Soil Properties under Tree Plantations, Crops and Pastures Irrigated with Paper Mill Effluent at Albury in 2015

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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. Cleared areas have either been replanted with a second rotation of radiata pine and eucalypts irrigated by drip-irrigation (214 ha in 2015) or were returned to agriculture to expand the existing area under crops and pastures irrigated by sprinkler systems (217 ha in 2015).

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 for the third year of the new program are presented in this report.

In 2015 seasonal rainfall (660 mm) was below average and irrigation of trees increased (5.8 ML/ha) while irrigation of crops and pastures remained low (2.0 ML/ha) compared with the previous year. Salt loads were higher in the plantation (5.8 t/ha) compared with crops and pastures (2.0 t/ha) reflecting the differences in irrigation. In general soil pH, salinity, extractable S and sodicity remained higher in effluent irrigated soils. Soil conditions at the end of the irrigation season in 2015 are summarized below:

- Soil pH remained higher and slightly alkaline in irrigated soil profiles under crops and pastures (pH_{Ca} range 6.7 to 7.3) compared with the more acidic conditions of unirrigated soils (pH_{Ca} range 6.0 to 6.2). Soil pH remained slightly acidic in soils under irrigated trees (pH_{Ca} range 6.4 to 6.8).
- Exchangeable sodium percentage (ESP) increased in surface soils (7% to 13%) and sub-soils (19% to 20%) of irrigated trees indicating that soil profiles in the plantation remained sodic (ESP > 6%). Surface soils of irrigated (ESP 2%) and unirrigated (ESP 2%) crops and pastures were non-sodic; in contrast conditions remained sodic in both irrigated (ESP 23%) and unirrigated (ESP 13%) sub-soils.
- Average salinity in root zones of irrigated soils increased to 1.3 dS/m under trees consistent with lower rainfall and higher irrigation (5.8 ML/ha). In contrast salinity remained low at 0.9 dS/m in the root zones of crops and pastures with low irrigation (2.0 ML/ha). Salinity in root zones of trees as well as crops and pastures was below the threshold value of 4.0 dS/m as required under the current EPA License.
- Extractable soil sulphate under irrigated trees increased to 15 mg/kg in surface soils and to 171 mg/kg in sub-soils. Levels of sulphate were low at 6 mg/kg in surface soils but remained high at 90 mg/kg in sub-soils under irrigated crops and pastures compared with 6 mg/kg in surface soil and 34 mg/kg at depth in unirrigated soils.

Average salinity in the root zones of trees (1.3 dS/m) and crops and pastures (0.9 dS/m) in 2015 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 tree 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 trees (radiata pine, blue gum and flooded gum) or were converted to crops and pastures. In 2015 rainfall was slightly below average for the region and irrigation was applied at low to intermediate rates to young trees (214 ha) and crops and pastures (217 ha).

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 since the project commenced. 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 results for the third year of the new program are presented in this report.

In 2015, soil samples were collected from the irrigated tree plantation 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 2015 as part of the revised EPA license agreement.

3. METHODS

Soil profile samples were collected in August 2015 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 two monitoring plots (3.02, 3.11) in radiata pine (*Pinus radiata*), one plot (1.26) in Sydney blue gum (*Eucalyptus saligna*) and one plot (3.15) in flooded gum (*Eucalyptus grandis*).

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 irrigated plantation areas converted to crops and pastures (irrigation resumed in 2007): irrigated (4) and unirrigated plots (2).
- Maryvale (commenced in 2003): irrigated (5) and unirrigated plots (2).
- Rosevale (commenced in 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} (EC of saturation extract) 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 irrigated trees 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 clear-felling irrigation of plantation blocks ceased to reduce soil moisture and increase soil bearing strength in order to minimize disturbance and compaction of soils by harvesting equipment. Irrigation was resumed at low rates after the establishment of second rotation plantings of radiata pine and eucalypt species in 2010 and 2011. In 2015 rainfall (660 mm) was below the long-term average for the location (694 mm), this was preceded by two years of low to average rainfall in 2013 and 2014 after two wet years with well above average rainfall in 2011 and 2012 (Figure 1).

In 2015 irrigation of young trees (5.8 ML/ha) was slightly higher but the total hydraulic load (rainfall plus irrigation: 12.4 ML/ha) was similar compared with the preceding three years (12.4, 11.0 and 12.7 ML/ha). The annual load of N, P, Zn and salts (TDS) in 2015 was estimated at 16.3, 1.6, 0.04, and 5810 kg/ha respectively (Appendix 3). The salt load in 2015 (5.8 t/ha) was similar compared with the preceding two years (5.4 and 5.6 t/ha in 2014 and 2013) and well above the loads (1.1 and 1.7 t/ha) applied during the wet years with low irrigation (Figure 1). Since 2012 treatment of effluent at the mill has decreased the salinity of irrigation water (EC range 1.2 to 1.4 dS/m) compared with previous years (EC range 1.7 to 2.1 dS/m) and this has reduced the salt load per unit of irrigation (ML/ha).

