Soil Properties under Tree Plantations, Crops and Pastures Irrigated with Paper Mill Effluent at Albury in 2013

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1. SUMMARY

In 1993 a plantation of radiata pine was established on agricultural land at Ettamogah for the re-use of effluent from the Norske Skog paper mill. Irrigation of trees commenced in 1995 and annual monitoring of tree condition, irrigation water and soil properties has been conducted as part of the EPA license agreement for the reuse of effluent. Harvesting of the tree plantation commenced in 2004 and was completed in 2012. Harvested plantation blocks have either been replanted with a second rotation of radiata pine and eucalypts irrigated by drip-irrigation (193 ha) or were returned to agriculture to expand the existing area under crops and pastures irrigated by sprinkler systems (208 ha).

Since the project commenced annual monitoring of soil properties has been conducted based on site-specific protocols developed for the re-use scheme as part of the EPA license agreement. In general irrigation with effluent has increased pH, salinity, sodicity and extractable sulphate in soil profiles while the impact on other soil properties has been relatively minor. The requirement for soil monitoring was reviewed in 2013 to identify soil properties most affected by effluent for future annual monitoring as part of a revised EPA license agreement. The revised monitoring program was implemented in 2013 and results are presented in this report.

In 2013 seasonal rainfall (585 mm) was below average and irrigation of trees (5.2 Ml/ha) and crops and pastures (2.9 Ml/ha) was higher compared with recent years of high rainfall and low irrigation. Likewise salt loads were higher (5.6 and 3.1 t/ha) in 2013 compared with preceding years. Higher irrigation of trees and to a lesser extent crops and pastures did increase pH, salinity, extractable sulphate and sodicity in surface soils following a decline in recent years of high rainfall and low irrigation while conditions in sub-soils were only marginally affected. Soil conditions at the end of the irrigation season in 2013 are summarized below:

- Soil pH remained higher in irrigated soil profiles under trees (pH_{Ca} range 6.4 to 6.6) and crops and pastures (pH_{Ca} range 6.5 to 7.2) compared with the slightly more acidic conditions of unirrigated soils (pH_{Ca} range 5.9 to 6.2).
- Exchangeable sodium percentage (ESP) has increased in surface soils of irrigated trees (10% to 15%) and remained high in sub-soils (20% to 21%) indicating sodic conditions (ESP > 6%) throughout the soil profiles in the plantation. In contrast surface soils of irrigated (ESP 4%) and unirrigated (ESP 2%) crops and pastures were non-sodic while sub-soils of irrigated (ESP 20%) and unirrigated (ESP 11%) showed that effluent has exacerbated sodic conditions at depth.
- Average salinity in root zones of irrigated soils increased slightly to 1.4 dS/m under trees reflecting higher irrigation and salt loads of the plantation. In contrast salinity was lower at 1.0 dS/m under crops and pastures consistent with lower irrigation and salt loads compared with the plantation in 2013. Salinity in root zones remained below the threshold value of 4.0 dS/m as required under the current EPA License.
- Extractable sulphate in irrigated soils increased to 30 mg/kg in surface soils and to 241 mg/kg in sub-soils under trees. Levels of sulphate were low at 8 mg/kg in surface soils but remained high at 138 mg/kg in sub-soils under irrigated crops and pastures; this compared with levels of 12 mg/kg in surface soil and 42 mg/kg at depth in unirrigated soils.

Average salinity in the root zones of trees (1.4 dS/m) and crops and pastures (1.0 dS/m) in 2013 remained below the threshold level of 4.0 dS/m for the re-use scheme under the current EPA License.

2. INTRODUCTION

Since 1995 effluent from the Norske Skog paper mill has been re-used to irrigate a radiata pine plantation and more recently agricultural land. Effluent from the mill is discharged to a large storage dam and then reticulated to irrigate the plantation using a drip irrigation system and agricultural crops and pastures using mobile sprinkler systems. Harvesting of the plantation commenced in 2004 and cleared areas have either been replanted with radiata pine and blue gum or were converted to crops and pastures. In 2013 rainfall was below average for the region and irrigation was applied at low to intermediate rates to young trees (193 ha) and crops and pastures (208 ha).

Since the project commenced, annual monitoring of tree condition, irrigation water, and soil properties has been conducted as part of the EPA license agreement for the re-use of effluent from the paper mill at Ettamogah. The results of the soil monitoring program based on site-specific protocols developed for the re-use scheme (Hopmans 2006) were reviewed in 2013 to identify soil properties most affected by effluent for an on-going monitoring program as part of a revised EPA license agreement. The revised soil monitoring program was implemented in 2013 and findings are presented in this report.

In 2013, soil samples were collected in the irrigated plantation of radiata pine and blue gum at Ettamogah. Soil samples were also collected from the areas of irrigated and unirrigated crops and pastures established on former plantation areas at Ettamogah and adjacent agricultural land at Maryvale and Rosevale. This report presents the results of soil chemical testing carried out in 2013 as part of the revised EPA license agreement.

3. METHODS

Soil profile samples were collected in August 2013 in accordance with the site-specific soil monitoring protocol (Hopmans 2006) retained in the revised EPA license agreement for the effluent re-use scheme at Ettamogah. Soil testing was limited to chemical properties most affected by irrigation with effluent including: pH, salinity, extractable sulphate and exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}).

Tree Plantation

Soil profile samples (0 - 10, 20 - 30, 50 - 60, and 80 - 90 cm) were collected from second rotation tree plantings irrigated with effluent including three monitoring plots (3.02, 3.11, 3.15) in radiata pine (*Pinus radiata*) and one plot (1.26) in Sydney blue gum (*Eucalyptus saligna*).

Crops and Pastures

Soil profile samples (0 - 10, 20 - 30, and 50 - 60 cm) were collected from plots (12) in crops and pastures irrigated by mobile sprinkler systems and from plots (5) in adjacent unirrigated areas at the following locations:

- Ettamogah, former plantation areas converted to crops and pastures (irrigation resumed in 2007): irrigated (4) and unirrigated plots (2).
- Maryvale (commenced 2003): irrigated (5) and unirrigated plots (2).
- Rosevale (commenced 2004): irrigated (3) and one unirrigated plot (1).

