Soil Properties under Tree Plantations, Crops and Pastures Irrigated with Paper Mill Effluent at Albury in 2018

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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 2018) or were returned to agriculture to expand the existing area under crops and pastures irrigated by sprinkler systems (238 ha in 2018).

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 soil testing in 2018 are presented in this report.

In 2018 seasonal rainfall (648 mm) was below average for the location (710 mm) and irrigation of trees (4.8 ML/ha) and crops and pastures (5.2 ML/ha) was higher compared with the previous year. Salt loads were slightly lower in the plantation (4.3 t/ha) compared with crops and pastures (4.6 t/ha) consistent with the difference in irrigation. In general soil pH, salinity, extractable sulphate and sodicity remained higher in effluent irrigated soils. Soil conditions at the end of the irrigation season in 2018 are summarized below:

- Soil pH remained higher and was slightly alkaline in irrigated soil profiles under crops and pastures (pH_{Ca} range 6.9 to 7.6) compared with the moderately acidic conditions of unirrigated soils (pH_{Ca} range 5.6 to 5.9). Soil pH remained slightly acidic in soils under irrigated trees (pH_{Ca} range 5.9 to 6.3).
- Exchangeable sodium percentage (ESP) increased with depth from surface soils (ESP 6%) to sub-soils (ESP 18%) indicating sodic conditions (ESP > 6%) prevailed in soil profiles under irrigated trees in 2018. Soils of unirrigated crops and pastures were non-sodic at the surface (ESP 1%) but sodicity increased with depth (ESP 7%). Irrigation increased sodicity in surface soils (ESP 8%) and sub-soils (ESP 23%) of crops and pastures.
- Average salinity in root zones of irrigated soils under trees increased to 1.4 dS/m with the higher salt load of 4.3 t/ha in 2018. Likewise average salinity in root zones of irrigated crops and pastures increased to 1.3 dS/m with a salt load of 4.6 t/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 sulphate in irrigated soils under trees increased in surface soils to 34 mg/kg and in sub-soils to 118 mg/kg in 2018. Levels of sulphate under irrigated crops and pastures increased to 21 mg/kg in surface soils and to 74 mg/kg in sub-soils compared with 3 mg/kg in surface soils and 12 mg/kg at depth in unirrigated soils.

Average salinity in the root zones of trees (1.4 dS/m) and crops and pastures (1.3 dS/m) in 2018 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 2018 rainfall (648 mm) was below average for the region (710 mm) and irrigation was applied at intermediate rates to trees (214 ha) and crops and pastures (238 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 soil testing in 2018 are presented in this report.

In 2018, 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 2018 as part of the revised EPA license agreement.

3. METHODS

Soil profile samples were collected in September 2018 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 Centre for Applied Sciences, Agriculture Victoria at Macleod 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 2018 rainfall (648 mm) was slightly below average for the location (710 mm), this was preceded by several years of approximately average rainfall from 2014 to 2017 (Figure 1). Irrigation of trees (4.8 ML/ha) increased in 2018 compared with the previous year (Figure 1) but the total hydraulic load (rainfall plus irrigation: 11.3 ML/ha) was similar compared with the preceding three years (11.3, 11.6 and 12.4 ML/ha). The annual load of N, P, Zn and salts (TDS) in 2018 was estimated at 10.4, 0.6, 0.01, and 4290 kg/ha respectively (Appendix 3). The salt load in 2018 (4.3 t/ha) increased compared with 2017 (3.3 t/ha) but was slightly less than the average salt load for the period 2012 to 2017 (4.8 ± 1.1 t/ha). Since 2012 lower chemical use 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) applied to trees as well as crops and pastures at Ettamogah.

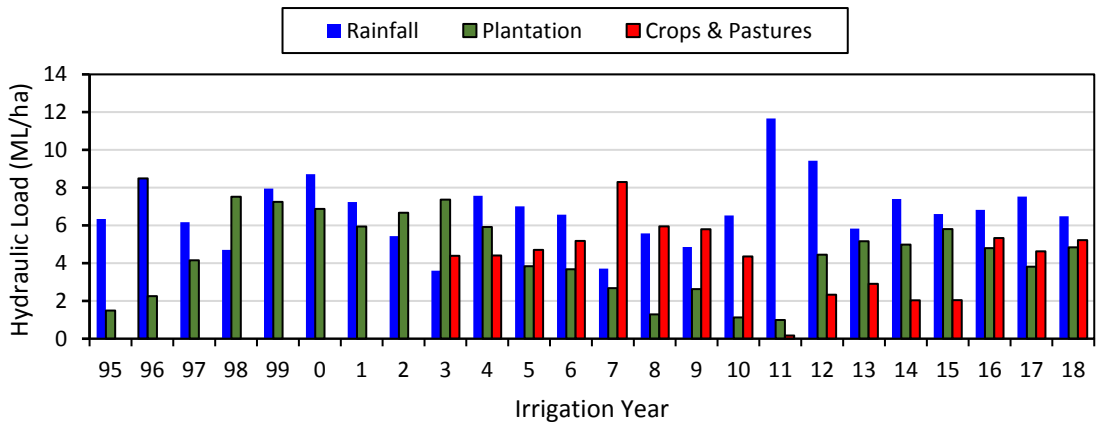

Figure 1. Seasonal rainfall (July – June) and annual irrigation (ML/ha) of the tree plantation at Ettamogah and crops and pastures at Ettamogah and Rosevale.