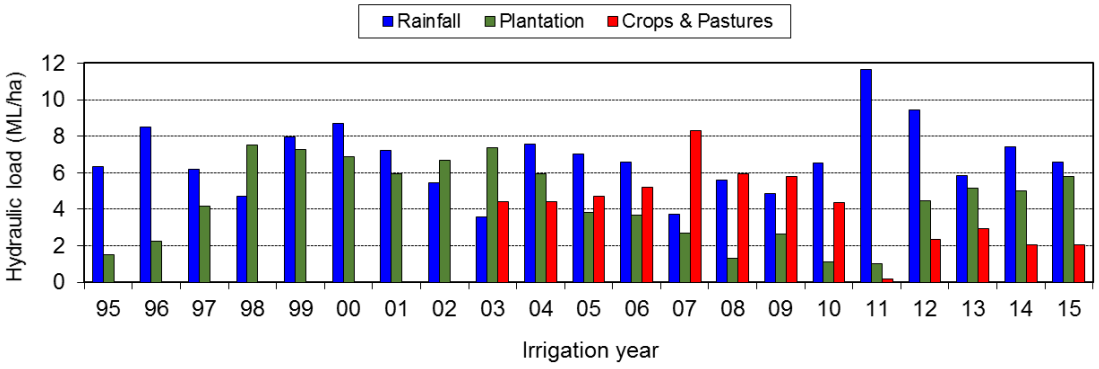

Figure 1. Seasonal rainfall (July – June) and annual irrigation (ML/ha) of the tree plantation at Ettamogah and crops and pastures at Ettamogah, Maryvale and Rosevale.

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, blue gum and flooded gum. The results of soil pH, salinity (EC), extractable S and exchangeable cations are shown in Appendix 1. Average values for irrigated soil profile layers in 2015 are presented in Table 1 together with past data for the plantation in Figure 2.

- In 2015 soil pH_{Ca} was slightly acidic (6.4) in the upper layers (0 - 10 and 20 - 30 cm) and ranged from 6.5 to 6.8 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 several wet years with low irrigation (Figure 2). Soil pH_{Ca} remains slightly acidic after four years of irrigation at rates of 4 to 6 ML/ha/yr since 2011.

- Salinity (EC_{se}) of the upper layers increased slightly to 0.8 and 1.1 dS/m with higher irrigation (6 ML/ha) and lower rainfall (660 mm) in 2015 compared with 2014. Likewise salinity in sub-soils has increased to 1.7 and 2.4 dS/m (Table 1). Salinity in soil profiles has increased consistent with higher irrigation and salt load (5.8 t/ha) in 2015 (Figure 2).

- Exchangeable cations (Ca, Mg and K) in soil profiles decreased in 2015 but remained within the historic range for the plots (Table 1 and Figure 2). Ratios of exchangeable Ca/Mg for each layer in soil profiles remained at similar levels compared with previous years and ratios declined with depth reflecting the increase in exchangeable Mg in sub-soils (Table 1).

- Exchangeable Na in surface soils increased slightly (0.5 and 0.9 cmolc/kg) compared with recent years (Figure 2). In contrast Na levels remained higher in sub-soils (1.9 and 2.5 cmolc/kg) consistent with the higher irrigation and salt load in 2015 (Figure 2).

- ESP (exchangeable sodium percentage) in surface soils (7% and 13%) indicate that slightly sodic conditions (ESP > 6%) persisted in 2015 (Table 1). ESP in the sub-soils increased (19% and 20%) indicating that soils remained sodic at depth (Figure 2).

- Levels of extractable S in soil profiles increased slightly to 15 and 31 mg/kg in surface soils and to 107 and 171 mg/kg in sub-soils consistent with the higher irrigation and salt load in 2015 (Figure 2). Levels of extractable S in soil profiles remained low compared with historic data.

