Agricultural Water Management

Shoalhaven Starches Pty Ltd

SHOALHAVEN STARCHES ETHANOL UPGRADE

WASTEWATER MANAGEMENT PLAN

INCORPORATING OEH CHANGES

Prepared for Shoalhaven Starches Pty Ltd

and

Cowman Stoddart Pty Ltd

by

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SHOALHAVEN STARCHES – WASTEWATER MANAGEMENT PLAN

DISCLAIMER

S. SUMMARY

The Wastewater Management Plan details the operation and acceptable limits for using wastewater from the Shoalhaven Starches Expansion Project for irrigation on the Environmental Farm.

The impact criteria are presented as acceptable levels of:

- The wastewater flow that can be applied to the Environmental Farm and not over-saturate the soil.
- Threshold concentrations of ions that could cause foliar damage during irrigation if exceeded.
- Chemical loads of each constituent in the wastewater that can be accommodated through removal processes.
- Measures of soil health that integrate the combined effect of various constituents on the soil.

The wastewater flow, foliar damage and soil health criteria are given as threshold values that should not be exceeded. On the other hand, the acceptable chemical loads are not determined by a single threshold value, but rather are set by the ability of the system to accommodate the annual applications through various removal processes. Tri-annual soil tests are used to quantify the resulting balance on a long-term basis.

Performance measures are also provided for the operation of the wastewater treatment processes and the irrigation system.

Monitoring requirements and remedial actions when thresholds are exceeded are detailed for each of the major constituents in the wastewater. The mass balances showed that the balance between inputs from wastewater and removal in fodder would be:

- Positive for calcium, magnesium, sodium, bicarbonate, sulphate and chloride.
- Negative for nitrogen, phosphorus and potassium.

The ions with a positive balance must be monitored to ensure that they do not accumulate to harmful levels in the soil, whereas those with a negative balance could have implications for plant nutrition.

S1. Checklists

The first table provides a checklist of the required actions for monitoring and related issues. It also details the sections in the report where more detail is provided.

Item	Reason	Frequency	How	Section
WASTEWATER				
Irrigation volume	Used in mass load calculations	As used	Operators	11.1
Composition – suite A high concentration	Identify surplus	Monthly	Chemical analyses	10, 11.1
Composition – suite B low concentration	Identify deficit and need for fertiliser	Monthly	Chemical analyses	10, 11.1
SOIL				
Composition– suite C	Detect changes over time	Annual	Soil cores (0-30cm)	11.2
Soil structure	Maintain structure	Annual	Dispersion test	11.2
HERBAGE- HARVESTED				
Harvested quantity	Used in mass removal calculations	At each harvest	Bale count by average weight	11.3
Composition - suite D	Mass removal and need for fertiliser	All cuts (bulked)	Chemical analysis	11.3
HERBAGE - GRAZED				
Animal grazing days	Used in mass removal calculations	Ongoing	Counts	11.3
Composition - suite D	Mass removal and need for fertiliser	Annual	Leaf plucks & chemical analysis	11.3
GROUNDWATER				
Composition– suite E	Detect leaching due to surplus	Annual	Chemical analyses	11.4
REMEDIATION				
Response	Correct undesirable effects	As required	Recommendations	10

Suite A chem. testing, high conc. – pH, EC, Mg, Na, HCO_3, Cl, SO_4.

Suite B chem. testing, low conc. – total N, total P, K, Ca.

Suite C chem. testing, soil – pH, EC, total P, K, (Exch.Ca, Mg, K, Na), soluble Na, Cl.

Suite D chem. testing, herbage – total N, P, K, Ca, Mg.

Suite E chem. testing, groundwater – Mg.

The second table outlines the key issues for operational planning, and where details may be found.

Item	Aim	How	Section
Crop types	Maintain high productivity	Continue with existing ryegrass and kikuyu pastures	4.3
Pasture productivity	Maintain high productivity	Use fertiliser and overseeding as required	4.3
Irrigation	Avoid overwatering	Deficit irrigation	4.4, 9
Soil quality	Avoid unacceptable salt accumulation	Monitor and change inputs or outputs where required	10
Nutrient removal	Reduce accumulation of surplus analytes in soil	Cut and removal of herbage	7

1. PURPOSE

In approving the Shoalhaven Starches Expansion Project (06-0228), the NSW Department of Planning set a number of specific environmental conditions, including Condition 25 that requires Shoalhaven Starches Pty Ltd to prepare a Wastewater Management Plan (WMP) that includes the following detail:

- An outline of the location, design and management of the irrigation, crop and grazing systems on the Environmental Farm;

- Measures to minimise soil and groundwater degradation, including:
  - Baseline data on soil and groundwater quality and characteristics;
  - Criteria to assess the impact of wastewater on soil quality;
  - Effluent treatment and irrigation system performance measures;
  - Details of the wastewater, soil, silage (or hay), and groundwater monitoring program;
  - Procedures for the reporting of monitoring results;
  - Procedures to prepare annual site nutrient and analyte budgets, and water balance;
  - Contingency measures to address exceedances, pollution triggers and problems with the wastewater management systems;
  - A description of how the effectiveness of actions can be monitored over time.

The primary objective of this WMP is to develop and document management strategies which fulfill the above requirements.

2. REFERENCES

The Plan references the following documents:

Cowman, P. (2008) Annual Surface Soil Testing Program. Report prepared for Manildra Group, Shoalhaven Starches Pty Ltd by Cowman Stoddart Pty Ltd, December 2008.

Cowman, P. (2009) Annual Surface Soil Testing Program. Report prepared for Manildra Group, Shoalhaven Starches Pty Ltd by Cowman Stoddart Pty Ltd, December 2009.

Cowman, P. (2010) Annual Surface Soil Testing Program. Report prepared for Manildra Group, Shoalhaven Starches Pty Ltd by Cowman Stoddart Pty Ltd, December 2010.

DEC (2004) *Environmental Guidelines: Use of Effluent by Irrigation.* Publ. Department of Environment and Conservation (NSW), DEC 2004/87, Sydney, October 2004.

DNR (1997) *Salinity Management Handbook*. The State of Queensland, Department of Natural Resources, Coorparoo, 1997.

Lawrie, R. (2009) Shoalhaven Starches Environmental Farm: 2008 Environmental Monitoring Report. Report prepared by NSW Department of Primary Industries for Shoalhaven Starches Pty Ltd, April 2009.

Lawrie, R. and Enman, B. (2010) Shoalhaven Starches Environmental Farm: 2009 Environmental Monitoring Report. Report prepared by NSW Department of Industry and Investment for Shoalhaven Starches Pty Ltd, April 2010.

Lawrie, R. and Enman, B. (2011) Shoalhaven Starches Environmental Farm: 2010 Environmental Monitoring Report. Report prepared by NSW Department of Industry and Investment for Shoalhaven Starches Pty Ltd, April 2011.

Murtagh, J., Lawrie, R. and Lugg, G (2008a) Shoalhaven Starches Ethanol Upgrade: Fitness for Purpose of Treated Wastewater, Agronomic Investigations. Report prepared for Shoalhaven Starches Pty Ltd and Cowman Stoddart Pty Ltd, June 2008.

Murtagh, J., Lawrie, R. and Lugg, G (2008b) Shoalhaven Starches Ethanol Upgrade: Fitness for Purpose of Treated Wastewater, Agronomic Investigations, Supplementary Information Including Monitoring Program. Report prepared for Shoalhaven Starches Pty Ltd and Cowman Stoddart Pty Ltd, July 2008.

NWQMS (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Paper No. 4. Australian and New Zealand Environment and Conservation Council, and Agriculture and Resource Management Council of Australia and New Zealand, October 2000.

NWQMS (2006) Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1). Natural Resource Management Ministerial Council, Environment Protection and Heritage Council, Australian Health Ministers' Conference, November 2006.