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 2018 are presented in Table 1 and annual data for the plantation are shown in Figure 2.

- In 2018 soil pH_{Ca} was slightly acidic (5.9 to 6.1) in the upper layers (0 - 10 and 20 - 30 cm) and ranged from 6.2 to 6.3 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 until 2010 (Figure 2) before declining to slightly acidic conditions during several wet years with low irrigation (Figure 1). In 2018 soil pH_{Ca} remains slightly acidic (Figure 2) after 6 years of irrigation at rates of 4 to 6 ML/ha/yr.

- Salinity (EC_{se}) increased slightly to 1.1 and 1.4 dS/m in the upper layers and to 1.7 and 1.6 dS/m in the subsoils in 2018 compared with previous years (Figure 2 and Table 1). Average salinity in soil profiles has increased consistent with the higher irrigation and salt load (4.3 t/ha) in 2018 compared with 2017 (3.2 t/ha).

- Exchangeable cations (Ca^{2+} and K^{+}) in soil profiles remained at similar levels in 2018 compared with previous years (Figure 2). Exchangeable Mg^{2+} remained at similar levels in the surface soils but decreased slightly in the sub-soils. Ratios of exchangeable Ca/Mg for each soil layer remained at similar values compared with previous years; Ca/Mg ratios declined with depth from 6 to 3 reflecting relatively higher levels of exchangeable Mg^{2+} in sub-soils (Table 1).

- Exchangeable Na^{+} in surface soils increased to 0.7 and 1.2 cmolc/kg in 2018 compared with 2017 (Figure 2). Likewise Na^{+} levels increased in sub-soils to 1.6 and 1.7 cmolc/kg consistent with the higher irrigation and salt load in 2018.

- ESP (exchangeable sodium percentage) in surface soils (6% and 17%) showed a return to sodic conditions (ESP > 6%) at 20-30 cm in 2018 (Table 1). Likewise ESP increased in the sub-soils (17% and 18%) indicating that soil profiles remained sodic at depth (Figure 2).

- Levels of extractable S in soil profiles increased to 34 and 73 mg/kg in surface soils and to 96 and 118 mg/kg in sub-soils consistent with the higher irrigation and salt load in 2018 (Table 1). Levels of extractable S in soil profiles have returned to the same range of values of recent years with similar salt loads (Figure 2).