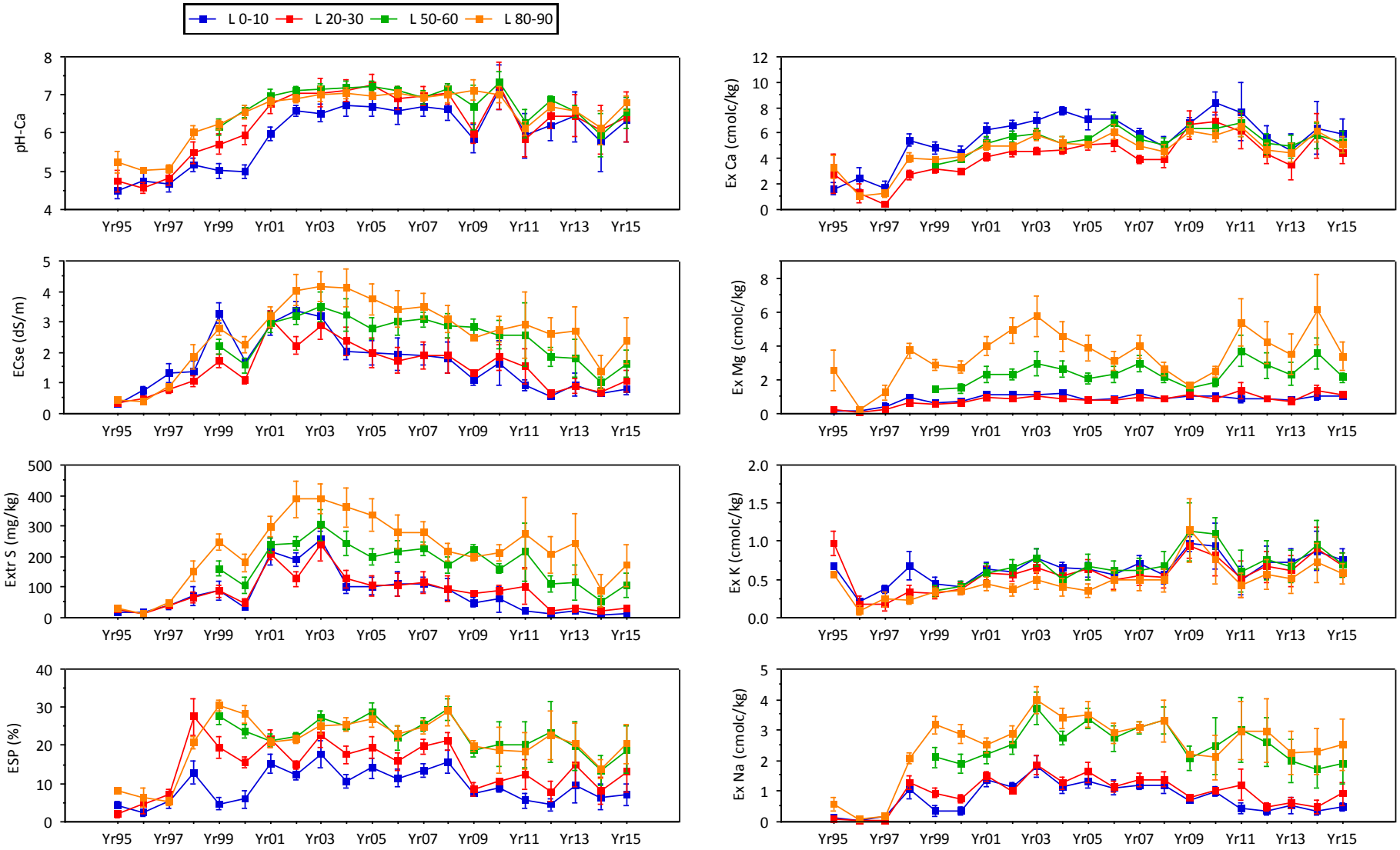

Figure 2. Average pH_{Ca}, EC_{se} (dS/m), extractable S (mg/kg), ESP (%), and exchangeable cations (cmolc/kg) in plantation soil profiles irrigated with effluent at Ettamogah since 1995 (bars indicate standard deviations). Monitoring of an additional soil profile layer (50 – 60 cm) commenced in 1999.

4.2. Crops and Pastures

Irrigation

Rainfall in 2015 (660 mm) was below the long-term average (694 mm) for the location and irrigation of crops and pastures was low at 2.0 ML/ha and similar to the previous three years (Figure 1). The total hydraulic load (rainfall plus irrigation) in 2015 (8.6 ML/ha) was similar in 2014 (9.4 ML/ha) and 2013 (8.7 ML/ha) and lower compared with the previous wet years (range 10.7 to 12.0 ML/ha). The average loads of N, P, Zn and salts (TDS) in 2015 were estimated at 4.9, 0.5, 0.01, and 2037 kg/ha respectively (Appendix 3). The salt load was lower (2.0 t/ha) this year compared with the previous three years (2.2, 3.1 and 2.8 t/ha).

Chemical Properties

Results of the chemical analysis of soil profiles under crops and pastures at Ettamogah, Maryvale and Rosevale are presented in Appendix 1. Mean values 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) show long-term changes since irrigation commenced at Maryvale (2003), Rosevale (2004) and Ettamogah where irrigation resumed in 2007 following the conversion from tree plantation to crops and pastures.

Comparison of irrigated (12) and unirrigated (5) plots indicated significant differences in pH, salinity (EC_{se}), exchangeable cations, ESP and extractable S in soil profiles due to irrigation with effluent (Table 1 and Figure 3). The effects of irrigation on soil properties are summarized below:

- Soil pH_{Ca} was neutral to slightly alkaline in irrigated soil profiles (pH_{Ca} 6.7 to 7.3) in 2015 while conditions were slightly acidic (pH_{Ca} 6.0 to 6.2) in the unirrigated soil (Table 1). The long-term trend shows that irrigation has increased pH_{Ca} to slightly alkaline conditions (pH > 7.0) in the surface soils (Figure 3). Likewise pH_{Ca} remained higher in irrigated sub-soils (6.7) compared with unirrigated sub-soils (pH 6.2).

- Salinity (EC_{se}) in irrigated surface soils was low (0.7 dS/m) but remained above the salt level (0.3 dS/m) in unirrigated plots in 2015 (Table 1). Salinity declined but remained higher at depth (1.7 dS/m) in irrigated compared with unirrigated (0.7 dS/m) sub-soils. This indicates leaching of salts from surface soils into the sub-soil after several wet years with low irrigation and salt loads in recent years.

- Levels of exchangeable Ca, K and Na were higher in irrigated surface soils but were similar in irrigated and unirrigated sub-soils (Table 1 and Figure 3). Exchangeable Mg was similar in irrigated and unirrigated surface soils but was lower in irrigated sub-soils. Ratios of exchangeable Ca/Mg were slightly higher in irrigated soils and declined with depth reflecting the higher levels of exchangeable Mg in sub-soils (Table 1).

- ESP was low (4%) in both irrigated and unirrigated surface soils (Table 1) indicating non-sodic conditions (ESP < 6%). In contrast sub-soils remained sodic at depth in irrigated (ESP 23%) as well as unirrigated soils (ESP 13%) in 2015 (Table 1). Sodicity was similar in irrigated and unirrigated soil profiles ranging from non-sodic conditions in surface soils to sodic at depth (Figure 3).

- Extractable S in irrigated surface soils was low (6 mg/kg) and similar in unirrigated soils (Table 1). In contrast extractable S remained higher in irrigated sub-soils (90 mg/kg) compared with unirrigated sub-soils (34 mg/kg) although levels have declined in recent years with lower irrigation and salt loads (Figure 3).

