

# Perennial pastures reduce runoff from saline discharge areas: a case study

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**ABSTRACT:** Perennial pastures are promoted as being able to use more water than their annual equivalents thus reducing recharge and the impacts of salinity upon the landscape. However, little is known about using perennials on discharge sites and their impact upon the environment. The national *Sustainable Grazing on Saline Lands* project aims to fill this knowledge gap. This paper reports on the hydrologic component of this research from one of the paired plots from the NSW field sites.

The field site is located near Gumble in the Lachlan Catchment. The paired plots consist of a “treated” and “untreated” paddock. The treated paddock has been sown with a mix of salt tolerant grasses and legumes and the untreated paddock has been left in the volunteer state.

Each paddock has been extensively instrumented to close the water balance. Monitoring began 18 months before the above mentioned treatment was applied. This has enabled actual treatment effects to be separated from naturally occurring site conditions.

Our results show that improved pastures on saline discharge areas use significantly more water than unimproved pastures. As a consequence of the increased water usage, there is significantly less saline water running off the sites to add to stream salinity.

This research demonstrates a win-win salinity solution; landholders being able to provide ‘out of season’ feed to stock from the perennial pastures; along with reducing runoff volumes from saline sites, and in turn minimising the volume of saline water in our river systems.

## **INTRODUCTION**

Re-introducing perennality into agricultural landscapes is seen as vital in the fight against salinity (Hatton and Nulsen 1999, Pannell and

Ewing 2006). In the higher parts of a catchment, woody and herbaceous perennials are seen as being able to use more water and therefore reduce recharge, but what about the lower parts of a catchment?

There have been studies investigating revegetation of saline lands for grazing (Barrett-Lennard 2002) but few investigating the off site environmental effects.

This study focuses on the effects of the establishment of salt-tolerant pastures on saline discharge sites on the export of salt and water as well as on animal production. Specifically to:

- Determine salt and water movement from salinised land under both volunteer/naturalised pasture and salt tolerant perennial pasture.
- Develop pasture management systems that maximise pasture and animal production, minimise negative on and off site environmental impacts and allow sustainable use of salt-affected land.
- Determine the economic value of the forage produced from these systems for wool and sheep production.

This paper will detail the results from the hydrologic component of this study.

## SITE DESCRIPTION

The study site is in the 750 ha Brays Flat Creek Catchment at Gumble (33°04'S, 148°36'E), this is a first order stream that drains into Mandagery Creek and forms part of the Lachlan Catchment. At the catchment outlet is a 10 ha saline scald which is the focus of this paper. Further information on the site is available in other papers in these proceedings (Crosbie et al. 2006, Hughes et al. 2006, Mitchell et al. 2006).

This scalded area contains 4 plots that have been extensively instrumented to monitor the water balance (Figure 1). Plots 1 and 3 have been sown with a 'shotgun mix' of salt tolerant grasses and legumes and plots 2 and 4 have been left in their volunteer state to act as a control. The aim of the field trial is to see if introducing a well managed perennial pasture onto the scalded area can reduce salt export from the site while providing out of season feed for grazing.

This work is part of the national *Sustainable Grazing on Saline Lands* project; the NSW node has 3 replicates of paired plots. Only plots 1 and 2 will be reported on within this paper.

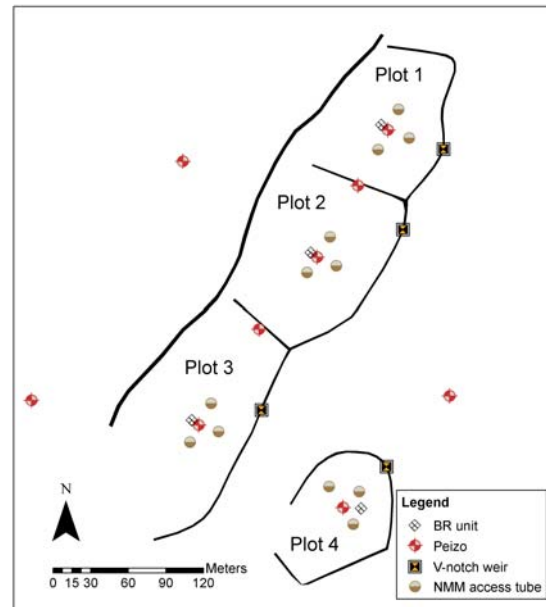
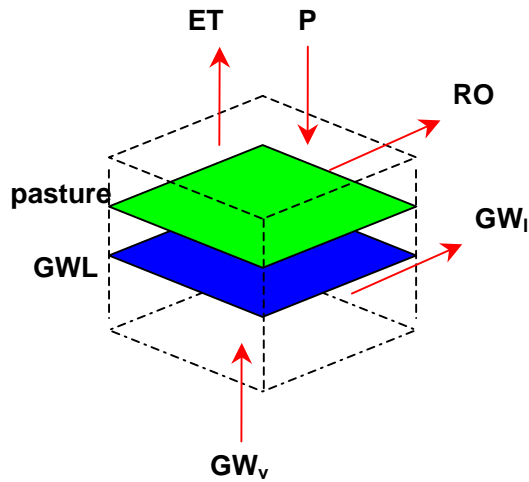