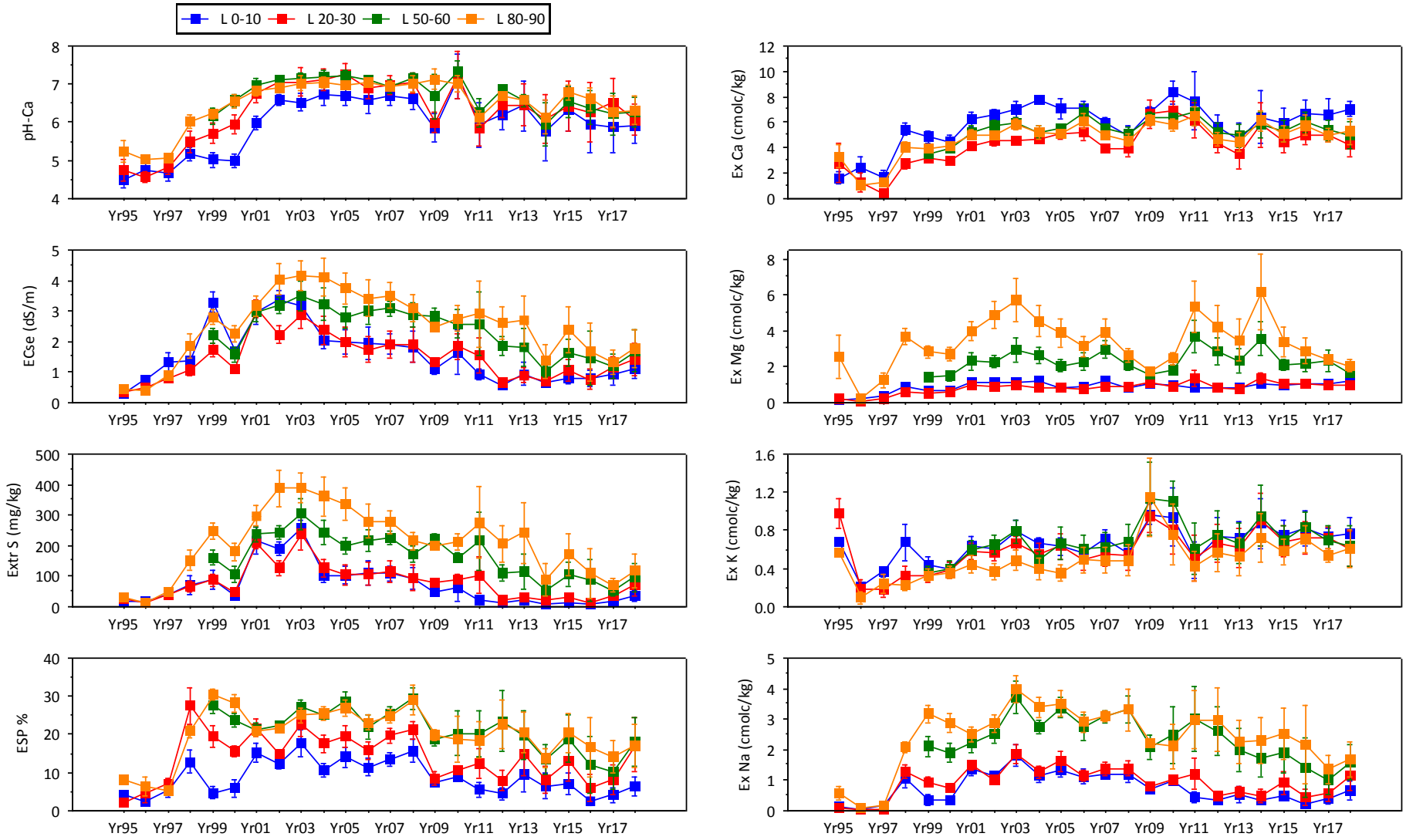

Figure 2. Average pH_{Ca}, EC_{se} (dS/m), extractable S (mg/kg), ESP (%), and exchangeable cations (cmolc/kg) in plantation soil profiles irrigated with effluent at Ettamogah since 1995 (bars indicate standard deviations). Monitoring of an additional soil profile layer (50 – 60 cm) commenced in 1999.

4.2. Crops and Pastures

Irrigation

Rainfall in 2018 (648 mm) was below average (710 mm) for the region and irrigation of crops and pastures was slightly higher at 5.2 ML/ha compared with 4.6 ML/ha in 2017 but similar in 2016 (5.3 ML/ha) (Figure 1). The total hydraulic load (rainfall plus irrigation) in 2018 (11.7 ML/ha) was similar in 2017 (12.2 ML/ha) and in 2016 (12.1 ML/ha). The average loads of N, P, Zn and salts (TDS) in 2018 were estimated at 13.2, 0.7, 0.01 and 4591 kg/ha respectively (Appendix 3). The salt load in in 2018 was higher (4.6 t/ha) compared with 2017 (3.9 t/ha) but was similar in 2016 (4.7 t/ha) while loads were lower in the previous four years (2.0, 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; differences between irrigated and unirrigated plots that were statistically significant ($P < 0.05$) are shown in red type. 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} 6.9 to 7.6) in 2018 while conditions were moderately acidic (pH_{Ca} 5.6 to 5.9) in the unirrigated soil (Table 1). The long-term trend shows that pH_{Ca} has increased from acidic to slightly alkaline conditions (pH > 7.0) in irrigated surface soils (Figure 3). Likewise pH_{Ca} remained higher in irrigated sub-soils (pH 6.9) compared with unirrigated sub-soils (pH 5.9).

- Salinity (EC_{se}) in irrigated surface soils increased slightly (1.1 and 1.2 dS/m) in 2018 and remained above the salt level (0.4 dS/m) in unirrigated plots (Table 1). Likewise salinity was higher at depth (1.6 dS/m) in irrigated compared with unirrigated (0.6 dS/m) sub-soils. The higher irrigation and salt load in 2018 has increased the salinity of soil profiles to similar levels compared with 2016 (Figure 3).

- Levels of exchangeable Ca^{2+}, Mg^{2+} and K^{+} were higher in irrigated surface soils but were similar in irrigated and unirrigated sub-soils (Table 1). Exchangeable Na^{+} was higher in irrigated soil profiles compared with unirrigated soils (Table 1). Ratios of exchangeable Ca/Mg were similar in irrigated and unirrigated soils, Ca/Mg ratios declined from 9 to 2 with depth reflecting the relatively higher levels of exchangeable Mg^{2+} in sub-soils (Table 1).

- ESP was low in unirrigated surface soils (1%) but increased in irrigated surface soils (8%) indicating a return to sodic conditions (ESP > 6%). Sodicity increased with depth in unirrigated soils (ESP 4% and 7%) and irrigation increased sodic conditions in sub-soils (ESP 16% and 23%) in 2018 (Table 1). This is consistent with the trend of elevated sodicity with depth in irrigated soil profiles (Figure 3).

- Extractable S was low (3 to 12 mg/kg) in unirrigated soil profiles (Table 1). Irrigation increased levels of extractable S throughout the soil profile (21 to 74 mg/kg) reflecting the higher salt load in 2018 (Table 1). The higher levels of extractable S in 2018 are consistent with levels in soil profiles in recent years with similar 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 2018.