Table 1. Average pH, salinity (EC), extractable S and exchangeable cations in soil profiles under trees, crops and pastures in 2015.

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	7.4	6.4	0.12	0.8	15	6.0	1.0	0.8	0.5	8.2	7	5.9
Ettamogah	Effluent	20-30	7.5	6.4	0.15	1.1	31	4.5	1.1	0.7	0.9	7.2	13	4.1
	Effluent	50-60	7.6	6.5	0.24	1.7	107	5.3	2.1	0.7	1.9	10.0	19	2.7
	Effluent	80-90	7.8	6.8	0.34	2.4	171	5.1	3.4	0.6	2.5	11.6	20	1.9
Crops & Pastures	Nil	0-10	7.1	6.0	0.05	0.3	6	4.8	0.8	0.2	0.2	5.9	3	6.2
Ettamogah, Maryvale	Nil	20-30	7.3	6.0	0.04	0.3	7	3.6	1.5	0.2	0.3	5.6	6	2.5
& Rosevale	Nil	50-60	7.5	6.2	0.11	0.7	34	4.6	5.6	0.3	1.6	12.1	13	1.0
	Effluent[#]	0-10	8.2	7.3	0.10	0.7	6	6.5	0.9	0.5	0.3	8.2	4	7.8
	Effluent	20-30	8.3	7.1	0.09	0.6	9	4.1	1.0	0.3	0.6	6.0	10	4.7
	Effluent	50-60	7.9	6.7	0.25	1.7	90	4.7	4.2	0.3	2.8	12.0	23	1.3

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

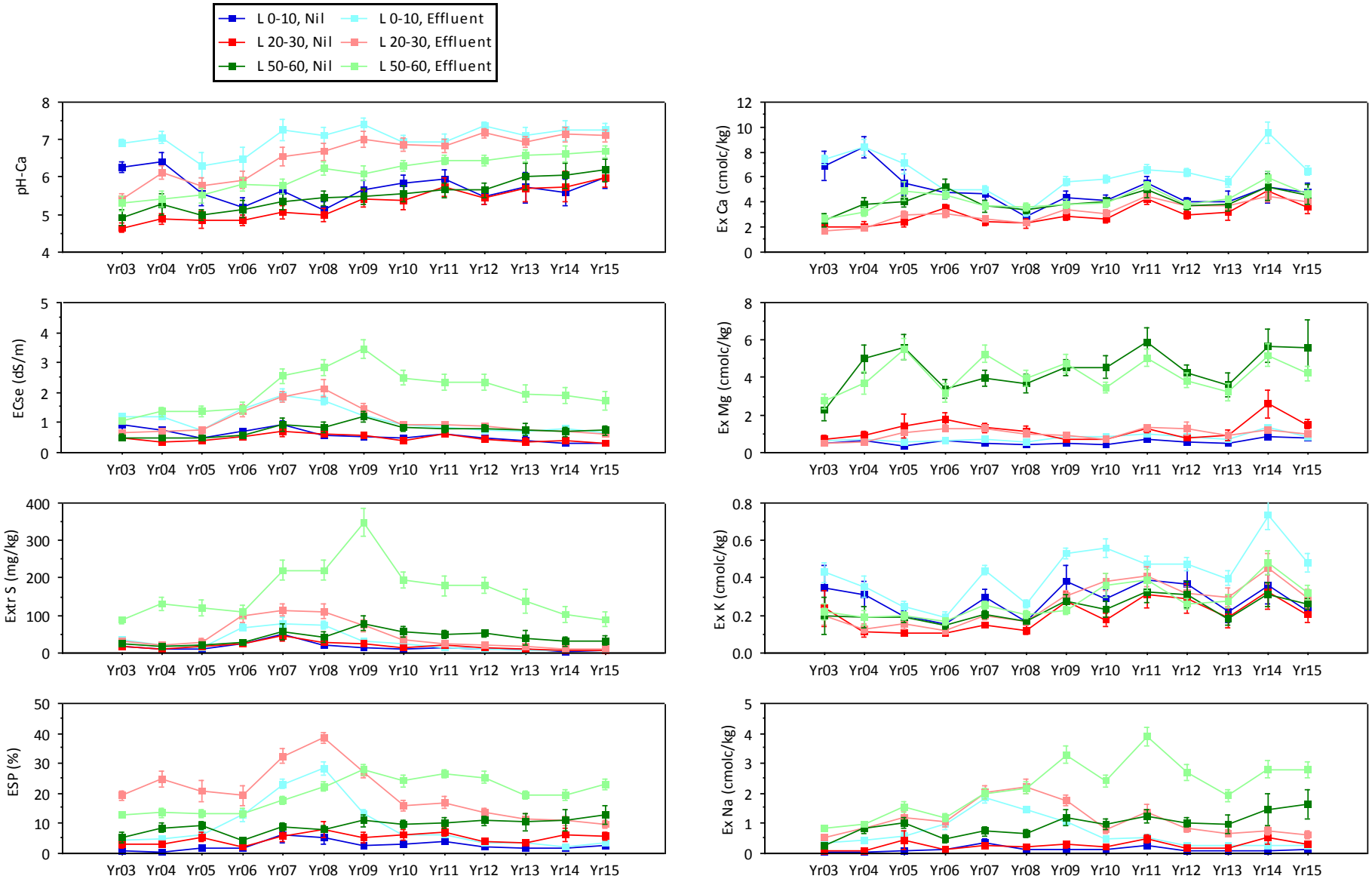

Figure 3. Average pH_{Ca}, EC_{se} (dS/m), extractable S (mg/kg), ESP (%), and exchangeable cations (cmolc/kg) in soil profiles of crops and pastures under irrigation with effluent and non-irrigated (natural rainfall) since 2003 (bars indicate standard deviations).