Figure 1. Site layout and instrumentation.

## METHODS

A control volume approach has been taken to investigate the water balance of the plots on which this experiment is based. The lateral extent of the control volume is defined by the bunds established to prevent run-on from outside the plots (Figure 1), the vertical extent of the control volume is from above the canopy of the pasture to below the water table. The use of a control volume simplifies the calculation of the water balance because many of the hydrological processes occurring within the control volume can be ignored (e.g. interception, infiltration and recharge). The only processes of interest result in mass being transferred either into or out of the control volume. This is shown diagrammatically in Figure 2.



**Figure 2. Schematic diagram of control volume for assessing the water balance of each plot.**

The water balance of each plot is defined as:

$$\Delta S = \sum \text{fluxes across CV} \quad (1)$$

$$\Delta S = P + ET + RO + GW_v + GW_l \quad (2)$$

Where  $\Delta S$  is the change in storage,  $P$  is precipitation,  $ET$  is evapotranspiration,  $RO$  is runoff,  $GW_v$  is the vertical groundwater flux and  $GW_l$  is the lateral groundwater flux. By convention positive fluxes are into the control volume and negative fluxes are out of the control volume.

The paired plot design of the experiment allows the treatment effects to be separated from site and climate effects. Double mass curves have been used to analyse the differences in fluxes crossing the control volume boundary pre and post treatment.

### Change in Storage

Soil moisture is measured using a neutron moisture meter. Each plot has 3 access tubes installed to a depth of 3 metres; the stored soil moisture in each tube is averaged to get a value for the stored soil moisture from each plot.

### Precipitation

Rainfall is measured in tipping bucket raingauges at 15 minutes intervals with a resolution of 0.2 mm. The values reported in this paper are the average of 4 raingauges located on the scald.

### Evapotranspiration

The Bowen Ratio Energy Balance methodology (Bowen 1926) has been used to calculate evapotranspiration from each of the plots in the experiment. The latent energy flux ( $\lambda E$ ) can be calculated from the available energy (net radiation ( $R_n$ ) minus ground heat flux ( $G$ )) and the Bowen Ratio ( $\beta$ ):

$$\lambda E = \frac{R_n - G}{\beta + 1} \quad (3)$$

$\beta$  is calculated as:

$$\beta = \gamma \frac{\Delta T}{\Delta e} \quad (4)$$

Where  $\gamma$  is the psychrometric constant,  $\Delta T$  and  $\Delta e$  are the change in temperature and vapour pressure respectively at two heights above the plant canopy.

$ET$  is calculated every 15 minutes from averages of  $R_n$ ,  $G$ ,  $\Delta T$  and  $\Delta e$  and then aggregated to daily totals.

### Runoff

The runoff is measured from each plot through a 60° V-notch weir. The salt load in the runoff is estimated from a relationship between electrical conductivity and total dissolved solids.

### Groundwater

The vertical groundwater flux was estimated from Darcy's Law from measurements made from a network of nested piezometers throughout the scalded area (Figure 1):

$$Q = kiA \quad (5)$$

Where  $Q$  is the volume of water,  $k$  is the hydraulic conductivity,  $i$  is the hydraulic gradient and  $A$  is the area.  $i$  is defined as:

$$i = \frac{\Delta h}{\Delta z} \quad (6)$$

Where  $\Delta h$  is the change in head in the nested piezometers and  $\Delta z$  is the difference in elevation between the screens on the nested piezometers.