Soil Chemical Tests

Soil testing was carried out at the inorganic chemistry laboratory of the Department of Environment and Primary Industries at Macleod in Victoria using standard methods (Rayment and Higginson 1992). Soil tests included the following:

- pH in water and in 0.01 M $CaCl_2$ both at a soil/water ratio of 1:5
- Electrical conductivity (EC) at a soil/water ratio of 1:5
- Extractable sulphur in 0.01M calcium phosphate
- Exchangeable cations using a compulsive exchange method (0.1M $BaCl_2$ – 0.1M NH_4Cl) after removal of soluble salts with aqueous ethanol (2 washes)

Soil Salinity

Salinity was measured as $EC_{1:5}$ (dS/m) on 1:5 soil-water extracts and EC_{se} was estimated using the site-specific relationship developed for soils at Ettamogah (Hopmans 2006):

$EC_{se} = 7.0 \times EC_{1:5}$ (n = 148, F = 2162, $R^2 = 0.94$)

Average salinity in root zones under trees (0 - 90 cm) and crops and pastures (0 - 60 cm) was calculated as a water-use-weighted (WUW) average EC_{se} based on weighting factors reflecting the gradient in plant water use with depth as published by Shaw (1999) and adapted for the soil monitoring protocol used at Ettamogah (Hopmans 2006).

Data Analysis

Annual mean values of soil properties of profile layers under tree plantations were used to examine changes over time compared with initial values reflecting baseline conditions prior to irrigation. Annual monitoring of soil properties of irrigated and unirrigated crops and pastures provides a direct comparison and analysis of variance procedures were used to interpret differences in soil profiles due to irrigation with effluent (Statview 1999).

4. RESULTS AND DISCUSSION

4.1. Tree Plantation

Irrigation

Prior to harvesting plantation blocks were not irrigated to reduce soil moisture and increase soil bearing strength in order to minimize disturbance and compaction of soils from equipment. Irrigation was resumed at low rates after the establishment of second rotation plantings of radiata pine and blue gum in 2010 and 2011. In 2013 rainfall (585 mm) was below the long-term average for the location (694 mm) but this was preceded by two wet years with well above average rainfall in 2011 and 2012 (Figure 1).

In 2013 irrigation of young trees increased to 5.2 ML/ha and the total hydraulic load (rainfall plus irrigation: 11.0 Ml/ha) was lower compared with previous years (12.7 and 13.9 Ml/ha). The annual load of N, P, Zn and salts (TDS) in 2013 was estimated at 15.4, 1.0, 0.10, and 5559 kg/ha respectively (Appendix 3). The salt load in 2013 (5.6 t/ha) was similar compared with last year (5.1 t/ha) and well above the loads (1.1 and 1.7 t/ha) applied in the preceding wet years when irrigation was low (Figure 1). Since 2012 treatment of effluent at the mill has decreased the salinity of irrigation water (EC 1.3 dS/m) compared with previous years (EC range 1.7 to 2.1 dS/m) and this has reduced salt loads per unit of irrigation.

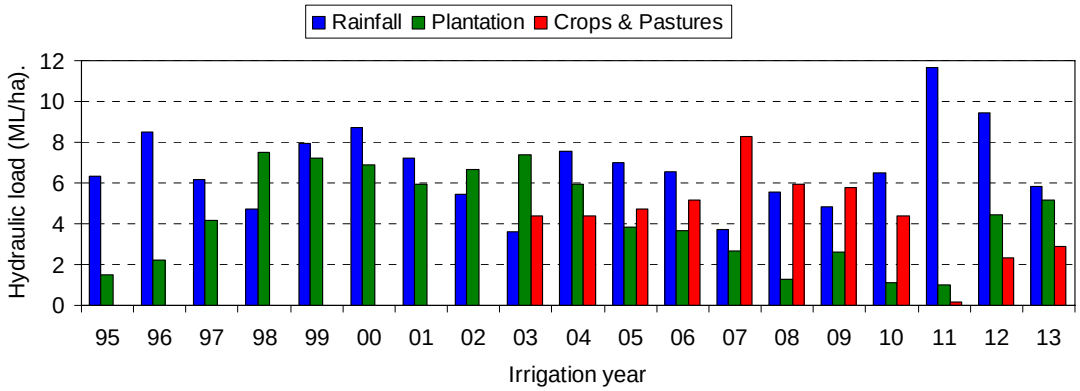

Figure 1. Seasonal rainfall (July – June) and annual irrigation (Ml/ha) of the tree plantation at Ettamogah and crops and pastures at Ettamogah, Maryvale and Rosevale.

Chemical Properties

Soil profile samples (0 to 90 cm) were collected at four plots (1.26, 3.02, 3.11 and 3.15) under radiata pine and blue gum. The results of soil pH, salinity (EC), extractable S, exchangeable cations are shown in Appendix 1. Average values for irrigated soil profile layers are presented in Table 1 and these were compared with past data for the plantation (Figure 2).

- In 2013 irrigation increased to 5.2 Ml/ha and pH_{Ca} in the soil profile was slightly acidic at 6.4 in the upper layers and 6.6 in the sub-soils (Table 1). Average soil pH_{Ca} in profiles has increased from 4.8 when irrigation commenced in 1995 to 7.0 in 2002 and remained at this level before declining to slightly acidic conditions during recent wet years with low irrigation (Figure 2).

- Salinity (EC_{se}) of the surface soil (0 -10 cm) increased slightly to 1.0 dS/m in response to higher irrigation in 2013 and remained at high levels of 1.8 and 2.7 dS/m in sub-soils (Table 1). Salinity in soil profiles has declined in recent years with high rainfall and low irrigation but this trend was reversed in response to higher irrigation in 2013.

- Exchangeable Ca in soil profiles has declined in recent wet years with low irrigation (Figure 2). Exchangeable Mg has not changed in surface soils but decreased in sub-soils. In contrast exchangeable K has returned to similar levels in soil profiles prior to recent wet years.

- Exchangeable Na in surface soils were at low levels (0.5 and 0.6 cmolc/kg) following recent wet years and were at similar values (< 0.6 cmolc/kg) when irrigation commenced in 1995. In contrast Na levels remained high in sub-soils at 2.0 and 2.3 cmolc/kg although there was a slight decline in recent years (Figure 2).

- ESP (exchangeable sodium percentage) has increased in the surface soil to 10% and 15% indicating a return to sodic conditions (ESP > 6%) consistent with higher irrigation in 2013 (Figure 2). ESP was high in the sub-soils (20%) indicating that soil profiles remained strongly sodic at depth.

- Levels of extractable S in soil profiles increased to 23 and 30 mg/kg in surface soils and remained high at 114 and 241 mg/kg in sub-soils (Figure 2). These results are consistent with the higher rate of irrigation in 2013.

