irrigation since commencing.
- Water quality- pH of 8.3; ECe of 1.5mS/cm; TDS ~920ppm; SAR of 7.2.
4.9.1 Soil physical properties:
The soils were finely structured, friable light to medium black clays. They were soils that were very high in organic matter, and high in shrink/swell clay mineral. Soil texture did not alter greatly with depth. Hard-nodular and soft carbonate was found below around 35 cm, with some profiles having a high soft lime content higher in the profile. The soils became slightly greyer with depth

The natural condition of these soils is one of being very well structured and friable. They naturally have very high inherent fertility. The two treatments did not present any strikingly different physical properties from each other when they were described and sampled.

4.9.2 Physical effects of irrigation:
Colour- Very little change.
Structure- The irrigated soils appeared to have very slightly less well defined aggregate structure than the control. However, the structure of the irrigated soil can still be called very well structured.

Soil strength- The irrigated soil, when crushed between finger and thumb, presented slightly higher resistance when compared to the control soils.

However, the penetrometer measurements indicate that the irrigated soils had a slightly lower strength than the controls. Variations in moisture content between the two treatments may account for the penetrometer differences.

Surface condition- The surface of the irrigated soils appeared to exhibit some minor surface sealing not found in the control soils.

4.9.3 Chemistry effects of irrigation:
The effects of the irrigation water on the irrigated soils when compared to the control have been summarised below:

pH  pH is very similar between the treatments, and given the level of variability measured within each treatment, the differences are unlikely to be significant.

Sodicity  The sodicity of the irrigated soils, as indicated by the SAR and ESP figures, is significantly higher than the control soils. The sodium percentage as indicated by the ESP values is approaching a level where a decline in structure and permeability...
might be expected in some soils. However, the mineralogy and high organic content of these soils mean that this is unlikely to occur.

Approximately 5 tonnes per hectare of gypsum have been spread on the irrigated soils. The equivalent of around another 3.5 tonnes per hectare have been applied in the irrigation water.

Salinity
Over the 12 years of irrigation, approximately 35 tonnes per hectare of salt has been applied to the soil. The irrigated soils presented higher salinities than the control throughout the profile. The salinity of the water applied was around 1.5 mS/cm. Below around 60cm the soil salinity becomes significantly higher than this, indicating some concentration of salts. However, for most of the pits measured the salinity of the rootzone was unlikely to be significantly affecting yields at this stage.

Around 15 t/ha of Chloride has been applied in the irrigation water. Chloride build up in the irrigated profiles (when compared to the dryland sites) equated to approximately 4 tonnes per hectare (2.5t/ha in the main rootzone).

Nutrition
Apart from nitrogen and phosphorus, most nutrients and trace elements were similar in both treatments.

Organic carbon
Similar between treatments.
4.10 COONAWARRA DRIP/SPRINKLER- TERRA ROSSA

4.10.1 Background:

• **Date soil sampled**- 27th February 2008
• **Number of years of irrigation**- Site 1: 40yrs; Site 2: 34yrs
• **Approximate water applied**- ~2M per yr
• **Gypsum**- 0t/ha of gypsum applied to irrigation since commencing.
• **Water quality (site 1)**- pH of 7.9; ECe of 1.5mS/cm; TDS ~850ppm; SAR of 3.5.
• **Water quality (site 2)**- pH of 8.4; ECe of 1.8mS/cm; TDS ~1100ppm; SAR of 5.5.
4.10.2 Soil physical properties:
The soils were all friable, finely structured red/brown light clays. These soils were very uniform, with morphology not varying greatly with depth (A1- 10cm; B21- 20cm; B22- 40cm; B23- 65cm; B24- 90cm). The lower profile was occasionally redder and lighter in colour than the surface. The mid profile was also occasionally a slightly heavier clay, although this was variable between pits. Depth of soil above fractured sheet calcrete was the main variable observed (K1- 40cm; K2- 65cm). The deeper profiles tended to be weakly structured below about 40 or 50cm.

The soils were naturally very well structured and free draining. Drainage of water would tend toward being excessive, similar to some sandy soils.

4.10.3 Physical effects of irrigation:
Colour- It is unlikely that any significant changes were observable. Site 2 exhibited brighter, redder colours on the irrigated site, however, it is likely this is simply a natural landscape feature, and not related to the treatments.

Structure- No differences were observed. The most sodic of the horizons measured were from pit 8 in the lower profile, and these also had the weakest structure of all the soil horizons measured. However, this difference in structure was very slight, and may simply relate to the greater depth of this soil.

Soil strength- All soils were very friable.

Surface condition- The surface condition of the soils was firm, with the vine rows being hard setting.