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 trees and irrigated and unirrigated agricultural crops and pastures are shown in Table 2.

- Average salinity in the root zones of trees in 2015 was estimated at 1.3 ± 0.7 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 tree plantation showed that root zone salinity increased marginally in 2015 (Figure 4).

- Average salinity in the root zones of crops and pastures irrigated with effluent at Ettamogah, Maryvale and Rosevale was estimated at 0.9 ± 0.3 dS/m (Table 2) and was below the threshold value of 4.0 dS/m. Root zone salinity has decreased in recent years (Figure 4) in response to lower irrigation and reduced salt loads.

- Average salinity in the root zones of unirrigated crops and pastures at Ettamogah, Maryvale and Rosevale was estimated at 0.4 ± 0.1 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 2015.

Site	Irrigated (yrs)	WUW EC_{se} (dS/m) Average	Std Dev[#]	Plots (n)	CoVar[†] (%)
Tree Plantation					
Ettamogah – Pine & Eucalypt	20	**1.3**	**0.7**	4	55
Irrigated Crops & Pastures					
Ettamogah, Maryvale & Rosevale	13	**0.9**	**0.3**	12	34
Unirrigated Crops & Pastures		**0.4**	**0.1**	5	36

[#] Std Dev: standard deviation

[†] CoVar: coefficient of variation

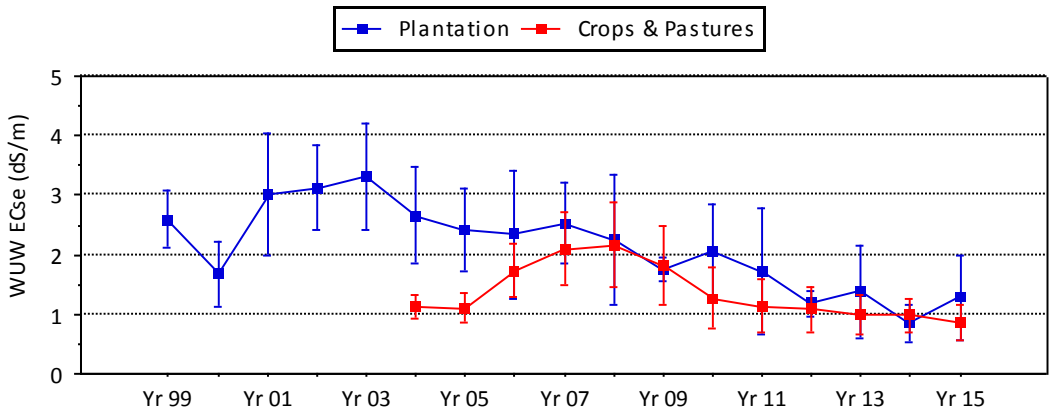

Figure 4. Average salinity (WUW EC_{se}) in the root zones of trees (0 – 90 cm) and crops and pastures (0 – 60 cm) irrigated with paper mill effluent. Bars indicate standard deviations.

5. CONCLUSIONS

In 2015 soil testing was carried out as part of the environmental monitoring program for the effluent re-use scheme to determine the effects of irrigation on soil properties in the root zones of trees, crops and pastures. Past monitoring of soils has shown that irrigation with effluent 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 testing has been confined to soil properties most affected by effluent.

In 2015 seasonal rainfall (660 mm) was below average and irrigation of trees (5.8 ML/ha) was slightly higher compared with preceding years while less irrigation was applied to crops and pastures (2.0 ML/ha). Salt loads (5.8 and 2.0 t/ha) reflected the differences in irrigation for each land use as well as the lower salinity of effluent (EC 1.3 dS/m in 2015) compared with past years (EC range 1.7 to 2.1 dS/m). In general soil pH, salinity, extractable S and sodicity remained higher in effluent irrigated soils. The results for soil testing conducted in 2015 are summarized below:

- Soil pH remained higher and slightly alkaline in irrigated soil profiles under crops and pastures (pH_{Ca} range 6.7 to 7.3) compared with the more acidic conditions of unirrigated soils (pH_{Ca} range 6.0 to 6.2). Soil pH remained slightly acidic in soils under irrigated trees (pH_{Ca} range 6.4 to 6.8).
- Exchangeable sodium percentage (ESP) increased in surface soils (7% to 13%) and in sub-soils (19% to 20%) of irrigated trees indicating that soil profiles in the plantation remained sodic (ESP > 6%). Surface soils of irrigated (ESP 2%) and unirrigated (ESP 2%) crops and pastures were non-sodic; in contrast conditions remained sodic in both irrigated (ESP 23%) and unirrigated (ESP 13%) sub-soils.
- Average salinity in root zones of irrigated soils increased to 1.3 dS/m under trees consistent with lower rainfall and higher irrigation (5.8 ML/ha). In contrast salinity remained low at 0.9 dS/m under crops and pastures with lower irrigation (2.0 ML/ha). Salinity in root zones of trees as well as crops and pastures was below the threshold value of 4.0 dS/m as required under the current EPA License.
- Extractable S in irrigated soils increased to 15 mg/kg in surface soils and to 171 mg/kg in sub-soils under trees. Levels of sulphate were low at 6 mg/kg in surface soils but remained high at 90 mg/kg in sub-soils under irrigated crops and pastures compared with 6 mg/kg in surface soil and 34 mg/kg at depth in unirrigated soils.