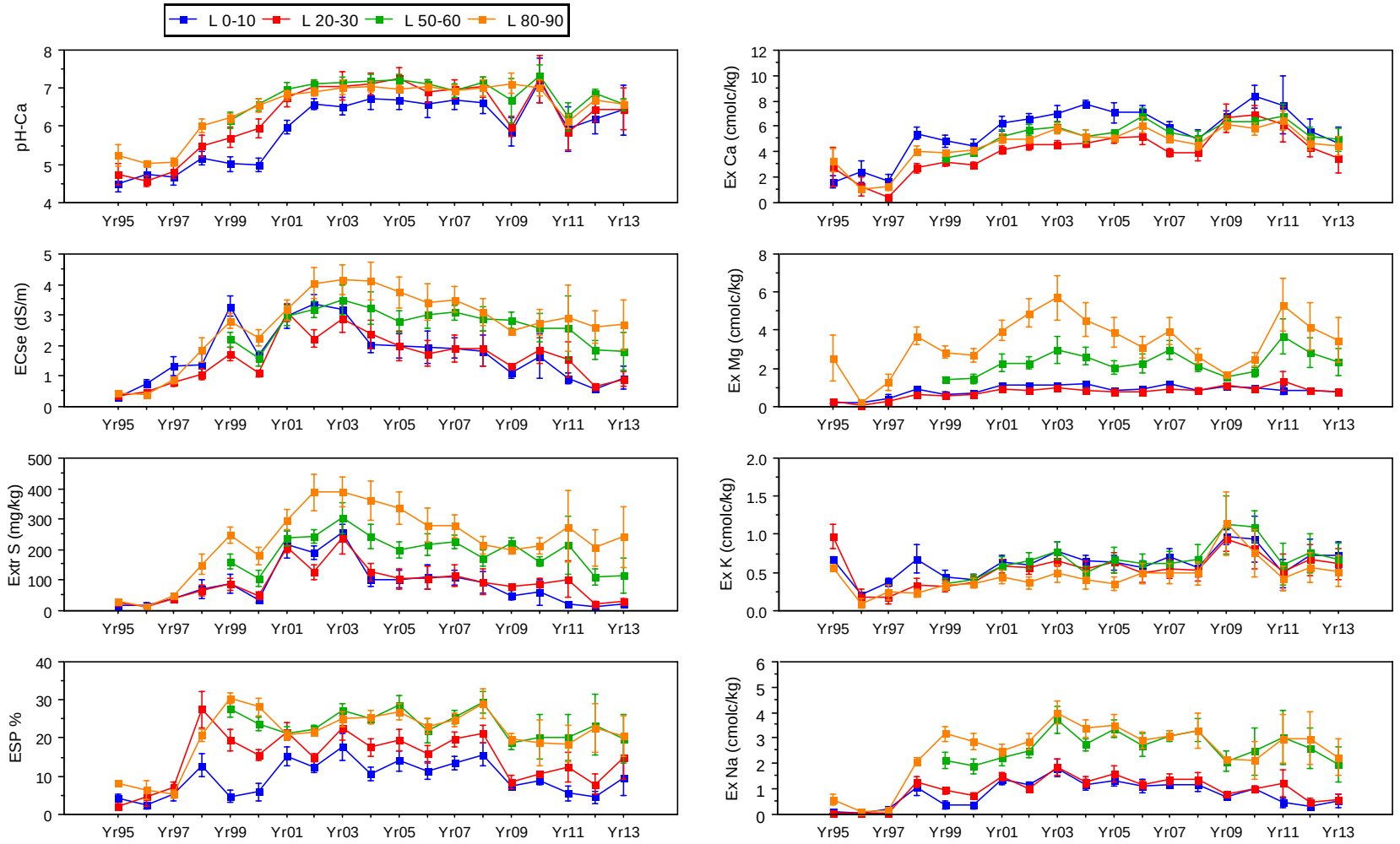

Figure 2. Average pH_{Ca}, EC_{se} (dS/m), extractable S (mg/kg), ESP (%), and exchangeable cations (cmolc/kg) in plantation soil profiles irrigated with effluent at Ettamogah since 1995 (bars indicate standard deviations). Monitoring of an additional soil profile layer (50 – 60 cm) commenced in 1999.

4.2. Crops and Pastures

Irrigation

In 2013 rainfall for the irrigation season (585 mm) was below the long-term average (694 mm) for the location and was preceded by several wet years (Figure 1). During this wet period crops and pastures were irrigated at a low rate (0.2 Ml/ha in 2011) increasing to 2.2 Ml/ha in 2012 and to 2.9 Ml/ha in 2013 as annual rainfall declined (Figure 1). The total hydraulic load (rainfall plus irrigation: 8.7 Ml/ha) in 2013 was lower compared with previous years (range 10.7 to 12.0 Ml/ha). The average loads of N, P, Zn and salts (TDS) in 2013 were estimated at 8.9, 0.6, 0.05, and 3139 kg/ha respectively (Appendix 3). The salt load was low (3.1 t/ha) and similar to 2012 (2.8 t/ha) compared with annual loads of 11 to 15 t/ha during years of low rainfall and high irrigation in 2007 and 2008 (Figure 1).

Chemical Properties

Results of the chemical analysis of soil profiles under crops and pastures at Ettamogah, Maryvale and Rosevale are presented in Appendix 1. Average results for soil pH, salinity (EC), sodicity (ESP), extractable S, exchangeable cations for profile layers are presented in Table 1; values in red type indicate that differences between irrigated and unirrigated plots were statistically significant ($P < 0.05$). Average pH_{Ca}, EC_{se}, ESP, extractable S and exchangeable cations for irrigated and non-irrigated soil profiles since 2003 (Figure 3) indicate long-term changes since irrigation commenced at Maryvale (2003), Rosevale (2004) and Ettamogah where irrigation resumed in 2007 following the conversion from trees to crops and pastures.

Comparison of irrigated (12) and unirrigated (5) plots indicated significant differences in pH, salinity (EC_{se}), exchangeable Na, ESP and extractable S in soil profiles due to irrigation with effluent (Table 1 and Figure 3). In contrast, exchangeable Ca, Mg and K were generally similar in irrigated and unirrigated soil profiles (Table1). The main effects of irrigation on soil properties are summarized below:

- Soil pH_{Ca} was higher in surface soils indicating neutral to slightly alkaline conditions (pH 7 to 8) under irrigation in 2013 while conditions were slightly acidic (pH 5 to 6) in the unirrigated soil (Table 1). Soil pH_{Ca} remained at 6.5 in irrigated sub-soils indicating little difference compared with unirrigated sub-soils (pH 6.2) in 2013. Comparison with past data indicates that irrigation has induced slightly alkaline conditions in the surface soils while sub-soils remain slightly acidic although pH is still increasing at depth (Figure 3).