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	7.0	5.9	0.16	1.1	34	7.0	1.2	0.8	0.7	9.7	6	5.8
Ettamogah	Effluent	20-30	7.3	6.1	0.20	1.4	73	4.2	1.0	0.6	1.2	7.0	17	4.2
	Effluent	50-60	7.4	6.2	0.24	1.7	96	5.0	1.7	0.6	1.6	8.9	18	3.3
	Effluent	80-90	7.4	6.3	0.25	1.8	118	5.3	2.1	0.6	1.7	9.6	17	3.0
Crops & Pastures	Nil	0-10	6.7	5.6	0.06	0.4	3	4.1	0.4	0.3	0.1	5.0	1	9.4
Ettamogah, Maryvale	Nil	20-30	6.9	5.8	0.05	0.4	5	3.2	0.8	0.2	0.2	4.3	4	4.8
& Rosevale	Nil	50-60	7.2	5.9	0.08	0.6	12	4.2	2.5	0.3	0.7	7.7	7	1.9
	Effluent[#]	0-10	8.7	7.6	0.17	1.2	21	6.9	0.8	0.6	0.7	9.0	8	8.2
	Effluent	20-30	8.6	7.4	0.16	1.1	41	3.9	0.9	0.3	0.9	6.0	16	4.7
	Effluent	50-60	8.2	6.9	0.23	1.6	74	4.8	2.7	0.3	2.3	10.1	23	2.1

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

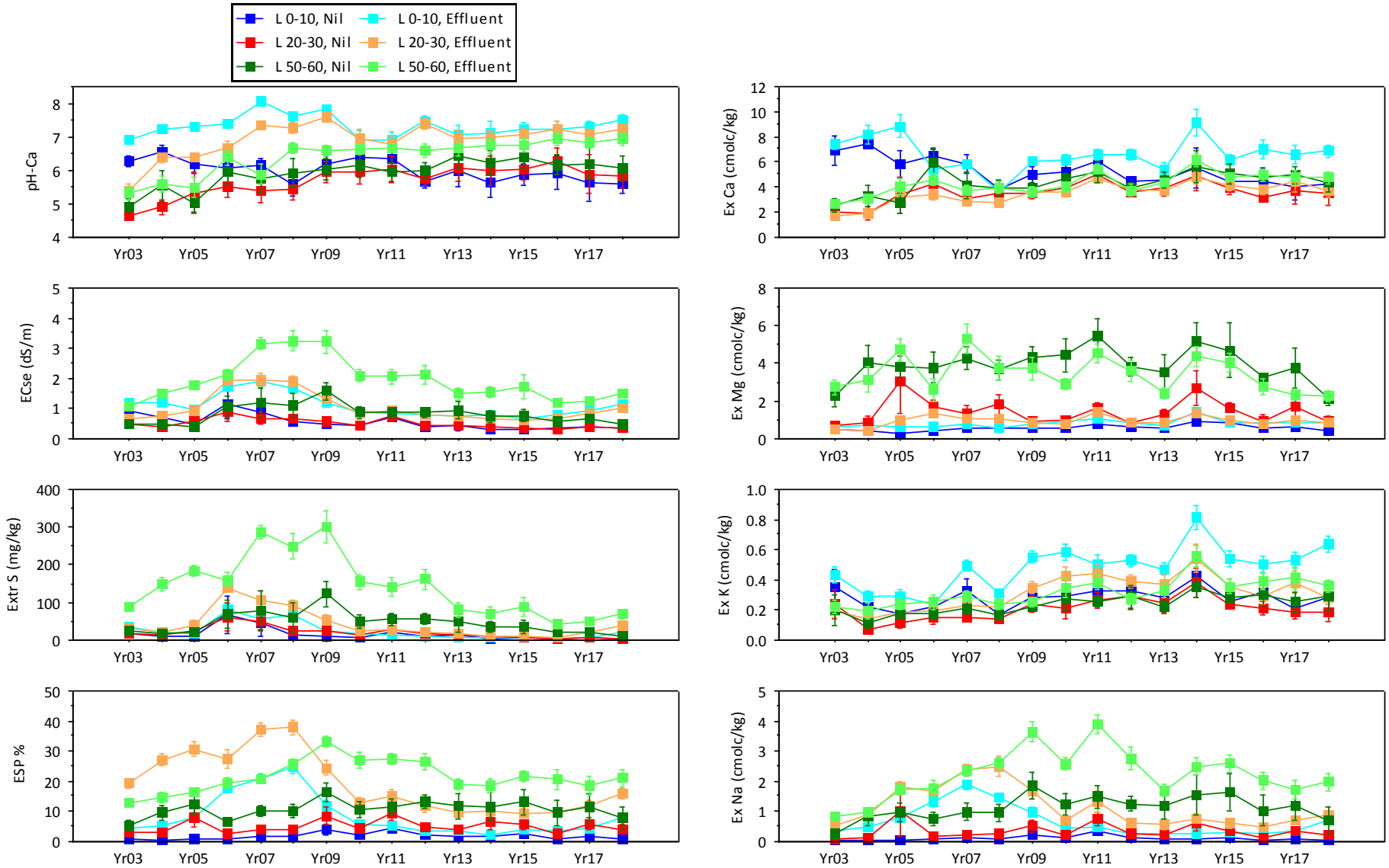

Figure 3. Average pH_{Ca}, EC_{se} (dS/m), extractable S (mg/kg), ESP (%), and exchangeable cations (cmolc/kg) in soil profiles of crops and pastures under irrigation with effluent and non-irrigated (natural rainfall) since 2003 (bars indicate standard deviations).

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 2018 was estimated at 1.4 ± 1.0 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 has remained at similar levels since 2015 (Figure 4).