The value of  $i$  calculated for each nest of piezometers was interpolated over the entire scald on a 10 m grid.

The hydraulic conductivity was determined in each piezometer using a slug test (Bouwer and Rice 1976), and the logarithm of the harmonic mean of  $k$  for each nest of piezometers was interpolated to a 10 m grid.

The gridded  $k$  and  $i$  data were substituted into Equation (5) and aggregated over each plot on a monthly basis to estimate the vertical component of groundwater flow into (or out of) the control volume.

The mass flux of salt ( $\dot{m}$ ) into the control volume was also calculated on a 10 m grid from:

$$\dot{m} = cQ \quad (7)$$

The concentration ( $c$ ) of salt was interpolated onto a 10 m grid based on EC measurements in the shallow piezometers.

The lateral flow of groundwater into and out of the control volume for each plot was calculated for the first 12 months of this data set but due to the volumes involved being negligible the calculations were not continued. It has been assumed that the net lateral groundwater flow into and out of the control volume is zero for the purposes of this paper.

### Double mass curves

Double mass curves were used to detect differences in the fluxes across the control volume boundary between the pre and post treatment time periods. Only data that we are confident is correct was included in the analysis for the double mass curves. For example, a flood event in November 2005 broke the bank of plot 2 resulting in a loss of data therefore this event was not included in the analysis.

Ideally, the double mass curve should result in a straight line for the pre treatment period and a straight line for the post treatment period. To detect whether there is a treatment effect upon the hydrology of these plots the statistics of the straight lines are compared.

A linear regression is used to fit a line to the data:

$$y = mx + c \quad (8)$$

The slope ( $m$ ) is an uncertain parameter and so has a mean value ( $\mu$ ) and a standard error ( $SE$ ) associated with it.

To find the probability that the mean value of the slope is equal pre and post treatment, the value of the standard normal deviate ( $Z$ ) needs to be found such that the confidence intervals ( $CI$ ) of the mean of the slope overlap.

$$CI = \mu \pm Z \cdot SE \quad (9)$$

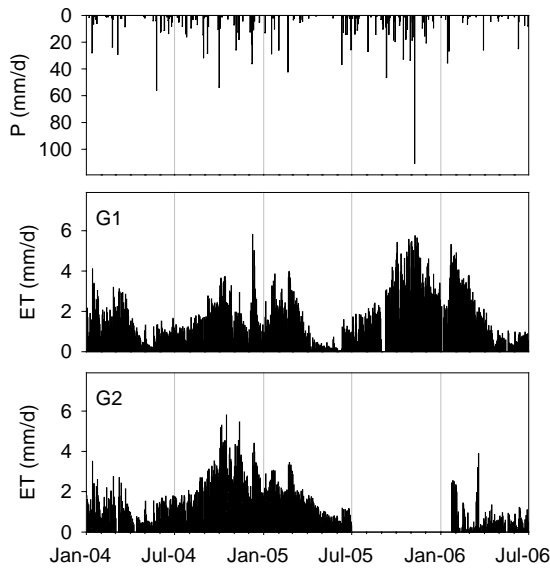
$$Z = \frac{\mu_{post} - \mu_{pre}}{SE_{post} + SE_{pre}} \quad (10)$$

From the calculated value of  $Z$  the probability that the mean of the slope pre and post treatment are the equal can be found from a two-tailed cumulative normal probability distribution.

## RESULTS

### Evapotranspiration

The results of the evapotranspiration monitoring can be seen in Figure 3. The two plots show a similar pattern in water use up until October 2004. At this time plot 1 was sprayed with a herbicide to prepare the plot for the sowing of the new pasture. The spraying had an immediate impact upon the ET with plot 1 well below the ET of plot 2 until February 2005. During the dry autumn of 2005 the ET in plot 1 decreased more rapidly than plot 2. Both plots responded immediately to rainfall in mid June 2005. Unfortunately plot 2 has no data from the second half of 2005 due to equipment malfunction. During this time plot 1, with its new pasture, was using more water than the corresponding period the year before. So far, 2006 has been very dry but plot 1 is still using water, much more than plot 2 and also more than it was using in the corresponding period in 2004.