- Salinity (EC_{se}) in irrigated surface soils was low at 0.8 dS/m and slightly higher compared with 0.4 dS/m in unirrigated plots in 2013 (Table 1). Salinity remained high at 2.0 dS/m at depth compared with 0.8 dS/m for unirrigated sub-soils. The decline in salinity (Figure 3) is consistent with leaching of salts from surface soils into the sub-soil under high seasonal rainfall and low salt loads in recent years.

- Levels of exchangeable Ca were slightly higher in irrigated surface soils while exchangeable Mg and K were similar in irrigated and unirrigated soil profiles (Table 1). Exchangeable Na was higher in irrigated soil profiles especially in sub-soils compared with unirrigated soils (Table 1). Irrigation has increased exchangeable Na and to a lesser extent exchangeable Ca and K but mainly in sub-soils, in contrast there has been little impact on exchangeable Mg (Figure 3).

- Sodicity (ESP) was low (4%) in irrigated surface soils (Table 1) indicating non-sodic conditions (ESP < 6%). In contrast conditions were sodic in sub-soils with ESP at 11% and 20% at depth (Table 1). Unirrigated soil profiles were moderately sodic at depth (ESP 11%). ESP in soil profiles has decreased indicating a decline in sodicity in recent years with low irrigation compared with the period of high irrigation however sub-soils remained strongly sodic (Figure 3).

- Levels of extractable S in surface soils remained low and were similar in unirrigated soils (Table 1). In contrast levels remained high in irrigated sub-soils (138 mg/kg) indicating an accumulation sulphate at depth (Figure 3).

Table 1. Average pH, salinity (EC), extractable S and exchangeable cations in soil profiles under trees, crops and pasture in 2013.

Site	Treatment	Layer	pH-w	pH-Ca	$EC_{1:5}$	EC_{se}	Extr S	Exch Ca	Exch Mg	Exch K	Exch Na	Sum Cations	ESP	Exch Ca/Mg
		cm			dS/m	dS/m	mg/kg	cmolc/kg	cmolc/kg	cmolc/kg	cmolc/kg	cmolc/kg	%	
Tree Plantation	Effluent[#]	0-10	7.6	6.4	0.14	1.0	23	4.7	0.8	0.7	0.5	6.8	10	5.6
Ettamogah	Effluent	20-30	7.7	6.5	0.13	0.9	30	3.5	0.8	0.6	0.6	5.5	15	4.5
	Effluent	50-60	7.8	6.6	0.26	1.8	114	5.0	2.3	0.7	2.0	10.0	20	2.9
	Effluent	80-90	7.6	6.6	0.38	2.7	241	4.4	3.5	0.5	2.3	10.7	21	1.9
Crops & Pastures	Nil	0-10	6.9	6.0	0.06	0.4	12	4.5	0.6	0.2	0.1	5.4	2	9.4
Ettamogah, Maryvale	Nil	20-30	7.0	5.9	0.06	0.4	12	3.6	1.1	0.2	0.2	5.1	4	4.3
& Rosevale	Nil	50-60	7.4	6.2	0.12	0.8	42	4.1	3.8	0.2	1.1	9.2	11	1.2
	Effluent[#]	0-10	8.1	7.2	0.11	0.8	8	5.8	0.7	0.4	0.3	7.2	4	8.3
	Effluent	20-30	8.2	7.0	0.12	0.8	18	3.9	1.0	0.3	0.7	5.9	11	4.5
	Effluent	50-60	7.7	6.5	0.28	2.0	138	4.2	3.2	0.3	2.0	9.7	20	1.7

[#] Values in red type indicate statistically significant differences ($P<0.05$) compared with the value for the corresponding unirrigated soil layer.