- Average salinity in the root zones of crops and pastures irrigated with effluent at Ettamogah, Maryvale and Rosevale was estimated at 1.3 ± 0.3 dS/m (Table 2) and was below the threshold value of 4.0 dS/m. Root zone salinity has increased slightly compared with previous years since 2011 (Figure 4).

- Average salinity in the root zones of unirrigated crops and pastures at Ettamogah, Maryvale and Rosevale was estimated at 0.4 ± 0.2 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 2018.

Site	Irrigated (yrs)	WUW EC_{se} (dS/m) Average	Std Dev[#]	Plots (n)	CoVar[†] (%)
Tree Plantation					
Ettamogah – Pine & Eucalypt	23	**1.4**	**1.0**	4	69
Irrigated Crops & Pastures					
Ettamogah, Maryvale & Rosevale	15	**1.3**	**0.3**	12	26
Unirrigated Crops & Pastures		**0.4**	**0.2**	5	42

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

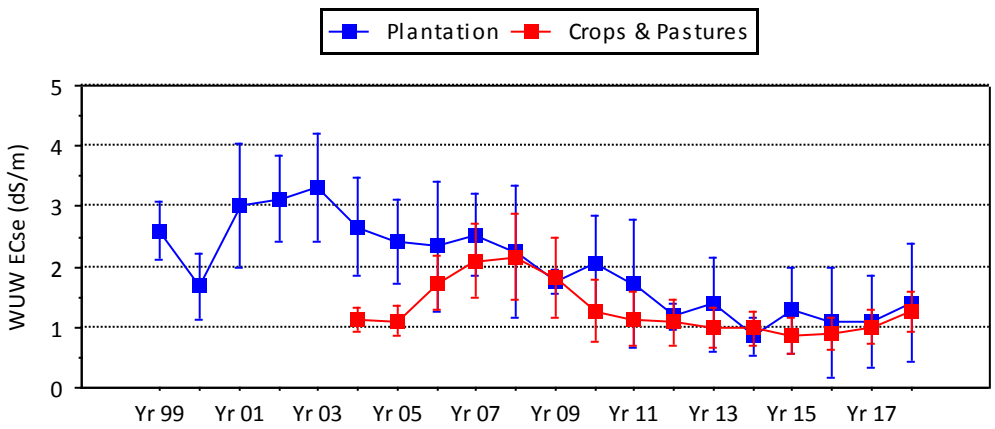

Figure 4. Average salinity (WUW EC_{se}) in the root zones of trees (0 – 90 cm) and crops and pastures (0 – 60 cm) irrigated with paper mill effluent. Bars indicate standard deviations.

5. CONCLUSIONS

In 2018 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 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 2018 seasonal rainfall (648 mm) was below average and irrigation of trees (4.8 ML/ha) was higher compared with the previous year (3.8 ML/ha). Irrigation of crops and pastures increased to 5.2 ML/ha from 4.6 ML/ha in the previous year. Total hydraulic loads (11.3 and 11.7 ML/ha) and salt loads (4.3 and 4.6 t/ha) were similar for each land use. In general soil pH, salinity, extractable S and sodicity remained higher in effluent irrigated soils. The results for soil testing conducted in 2018 are summarized below:

- Soil pH remained higher and was slightly alkaline in irrigated soil profiles under crops and pastures (pH_{Ca} range 6.9 to 7.6) compared with the moderately acidic conditions of unirrigated soils (pH_{Ca} range 5.6 to 5.9). Soil pH remained slightly acidic in soils under irrigated trees (pH_{Ca} range 5.9 to 6.3).
- Exchangeable sodium percentage (ESP) increased with depth from surface soils (6%) to sub-soils (18%) indicating sodic conditions (ESP > 6%) prevailed in soil profiles under irrigated trees in 2018. Soils of unirrigated crops and pastures were non-sodic at the surface (ESP 1%) but sodicity increased with depth (ESP 7%). Irrigation increased sodicity in surface soils (ESP 8%) and sub-soils (ESP 23%) of crops and pastures.
- Average salinity in root zones of irrigated soils under trees increased to 1.4 dS/m with the higher salt load of 4.3 t/ha in 2018. Likewise average salinity in root zones of irrigated crops and pastures increased to 1.3 dS/m with a salt load of 4.6 t/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 sulphate in irrigated soils under trees increased in surface soils to 34 mg/kg and in sub-soils to 118 mg/kg in 2018. Levels of sulphate under irrigated crops and pastures increased to 21 mg/kg in surface soils and to 74 mg/kg in sub-soils compared with 3 mg/kg in surface soils and 12 mg/kg at depth in unirrigated soils.

Average salinity in the root zones of trees (1.4 dS/m) and crops and pastures (1.3 dS/m) in 2018 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 2018.