3. ACRONYMS AND ABBREVIATIONS

BVF	Bulk volume fermentator
CEC	Cation exchange capacity (meq/100g)
COD	Chemical oxygen demand
DEC	Department of Environment and Conservation (NSW)
EC	Electrical conductivity (dS/m)
$EC_{1:5}$	Electrical conductivity of a 1:5 soil:water extract (dS/m)
ECE	Electrical conductivity of a soil paste (dS/m)
ESP	Exchangeable sodium percentage (%)
MBR	Membrane bio reactor
NWQMS	National Water Quality Management Strategy
OEH	Office Environment & Heritage, NSW
PSC	Phosphorus sorption capacity (kg/ha/m)
RO	Reverse osmosis
RSC	Residual sodium carbonate (meq/L)
SAR	Sodium adsorption ratio
TDS	Total dissolved salts
ULP RO	Ultra low pressure reverse osmosis

Chemical abbreviations

Ca	calcium	Cl	chloride	HCO_3	bicarbonate
K	potassium	Mg	magnesium	N	nitrogen
Na	sodium	P	phosphorus	SO_4	sulphate
TN	total nitrogen	TP	total phosphorus		

4. DESIGN AND MANAGEMENT OF ENVIRONMENTAL FARM

4.1 Local environment

The monthly rainfall and evapotranspiration at Nowra are summarised in Table 1, using records from the Bureau of Meteorology. The rainfall records covered 71 years from 1940-2010 and included a variety of wet and dry years. The pan evaporation records were converted to potential rates of evapotranspiration from a mixed summer-grass/ryegrass pasture by multiplying by appropriate pan and crop coefficients.

Table 1 Mean monthly rainfall and potential evapotranspiration.

Month	J	F	M	A	M	J	J	A	S	O	N	D	Yr
Rain (mm/mth)	88	126	103	95	92	113	54	65	61	90	83	77	1049
Evapotranspiration pasture (mm/mth)	126	103	95	46	69	56	57	70	100	135	136	130	1123

The annual rainfall distribution varied as follows:

Driest	1/10-dry	Median	1/10-wet	Wettest
515mm	605mm	976mm	1611mm	2248mm

Points of note are:
- The area receives a moderate rainfall that averages 1049 mm/yr;
- Mean rainfall is less than potential evapotranspiration from July-January. Hence, these are the months when irrigation will be most needed, but variation in rainfall can also create an irrigation demand in any month;
- The depressed evapotranspiration in April accounts for the effect of renovation before oversowing with ryegrass.

The pasture evapotranspiration was based on a mixed summer-grass/ryegrass pasture and the higher water use of the ryegrass meant that the seasonal trend also reflected the changing species composition between the warmer and cooler months.

4.2 Site Description

The Environmental Farm is 960 hectares of which approximately half is irrigated. The spray irrigation infrastructure consists of seven centre pivots and 185 irrigation-runs/transects for travelling irrigators.

The underground network of poly pipe, which distributes the wastewater, is approximately 44 kilometres in length. There are 4 main irrigation lines from which lateral lines branch to licensed irrigation paddocks.

The size of this irrigation enterprise determines the choice of the method to schedule the application of wastewater. Instrumentation which precisely measures the soil water content is specific to the location within a block and to the depth installed. These limitations, together with the cost of instrumentation of paddocks or even the number of soil types across the farm would outweigh the usefulness of such an exercise.

4.3 Cropping and grazing systems

The Environmental Farm uses a “cut and remove” strategy to manage the application of salts in wastewater by removing much if not all of the applied salts. The strategy involves taking regular silage cuts from the irrigated areas, while the non irrigated areas are managed as grazed pastures.

Balancing the chemical and physical attributes of the soil with pasture removal enables a continuing cycle of agricultural benefit from the industrial Plant.

The centre pivot irrigators are sown with Italian ryegrass in autumn and provide production through to summer. Summer grasses are dominant in the pastures during summer and autumn. Thus the pastures under the centre pivots are in continuous production enabling an active removal of salts. To make silage the pastures are cut, teddered and baled. The bales are either sold or kept for farm stock as feed for winter. The cycle of harvest is altered according to the weather situation.

The remainder of the irrigation area is serviced by travelling irrigators. The pasture is dominated by naturalised kikuyu which is a summer active species. Some of these areas have also been undersown with Italian ryegrass to provide green feed during the winter.

There are approximately 1300 head of beef cattle. Young steers weighing 350kg are bought and sold when they reach about 650 kg depending on the market. Adolescent beasts need more energy for this growth period and therefore are more effective than mature beasts. They graze the fast growing kikuyu pastures. Animals on the hoof have an advantage over mechanical harvesting after rainfall events. The mobs are rotated within the farm so that no pasture is over grazed. The aim is to have effective grass removal by animals thus exporting nutrients via beef.

4.4 Irrigation Scheduling and Practices

The basic aims of irrigation management by Shoalhaven Starches are to:

- Apply frequent, small amounts of wastewater during each irrigation so that there is a constant turnover of the wastewater in the irrigation mains to keep the wastewater fresh within the mains;
- To avoid overwatering the soil so there is no surface runoff or deep percolation of the applied wastewater;
- Minimise odour production;
- Maintain a productive vegetative cover across appropriate areas of the Environmental Farm.

Experience over a number of years has shown that operator skills coupled with the chemical limitations of the wastewater provided the best outcome in terms of timeliness, efficiency, odour reduction and operational cost. Commercially available instrumentation and strategies are valuable learning tools. Also, the irrigation intervals for each paddock are related to soil type.

Further details regarding irrigation scheduling are outlined in Appendix 2.

5. WASTEWATER TREATMENT PROCESSES

The process treatment of wastewater is outlined in the following flow-chart.

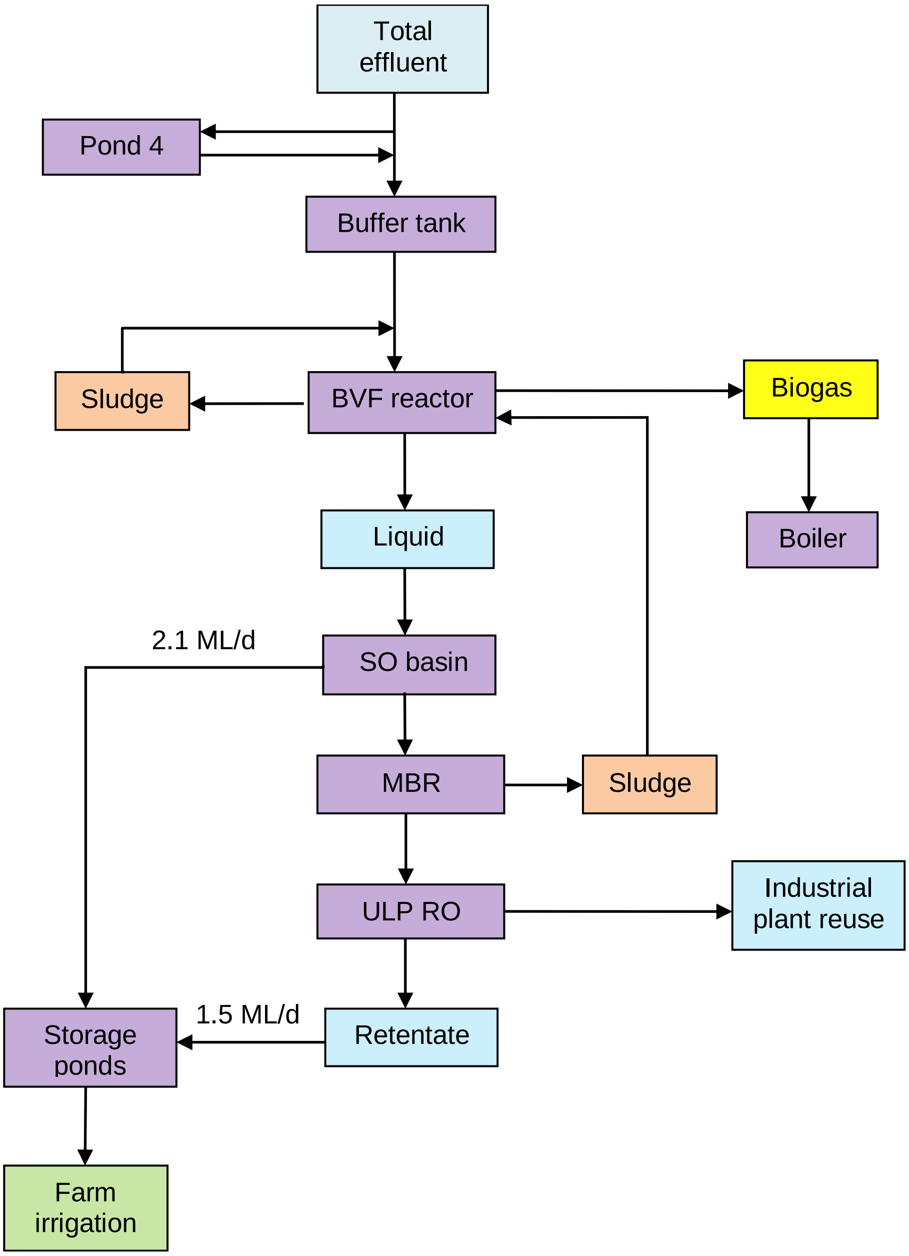

Figure 1. Wastewater treatment processes

Surplus flow or COD load is diverted to pond 4 where it is held pending treatment at a more suitable time.