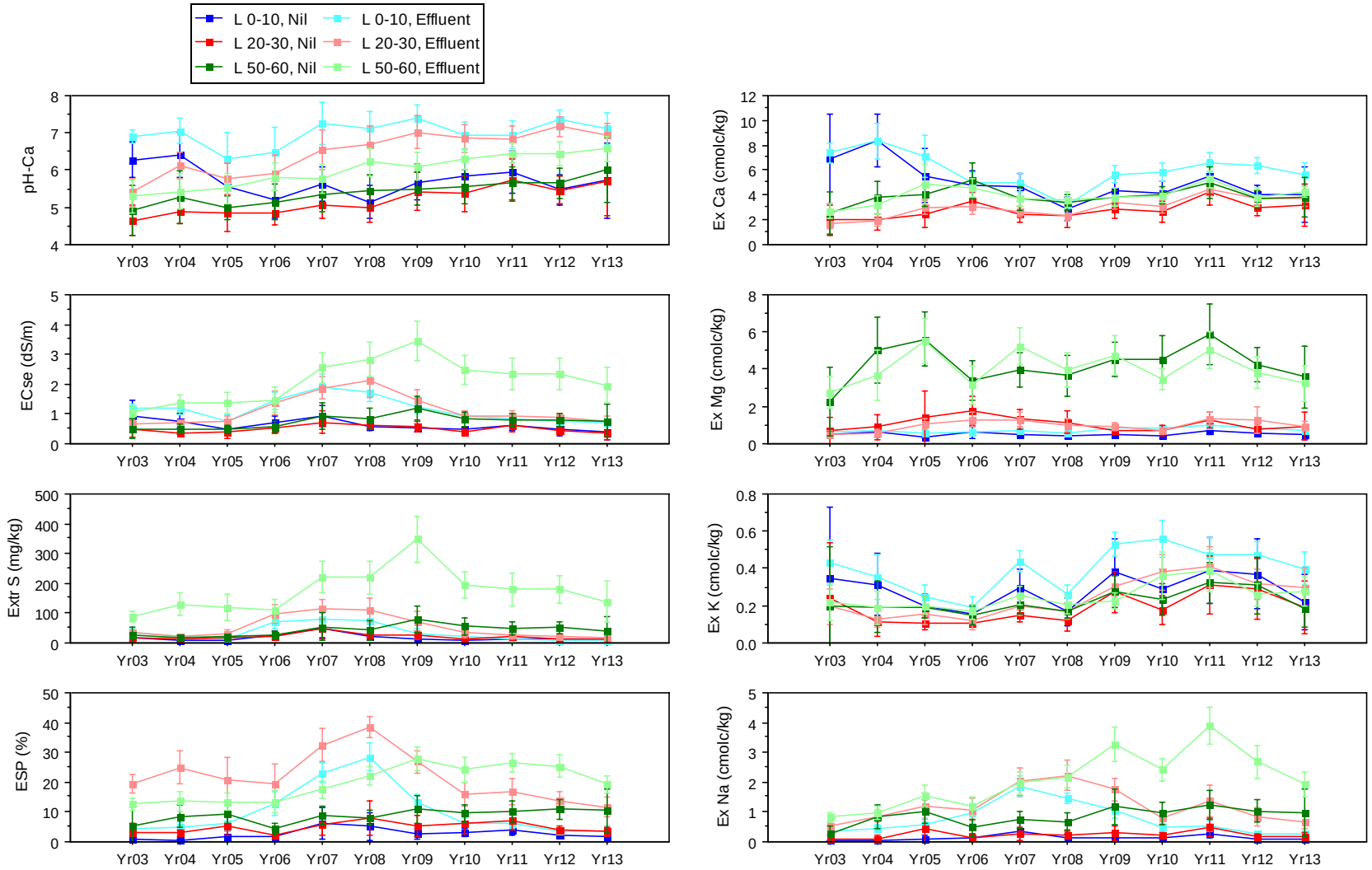

Figure 3. Average pH_{Ca}, EC_{se} (dS/m), extractable S (mg/kg), ESP (%), and exchangeable cations (cmolc/kg) in soil profiles of crops and pastures under irrigation with effluent and non-irrigated (natural rainfall) since 2003 (bars indicate standard deviations).

4.3. Salinity in Root Zones of Trees, Crops and Pastures

Average water-use weighted salinity (WUW EC_{se}) in soil profiles of trees and crops and pastures were calculated in accordance with the soil monitoring protocol for the effluent re-use scheme (Appendix 2). Average salinity in the root zones of irrigated tree plantations and irrigated and unirrigated agricultural crops and pastures are shown in Table 2.

- Average salinity in the root zones of trees in 2013 was estimated at 1.4 ± 0.8 dS/m (Table 2) and was below the salinity threshold level of 4.0 dS/m as required under the current EPA License. Long-term monitoring of the effluent irrigated plantation showed that root zone salinity increased slightly in 2013 compared with last year (Figure 4).

- Average salinity in the root zones of crops and pastures irrigated with effluent at Ettamogah, Maryvale and Rosevale was estimated at 1.0 ± 0.3 dS/m (Table 2) and was below the threshold value of 4.0 dS/m. Root zone salinity has decreased since 2008 (Figure 4) in response to lower irrigation and salt loads during recent wet years.

- Average salinity in the root zones of unirrigated crops and pastures at Ettamogah, Maryvale and Rosevale was estimated at 0.5 ± 0.3 dS/m (Table 2).

Table 2. Average water-use weighted salinity (WUW EC_{se}) in root zones under trees, crops and pastures irrigated with paper mill effluent in 2013.

Site	Irrigated (yrs)	WUW EC_{se} (dS/m) Average	Std Dev[#]	Plots (n)	CoVar[†] (%)
Tree Plantation					
Ettamogah – Pine & Eucalypt	18	**1.4**	**0.8**	4	57
Irrigated Crops & Pastures					
Ettamogah, Maryvale & Rosevale	11	**1.0**	**0.3**	12	33
Unirrigated Crops & Pastures		**0.5**	**0.3**	5	68

[#] Std Dev: standard deviation
[†] CoVar: coefficient of variation

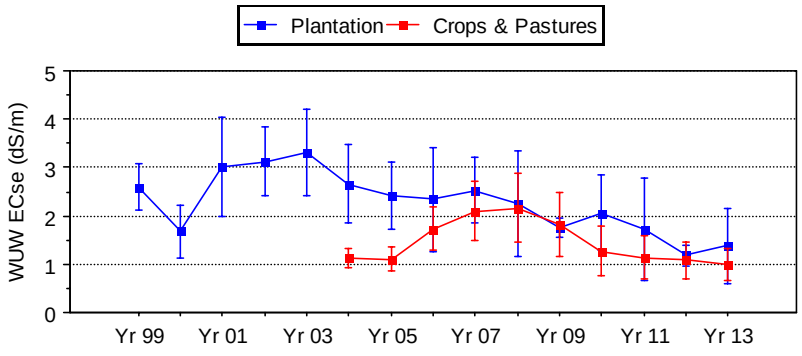

Figure 4. Average salinity (WUW EC_{se}) in the root zones of trees (0 – 90 cm) and crops and pastures (0 – 60 cm) irrigated with paper mill effluent. Bars indicate standard deviations.

5. CONCLUSIONS

In 2013 soil testing was carried out as part of the environmental monitoring program for the waste water re-use scheme to determine the effects of irrigation with effluent on soil properties in the root zones of trees, crops and pastures. Past monitoring of soils has shown that irrigation increased pH, salinity, sodicity and sulphate in soil profiles while the effects on other properties have been relatively minor. The requirement for on-going monitoring was reviewed in 2013 and soil testing has been confined to properties most affected by effluent.

In 2013 seasonal rainfall (585 mm) was below average and irrigation of trees (5.2 Ml/ha) and crops and pastures (2.9 Ml/ha) was higher compared with recent years of high rainfall and low irrigation. Likewise salt loads were higher (5.6 and 3.1 t/ha) in 2013 although loads in 2013 would have been reduced by the lower salinity of effluent (EC 1.3 dS/m) compared with past years (EC range 1.7 to 2.1 dS/m). Higher irrigation of trees and to a lesser extent crops and pastures did increase pH, salinity, extractable S and sodicity in surface soils following a decline in recent years with high rainfall and low irrigation while conditions in sub-soils were only marginally affected. The results for soil testing conducted in 2013 are summarized below:

- Soil pH remained higher in irrigated soil profiles under trees (pH_{Ca} range 6.4 to 6.6) and crops and pastures (pH_{Ca} range 6.5 to 7.2) compared with the slightly more acidic conditions of unirrigated soils (pH_{Ca} range 5.9 to 6.2).
- Exchangeable sodium percentage (ESP) has increased in surface soils of irrigated trees (10% to 15%) and remained high in sub-soils (20% to 21%) indicating sodic conditions (ESP > 6%) throughout the soil profiles in the plantation. In contrast surface soils of irrigated (ESP 4%) and unirrigated (ESP 2%) crops and pastures were non-sodic while sub-soils of irrigated (ESP 20%) and unirrigated (ESP 11%) showed that effluent has exacerbated sodic conditions at depth.
- Average salinity in root zones of irrigated soils increased slightly to 1.4 dS/m under trees reflecting higher irrigation and salt loads of the plantation in 2013. In contrast salinity was lower at 1.0 dS/m under crops and pastures compared with the plantation. Salinity in root zones remained below the threshold value of 4.0 dS/m as required under the current EPA License.
- Extractable sulphate in irrigated soils increased to 30 mg/kg in surface soils and to 241 mg/kg in sub-soils under trees. Levels of sulphate were low at 8 mg/kg in surface soils but remained high at 138 mg/kg in sub-soils under irrigated crops and pastures; this compared with levels of 12 mg/kg in surface soil and 42 mg/kg at depth in unirrigated soils.