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	7.2	8.3	0.29	82	8.0	1.5	0.7	1.5
1.26	Irrigated	20-30	6.9	8.2	0.41	181	3.5	0.9	0.4	2.4
1.26	Irrigated	50-60	6.7	7.8	0.51	232	4.2	1.8	0.4	2.9
1.26	Irrigated	80-90	6.8	7.9	0.50	265	4.7	2.3	0.3	3.0
Radiata pine										
3.02	Irrigated	0-10	5.0	6.2	0.07	4	5.5	1.0	1.1	0.1
3.02	Irrigated	20-30	5.0	6.2	0.06	8	4.0	1.1	0.9	0.2
3.02	Irrigated	50-60	5.3	6.5	0.07	22	4.4	1.4	0.8	0.4
3.02	Irrigated	80-90	5.5	6.8	0.07	24	4.4	1.6	0.8	0.5
3.11	Irrigated	0-10	5.6	6.6	0.16	40	6.9	1.1	1.0	0.5
3.11	Irrigated	20-30	6.1	7.1	0.19	58	6.8	1.1	1.0	0.7
3.11	Irrigated	50-60	7.1	8.2	0.18	42	8.2	1.3	1.1	1.0
3.11	Irrigated	80-90	7.1	8.2	0.17	44	8.2	1.5	1.1	1.0
Flooded gum										
3.15	Irrigated	0-10	5.8	7.0	0.11	10	7.7	1.3	0.3	0.5
3.15	Irrigated	20-30	6.2	7.7	0.15	44	2.6	0.9	0.2	1.2
3.15	Irrigated	50-60	6.0	7.3	0.21	89	3.4	2.2	0.2	2.1
3.15	Irrigated	80-90	5.8	6.9	0.27	140	3.7	2.9	0.2	2.2

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	7.4	8.5	0.23	52	7.1	1.1	0.6	1.1
1.03	Irrigated	20-30	7.2	8.5	0.12	30	2.6	0.6	0.3	0.6
1.03	Irrigated	50-60	7.0	8.4	0.16	47	4.5	1.6	0.4	1.4
MVP5-2.03	Irrigated	0-10	7.7	8.9	0.19	32	6.2	0.9	0.6	1.1
MVP5-2.03	Irrigated	20-30	7.6	8.7	0.20	60	2.8	0.6	0.2	0.8
MVP5-2.03	Irrigated	50-60	7.3	8.7	0.22	68	6.0	2.4	0.4	2.3
MVP5	Irrigated	0-10	6.2	7.5	0.10	7	4.0	0.7	0.6	0.5
MVP5	Irrigated	20-30	6.2	7.6	0.11	32	2.5	0.6	0.1	0.7
MVP5	Irrigated	50-60	6.1	7.1	0.17	65	4.4	2.2	0.3	0.8
MVC5	Unirrigated	0-10	5.8	6.8	0.03	1	3.3	0.5	0.2	0.04
MVC5	Unirrigated	20-30	6.5	7.9	0.05	3	3.2	1.0	0.3	0.4
MVC5	Unirrigated	50-60	6.8	8.6	0.10	8	5.5	2.4	0.5	2.0
MVP4-2.13	Irrigated	0-10	7.9	9.0	0.22	38	6.2	0.9	0.6	1.1
MVP4-2.13	Irrigated	20-30	7.3	8.4	0.20	75	2.1	0.9	0.2	0.8
MVP4-2.13	Irrigated	50-60	7.1	8.3	0.32	118	5.0	4.3	0.4	3.1
MVC4-2.15	Unirrigated	0-10	5.2	6.4	0.05	4	4.9	0.5	0.5	0.04
MVC4-2.15	Unirrigated	20-30	5.9	6.8	0.07	11	3.5	0.5	0.3	0.1
MVC4-2.15	Unirrigated	50-60	5.9	7.0	0.08	23	4.3	1.4	0.3	0.2
Rosevale										
RVP1.1.1	Irrigated	0-10	8.1	9.1	0.21	19	7.3	0.8	0.3	0.9
RVP1.1.1	Irrigated	20-30	7.8	8.8	0.28	66	7.1	2.1	0.2	2.1
RVP1.1.1	Irrigated	50-60	7.1	8.4	0.43	147	6.8	6.2	0.2	4.5
RVP1.2.1	Irrigated	0-10	7.9	8.9	0.20	20	7.4	0.7	0.4	0.6
RVP1.2.1	Irrigated	20-30	8.0	9.0	0.17	33	4.0	0.4	0.2	0.7
RVP1.2.1	Irrigated	50-60	6.5	8.1	0.26	69	3.5	2.7	0.2	3.5
RVP2.1.1	Irrigated	0-10	7.6	8.8	0.17	19	6.2	0.8	0.4	0.6
RVP2.1.1	Irrigated	20-30	7.4	8.3	0.17	61	2.4	0.4	0.1	0.5
RVP2.1.1	Irrigated	50-60	6.5	7.9	0.18	47	4.2	3.7	0.2	2.2
RVP2.1.2	Unirrigated	0-10	5.8	6.7	0.09	4	3.5	0.5	0.6	0.1
RVP2.1.2	Unirrigated	20-30	5.9	6.6	0.07	5	1.9	0.3	0.1	0.04
RVP2.1.2	Unirrigated	50-60	5.4	6.4	0.14	15	3.7	4.1	0.2	0.5