Average salinity in the root zones of trees (1.3 dS/m) and crops and pastures (0.9 dS/m) in 2015 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 2015.

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	8.0	8.8	0.19	10	8.5	1.1	0.6	0.6
1.26	Irrigated	20-30	8.1	9.2	0.29	39	5.3	1.1	0.6	1.8
1.26	Irrigated	50-60	7.5	8.7	0.38	134	5.6	2.3	0.7	3.3
1.26	Irrigated	80-90	7.3	8.4	0.54	262	5.2	4.0	0.5	4.4
Radiata pine										
3.02	Irrigated	0-10	5.3	6.3	0.07	10	5.2	0.8	0.9	0.3
3.02	Irrigated	20-30	5.1	6.0	0.07	23	3.9	0.9	0.8	0.2
3.02	Irrigated	50-60	6.1	7.1	0.11	37	5.4	1.5	0.8	0.6
3.02	Irrigated	80-90	6.6	7.7	0.16	53	4.8	1.9	0.7	1.3
3.11	Irrigated	0-10	6.3	7.3	0.08	5	7.0	1.1	1.1	0.2
3.11	Irrigated	20-30	6.6	7.7	0.09	13	6.4	1.2	1.0	0.4
3.11	Irrigated	50-60	6.9	8.0	0.15	51	7.1	1.9	1.0	0.9
3.11	Irrigated	80-90	6.9	7.9	0.16	56	6.7	2.1	0.9	0.9
Flooded gum										
3.15	Irrigated	0-10	5.8	7.0	0.13	35	3.2	0.9	0.4	0.8
3.15	Irrigated	20-30	5.8	7.1	0.15	49	2.4	1.2	0.3	1.3
3.15	Irrigated	50-60	5.6	6.5	0.31	204	3.0	2.9	0.2	2.8
3.15	Irrigated	80-90	6.3	7.1	0.52	316	3.7	5.4	0.3	3.4

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	6.8	7.9	0.08	9	5.1	1.2	0.7	0.3
1.03	Irrigated	20-30	7.1	8.3	0.06	4	3.2	0.7	0.3	0.4
1.03	Irrigated	50-60	6.9	8.4	0.14	34	5.0	2.8	0.5	2.2
MVP5-2.03	Irrigated	0-10	7.1	8.3	0.09	5	6.4	1.0	0.7	0.5
MVP5-2.03	Irrigated	20-30	7.2	8.5	0.10	9	5.4	1.3	0.6	0.9
MVP5-2.03	Irrigated	50-60	7.1	8.6	0.16	41	5.5	3.4	0.6	3.0
MVP5	Irrigated	0-10	5.6	6.7	0.07	7	3.4	0.7	0.2	0.4
MVP5	Irrigated	20-30	5.6	6.7	0.06	16	2.6	0.8	0.1	0.3
MVP5	Irrigated	50-60	5.6	6.3	0.14	95	4.1	4.9	0.2	1.1
MVC5	Unirrigated	0-10	6.3	7.2	0.05	4	4.6	0.8	0.3	0.1
MVC5	Unirrigated	20-30	6.6	8.0	0.06	4	3.3	1.1	0.3	0.5
MVC5	Unirrigated	50-60	6.7	8.3	0.11	29	4.1	2.9	0.3	2.3
MVP4-2.13	Irrigated	0-10	7.6	8.5	0.12	6	6.6	1.1	0.7	0.5
MVP4-2.13	Irrigated	20-30	6.8	8.1	0.16	30	4.2	1.9	0.5	1.7
MVP4-2.13	Irrigated	50-60	7.6	8.3	0.67	238	6.5	6.0	0.3	3.2
MVC4-2.15	Unirrigated	0-10	6.1	7.0	0.06	11	6.2	1.0	0.3	0.2
MVC4-2.15	Unirrigated	20-30	6.3	7.3	0.07	19	5.1	1.5	0.3	0.3
MVC4-2.15	Unirrigated	50-60	6.3	7.2	0.16	84	5.4	3.1	0.3	0.9
Rosevale										
RVP1.1.1	Irrigated	0-10	7.8	8.5	0.12	4	8.3	0.8	0.3	0.2
RVP1.1.1	Irrigated	20-30	7.4	8.8	0.11	12	3.9	1.4	0.1	0.9
RVP1.1.1	Irrigated	50-60	6.9	8.1	0.32	132	7.0	5.8	0.2	3.4
RVP1.2.1	Irrigated	0-10	7.7	8.4	0.11	12	8.3	0.8	0.3	0.3
RVP1.2.1	Irrigated	20-30	7.3	8.3	0.07	5	4.0	0.6	0.1	0.3
RVP1.2.1	Irrigated	50-60	5.9	7.2	0.23	84	3.5	5.1	0.3	4.4
RVP2.1.1	Irrigated	0-10	6.9	8.0	0.08	11	6.0	0.9	0.3	0.3
RVP2.1.1	Irrigated	20-30	6.9	8.4	0.07	4	3.8	0.8	0.1	0.7
RVP2.1.1	Irrigated	50-60	6.5	7.9	0.19	68	3.2	3.5	0.2	2.3
RVP2.1.2	Unirrigated	0-10	6.3	7.4	0.05	4	5.8	0.6	0.1	0.2
RVP2.1.2	Unirrigated	20-30	5.9	7.2	0.03	3	2.1	0.9	0.1	0.2
RVP2.1.2	Unirrigated	50-60	5.4	6.8	0.09	26	2.9	9.3	0.2	1.6