The irrigation water consists of a blend of water drawn from the SO basin and the retentate from the RO plant. Performance measures for the wastewater treatment system are presented in Section 9.

6. BASELINE DATA ON SOIL AND GROUNDWATER

6.1 Soil

Extensive monitoring over a number of years has provided considerable detail regarding changes in soil properties since reuse irrigation commenced. Some results are given below to illustrate the changes over time. More details are provided in the annual "Environmental Monitoring Reports" prepared by Dr. Roy Lawrie and other staff of Industry & Investment, NSW (Lawrie 2009, Lawrie and Enman 2010, 2011). Detail is also provided in reports of the "Surface Soil Testing Program" (Cowman, 2008, 2009, 2010).

6.1.1 Soil salinity

Changes in soil salinity since reuse irrigation commenced are particularly relevant to the new project. Details taken from Murtagh et al. (2008a) plus the 2008-2010 results, are summarised in the following tables, which give the soil salinity in terms of the root-density weighted mean electrical conductivity in the upper 50cm of soil (labelled EC_w in the 2008 report, and as $EC_{1:5}$ in this report). The weighted value gave more emphasis to the electrical conductivity in the surface layers were plants obtain most water.

Table 2 details the $EC_{1:5}$ in years when samples were taken, and Table 3 provides the same values after applying paddock-based weighting to correct for different levels of salinity in each paddock. This adjustment was required because different paddocks were sampled in different years. Full details are provided in Murtagh et al. (1998a). Table 2 provides appropriate background values of the soil salinity in particular paddocks, whereas Table 3 should be used to assess general changes across the entire Environmental Farm.

Table 2 The root-density weighted EC concentrations ($EC_{1:5}$) in various paddocks in years when samples were taken.

	Paddock						
	21 Levee	38 Backslope	39 Swamp	110 P1	130 P3	140 Soper	Annual mean
				$EC_{1:5}$ (dS/m)			
1995		0.90		0.64	0.68		0.74
1996			1.19				1.19
1997							
1998			1.19				1.19
1999	0.14	0.70		0.65	1.43	1.08	0.80
2000				0.87	1.32		1.10
2001	0.55					0.95	0.75
2002		0.94	1.18				1.06
2003				1.17	2.23		1.70
2004	0.70					2.04	1.37
2005		0.90	1.16				1.03
2006				0.42	1.73		1.07
2007	0.28					1.24	0.76
2008		0.60	0.59				0.60
2009				0.44	1.01		0.72
2010	0.56					1.38	0.97
Paddock mean	0.45	0.81	1.06	0.70	1.40	1.34	0.96

Table 3 The root-density weighted and paddock weighted mean EC concentrations in various paddocks, and annual means.

	Paddock						
	21 Levee	38 Backslope	39 Swamp	110 P1	130 P3	140 Soper	Annual mean
				$EC_{1:5}$ (dS/m)			
1995		1.07		0.87	0.47		0.80
1996			1.07				1.07
1997							
1998			1.07				1.07
1999	0.30	0.83		0.90	0.98	0.78	0.76
2000				1.20	0.91		1.05
2001	1.19					0.68	0.94
2002		1.11	1.07				1.09
2003				1.61	1.53		1.57
2004	1.50					1.46	1.48
2005		1.07	1.05				1.06
2006				0.57	1.18		0.88
2007	0.60					0.89	0.74
2008		0.72	0.54				0.63
2009				0.60	0.69		0.65
2010	1.21					0.99	1.10

* The paddock weight was the overall mean $EC_{1:5}$ (0.96 dS/m) divided by the mean $EC_{1:5}$ for each paddock given in Table 2.

There were two distinct phases in the quality of the wastewater applied to the Environmental Farm and the resultant changes in soil salinity:

- Phase 1- 1995-2004: The wastewater was heavily limed as part of the odour-control process and had a high solids concentration. This increased the soil salinity to a peak level of 1.56 dS/m in 2004.
- Phase 2 – 2005-2010 and beyond: Some of the wastewater was processed through DDG dryers to remove solids, and less lime was added. As a consequence the soil salinity declined rapidly to a low weighted value of 0.64 dS/m in 2008, maintained this level in 2009, but increased to 1.10 dS/m in 2010. The 2010 increase particularly reflected the variation in salinity of paddock 21 for reasons that were not clear but still remained well below the peak levels in 2003-2004. Also it must be kept in mind that the tri-annual paddock-sampling best describes long-term trends rather than year-to-year variation.

6.1.2 Other chemical properties

Results of chemical tests on surface samples (0-20cm) are given below. Tests were done on 30 different paddocks, using a three-year rotation that tested about 10 paddocks each year. The full set of results in 2009 are presented in Tables 4 and 5 to show the extent of variation between paddocks. In addition, annual means were used to show changes over time of some key measures in Figures 2-4. When calculating the means, values that were listed in the test results as greater than some high value were taken to equal that high value.

Table 4 Chemical properties of surface soil taken from various paddocks in 2009.

Paddock	pH ($CaCl_2$)	Available P (Bray test) (mg/kg)	PSC (mg/kg)	Total N (%)	Organic C (%)
6	8.1	>350	576	1.16	8
13	8.0	97	772	0.84	7
18	7.8	171	713	0.82	7
24	8.0	69	447	0.45	4
25	8.2	>350	684	2.0	14
32	7.9	>350	751	1.7	12
41	8.1	>350	760	2.05	13
45	7.8	100	734	0.7	6
56	7.8	152	748	1.09	9

Reflecting past practice, all soils had a very high concentration of available P, but because the phosphorus sorption capacities (PSC) were also high there was no risk of phosphorus leaching.

The organic carbon concentrations were also very high. This was viewed as an advantage because of the effect of organic matter on soil structural stability and the retention of nutrients such as nitrogen.

Table 5 Exchangeable cation concentrations in surface soil taken from various paddocks in 2009.

Paddock	Cation concentration (cmol[+]/kg)				Cation percent			
	Ca	Mg	Na	K	Ca	Mg	Na *	K
6	31.9	2.7	3.2	1.8	81	7	8	5
13	31.4	2.6	4.9	1.1	79	6	12	3
18	38.1	4.3	5.5	1.4	77	9	11	3
24	20.4	1.5	2.2	0.6	83	6	9	2
25	39.7	3.4	3.8	1.6	82	7	8	3
32	47.2	6.9	7.5	2.8	73	11	12	4
41	45.2	5.9	7.4	2.4	74	10	12	4
45	39.1	3.1	2.8	1.3	85	7	6	3
56	41.2	2.0	2.6	1.2	88	4	5	2

* = ESP (%)

Reflecting the heavy addition of lime to wastewater over previous years, the surface soil had a high concentration of calcium and this dominated the exchange complex.

Based on the ESP, the surface soil from most paddocks was sodic (ESP > 6%). However, samples taken from the surface soil in paddock numbers 38 and 39 in late 2008 showed no slaking or dispersion after 20 hours shaking in the Emerson aggregate stability test. It was concluded that the soil aggregates were stabilised by organic matter and did not disperse when wetted. Also the high soil salinity would tend to offset the potential effect of sodicity on soil stability.

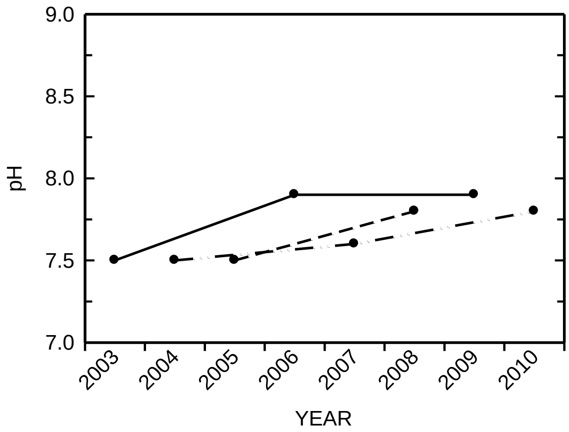

Figure 2 Changes in surface-soil pH over time.

The surface-soil pH increased slightly since 2003-2005, and it is uncertain at this stage whether there will be further increases in the future.