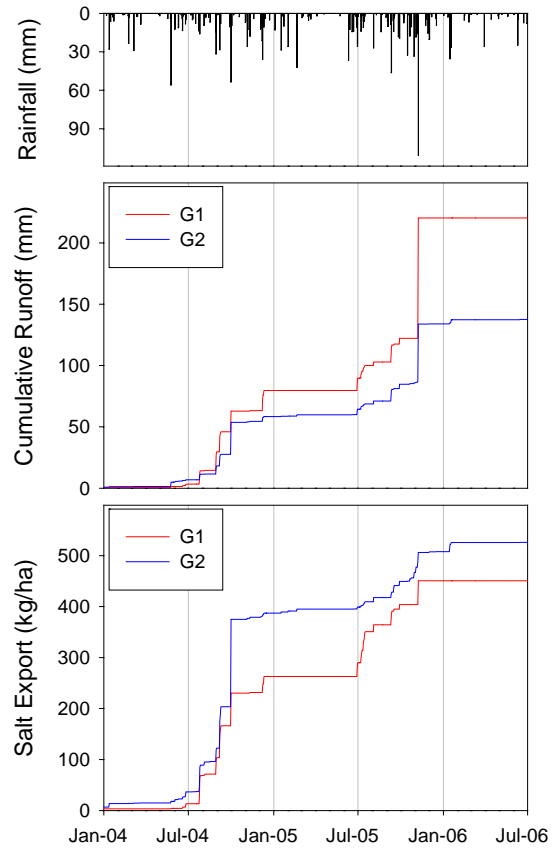


**Figure 3. Daily evapotranspiration as determined by Bowen Ratio Energy Balance methodology.**

**Runoff**

The runoff data collected is shown in Figure 4 as cumulative runoff in mm and cumulative salt export in kg/ha to normalise the two plots for area. In total, plot 1 has exported more water but plot 2 has exported more salt. Even though plot 1 has exported more water it has done so from fewer rainfall events; plot 2 will produce runoff from less rainfall than plot 1.

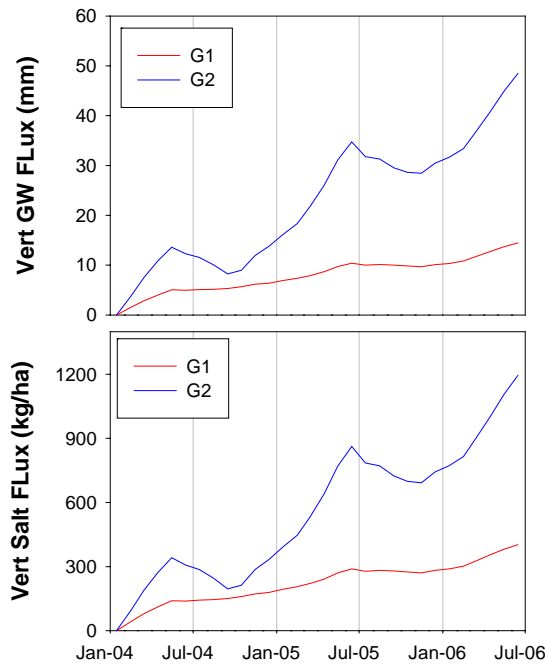
The dominant spike in the rainfall plot in Figure 4 is 8 November 2005. This rainfall event totalled 130 mm (over a 24 hr period on the 7-8 Nov) with a 4 hr period recording 100 mm. According to IFD analysis this exceeds the 1 in 200 year average return interval for a 4.5 hr storm (Pilgrim 1987). In plot 1 this storm resulted in 98 mm of runoff but in plot 2 it broke the bund and so all the water exported did not pass through the gauge. This storm event was therefore not included in the double mass curve analysis.



**Figure 4. Cumulative runoff and salt export.**

**Groundwater**

The cumulative groundwater fluxes of water and salt are shown in Figure 5. Immediately it can be seen that plot 2 has a greater inflow of both water and salt from groundwater, this is due to the lower hydraulic conductivity of plot 1. In the winter/spring of 2004 plot 1 had one month where water left the control volume (recharge) and plot 2 had 4 months. In 2005 there was considerably more rainfall in the winter/spring period and plot 1 had 4 months of groundwater recharge and plot 2 had 5 months. Even though there is some recharge in both plots they are both a net discharge site as can be seen by the increasing cumulative fluxes of water and salt in Figure 5.