Average salinity in the root zones of trees (1.4 dS/m) and crops and pastures (1.0 dS/m) in 2013 remained below the threshold level of 4.0 dS/m for the re-use scheme under the current EPA License.

6. REFERENCES

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Appendix 1. Results of chemical analysis of soils of the tree plantation at Ettamogah and crops and pastures at Ettamogah, Maryvale and Rosevale in 2013.

Plantation at Ettamogah

Species & Plot	Treatment	Depth (cm)	pH_{Ca}	pH_{W}	$EC_{1:5}$ (dS/m)	Extr S (mg/kg)	Exch Ca (cmolc/kg)	Exch Mg (cmolc/kg)	Exch K (cmolc/kg)	Exch Na (cmolc/kg)
Blue gum										
1.26	Irrigated	0-10	8.2	9.3	0.28	43	3.7	0.8	0.5	1.3
1.26	Irrigated	20-30	7.8	9.0	0.23	62	2.1	0.5	0.3	1.0
1.26	Irrigated	50-60	6.9	8.3	0.31	118	4.1	2.0	0.5	3.1
1.26	Irrigated	80-90	6.5	7.5	0.48	309	3.4	3.4	0.2	3.4
Radiata pine										
3.02	Irrigated	0-10	5.2	6.3	0.06	7	4.7	0.8	0.8	0.1
3.02	Irrigated	20-30	5.1	6.3	0.08	20	3.5	1.0	0.8	0.4
3.02	Irrigated	50-60	6.3	7.7	0.13	47	4.3	1.6	0.8	1.2
3.02	Irrigated	80-90	6.4	7.5	0.25	118	3.5	2.1	0.6	1.5
3.11	Irrigated	0-10	6.5	7.5	0.07	4	8.1	1.1	1.2	0.1
3.11	Irrigated	20-30	6.8	7.8	0.09	8	6.7	1.1	1.1	0.2
3.11	Irrigated	50-60	6.8	7.9	0.11	20	7.7	1.3	1.2	0.4
3.11	Irrigated	80-90	6.8	7.9	0.15	46	6.7	1.6	1.1	0.7
3.15	Irrigated	0-10	5.8	7.2	0.13	36	2.3	0.5	0.4	0.6
3.15	Irrigated	20-30	6.2	7.7	0.12	31	1.7	0.4	0.2	0.8
3.15	Irrigated	50-60	6.3	7.2	0.49	272	3.8	4.4	0.2	3.2
3.15	Irrigated	80-90	6.6	7.4	0.67	493	4.2	6.9	0.2	3.5

Crops and Pastures

Plot	Treatment	Depth (cm)	pH_{-Ca}	pH_{-W}	$EC_{1:5}$ (dS/m)	Extr S (mg/kg)	Exch Ca (cmolc/kg)	Exch Mg (cmolc/kg)	Exch K (cmolc/kg)	Exch Na (cmolc/kg)
Ettamogah										
1.03	Irrigated	0-10	7.3	8.0	0.18	15	5.2	0.9	0.6	0.5
1.03	Irrigated	20-30	7.3	8.4	0.12	23	2.4	0.4	0.3	0.4
1.03	Irrigated	50-60	7.1	8.3	0.20	77	4.6	1.8	0.5	1.5
MVP5-2.03	Irrigated	0-10	6.9	7.9	0.09	9	5.4	0.8	0.6	0.3
MVP5-2.03	Irrigated	20-30	7.0	8.3	0.10	18	4.1	0.9	0.6	0.6
MVP5-2.03	Irrigated	50-60	6.7	7.9	0.24	108	4.3	2.2	0.4	2.0
MVP5	Irrigated	0-10	4.9	6.0	0.05	9	2.2	0.4	0.2	0.1
MVP5	Irrigated	20-30	5.6	6.5	0.04	7	1.9	0.5	0.1	0.1
MVP5	Irrigated	50-60	5.2	6.3	0.09	38	2.9	3.4	0.1	0.6
MVC5	Unirrigated	0-10	6.0	6.8	0.05	2	4.2	0.7	0.4	0.1
MVC5	Unirrigated	20-30	6.6	7.8	0.05	4	3.2	0.8	0.4	0.2
MVC5	Unirrigated	50-60	6.9	8.4	0.13	35	4.1	2.7	0.3	2.2
MVP4-2.13	Irrigated	0-10	7.1	8.2	0.11	18	4.4	0.9	0.5	0.6
MVP4-2.13	Irrigated	20-30	6.1	7.4	0.21	71	2.9	1.7	0.3	1.6
MVP4-2.13	Irrigated	50-60	6.3	7.4	0.27	129	3.9	3.5	0.3	2.0
MVC4-2.15	Unirrigated	0-10	6.5	7.2	0.14	50	7.1	0.8	0.4	0.3
MVC4-2.15	Unirrigated	20-30	6.7	7.5	0.12	47	5.0	0.9	0.3	0.3
MVC4-2.15	Unirrigated	50-60	6.5	7.2	0.24	132	5.1	2.4	0.3	0.8
Rosevale										
RVP1.1.1	Irrigated	0-10	7.8	8.6	0.12	5	8.1	0.8	0.3	0.2
RVP1.1.1	Irrigated	20-30	7.2	8.7	0.13	11	4.2	1.2	0.1	1.2
RVP1.1.1	Irrigated	50-60	6.3	7.1	0.62	459	4.7	6.7	0.1	3.4
RVP1.2.1	Irrigated	0-10	7.7	8.5	0.12	6	7.9	0.7	0.2	0.2
RVP1.2.1	Irrigated	20-30	7.5	8.7	0.15	14	4.7	1.8	0.1	1.1
RVP1.2.1	Irrigated	50-60	6.4	7.3	0.51	281	4.3	6.1	0.2	2.8
RVP2.1.1	Irrigated	0-10	7.0	8.3	0.09	8	4.3	0.7	0.2	0.5
RVP2.1.1	Irrigated	20-30	6.8	8.3	0.12	18	4.4	1.4	0.1	1.0
RVP2.1.1	Irrigated	50-60	5.8	6.8	0.34	191	2.8	4.4	0.1	2.2
RVP2.1.2	Unirrigated	0-10	5.8	6.8	0.04	5	4.3	0.4	0.1	0.1
RVP2.1.2	Unirrigated	20-30	5.4	6.5	0.03	2	2.0	0.3	0.0	0.0
RVP2.1.2	Unirrigated	50-60	5.3	6.7	0.06	14	2.4	4.9	0.1	0.6