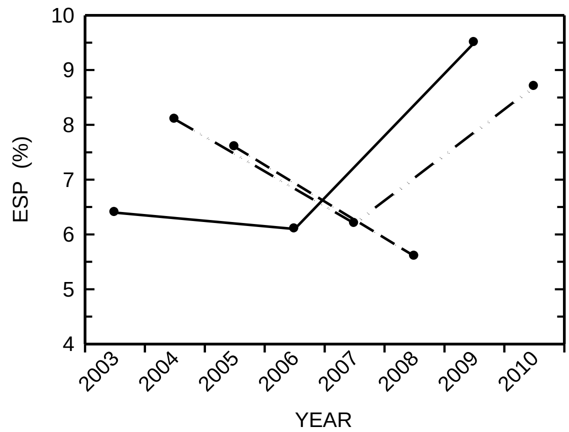

Figure 3 Changes in surface-soil ESP over time.

The initial downward trend in surface-soil ESP was reversed with increases during 2009 and 2010. The increases could be reversed in the future with the recent change to retentate irrigation.

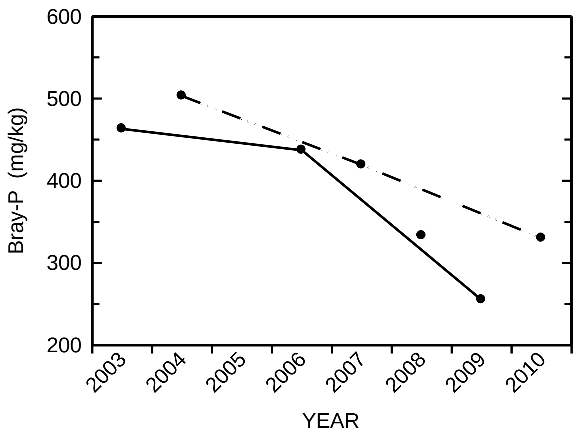

Figure 4 Changes in surface-soil Bray phosphorus over time.

There has been a consistent decline in the phosphorus concentration in surface soil over time.

6.2 Groundwater

Groundwater quality measurements were available for four measuring sites. Full details of the measurements, and earlier measurements, are provided in the Annual Environmental Monitoring Reports.

Table 6 Chemical properties of groundwater taken from four sampling sites.

Analyte	Units	Swamp paddock	P1 Paper mill	P3 Walsh	P4
Year sampled		2008	2009	2009	2010
pH		6.0	4.3	7.0	5.4
EC	dS/m	2.8	3.8	6.3	7.0
Chloride	mg/L	210	480	720	1400
Sulphate	mg/L	960	900	1530	-
Nitrate-N	mg/L	<0.02	9.5	<0.02	<0.02
Total N	mg/L	5	27	8	17
Total P	mg/L	0.4	0.04	0.54	8.8

The composition of groundwater varied between sampling sites as instanced by the differences between the two samples taken in 2009. In general, the groundwater was saline to very saline, and contained a high sulphate concentration which reflected the widespread distribution of acid sulfate soils.

7. WASTEWATER – QUANTITY AND QUALITY

A mixture of water drawn from the SO basin and retentate from the RO plant is used for irrigation on the Environmental Farm. The irrigation water also includes a small quantity of stockpiled water from the condensate pond. The average composition as of 8 August 2011 is detailed in the following table.

Table 7 Flow rate and chemical composition of water from the SO basin, retentate and irrigation water.

Item	Unit	Amount		
		SO basin	Retentate	Irrigation water
Flow	ML/d	2.1	1.5	3.6
TDS	mg/L	1,000	4,130	1,500
Ca	mg/L	13	40	46
Mg	mg/L	105	432	140
Na	mg/L	160	559	238
K	mg/L	24	77.5	32
HCO_3	mg/L	650	1,778	845
SO_4	mg/L	25	67	81
Cl	mg/L	71	474	126
Total N	mg/L	61	115.5	37
Total P	mg/L	18	26	18

8. IMPACT ASSESSMENT CRITERIA – WASTEWATER

8.1 Aim

The primary aim of managing the amount and composition of wastewater is to ensure that the Environmental Farm can assimilate the water and salts that are applied through irrigation.

8.2 Objectives

- Use irrigation to enhance the productivity of the Environmental Farm.
- Avoid overwatering the soil.
- Avoid applying more salts than the farming system can assimilate.
- Avoid increasing the soil salinity and sodicity to harmful levels.

8.3 Impact criteria

The impact criteria (Table 8 and Appendix 1) are presented as threshold levels of acceptable amounts of:

- The wastewater flow that can be applied to the Environmental Farm and not over-saturate the soil.
- Threshold concentrations of ions that could cause foliar damage during irrigation if exceeded.
- Chemical loads of each constituent in the wastewater that can be accommodated through removal processes.
- Measures of soil health that integrate the combined effect of various constituents on the soil.

The acceptable chemical loads are not determined by a single threshold value, but rather are set by the ability of the system to accommodate the annual applications especially through various removal processes. For a number of constituents, the rate of removal in harvested fodder will be the dominant removal process, and potential rates are given in Table 8. Note that these criteria are expressed as loads that equal the concentrations of each constituent in the wastewater multiplied by the irrigation volume

Given the multifaceted nature of the chemical load criteria, their assessment should be done in steps (Figure 5).

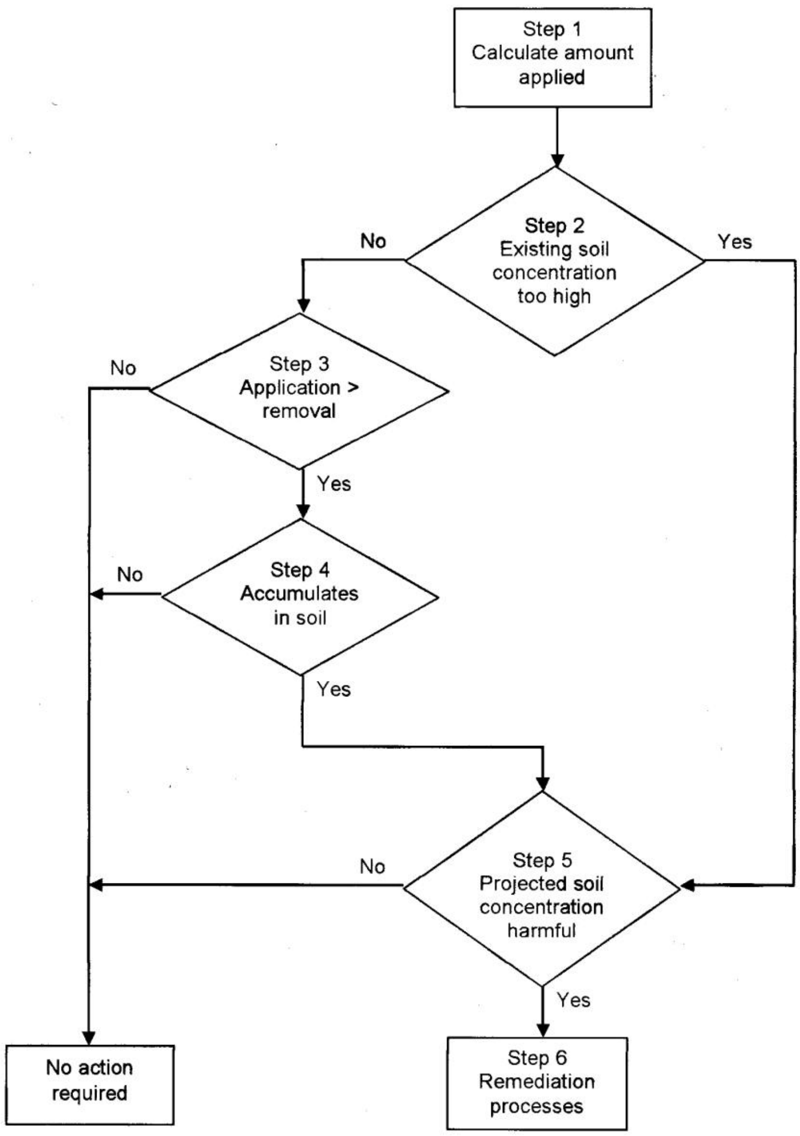

Figure 5 Steps for assessing the impact of the chemical load of individual constituents applied during irrigation.

Step 1: Calculate the amount applied per hectare.
Step 2: Assess whether existing soil concentration, pre-application, is at undesirable level.

If existing soil concentration is acceptable:
Step 3: Ascertain whether the application rate is greater than the potential rate of removal in harvested fodder (Table 8). If not, the constituent in question will not accumulate in the soil and no further investigation is required. Examples are given in Table 10.
Step 4: If a constituent remains in surplus after considering removal in harvested fodder, assess whether it will accumulate in the soil or will be removed through other processes such as leaching. Given the uncertainties of estimated losses such as those due to leaching, soil tests should be used to assess accumulation in the soil.