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)
Maryvale										
MVP2a.1	Irrigated	0 - 10	7.9	8.8	0.18	15	7.9	0.8	0.7	0.7
MVP2a.1	Irrigated	20 - 30	7.5	8.7	0.15	35	4.7	0.9	0.5	0.8
MVP2a.1	Irrigated	50 - 60	7.5	8.6	0.20	44	6.5	1.4	0.6	1.0
MVP2b.1	Irrigated	0 - 10	7.3	8.5	0.10	7	6.5	0.8	0.7	0.4
MVP2b.1	Irrigated	20 - 30	7.4	8.6	0.11	15	5.4	0.9	0.5	0.7
MVP2b.1	Irrigated	50 - 60	7.2	8.5	0.16	36	6.4	1.6	0.5	1.7
MVP2c.2	Irrigated	0 - 10	7.9	9.0	0.21	28	7.6	0.9	0.6	0.8
MVP2c.2	Irrigated	20 - 30	7.7	9.0	0.16	42	3.8	0.9	0.2	1.2
MVP2c.2	Irrigated	50 - 60	7.3	8.9	0.24	60	3.5	1.9	0.2	3.0
MVP3a.1	Irrigated	0 - 10	7.5	8.5	0.14	6	8.7	1.0	1.0	0.4
MVP3a.1	Irrigated	20 - 30	7.4	8.6	0.14	28	6.0	1.1	0.4	0.7
MVP3a.1	Irrigated	50 - 60	6.9	8.5	0.18	53	3.7	1.9	0.3	1.8
MVP3b.1	Irrigated	0 - 10	7.7	8.7	0.12	6	7.8	0.8	0.4	0.3
MVP3b.1	Irrigated	20 - 30	7.0	8.6	0.14	21	3.3	1.4	0.2	1.5
MVP3b.1	Irrigated	50 - 60	6.1	7.3	0.27	130	2.5	2.9	0.2	2.7
MVC2a	Unirrigated	0 - 10	6.4	7.3	0.08	2	6.3	0.5	0.3	0.05
MVC2a	Unirrigated	20 - 30	6.0	7.3	0.05	5	6.1	1.8	0.1	0.3
MVC2a	Unirrigated	50 - 60	6.3	7.7	0.06	7	5.4	2.8	0.2	0.5
MVC3c	Unirrigated	0 - 10	5.1	6.3	0.03	1	2.6	0.3	0.1	0.1
MVC3c	Unirrigated	20 - 30	4.8	6.2	0.02	1	1.4	0.4	0.04	0.1
MVC3c	Unirrigated	50 - 60	5.2	6.5	0.03	6	2.3	1.8	0.1	0.2

Appendix 2. Salinity in root zones of trees, crops and pastures in 2018.

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	0.289	2.02	0.41	0.83	
Ettamogah	Unit 4	1.26	Effluent	20-30	0.406	2.84	0.21	0.60	
Ettamogah	Unit 4	1.26	Effluent	50-60	0.513	3.59	0.25	0.90	
Ettamogah	Unit 4	1.26	Effluent	80-90	0.495	3.47	0.13	0.45	2.77
Ettamogah	Unit 1	3.02	Effluent	0-10	0.075	0.52	0.41	0.21	
Ettamogah	Unit 1	3.02	Effluent	20-30	0.056	0.39	0.21	0.08	
Ettamogah	Unit 1	3.02	Effluent	50-60	0.068	0.47	0.25	0.12	
Ettamogah	Unit 1	3.02	Effluent	80-90	0.070	0.49	0.13	0.06	0.48
Ettamogah	Unit 2	3.11	Effluent	0-10	0.159	1.12	0.41	0.46	
Ettamogah	Unit 2	3.11	Effluent	20-30	0.192	1.34	0.21	0.28	
Ettamogah	Unit 2	3.11	Effluent	50-60	0.180	1.26	0.25	0.31	
Ettamogah	Unit 2	3.11	Effluent	80-90	0.172	1.20	0.13	0.16	1.21
Ettamogah	Unit 4	3.15	Effluent	0-10	0.112	0.78	0.41	0.32	
Ettamogah	Unit 4	3.15	Effluent	20-30	0.149	1.04	0.21	0.22	
Ettamogah	Unit 4	3.15	Effluent	50-60	0.211	1.47	0.25	0.37	
Ettamogah	Unit 4	3.15	Effluent	80-90	0.272	1.90	0.13	0.25	1.16
								Average	**1.40**
								Std Dev	**0.97**
								Covar%	**69**