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	7.6	8.4	0.11	3	7.0	0.7	0.6	0.2
MVP2a.1	Irrigated	20 - 30	7.5	8.4	0.08	3	4.4	0.6	0.4	0.2
MVP2a.1	Irrigated	50 - 60	7.0	8.5	0.14	25	4.7	1.8	0.5	1.8
MVP2b.1	Irrigated	0 - 10	7.5	8.3	0.10	4	6.9	0.8	0.6	0.3
MVP2b.1	Irrigated	20 - 30	7.2	8.4	0.10	7	6.2	1.3	0.4	0.7
MVP2b.1	Irrigated	50 - 60	7.0	8.5	0.18	41	4.9	3.4	0.3	3.2
MVP2c.2	Irrigated	0 - 10	7.5	8.2	0.08	2	6.1	0.6	0.3	0.2
MVP2c.2	Irrigated	20 - 30	7.6	8.6	0.06	5	2.8	0.4	0.1	0.2
MVP2c.2	Irrigated	50 - 60	6.2	7.3	0.28	127	3.8	5.0	0.3	2.8
MVP3a.1	Irrigated	0 - 10	7.5	8.3	0.11	7	7.7	1.0	0.6	0.2
MVP3a.1	Irrigated	20 - 30	7.2	8.3	0.08	4	5.0	0.9	0.4	0.5
MVP3a.1	Irrigated	50 - 60	6.8	8.0	0.18	50	5.0	3.3	0.3	2.3
MVP3b.1	Irrigated	0 - 10	7.7	8.4	0.11	5	6.5	0.8	0.4	0.1
MVP3b.1	Irrigated	20 - 30	7.4	8.6	0.10	9	3.3	1.0	0.3	0.7
MVP3b.1	Irrigated	50 - 60	6.5	7.7	0.32	147	3.2	5.7	0.2	3.9
MVC2a	Unirrigated	0 - 10	6.1	7.3	0.05	6	5.4	0.7	0.2	0.2
MVC2a	Unirrigated	20 - 30	6.0	7.5	0.05	5	4.7	2.3	0.1	0.5
MVC2a	Unirrigated	50 - 60	6.9	8.3	0.15	22	7.2	9.0	0.3	3.0
MVC3c	Unirrigated	0 - 10	4.9	6.4	0.03	3	1.9	0.9	0.2	0.1
MVC3c	Unirrigated	20 - 30	5.1	6.3	0.02	3	2.9	1.7	0.2	0.1
MVC3c	Unirrigated	50 - 60	5.6	6.8	0.03	7	3.5	3.8	0.2	0.3

Appendix 2. Salinity in root zones of trees, crops and pastures in 2015.

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	0.186	1.30	0.41	0.53	
Ettamogah	Unit 4	1.26	Effluent	20-30	0.295	2.06	0.21	0.43	
Ettamogah	Unit 4	1.26	Effluent	50-60	0.378	2.65	0.25	0.66	
Ettamogah	Unit 4	1.26	Effluent	80-90	0.538	3.77	0.13	0.49	2.12
Ettamogah	Unit 1	3.02	Effluent	0-10	0.069	0.48	0.41	0.20	
Ettamogah	Unit 1	3.02	Effluent	20-30	0.070	0.49	0.21	0.10	
Ettamogah	Unit 1	3.02	Effluent	50-60	0.108	0.76	0.25	0.19	
Ettamogah	Unit 1	3.02	Effluent	80-90	0.157	1.10	0.13	0.14	0.63
Ettamogah	Unit 2	3.11	Effluent	0-10	0.076	0.53	0.41	0.22	
Ettamogah	Unit 2	3.11	Effluent	20-30	0.088	0.62	0.21	0.13	
Ettamogah	Unit 2	3.11	Effluent	50-60	0.150	1.05	0.25	0.26	
Ettamogah	Unit 2	3.11	Effluent	80-90	0.156	1.09	0.13	0.14	0.75
Ettamogah	Unit 4	3.15	Effluent	0-10	0.134	0.94	0.41	0.38	
Ettamogah	Unit 4	3.15	Effluent	20-30	0.148	1.04	0.21	0.22	
Ettamogah	Unit 4	3.15	Effluent	50-60	0.308	2.15	0.25	0.54	
Ettamogah	Unit 4	3.15	Effluent	80-90	0.515	3.61	0.13	0.47	1.61
								Average	**1.28**
								Std Dev	**0.71**
								Covar%	**55**