If projected soil concentration is high:
Step 5: Assess whether projected soil concentration is harmful. If so, go to step 6.

Step 6: If projected soil concentration is harmful. If so, assess impact on an individual constituent basis after taking into account whether potential rate of removal will give a net reduction in soil concentration (Section 10).

Table 8 Impact assessment criteria for wastewater.

Item	Threshold	Potential removal		Threat	Response if threshold exceeded
		In harvested fodder	Other processes		
Wastewater flow					
Annual volume	1,753 ML/yr			Overwatering or discharges	Increase storage capacity
Foliar sensitivity					
Sodium	460 mg/L			Foliar damage (kikuyu)	Avoid watering during middle of day
Chloride	700 mg/L			Foliar damage (kikuyu)	Avoid watering during middle of day
Chemical load					
pH ($CaCl_2$)	> 8.0				Reduce calcium addition
pH ($CaCl_2$)	< 5.0				Add lime
COD	50 tonne/d in dirty-water flow			Overloading BVF reactor	Temporarily store in pond 4
Calcium	Use pH as indicator	40 kg/ha/yr	Slight	Increase soil pH	Decrease if soil pH exceeds threshold
Magnesium	Ca:Mg ratio < 0.5	13 kg/ha/yr	Slight	Soil dispersion	Decrease if soil Ca:Mg ratio < 0.5
Sodium	ECE >3.8 dS/m ESP > 6%	41 kg/ha/yr	High	Salinity & sodicity	Check soil salinity & sodicity indicators
Potassium	ECE >3.8 dS/m	316 kg/ha/yr	Moderate	Salinity	Check soil salinity indicators
Bicarbonate	ESP > 6%	187 kg/ha/yr	Moderate	Sodicity through Ca precipitation	Check soil sodicity indicators
Sulphate	pH < 5.0	17 kg/ha/yr	High	Salinity	Add lime
Chloride	> 3 mg/g	15 kg/ha/yr	High	Salinity	Check soil salinity indicators
Total N	> 1.5 g/kg	308 kg/ha/yr	Moderate	Leaching to groundwater	Reduce application, increase removal in fodder
Bray P	> 500 mg/kg	148 kg/ha/yr	Moderate	Leaching to groundwater	Reduce application, increase removal in fodder
Soil health					
TDS	11 t/ha/yr			Salinity	Check soil salinity indicators
ECE	3.8 dS/m			Reduced productivity	Reduce salt addition
ESP	6%			Soil dispersion	More detailed analysis considering both salinity & sodicity

9. WASTEWATER TREATMENT PERFORMANCE MEASURES

The performance of the wastewater treatment system, from the irrigation reuse perspective, can be assessed by using the composition of the wastewater to calculate the chemical load from irrigation and to contrast this against the threshold values that constitute the impact assessment criteria (Table 8). The comparison should be made for individual ions, and for the TDS concentration.

- When the load from individual ions in the wastewater is less than the impact threshold (Table 8) then that ion is at an acceptable concentration for irrigation;
- If the ionic load exceeds the impact threshold, but the concentration is close to the expected values (Table 7) then further investigation is required (Table 8);
- If the concentration exceeds the expected value and the load exceeds the impact threshold, then the treatment processes should also be reviewed.

10. IRRIGATION SYSTEM PERFORMANCE MEASURES

Table 9 Irrigation system performance measures.

Item	Threshold	Threat	Response if threshold exceeded
Irrigation volume	On average, 1753 ML/yr or 4.8 ML/d	Overwatering	(a) Short-term: divert post-SO water for re-processing and factory use (b) Long-term: Increase irrigation area or storage capacity
Storage capacity	823ML (with average of 1,753 ML/yr)	Discharges	(a) Short-term: divert post-SO water for re-processing and factory use (b) Long-term: Increase irrigation area or storage capacity
Irrigation strategy	Deficit irrigation	Waterlogging	Reduce application volume

The current 514ha of irrigation and 823ML storage capacity provides sufficient capacity for an average wastewater flow of 1,753 ML/yr. This flow can be accommodated under all, including very wet, conditions. The 1,753 ML/yr does not represent the maximum irrigation volume in any one year; eg much larger volumes up to at least 3,000 ML/yr can be applied to the crops in very dry years. Rather the 1,753 ML/yr represents a planning limit when it is not known how wet or dry the next year will be. If it turns out to be dry, then more water can be diverted to irrigation perhaps by altering the volumes to be treated through the RO plant.

11. MONITORING MASS BALANCE AND REMEDIAL ACTIONS

The management plan uses mass balances to document the input/output relations on the Environment Farm for relevant analytes in the wastewater, and to identify those processes that require monitoring. The general aim is to show the fate of each analyte and whether the process is environmentally sustainable. The mass balances only relate to the analytes in wastewater and not the general supply of nutrients from soil to plants, although some comments are given on the implications for plant nutrition. Many of the analytes that are covered in the report represent plant nutrients, but others such as chlorides are potential contaminants.

The various ions in the wastewater were placed in group A if the mass applied per hectare exceeded the potential removal per hectare (Appendix 1, Table 3). Otherwise, they were placed in group B. The grouping was used to identify which ions would be in surplus and hence required monitoring that focused on the avoidance of harmful accumulation, versus those in deficit and possibly requiring supplementary fertiliser.

The annual application rate was calculated from the ionic composition of wastewater (Table 7) and a flow rate of 3.6 ML/d spread over 487ha. The potential removal rates were taken from Table 3 in Appendix 1.

Table 10 The balance between the application and removal rates of each ion.

Ion	Applied (kg/ha/yr)	Potential removal (kg/ha/yr)	Surplus	Group
Calcium	124	40	yes	A
Magnesium	378	13	yes	A
Sodium	643	41	yes	A
Potassium	86	316	no	B
Bicarbonate	2282	187	yes	A
Sulphate	219	52	yes	A
Chloride	340	15	yes	A
Total nitrogen	100	308	no	B
Total phosphorus	49	148	no	B

Leaching irrigation

Since sodium and chloride ions, and many of their salts, are quite soluble, their concentration in soil can be reduced by applying excess irrigation that will increase the leaching to groundwater (DEC 2004). Issues to be addressed when using this procedure are:

- Although leaching irrigations are designed to saturate the soil, over-watering should limit percolation to no more than 15mm per month in the first instance (DEC 2004). Only increase the leaching irrigation if the 15mm/mth proves to be insufficient to induce sufficient leaching of sodium and chloride.
- Cease leaching irrigations if the detrimental effect from other salts applied in the irrigation water prove to outweigh the positive leaching effect on the soil.
- Confirm that the additional leaching will not adversely affect the groundwater. This is not expected to be an issue given the existing high levels of salinity in the groundwater (Table 6).

11.1 Calcium

More calcium will be applied than removed, but since some calcium salts are likely to precipitate the overall impact on the calcium content of the soil solution will be small.

Monitoring

No monitoring is required from the contamination perspective, but as calcium is an important component on the exchange complex, application amounts and soil monitoring (exchangeable calcium) are recommended. The concentration in fodder is also required to monitor the removal rate. Items to be monitored are:

- Wastewater
- Soil
- Fodder

Remedial actions

Apply lime or gypsum where necessary to increase the proportion of calcium on the exchange complex, or to improve soil structure. Use lime if a pH increase is also desirable, otherwise use gypsum.

11.2 Magnesium

The wastewater will add a considerable quantity of magnesium and the removal rate in fodder will account for only 1% of the application rate leaving a considerable surplus in the soil. However, as discussed in Murtagh et al. (2009a) there is considerable scope to reduce the amount should that prove to be desirable.

Some, and perhaps much, of the surplus magnesium will precipitate out in the soil thus reducing its impact. This precipitation together with the general immobility of magnesium will limit, if not stop, the magnesium leaching to deep layers.

Monitoring

Surplus magnesium can cause nutrient imbalances for plants and soil structural problems, and the recommended monitoring was designed to detect adverse trends in these aspects.

- Wastewater
- Soil (including dispersion)
- Fodder
- Groundwater

Remedial actions

If tests show that magnesium is becoming dominant on the exchange complex, remedial actions are:

- Investigate the potential to reduce the magnesium concentration within the ethanol plant;
- Ensure that the maximum amount of forage is cut and removed from the paddock as silage or hay. This will maximise the magnesium removal rate;
- Apply lime or gypsum to increase the proportion of calcium on the exchange complex, and to improve soil structure should the soil structural stability be at risk.