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	0.234	1.64	0.53	0.87	
Ettamogah	Unit 3	1.03	Effluent	20-30	0.123	0.86	0.28	0.24	
Ettamogah	Unit 3	1.03	Effluent	50-60	0.161	1.12	0.19	0.21	1.32
Ettamogah	Unit 2	MVP5-2.03	Effluent	0-10	0.194	1.36	0.53	0.72	
Ettamogah	Unit 2	MVP5-2.03	Effluent	20-30	0.199	1.39	0.28	0.39	
Ettamogah	Unit 2	MVP5-2.03	Effluent	50-60	0.224	1.56	0.19	0.30	1.41
Ettamogah	Unit 2	MVP5	Effluent	0-10	0.097	0.68	0.53	0.36	
Ettamogah	Unit 2	MVP5	Effluent	20-30	0.109	0.76	0.28	0.21	
Ettamogah	Unit 2	MVP5	Effluent	50-60	0.167	1.17	0.19	0.22	0.80
Ettamogah	Unit 3	MVP4-2.13	Effluent	0-10	0.222	1.55	0.53	0.82	
Ettamogah	Unit 3	MVP4-2.13	Effluent	20-30	0.196	1.37	0.28	0.38	
Ettamogah	Unit 3	MVP4-2.13	Effluent	50-60	0.316	2.21	0.19	0.42	1.63
Maryvale	Unit 2	MVP2a.1	Effluent	0-10	0.175	1.23	0.53	0.65	
Maryvale	Unit 2	MVP2a.1	Effluent	20-30	0.154	1.08	0.28	0.30	
Maryvale	Unit 2	MVP2a.1	Effluent	50-60	0.198	1.39	0.19	0.26	1.22
Maryvale	Unit 2	MVP2b.1	Effluent	0-10	0.097	0.68	0.53	0.36	
Maryvale	Unit 2	MVP2b.1	Effluent	20-30	0.112	0.78	0.28	0.22	
Maryvale	Unit 2	MVP2b.1	Effluent	50-60	0.159	1.12	0.19	0.21	0.79
Maryvale	Unit 4	MVP2c.2	Effluent	0-10	0.206	1.44	0.53	0.77	
Maryvale	Unit 4	MVP2c.2	Effluent	20-30	0.164	1.15	0.28	0.32	
Maryvale	Unit 4	MVP2c.2	Effluent	50-60	0.239	1.67	0.19	0.32	1.40
Maryvale	Unit 4	MVP3a.1	Effluent	0-10	0.136	0.95	0.53	0.51	
Maryvale	Unit 4	MVP3a.1	Effluent	20-30	0.135	0.95	0.28	0.27	
Maryvale	Unit 4	MVP3a.1	Effluent	50-60	0.178	1.24	0.19	0.24	1.01
Maryvale	Unit 4	MVP3b.1	Effluent	0-10	0.120	0.84	0.53	0.45	
Maryvale	Unit 4	MVP3b.1	Effluent	20-30	0.141	0.99	0.28	0.28	
Maryvale	Unit 4	MVP3b.1	Effluent	50-60	0.272	1.90	0.19	0.36	1.08
Rosevale	Unit 3	RVP1.1.1	Effluent	0-10	0.206	1.44	0.53	0.77	
Rosevale	Unit 3	RVP1.1.1	Effluent	20-30	0.281	1.97	0.28	0.55	
Rosevale	Unit 3	RVP1.1.1	Effluent	50-60	0.434	3.04	0.19	0.58	1.89
Rosevale	Unit 3	RVP1.2.1	Effluent	0-10	0.200	1.40	0.53	0.74	
Rosevale	Unit 3	RVP1.2.1	Effluent	20-30	0.172	1.21	0.28	0.34	
Rosevale	Unit 3	RVP1.2.1	Effluent	50-60	0.260	1.82	0.19	0.35	1.43
Rosevale	Unit 4	RVP2.1.1	Effluent	0-10	0.168	1.18	0.53	0.62	
Rosevale	Unit 4	RVP2.1.1	Effluent	20-30	0.168	1.18	0.28	0.33	
Rosevale	Unit 4	RVP2.1.1	Effluent	50-60	0.182	1.27	0.19	0.24	1.19
								Average	**1.26**
								SDEV	**0.32**
								COVAR%	**25.5**

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	0.034	0.24	0.53	0.13	
Ettamogah	Unit 4	MVC5	Nil	20-30	0.053	0.37	0.28	0.10	
Ettamogah	Unit 4	MVC5	Nil	50-60	0.096	0.67	0.19	0.13	0.36
Ettamogah	Unit 4	MVC4-2.15	Nil	0-10	0.052	0.37	0.53	0.19	
Ettamogah	Unit 4	MVC4-2.15	Nil	20-30	0.073	0.51	0.28	0.14	
Ettamogah	Unit 4	MVC4-2.15	Nil	50-60	0.080	0.56	0.19	0.11	0.44
Maryvale	Unit 2	MVC2a	Nil	0-10	0.080	0.56	0.53	0.30	
Maryvale	Unit 2	MVC2a	Nil	20-30	0.049	0.34	0.28	0.10	
Maryvale	Unit 2	MVC2a	Nil	50-60	0.065	0.45	0.19	0.09	0.48
Maryvale	Unit 4	MVC3c	Nil	0-10	0.028	0.19	0.53	0.10	
Maryvale	Unit 4	MVC3c	Nil	20-30	0.016	0.11	0.28	0.03	
Maryvale	Unit 4	MVC3c	Nil	50-60	0.027	0.19	0.19	0.04	0.17
Rosevale	Unit 4	RVP2.1.2	Nil	0-10	0.088	0.61	0.53	0.32	
Rosevale	Unit 4	RVP2.1.2	Nil	20-30	0.070	0.49	0.28	0.14	
Rosevale	Unit 4	RVP2.1.2	Nil	50-60	0.141	0.99	0.19	0.19	0.65
								Average	**0.42**
								SDEV	**0.18**
								COVAR%	**41.9**

Appendix 3. Annual rainfall, pan evaporation, irrigation and loads of nitrogen, phosphorus, zinc and total dissolved solids (TDS) in effluent applied from 1st July 2017 to 30th June 2018 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
2017 - 2018	648	1354	6.5	4.8	11.3	5.2	11.7	10.4	13.2	0.61	0.66	0.01	0.01	4290	4591