**Figure 5. Cumulative vertical fluxes of water and salt from groundwater into the control volume for each plot.**

**Water balance**

A water balance has been calculated for the pre and post treatment periods for each plot using Equation (2), and these results are shown in Table 1 and Table 2. In calculating the water balance the error of each component will accumulate in the calculated  $\Delta S$  term, by also measuring this term the total error of the system can be calculated as the difference between calculated and measured change in storage. In the pre-treatment case the error was 6% and 4% of rainfall for plots 1 and 2 respectively. Post treatment was not as good with 13% error in plot 1 and for plot 2 no error could be calculated due to the lack of ET data.

**Table 1. Pre-treatment components of the water balance 1/1/04 – 30/9/04.**

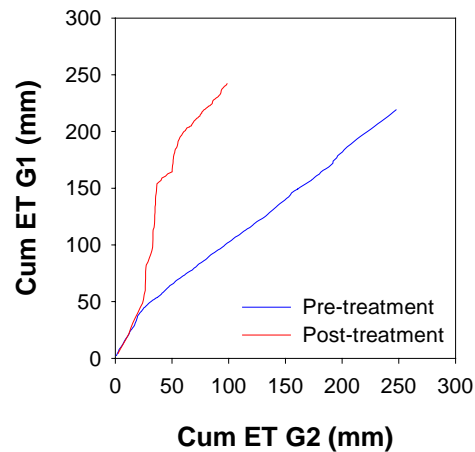
Component (mm)	Plot 1	Plot 2
Rainfall	446	446
Evapotranspiration	-360	-353
Runoff	-46	-27
Groundwater	7	12
Calculated $\Delta S$	47	78
Measured $\Delta S$	75	58
Error	-28	20

**Table 2. Post-treatment components of the water balance 1/7/05 – 30/6/06.**

Component (mm)	Plot 1	Plot 2
Rainfall	768	768
Evapotranspiration	-807	
Runoff	-131	-73
Groundwater	4	14
Calculated $\Delta S$	-166	
Measured $\Delta S$	-61	-11
Error	-105	

**Double mass curves**

The slopes of the double mass curves for ET pre and post treatment (Figure 6) are statistically significantly different (Table 3). In the pre-treatment case, plot 1 was only using 80% of the water that plot 2 was using. During the post-treatment period, plot 1 was using more than double the water of plot 2.



**Figure 6. Double mass curves for cumulative evapotranspiration pre and post treatment.**

The slopes of the double mass curves for runoff pre and post treatment (Figure 7) are statistically significantly different (Table 3). For the pre-treatment period plot 1 was running 90% more than plot 2, and in the post-treatment period this has been reduced where plot 1 is now running only 30% more water than plot 2.

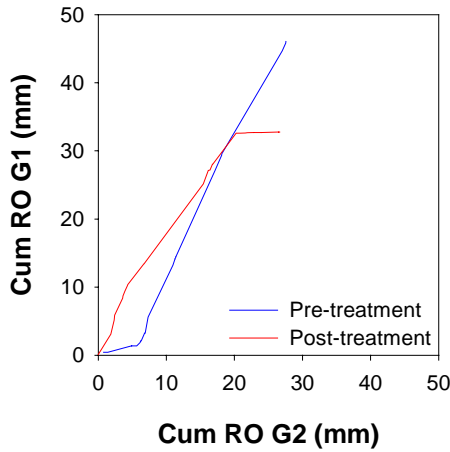


Figure 7. Double mass curve for cumulative runoff.

The slopes of the double mass curves for salt export in runoff pre and post treatment (Figure 8) are not significantly different (Table 3). In the pre-treatment period, plot 1 was exporting 91% of the salt of plot 2. In the post treatment period the double mass curve is not a straight line which suggests a new equilibrium has not yet occurred (see discussion section).

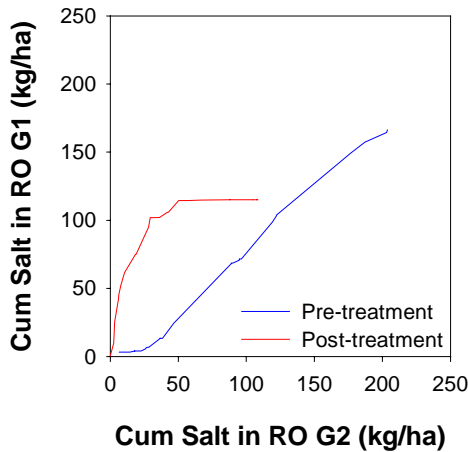


Figure 8. Double mass curve for cumulative salt export in runoff.