Crops and Pastures

Plot	Treatment	Depth (cm)	pH_{Ca}	pH_{W}	$EC_{1:5}$ (dS/m)	Extr S (mg/kg)	Exch Ca (cmolc/kg)	Exch Mg (cmolc/kg)	Exch K (cmolc/kg)	Exch Na (cmolc/kg)
Maryvale										
MVP2a.1	Irrigated	0 - 10	7.5	8.3	0.11	7	6.8	0.6	0.5	0.1
MVP2a.1	Irrigated	20 - 30	7.2	8.3	0.09	7	4.4	0.7	0.6	0.2
MVP2a.1	Irrigated	50 - 60	7.3	8.6	0.18	26	5.0	1.4	0.6	1.5
MVP2b.1	Irrigated	0 - 10	7.0	8.0	0.07	3	5.2	0.6	0.5	0.1
MVP2b.1	Irrigated	20 - 30	7.0	8.0	0.08	5	5.2	0.9	0.6	0.1
MVP2b.1	Irrigated	50 - 60	6.8	8.3	0.11	16	5.0	1.3	0.4	1.1
MVP2c.2	Irrigated	0 - 10	7.7	8.5	0.10	4	6.0	0.7	0.4	0.2
MVP2c.2	Irrigated	20 - 30	7.6	8.8	0.12	10	4.3	0.9	0.3	0.7
MVP2c.2	Irrigated	50 - 60	7.1	8.6	0.24	71	3.7	2.4	0.2	2.6
MVP3a.1	Irrigated	0 - 10	7.6	8.5	0.12	8	6.8	0.6	0.4	0.2
MVP3a.1	Irrigated	20 - 30	7.3	8.6	0.12	19	4.7	0.8	0.4	0.6
MVP3a.1	Irrigated	50 - 60	6.9	8.3	0.22	69	5.4	2.6	0.3	2.1
MVP3b.1	Irrigated	0 - 10	7.6	8.5	0.13	5	7.2	0.7	0.5	0.2
MVP3b.1	Irrigated	20 - 30	7.5	8.8	0.12	13	3.6	0.6	0.2	0.6
MVP3b.1	Irrigated	50 - 60	6.4	7.4	0.37	186	4.1	2.9	0.2	1.9
MVC2a	Unirrigated	0 - 10	6.8	7.7	0.05	3	5.3	0.3	0.2	0.0
MVC2a	Unirrigated	20 - 30	6.0	7.3	0.06	6	5.3	2.2	0.1	0.4
MVC2a	Unirrigated	50 - 60	6.9	8.2	0.14	19	6.0	6.2	0.1	1.6
MVC3c	Unirrigated	0 - 10	4.6	5.9	0.02	3	1.6	0.5	0.2	0.0
MVC3c	Unirrigated	20 - 30	4.9	6.1	0.03	3	2.3	1.2	0.2	0.1
MVC3c	Unirrigated	50 - 60	5.4	6.6	0.04	10	3.0	2.7	0.1	0.2

Appendix 2. Salinity in root zones of trees, crops and pastures in 2013.

Ettamogah Plantation

Site	Soil Unit	Plot	Treatment	Layer (cm)	$EC_{1:5}$ (dS/m)	EC_{se} (dS/m)	WU Factor	WUW EC_{se} (dS/m) Layer	Profile
Ettamogah	Unit 4	1.26	Effluent	0-10	0.285	1.99	0.41	0.82	
Ettamogah	Unit 4	1.26	Effluent	20-30	0.228	1.60	0.21	0.34	
Ettamogah	Unit 4	1.26	Effluent	50-60	0.312	2.19	0.25	0.55	
Ettamogah	Unit 4	1.26	Effluent	80-90	0.476	3.33	0.13	0.43	2.13
Ettamogah	Unit 1	3.02	Effluent	0-10	0.060	0.42	0.41	0.17	
Ettamogah	Unit 1	3.02	Effluent	20-30	0.079	0.55	0.21	0.12	
Ettamogah	Unit 1	3.02	Effluent	50-60	0.133	0.93	0.25	0.23	
Ettamogah	Unit 1	3.02	Effluent	80-90	0.245	1.72	0.13	0.22	0.74
Ettamogah	Unit 2	3.11	Effluent	0-10	0.070	0.49	0.41	0.20	
Ettamogah	Unit 2	3.11	Effluent	20-30	0.086	0.60	0.21	0.13	
Ettamogah	Unit 2	3.11	Effluent	50-60	0.108	0.76	0.25	0.19	
Ettamogah	Unit 2	3.11	Effluent	80-90	0.147	1.03	0.13	0.13	0.65
Ettamogah	Unit 4	3.15	Effluent	0-10	0.126	0.88	0.41	0.36	
Ettamogah	Unit 4	3.15	Effluent	20-30	0.116	0.81	0.21	0.17	
Ettamogah	Unit 4	3.15	Effluent	50-60	0.489	3.42	0.25	0.86	
Ettamogah	Unit 4	3.15	Effluent	80-90	0.668	4.68	0.13	0.61	1.99
								Average	1.38
								Std Dev	0.79
								Covar%	57