4.10.4 Chemistry effects of irrigation:
The effects of the irrigation water on the irrigated soils when compared to the control have been summarised below:

**pH** The soil pH of the irrigation differs from the control, in that the control is neutral in the surface and moderately acidic at depth. This is probably somewhat related to nitrate leaching over time, and may be natural or may be a consequence of fertilisers and legumes since development. The irrigation in contrast is slightly alkaline in the surface, becoming more neutral at depth.
**Sodicity**  The irrigation has increased the proportion of sodium interacting with the cation exchange, particularly in the lower profile where salts are in higher concentrations. However, there are no clear indications that this has compromised soil structure or reduced permeability.

**Calcium**  No gypsum has been applied to the irrigated sites. However, the equivalent Ca of around 35 tonnes per hectare of gypsum has been applied in the irrigation water to site 1. The equivalent Ca of around 25 tonnes per hectare of gypsum has been applied in the irrigation water to site 2.

**Salinity**  Over the approximately 40 year period of site 1 having been irrigated, approximately 70 tonnes per hectare of salt have been applied. Over the approximately 34 year period of site 2 having been irrigated, approximately 75 tonnes per hectare of salt have been applied. The salinity of the irrigation water is around 1.5 and 1.8 mS/cm for sites 1 and 2 respectively, however, none of the soil measurements come close to this concentration of salt, indicating that salts are being flushed effectively.

**Nutrition**  Aside from the non-irrigated sites having far higher extractable P than the irrigated sites (no doubt relating to differences in the amount and method of application), there were no significant nutrient differences found between the treatments.

**Organic carbon**  Organic carbon levels were similar between sites.
5 SUMMARIES AND DISCUSSION

For all the sites studied, the variability observed in the physical appearance of the soil pits presented a lot of overlap between the two treatments. Most differences observed in colour, structure and texture were just as great within the treatments as between them.

5.1 IMPROVEMENTS BROUGHT ON BY IRRIGATION-

pH- Many SE surface soils are strongly acidic, usually due to leaching of nitrates and removals of alkaline products. Many of the acidic soils in this study were acidic to the point where they may negatively impact on plant growth, mainly through aluminium toxicity. In this study, the irrigation water has moved all the irrigated soils measured toward a more neutral or alkaline pH. This may impact on some acid tolerant plants, however, the change can generally be considered a positive one. None of the soils achieved alkaline pHs in the surface that would be considered strongly alkaline. On neutral to alkaline soils the water has had less of an impact on pH.

Soil biological activity- There were some slight indications that the irrigation may have enhanced biological activity in the soil. This related to observed increases in earthworm activity, and increases non-cultivated sites in soil organic carbon content.

Calcium content- While the irrigation water added salts to the soils, the salts contained a significant proportion of calcium. This is likely to interact favourably with the soils’ cation exchange, will reduce the SAR of the soil water, and may be less prone than other salts to being leached from the soil due to calcium’s interaction with bicarbonate (present in high amounts in the irrigation water). The amount of calcium supplied in the irrigation water ranged from 0.1 to 0.6 tonnes per ML equivalent of gypsum.

5.2 POTENTIAL NEGATIVE IMPACTS BROUGHT ON BY IRRIGATION-

Salinity- All the irrigated soils had elevated salinity levels in the surface. The concentration of salts in the irrigation water governs the concentration of salts initially entering the soil. Consequently, those soils with salinities greater than the irrigation water indicate some concentration of salts, while those with lower salinities indicate flushing of salts with rainwater.

Of the sites studied, 4 sites appeared to be significantly concentrating salts. These were the three Neuarpurr pivot sites and the Bool lagoon pivot site. The former 3 sites were all poorly drained in the subsoil, and under natural conditions would store similar levels of salts to those found in the irrigated sites. Under natural rainfall it is likely these soils only allow water down to around 70 or 80cm (referred to as the long term wetting front). Also, some water drains through the coarse cracks in the soil, and so doesn’t effectively flush salt from the soil aggregates. The Hynam soil is very similar to these soils, however it does not appear to be concentrating salts. This may be due to the higher volumes of water applied.

At the Bool lagoon site, salts do not appear to be flushing effectively from the lower profile. These black clay soils hold a lot of water, and it is possible that not enough water (and rainfall) has been applied to pass through the lower profile.

Sodicity- The loam on clay soils in this study were all naturally strongly sodic, particularly in the subsoil. The coarse structure and slow drainage potential of these soils reflects this
level of sodicity. In general, the irrigation does not seem to have altered the level of sodicity greatly from the natural condition. Consequently it seems that the influence of irrigation on the current soil condition is unlikely to change the status quo.

The main factor influencing soil sodicity did not appear to be the total amount of salts applied, or even the SAR of the irrigation water (within limits). The main influence seemed to be the concentration of the salts within the soil.

The influence of higher sodicity is unclear. The black flats soils have high organic matter contents, and high shrink/swell clays. These soils are unlikely to become dispersive even at moderate sodicity levels. The other soils are most sodic in the lower profile where the soil matrix supports the soil, and soil salinity is generally higher.