The slopes of the double mass curves for the groundwater flow into the control volume pre and post treatment (Figure 9) are statistically significantly different at the 5% level (Table 3). In the pre treatment period plot 1 had 40% of the inflow of plot 2, in the post treatment period this fell to 25%.

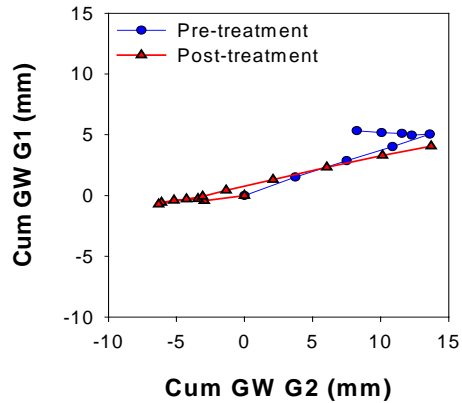


Figure 9. Double mass curve for cumulative groundwater flow into control volume.

The slopes of the double mass curves for the salt flow from groundwater into the control volume are not significantly different at the 5% level.

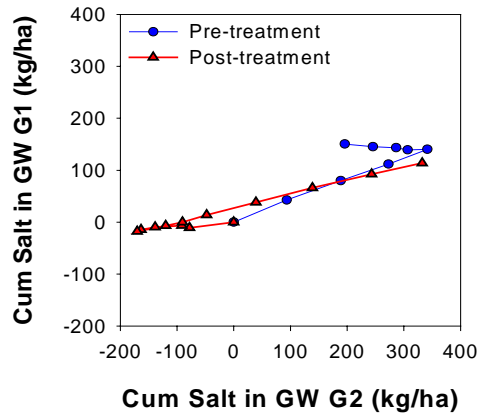


Figure 10. Double mass curve for cumulative salt flow into control volume.

Table 3. Statistics on the slopes of the double mass curves.

	ET	RO	RO Salt	GW	GW Salt
$r^2_{pre}$	0.99	0.97	0.99	0.83	0.79
$\mu_{pre}$	0.80	1.92	0.91	0.40	0.44
$SE_{pre}$	0.005	0.051	0.011	0.069	0.085
$r^2_{post}$	0.89	0.96	0.67	0.97	0.96
$\mu_{post}$	2.43	1.31	0.89	0.25	0.27
$SE_{post}$	0.069	0.039	0.097	0.012	0.016
Z	22	6.9	0.15	1.87	1.64
$P(\mu_{pre}=\mu_{post})$	0	0	0.44	0.03	0.05

## DISCUSSION

The apparent large treatment effect upon evapotranspiration will not persist when a full year of data is collected. The new pasture in plot 1 contains some summer active species that are not present in plot 2 and so for the time period available plot 1 is using more water than plot 2. During the winter/spring period the water use of the two plots should become closer.

The runoff data shows a considerable decrease in runoff of water for the post treatment time period but curiously an increase in the export of salt.

The post treatment double mass curve for salt export is not a straight line but a curve. This is characteristic of the two plots not being in equilibrium with each other. Initially the salt export was much higher in plot 1 than plot 2; this is believed to be due to the disturbance of the soil surface during the sowing of the new pasture. The bare scalded areas would have been hydrologically inactive; the conductivity would have been extremely low preventing infiltration and causing runoff (Greene 1992). These areas store salt close to the surface (W.S. Semple pers. comm.) from the upward flux of groundwater and after being disturbed have the opportunity to interact with rainfall and mobilise the salt. In time, a new equilibrium will be reached which will result in a straight line on the double mass curve.

This experiment has another six months of field data collection to go; hopefully this will be sufficient to draw conclusions about the ET and runoff issues above.

## CONCLUSIONS

This study has shown that the establishment of perennial pastures on a saline discharge area can result in an increase in evapotranspiration leading to a decrease in runoff. However, it has been noted that following establishment of the pasture on the treated plot more salt has been exported post treatment. This result is expected to be a temporary effect due to the disturbance the site underwent during sowing. Continued monitoring of the post treatment effects will further strengthen the results, and determine the longer term effects of the imposed treatment.

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