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	0.085	0.59	0.53	0.31	
Ettamogah	Unit 3	1.03	Effluent	20-30	0.064	0.45	0.28	0.12	
Ettamogah	Unit 3	1.03	Effluent	50-60	0.141	0.98	0.19	0.19	0.63
Ettamogah	Unit 2	MVP5-2.03	Effluent	0-10	0.087	0.61	0.53	0.32	
Ettamogah	Unit 2	MVP5-2.03	Effluent	20-30	0.098	0.69	0.28	0.19	
Ettamogah	Unit 2	MVP5-2.03	Effluent	50-60	0.159	1.11	0.19	0.21	0.73
Ettamogah	Unit 2	MVP5	Effluent	0-10	0.070	0.49	0.53	0.26	
Ettamogah	Unit 2	MVP5	Effluent	20-30	0.058	0.40	0.28	0.11	
Ettamogah	Unit 2	MVP5	Effluent	50-60	0.141	0.99	0.19	0.19	0.56
Ettamogah	Unit 3	MVP4-2.13	Effluent	0-10	0.120	0.84	0.53	0.44	
Ettamogah	Unit 3	MVP4-2.13	Effluent	20-30	0.163	1.14	0.28	0.32	
Ettamogah	Unit 3	MVP4-2.13	Effluent	50-60	0.667	4.67	0.19	0.89	1.65
Maryvale	Unit 2	MVP2a.1	Effluent	0-10	0.107	0.75	0.53	0.40	
Maryvale	Unit 2	MVP2a.1	Effluent	20-30	0.080	0.56	0.28	0.16	
Maryvale	Unit 2	MVP2a.1	Effluent	50-60	0.140	0.98	0.19	0.19	0.74
Maryvale	Unit 2	MVP2b.1	Effluent	0-10	0.097	0.68	0.53	0.36	
Maryvale	Unit 2	MVP2b.1	Effluent	20-30	0.096	0.67	0.28	0.19	
Maryvale	Unit 2	MVP2b.1	Effluent	50-60	0.183	1.28	0.19	0.24	0.79
Maryvale	Unit 4	MVP2c.2	Effluent	0-10	0.078	0.55	0.53	0.29	
Maryvale	Unit 4	MVP2c.2	Effluent	20-30	0.064	0.45	0.28	0.13	
Maryvale	Unit 4	MVP2c.2	Effluent	50-60	0.282	1.97	0.19	0.37	0.79
Maryvale	Unit 4	MVP3a.1	Effluent	0-10	0.108	0.76	0.53	0.40	
Maryvale	Unit 4	MVP3a.1	Effluent	20-30	0.079	0.56	0.28	0.16	
Maryvale	Unit 4	MVP3a.1	Effluent	50-60	0.177	1.24	0.19	0.24	0.79
Maryvale	Unit 4	MVP3b.1	Effluent	0-10	0.111	0.78	0.53	0.41	
Maryvale	Unit 4	MVP3b.1	Effluent	20-30	0.101	0.71	0.28	0.20	
Maryvale	Unit 4	MVP3b.1	Effluent	50-60	0.322	2.25	0.19	0.43	1.04
Rosevale	Unit 3	RVP1.1.1	Effluent	0-10	0.117	0.82	0.53	0.43	
Rosevale	Unit 3	RVP1.1.1	Effluent	20-30	0.105	0.74	0.28	0.21	
Rosevale	Unit 3	RVP1.1.1	Effluent	50-60	0.322	2.25	0.19	0.43	1.07
Rosevale	Unit 3	RVP1.2.1	Effluent	0-10	0.111	0.78	0.53	0.41	
Rosevale	Unit 3	RVP1.2.1	Effluent	20-30	0.066	0.46	0.28	0.13	
Rosevale	Unit 3	RVP1.2.1	Effluent	50-60	0.233	1.63	0.19	0.31	0.85
Rosevale	Unit 4	RVP2.1.1	Effluent	0-10	0.079	0.55	0.53	0.29	
Rosevale	Unit 4	RVP2.1.1	Effluent	20-30	0.073	0.51	0.28	0.14	
Rosevale	Unit 4	RVP2.1.1	Effluent	50-60	0.187	1.31	0.19	0.25	0.68
								Average	**0.86**
								SDEV	**0.29**
								COVAR%	**33.7**

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	0.046	0.32	0.53	0.17	
Ettamogah	Unit 4	MVC5	Nil	20-30	0.056	0.39	0.28	0.11	
Ettamogah	Unit 4	MVC5	Nil	50-60	0.109	0.76	0.19	0.15	0.42
Ettamogah	Unit 4	MVC4-2.15	Nil	0-10	0.062	0.43	0.53	0.23	
Ettamogah	Unit 4	MVC4-2.15	Nil	20-30	0.067	0.47	0.28	0.13	
Ettamogah	Unit 4	MVC4-2.15	Nil	50-60	0.155	1.09	0.19	0.21	0.57
Maryvale	Unit 2	MVC2a	Nil	0-10	0.050	0.35	0.53	0.19	
Maryvale	Unit 2	MVC2a	Nil	20-30	0.047	0.33	0.28	0.09	
Maryvale	Unit 2	MVC2a	Nil	50-60	0.148	1.04	0.19	0.20	0.47
Maryvale	Unit 4	MVC3c	Nil	0-10	0.027	0.19	0.53	0.10	
Maryvale	Unit 4	MVC3c	Nil	20-30	0.022	0.15	0.28	0.04	
Maryvale	Unit 4	MVC3c	Nil	50-60	0.030	0.21	0.19	0.04	0.18
Rosevale	Unit 4	RVP2.1.2	Nil	0-10	0.051	0.36	0.53	0.19	
Rosevale	Unit 4	RVP2.1.2	Nil	20-30	0.032	0.22	0.28	0.06	
Rosevale	Unit 4	RVP2.1.2	Nil	50-60	0.088	0.62	0.19	0.12	0.37
								Average	**0.40**
								SDEV	**0.14**
								COVAR%	**35.6**

Appendix 3. Annual rainfall, pan evaporation, irrigation and loads of nitrogen, phosphorus, zinc and total dissolved solids (TDS) in effluent applied from 1st July 2014 to 30th June 2015 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
2014 - 2015	660	1375	6.6	5.8	12.4	2.0	8.6	16.3	4.9	1.6	0.45	0.04	0.01	5810	2037