<table>
<thead>
<tr>
<th>Summary table of chemistry from the irrigated soils</th>
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<tr>
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<tr>
<td>Water</td>
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<td>H 1</td>
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<tr>
<td>H 2</td>
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<tr>
<td>SAR</td>
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<tr>
<td>H 4</td>
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<tr>
<td>H 5</td>
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<tr>
<td>H 6</td>
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<td>H 4</td>
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<td>H 5</td>
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<td>H 6</td>
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</tbody>
</table>
A note on calcium- Calcium salts generally reside in the soil for longer periods of time than other salts, such as sodium, due to its tendency to precipitate as CaCO3 (lime). This was reflected in the ratio of sodium to calcium being lower than that of the irrigation water applied in all the irrigated surface soils. Calcium also has a stronger attachment to the cation exchange than sodium due to its stronger positive charge.

5.3 LESS CLEAR INTERACTIONS RELATING TO IRRIGATION-
Structure and strength- The data collected showed no clear link between the irrigation treatments and any changes in structural properties or soil strength. Indicators of reduced drainage, such as mottling and duller greyer colours, were not generally observed to be affected by the treatments. The bulk density and penetrometer measurements made also showed no clear relationship to the treatments. Note the differences in the bulk densities measured below are matched somewhat by the natural variability of the site, indicated by the standard deviation (st dev), and may not be significant.

<table>
<thead>
<tr>
<th>Property</th>
<th>Irrigated</th>
<th>Dry land</th>
<th>Irrigated st dev</th>
<th>Dry st dev</th>
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</thead>
<tbody>
<tr>
<td>Coonawarra</td>
<td>1.42</td>
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<td>NW Neuarpurr</td>
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<td>0.04</td>
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<tr>
<td>Hynam</td>
<td>1.60</td>
<td>1.53</td>
<td>0.02</td>
<td>0.06</td>
</tr>
</tbody>
</table>

The physical condition of the soil appeared to be unaltered by the higher sodicity of most of the soils. It should be noted that the soils were also higher salinity, which would offset the dispersive influence of the high sodium. It is unclear what the influence of rainfall would be on the salinity of many of these soils, however, it is likely that even after the winter rains that the subsurface and subsoil layers would still be higher salinity than the natural soils in most cases.

Nutrition- The irrigated soils tended to be higher in extractable phosphorus, probably due to increased application of fertiliser. The irrigated soils also generally had very slightly higher extractable trace elements, although it is unclear whether (should these differences be significant) this can be related to trace elements applied as fertilisers, or as a component of the salts in the irrigation water, or whether the increased extractability is
related to other changes such as pH and soil moisture. Extractable iron was generally significantly lower in the irrigation treatments, however, this is unlikely to impact on plant yields.

6 RECOMMENDATIONS

The following recommendations are based on the results of the 10 case studies:

- Where the sodicity of the soil is naturally quite high, irrigation with low to moderate SAR water may not increase sodicity, and may not reduce permeability. Calcium added with the water, or applied as gypsum, may result in soils becoming less sodic.
- Strong texture contrast soils with poorly structured clay subsoils are problematic for leaching salts. Drainage in the mid and lower profile is slow, and tends to follow preferred pathways such as root channels and coarse soil structures. Consequently, it is recommended that soil salinity monitoring at a range of depths across a paddock may be required to determine seasonal fluctuations and longer term trends in salinity. In some cases higher irrigation volumes may be needed to be applied to flush salts.
- Longer term and more extensive monitoring studies are required to determine the long term effects of irrigation on salt loads, sodicity and soil permeability across a range of soil types and irrigation systems.
- To study soil strength more thoroughly it is probably necessary to conduct further laboratory measurements at a consistent water content.
- To study soil porosity more thoroughly it may be necessary investigate microscopic changes in soil pores.

Note: The study is limited both in the number of soils and the irrigation systems measured. Consequently, the results and recommendations made in this report are indicative only.

Relationships worth exploring:
- The interaction with high bicarbonate in SE groundwater.
- The transit times of salts. It may be that Ca salts have a greater influence on the soil because they remain in the soil longer.
- Implications for gypsum applications, and for interpreting SAR.
- Longer term salinity monitoring (particularly chloride).
- The influence of high organic matter on resisting dispersion.
- The influence of high shrink/swell clays (smectites) on resisting dispersion.
- More physical assessments such as bulk density, porosity, drainage.
#### APPENDIX 1

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>Coonawarra 2</th>
<th>Coonawarra 1</th>
<th>Padthaway</th>
<th>Western Flat</th>
<th>Hynam</th>
<th>Reedy Ck</th>
<th>Wirrega</th>
<th>NW Neu</th>
<th>Central Neu</th>
<th>E Neu</th>
<th>Bool</th>
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<tbody>
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<td>CARBONATE (mg/L)</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>BICARBONATE (mg/L)</td>
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<td>394.07</td>
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<td>&lt;0.1</td>
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<td>7</td>
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<td>S (mg/L)</td>
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<td>2.82</td>
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