11.3 Sodium

Up to 5% of the applied sodium can be removed in harvested fodder, leaving 729 kg/ha/yr in the soil. Because of the general mobility of sodium ions, much of the surplus sodium will leach. Given that both the groundwater and receiving waters are brackish, the addition of this relatively small amount of sodium is not viewed as constituting environmental harm and in fact the ongoing leaching of sodium should be encouraged to maintain soil health.

<u>Monitoring</u>

The main environmental issues with sodium relate to soil sodicity and salinity, and the monitoring was designed to detect any trends in these directions. It is not important to monitor the removal of sodium since the accumulation of sodium in soil is the issue to be watched.

- Wastewater
- Soil (EC, soluble, exchangeable and dispersion)

<u>Remedial actions</u>

- Apply surplus water using one or more irrigations (leaching irrigation) to leach sodium from the soil.

11.4 Potassium

Potassium is not normally viewed as a potential contaminant but is included here because of its importance as a plant nutrient.

The main issue with potassium is the large negative input/output balance and its implications for plant nutrition and the need to apply fertiliser. Under current conditions, the grasses have a generous supply of potassium which is reflected in the high fodder concentration of 41 mg/g. With the moderate application of potassium in the wastewater, the potassium concentration in soil will gradually decline.

<u>Monitoring</u>

No monitoring is required from the contamination perspective, but the following are recommended as aids for developing a fertiliser regime:

- Wastewater
- Soil
- Fodder

<u>Remedial actions</u>

- Apply potassium fertiliser as required.

11.5 Bicarbonate

The alkaline nature of bicarbonate is viewed as a positive given the widespread presence of acid production from local acid sulfate soils. Continued application of large quantities of bicarbonate will cause calcium and magnesium to precipitate as carbonates. This would also be a positive in relation to the ongoing application of magnesium, and for a number of years the large store of calcium in the soil store would offset any precipitation of this element. It is not thought that any of the bicarbonates would leach and even if they did their presence could not be detected in the brackish groundwater.

Monitoring

The soil monitoring should be directed towards the consequences of bicarbonate application, rather than directly assaying for bicarbonate:
- Wastewater
- Soil (pH)

Remedial actions

If there is evidence that continued application of large amounts of bicarbonates is reducing the available calcium or magnesium:
- Use fertiliser to apply additional calcium or magnesium;
- Investigate the potential to reduce the bicarbonate concentration within the ethanol plant.

11.6 Sulphate

The sulphur mass balance showed that some of the applied sulphur was removed in fodder. The remaining amount could either bind as the sulphate ion to form acid or a salt, or leach as sulphate to lower layers.

Monitoring

Since the large background presence of sulphates would mask the small amount from wastewater, there would be no point in attempting to monitor the contribution from wastewater. Accordingly the recommended monitoring was limited to the inputs from wastewater:
- Wastewater

Remedial actions

- Apply lime if there is a pH drop associated with sulphate accumulation.

11.7 Chloride

The fodder removed a small proportion of the applied chloride, leaving 317 kg/ha/yr in the soil. Because of the general mobility of chloride ions and salts the surplus chloride would leach. Given that both the groundwater and receiving waters are brackish, the addition of this relatively small amount of chloride was not viewed as damaging and in fact the ongoing leaching of chloride should be encouraged to maintain soil health.

Monitoring

The main environmental issue with chloride relates to soil salinity, and the monitoring was designed to detect any adverse trends.
- Wastewater
- Soil

Remedial actions

- Apply surplus water using one or more irrigations (leaching irrigation) to leach chloride from the soil.

11.8 Nitrogen

The mass balance shows a negative imbalance between the expected nitrogen input and the current removal in fodder. Note also that some nitrogen will be lost through volatilisation. Unless fertiliser is used to apply additional nitrogen, both the fodder yield and nitrogen concentration in the fodder will drop. This is an important issue because the large fodder yield is important for removing quantities of other analytes from the Farm.

<u>Monitoring</u>

Under these circumstances, monitoring should be used to confirm that wastewater adds little nitrogen, and the removal rate should be monitored as an aid for fertiliser use. Items to be monitored are:
- Wastewater
- Fodder (or tissue N if paddock is grazed rather than cut for fodder)

Soil monitoring of nitrogen was not included because the large quantity of background nitrogen will obscure changes in available nitrogen. Tissue analyses give a better understanding of available levels and when there are large amounts that could induce nitrogen leaching.

<u>Remedial actions</u>

In the unlikely event that the tissue sampling shows a luxury concentration of nitrogen (greater than 45 mg/g), the following actions should be taken:
- Ensure that the maximum amount of forage is cut and removed from the paddock as silage or hay. This will maximise the nitrogen removal rate;
- Begin monitoring the groundwater for nitrates to test whether nitrogen is leaching;
- Reduce the irrigation rate where possible.

11.9 Phosphorus

Past applications of phosphorus in wastewater created a large soil store. As a consequence the grasses have luxury uptake and remove a relatively large quantity of phosphorus. This will result in a slow decline in soil phosphorus, and the monitoring is designed to confirm that this is happening.

<u>Monitoring</u>

Monitoring is required to confirm that the soil phosphorus remains bound and is not leaching. The monitoring should document the total phosphorus concentrations in:
- Wastewater
- Soil
- Fodder

The current sampling for phosphorus by depth at the rotating sites should continue. The sampling by depth will reveal whether phosphorus is leaching down the soil profile.

Remedial actions

If tests show that phosphorus is moving down the soil profile, remedial actions are:

- Ensure that the maximum amount of forage is cut and removed from the paddock as silage or hay. This will maximise the phosphorus removal rate;
- Begin monitoring the groundwater for phosphorus to test whether phosphorus is leaching;
- Examine the potential to reduce the phosphorus concentration within the manufacturing plants;
- Reduce the irrigation rate where possible.

11.10 Overview

The mass balances showed that the balance between inputs from wastewater and removal in fodder would be:

- Positive for calcium, magnesium, sodium, bicarbonate, sulphate and chloride.
- Negative for nitrogen, phosphorus and potassium.

Of the six analytes with a positive balance, only sodium and chloride are likely to strongly leach and this was viewed as desirable to limit the development of soil salinity. Nor did their leaching contribute to environmental harm because of the saline nature of the receiving waters. Whilst magnesium is unlikely to leach to any extent and is also present in the receiving waters, there will be a large surplus and monitoring of both the soil and groundwater should be used to detect where it accumulates. Monitoring will be required to assess the effects of ongoing additions of bicarbonate, while the sulphate additions will be masked by the background levels,

The negative mass balances with nitrogen and potassium will have implications for plant nutrition, but not with phosphorus because of the large concentration in the soil.

12. DETAILS OF MONITORING

12.1 Wastewater

It is important that the wastewater be analysed on a regular basis to obtain an accurate record of applications to the Environment Farm. Monthly sampling is recommended but it is understood that more frequent sampling is required to meet licence conditions.

Items to be monitored are:

- Irrigation volumes (as per current)
- Chemical composition – pH, EC, TDS, total N, total P, potassium, calcium, magnesium, sodium, bicarbonate, sulphate, chloride.
- Frequency – monthly.

Note that nitrate analysis was not included above, the reason being that the nitrogen mass balance showed that there was no environmental risk from nitrogen supplies and given the complications of sampling for nitrate it is not worth the effort.

12.2 Soil

The existing soil testing program should be continued because it provides a long-term description of trends in soil chemistry. The existing program includes profile sampling from two paddocks each year, and following a three-year paddock rotation around the irrigation areas. This gives two samples, by depth, each year.

In addition, a supplementary soil monitoring program should be instigated to:

- Monitor analytes that are not covered by the existing program;
- Sample from two fixed positions to provide an uninterrupted time trend of changes in chemical composition;
- Confine this program to surface soil (0-30cm), as issues that require profile sampling are already catered for in the existing soil testing program.
- Frequency – annually.

Since the main objective of the supplementary monitoring is to detect changes in soil composition over time rather than describing the soil composition across the total irrigated area, it is recommended that the annual monitoring be concentrated within two sampling sites. This will provide more consistent estimates of the annual trends than sampling over a wider area.

Two important issues are:

- Restrict each sampling zone to a reasonably small area by defining a fixed area of about 250 m^2 and always take samples from within this area. The fixed-area sampling has the advantage that the sample mean will have less variation that one based on a larger area, leading to better estimates of changes over time in the various measurements.

- Take sufficient samples from within a sampling area to get an accurate estimate of the mean. Each group of samples can be bulked so that they will be analysed by a single chemical test per sampling area The important point is that they be drawn from a number of positions to average out the natural variation within the sampling area.