Ettamogah, Maryvale and Rosevale Crops and Pasture: Irrigated Plots

Site	Soil Unit	Plot	Treatment	Layer (cm)	$EC_{1:5}$ (dS/m)	EC_{se} (dS/m)	WU Factor	WUW EC_{se} (dS/m) Layer	Profile
Ettamogah	Unit 3	1.03	Effluent	0-10	0.182	1.28	0.53	0.68	
Ettamogah	Unit 3	1.03	Effluent	20-30	0.120	0.84	0.28	0.23	
Ettamogah	Unit 3	1.03	Effluent	50-60	0.204	1.43	0.19	0.27	1.18
Ettamogah	Unit 2	MVP5-2.03	Effluent	0-10	0.091	0.63	0.53	0.34	
Ettamogah	Unit 2	MVP5-2.03	Effluent	20-30	0.104	0.72	0.28	0.20	
Ettamogah	Unit 2	MVP5-2.03	Effluent	50-60	0.239	1.67	0.19	0.32	0.86
Ettamogah	Unit 2	MVP5	Effluent	0-10	0.050	0.35	0.53	0.19	
Ettamogah	Unit 2	MVP5	Effluent	20-30	0.039	0.27	0.28	0.08	
Ettamogah	Unit 2	MVP5	Effluent	50-60	0.086	0.60	0.19	0.11	0.38
Ettamogah	Unit 3	MVP4-2.13	Effluent	0-10	0.111	0.78	0.53	0.41	
Ettamogah	Unit 3	MVP4-2.13	Effluent	20-30	0.205	1.44	0.28	0.40	
Ettamogah	Unit 3	MVP4-2.13	Effluent	50-60	0.268	1.87	0.19	0.36	1.17
Maryvale	Unit 2	MVP2a.1	Effluent	0-10	0.114	0.80	0.53	0.42	
Maryvale	Unit 2	MVP2a.1	Effluent	20-30	0.088	0.62	0.28	0.17	
Maryvale	Unit 2	MVP2a.1	Effluent	50-60	0.176	1.23	0.19	0.23	0.83
Maryvale	Unit 2	MVP2b.1	Effluent	0-10	0.067	0.47	0.53	0.25	
Maryvale	Unit 2	MVP2b.1	Effluent	20-30	0.083	0.58	0.28	0.16	
Maryvale	Unit 2	MVP2b.1	Effluent	50-60	0.113	0.79	0.19	0.15	0.56
Maryvale	Unit 4	MVP2c.2	Effluent	0-10	0.099	0.69	0.53	0.37	
Maryvale	Unit 4	MVP2c.2	Effluent	20-30	0.118	0.83	0.28	0.23	
Maryvale	Unit 4	MVP2c.2	Effluent	50-60	0.237	1.66	0.19	0.32	0.91
Maryvale	Unit 4	MVP3a.1	Effluent	0-10	0.123	0.86	0.53	0.45	
Maryvale	Unit 4	MVP3a.1	Effluent	20-30	0.121	0.85	0.28	0.24	
Maryvale	Unit 4	MVP3a.1	Effluent	50-60	0.221	1.55	0.19	0.29	0.99
Maryvale	Unit 4	MVP3b.1	Effluent	0-10	0.126	0.88	0.53	0.47	
Maryvale	Unit 4	MVP3b.1	Effluent	20-30	0.116	0.81	0.28	0.23	
Maryvale	Unit 4	MVP3b.1	Effluent	50-60	0.372	2.60	0.19	0.49	1.19
Rosevale	Unit 3	RVP1.1.1	Effluent	0-10	0.124	0.87	0.53	0.46	
Rosevale	Unit 3	RVP1.1.1	Effluent	20-30	0.126	0.88	0.28	0.25	
Rosevale	Unit 3	RVP1.1.1	Effluent	50-60	0.615	4.31	0.19	0.82	1.52
Rosevale	Unit 3	RVP1.2.1	Effluent	0-10	0.123	0.86	0.53	0.46	
Rosevale	Unit 3	RVP1.2.1	Effluent	20-30	0.146	1.02	0.28	0.29	
Rosevale	Unit 3	RVP1.2.1	Effluent	50-60	0.512	3.58	0.19	0.68	1.42
Rosevale	Unit 4	RVP2.1.1	Effluent	0-10	0.092	0.64	0.53	0.34	
Rosevale	Unit 4	RVP2.1.1	Effluent	20-30	0.117	0.82	0.28	0.23	
Rosevale	Unit 4	RVP2.1.1	Effluent	50-60	0.336	2.35	0.19	0.45	1.02
								Average	1.00
								Std Dev	0.33
								Covar%	33

Ettamogah, Maryvale and Rosevale Crops and Pasture: Unirrigated Plots

Site	Soil Unit	Plot	Treatment	Layer (cm)	$EC_{1:5}$ (dS/m)	EC_{se} (dS/m)	WU Factor	WUW EC_{se} (dS/m) Layer	Profile
Ettamogah	Unit 4	MVC5	Nil	0-10	0.049	0.34	0.53	0.18	
Ettamogah	Unit 4	MVC5	Nil	20-30	0.054	0.38	0.28	0.11	
Ettamogah	Unit 4	MVC5	Nil	50-60	0.131	0.92	0.19	0.17	0.46
Ettamogah	Unit 4	MVC4-2.15	Nil	0-10	0.137	0.96	0.53	0.51	
Ettamogah	Unit 4	MVC4-2.15	Nil	20-30	0.120	0.84	0.28	0.23	
Ettamogah	Unit 4	MVC4-2.15	Nil	50-60	0.236	1.65	0.19	0.31	1.06
Maryvale	Unit 2	MVC2a	Nil	0-10	0.053	0.37	0.53	0.20	
Maryvale	Unit 2	MVC2a	Nil	20-30	0.057	0.40	0.28	0.11	
Maryvale	Unit 2	MVC2a	Nil	50-60	0.136	0.95	0.19	0.18	0.49
Maryvale	Unit 4	MVC3c	Nil	0-10	0.023	0.16	0.53	0.09	
Maryvale	Unit 4	MVC3c	Nil	20-30	0.026	0.18	0.28	0.05	
Maryvale	Unit 4	MVC3c	Nil	50-60	0.039	0.27	0.19	0.05	0.19
Rosevale	Unit 4	RVP2.1.2	Nil	0-10	0.043	0.30	0.53	0.16	
Rosevale	Unit 4	RVP2.1.2	Nil	20-30	0.027	0.19	0.28	0.05	
Rosevale	Unit 4	RVP2.1.2	Nil	50-60	0.059	0.41	0.19	0.08	0.29
								Average	0.50
								Std Dev	0.34
								Covar%	68

Appendix 3. Annual rainfall, pan evaporation, irrigation and loads of nitrogen, phosphorus, zinc and total dissolved solids (TDS) in effluent applied from 1st July 2012 to 30th June 2013 to tree plantations, crops and pastures.

Irrigation year 1 July - 30 June	Rainfall (mm)	Evaporation (mm)	Rainfall (ML/ha)	Irrigation: trees (ML/ha)	Total hydraulic load: trees (ML/ha)	Irrigation: pasture (ML/ha)	Total hydraulic load: pasture (ML/ha)	N trees (kg/ha)	N pasture	P trees (kg/ha)	P pasture	Zn trees (kg/ha)	Zn pasture	TDS trees (kg/ha)	TDS pasture
2012 - 2013	583	1425	5.8	5.2	11.0	2.9	8.7	15.4	8.9	1.0	0.60	0.10	0.05	5559	3139