It is recommended that the sampling use the following routine:

- Use two sampling areas. The areas should be reasonably representative of the irrigated paddocks as a whole and receive an average application of wastewater. Each area should be about 250 m^2 and they must be easily located.

- At each sampling area, take 10 cores of the surface soil. The sampling must cover the full sampling area and avoid unrepresentative spots eg bare soil. Bulk and mix the soil samples and take a single sub-sample for chemical tests.

Thus the soil sampling will produce two samples for chemical tests.

In the absence of control areas that have received no chemical inputs from wastewater and also are matched with the sampling areas, the time trends in the concentrations of the various analytes will provide the main basis for detecting changes due to reuse irrigation.

Items to be monitored are:
- Chemical composition – pH, EC, total P, soluble sodium, chloride, exchangeable cations.
- Soil structural stability.

Samples should be tested for both water-extractable cations and for exchangeable cations, with the difference between the two measures giving the adjusted exchangeable cation concentrations. The adjusted values should be used to calculate the ESP because water soluble sodium has no dispersive properties in soil.

12.3 Plant tissue or silage

The removal rate of the various analytes represents an important component in the mass balances. The removal rate will be estimated from:
- Where herbage is cut and removed for silage, the removal rate equals the quantity removed times the herbage composition;
- Where herbage is grazed, the expected removal in animal tissue. While the herbage composition is not required for this calculation, the composition should still be monitored to assess general fertiliser requirements. More refined estimates would include nitrogen losses through volatilisation and nutrient redistribution in excreta that is deposited on unirrigated areas.

The weight of harvested material can be calculated from the number of bales removed, times the average weight of a bale. Records should be kept of the number of beast grazing days on the grazed areas.

To simplify the testing of plant tissue from harvested areas, samples can be taken from material cut for silage. The samples should consist solely of leaf material, with no stems, or alternatively include stems in chopped material but adjust using a typical leaf to stem ratio.

To provide consistency over time, as with soil testing, samples should be taken from the same position each year. A total of three test samples should be collected.

Since the tissue concentrations can vary over the year, samples should be taken from all silage cuts. The sequence of samples can be retained and bulked to obtain one representative sample (from each sampling position) for chemical analysis each year.

Leaf plucks should be taken from two, pre-set sampling sites within the grazed areas. The sampling should be done in early spring, before active growth commences. A single sampling per year will suffice while no problems are being encountered.

The samples are to be analysed for:
- Total nitrogen, phosphorus, potassium, calcium and magnesium.

12.4 Groundwater

The recommended chemical testing of groundwater is at a low intensity because:
- The deficit irrigation regime ensures there is no percolation after irrigation, and the interval between irrigation and heavy rain provides more time for chemicals to precipitate in the soil, bind to soil particles or be absorbed by roots.
- Some of the applied analytes (N, K and Ca) will have a balanced or negative mass balance and hence are unlikely to leach.
- Other applied analytes (Na, Cl and SO_4) that will leach are naturally present in substantial concentrations in the receiving waters.

Hence the only analyte to be monitored under this protocol is magnesium, and annual sampling will suffice unless elevated magnesium levels develop. Note that groundwater at reference sites is currently sampled as part of the existing monitoring program and this program should continue.

In order to mesh the two sampling regimes, the existing system of using the "CB" testwell to obtain control samples, and soil sampling holes to obtain groundwater at other sites should be continued. The change that the current investigation will introduce is to include tests for magnesium, and to collect groundwater samples from the two new sites that are to be introduced as part of the soil sampling program.

The sampling procedure from testwells is:
- Pump out the testwell no more than 24 hrs prior to sampling and allow sufficient time to recharge.
- Use a bailer to collect a sample from throughout the depth of inflow groundwater.
- Flush the sample bottle with sample and then fill to capacity leaving virtually no air space when capped. Obtain a smaller duplicate sample for retention.

The sampling procedure from groundwater at reference sites is:
- On the first hole, soil sample the first 20 cm. Continue to auger through to the groundwater. Mark hole and continue sampling the other profiles required for bulking at the reference site.
- Collect by pump or bailer the fresh groundwater made in the first hole.
- Flush the sample bottle with sample and then fill to capacity leaving virtually no air space when capped. Obtain a smaller duplicate sample for retention.

13. REPORTING OF MONITORING RESULTS AND BUDGETS

The reporting of monitoring results should:

- Provide tables of basic results in a consistent manner that simplifies comparisons between different reports;
- Raw results, including laboratory methods, should be attached as appendices;
- Facilitate comparisons with the impact assessment criteria, and where necessary be converted to the same units;
- Indicate conclusions drawn and recommended responses.

13.1 Basic results

Data should be provided on the following:

Wastewater

- Total volume used for irrigation during the test period;
- Chemical composition;
- Derived parameter: SAR

Irrigation system

- Area irrigated;
- Volume in storage at beginning and end of the test period;
- Significant alterations to irrigation area and operation.

Soil

- Chemical composition;
- Stability of soil structure;
- Derived parameters: ECE, ESP, CEC

Herbage

- Chemical composition;
- Quantity harvested.

Groundwater

- Chemical composition.

13.2 Comparison with impact assessment criteria

- The actual application rates of wastewater and each ion should be calculated using the same units as the impact assessment criteria in Section 7.

- The actual application rates, $EC_{1:5}$ and ESP should be contrasted with the impact assessment criteria.

- When the criteria are exceeded, details of the appropriate response (Table 4) should be provided.

13.3 Time trends

It is recognised that the monitoring will be applied to an inherently variable system. Some of the variability will be weather induced, some will reflect sampling variation, and some will be unexplained. As a consequence, an important aspect of the sampling program will be to decide which unacceptable test results reflect faults that must be rectified, and which simply reflect variation within the system.

This aspect should be addressed through an analysis of time trends. In this regard:

- The sampling and testing must be done in a consistent manner;
- Time trends of the major parameters should be presented in each monitoring report.

13.4 Water and salt budgets

- A water budget, using local rainfall and evapotranspiration, should be used to estimate the runoff, percolation and leaching fraction during the sampling period.
- The leaching fraction can be used to estimate the leaching losses of the free ions down the soil profile.
- Basic nutrient or salt budgets should be used to estimate the quantity of each ion that is retained in the soil.

14. EFFECTIVENESS OF REUSE SYSTEM OVER TIME

Time trends of the important parameters will provide the best measure of the effectiveness of the reuse system over time. As discussed above, the monitoring has a degree of unavoidable variation and in addition there will be lags before the system will respond to remedial measures. Hence close attention should be paid to time trends in relevant parameters, especially after implementing a remedial action.

The key measures of the effectiveness of the reuse system are soil salinity and soil sodicity. The other measures provide more detail that can identify which salt loads must be reduced if problems develop.

APPENDIX 1 - DERIVATION OF IMPACT ASSESSMENT CRITERIA

The impact criteria were defined as a series of threshold values that equalled either the assimilative capacity of the Environmental Farm or the level at which environmental harm was likely to occur. Separate criteria are given for the hydraulic capacity, for each of the major ions in the wastewater, and for their combined effect based on the TDS concentration.

Hydraulic impact assessment criteria

With irrigation, the hydraulic impact assessment criteria was the maximum volume that could be applied without overwetting the soil after taking the effect of rain into account. There also was a need for sufficient storage capacity to transfer surplus wastewater from wet periods when irrigation was limited, to drier periods. This gave a two-step process:

- The potential hydraulic capacity was the maximum volume of water that could be used for irrigation, assuming an unlimited supply. That is, without regard for the use of storages to transfer water from wet to dry periods.
- The second step, addressed the limiting effect of the storage capacity on the use and storage of water during wet periods, and thus defined the actual hydraulic capacity.

The potential hydraulic capacity (Table 1) was estimated from a daily water balance analysis (Murtagh et al. 2008a) based on local rainfall, and when combined with the available storage capacity of 823ML provided the actual hydraulic capacity (Table 2).

Table 1 The potential hydraulic capacity.

Irrigator	Irrigation efficiency (%)	Irrigation strategy *	Maximum gross volume per hectare (ML/ha/yr)	Area (ha)	Total volume (ML/yr)
Centre pivot	85	20/30	7.4	215	1,591
Traveller	80	25/35	7.5	272	2,040
Total				487	3,631

* The irrigation strategy is the volume of water applied during each watering (mm), over the soil water deficit that initiated a watering.

Table 2 The actual hydraulic capacity.

Irrigation area (ha)	Storage capacity (ML)	Wastewater flow	
		ML/d	ML/yr
487	823	4.8	1,753

Although the potential rate of evapotranspiration by the pasture would allow it to use 3,631 ML/yr, the practicalities of storing wastewater during wet periods and the available storage capacity of 823ML limit the actual hydraulic capacity to 1,753 ML/yr, which represents the hydraulic impact assessment criteria. Note however, that if the hydraulic load exceeded 1,753 ML/yr, the actual hydraulic capacity could be increased by adding to the storage capacity.

Salt impact assessment criteria

Four criteria determined the impact assessment criteria for applied salts:
1. The removal thresholds which were based on the quantity removed in harvested fodder, plus gaseous losses or soil adsorption for selected salts (Table 3);
2. The concentration thresholds which were the concentrations in irrigation water that would damage foliage (Table 4);
3. The soil salinity threshold which assessed the combined effect of all ions on soil salinity;
4. The soil sodicity threshold which was quantified through the soil exchangeable sodium percentage (ESP).

1. Removal thresholds

The removal thresholds indicate how much of each ion will be removed from the Environmental Farm. The harvesting and removal of fodder for silage or hay constitutes the most important removal process, but some bicarbonate, nitrogen and phosphorus is also removed through other processes.

The Environment Farm is used to grow ryegrass or kikuyu pasture that is cut for silage, and the average silage yield over three years of 7.64 t dry matter per hectare per year was used to calculate the rate of removal.

The analyte concentrations in harvested material were taken from one of two groups:
- A high concentration was used when the soil was rich in an analyte, leading to luxury uptake by the pasture.
- Average concentrations were used when the soil had lower concentrations of an analyte.

Since the irrigation system is managed according to the principles of deficit irrigation, all of the irrigation water enters the soil and there is no surplus that could run off. As a result all the applied salts will enter the soil and will not mix with runoff that can occur after rain. Consequently no provision for runoff losses were included in the calculations.

Table 3 Removal thresholds for applied salts .

Ion	Removal (kg/ha/yr)			
	Harvested fodder	Gaseous losses	Adsorbed by soil	Total
Calcium	40 = 7.64 t/ha/yr * 5.3 mg/g	0	0	40
Magnesium	13 = 7.64 t/ha/yr * 1.72 mg/g	0	0	13
Sodium	41 = 7.64 t/ha/yr * 5.42 mg/g	0	0	41
Potassium	316 = 7.64 t/ha/yr * 41.4 mg/g	0	0	316
Bicarbonate	0	0	187 [a] Precipitation	187
Sulphate	52 = 7.64 t/ha/yr * 6.84 mg/g	0	0	52
Chloride	15 = 7.64 t/ha/yr * ~2 mg/g	0	0	15
Total nitrogen	237 = 7.64 t/ha/yr * 31 mg/g	30% of applied N	0	308
Total phosphorus	34 = 7.64 t/ha/yr * 4.46 mg/g	0	114 = 1.5% of PSC [b] of 7590 kg/ha/m	148

[a] Equivalent mass to applied Ca and Mg, that is residual sodium carbonate (RSC)=0.

[b] PSC: Phosphorus sorption capacity

If the quantity applied exceeds the removal threshold then further investigation is required to determine if leaching will account for the excess.

The RSC test is used to assess the bicarbonate concentration:

1. RSC = $(CO_3^{--} + HCO_3^{-}) - (Ca^{++} + Mg^{++})$ in meq/L.
2. If RSC < 0 then bicarbonate concentration acceptable
3. If RSC > 0 then investigate Ca removal from soil solution and possible effect on soil ESP.

2. Concentration thresholds

The two ions that could damage foliage are sodium and chloride, and their concentration thresholds for kikuyu and white clover were derived from the National Guidelines for Water Recycling (NWQMS 2006).

Table 4 Concentration thresholds for sodium and chloride.

Ion	Threshold (mg/L)	
	Kikuyu	White clover
Sodium	460	230
Chloride	700	350

Given the relative importance of kikuyu in the pastures, the kikuyu values were adopted as the concentration thresholds.

3. Soil salinity threshold

The effect of wastewater on soil salinity at the Environmental Farm is complicated by the composition of the wastewater. Since it is not dominated by soluble salts such as sodium chloride, classical models to predict soil salinity from the electrical conductivity (EC) of irrigation water do not apply. For this reason, previous analyses (Murtagh et al. 2008a) derived an empirical relation between the 8 years of annual measurements of soil salinity and the TDS load. The data and a fitted curvilinear relationship is reproduced in Figure 1. Note that whereas the EC of the soil extract was referred to as EC_w in the Murtagh et al. report, it is labelled $EC_{1:5}$ in this report.

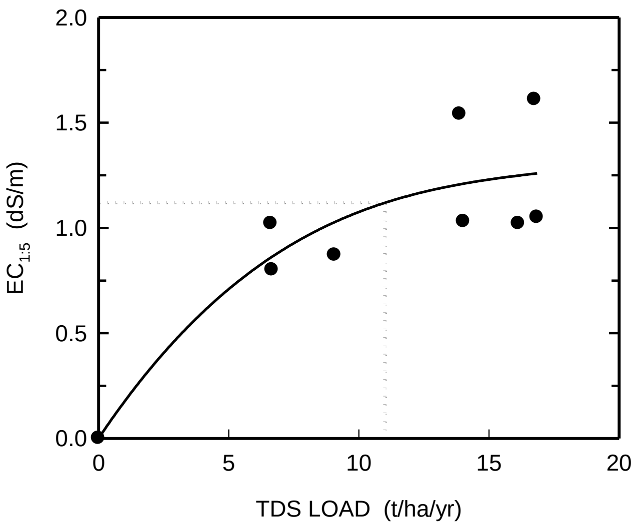

Figure 1 The relation between the annual TDS load in wastewater and the corresponding soil salinity at the Environmental Farm. The dotted line indicates the salinity threshold.

The salinity threshold was set at a soil salinity of 5.6 dS/m, a value below which the growth of ryegrass will not be affected (DEC 2004). This value is the electrical conductivity in a saturated paste (ECE). With a conversion factor of 5 (Murtagh et al. 2008a), the equivalent EC in a 1:5 solution ($EC_{1:5}$) is 1.12 dS/m.

Thus the salinity threshold was an $EC_{1:5}$ value of 1.12 dS/m, and the corresponding TDS load from Figure 1 is 11 t/ha/yr. While the soil salinity threshold was defined by the $EC_{1:5}$ value, the TDS load provides an interim measure that can be used until the soil measurements are available.

The electrical conductivity is determined from samples taken down the soil profile, and the $EC_{1:5}$ value is a weighted mean with a weight of five for the uppermost sample (0-10cm depth) ranging to a weight of one for the 40-50cm sample (Murtagh et al. 2008a).

It is recognised that an ECE of 5.6 dS/m is above the salinity threshold for other species that are grown on the Environmental Farm, including kikuyu and white clover. Their thresholds are 3.0 dS/m (DNR 1997) and 1.45 dS/m (DEC 2004) respectively, and the estimated reduction in their growth at the threshold ECE of 5.6 dS/m is 8% and 49% respectively. Since these effects have been tolerated over the years that the Environmental Farm has operated at similar ECEs, the 5.6 dS/m threshold was adopted for future operations.

4. Sodicity threshold

If the exchangeable sodium percentage (ESP) is less than 6% the soil is non-sodic (NWQMS 2006).

If not, the combined effect of sodicity and salinity must be considered to assess whether soil dispersion is likely to occur (NWQMS 2006).

APPENDIX 2 Irrigation Scheduling

The basic aims of the irrigation management by Shoalhaven Starches are to:

- Apply frequent, small amounts of wastewater during each irrigation so that there is a constant turnover of the wastewater in the irrigation mains to keep the wastewater fresh within the mains;
- To avoid overwatering the soil so there is no surface runoff or deep percolation of the applied wastewater;
- Maintain a productive vegetative cover across appropriate areas of the Environmental Farm.

Irrigation scheduling techniques

1. Deficit irrigation

The irrigation strategy formalises the management of the irrigation system. It is commonly described as *deficit irrigation* and is defined by two parameters:

- The *trigger deficit*, which is the soil water deficit that will initiate irrigation. It is expressed in units of mm of soil water deficit below the maximum available soil water content (field capacity);
- The *irrigation volume,* which equals the amount of water (mm) to be applied as irrigation.

The frequency of irrigation can be increased by commencing irrigation at a smaller trigger deficit.

Different irrigation strategies are followed with wastewater reuse and farm irrigation, and one point of difference is the setting of the irrigation volume.

With other farm irrigation systems, sufficient water is applied to completely remove the water deficit. In other words, the irrigation volume will equal the trigger deficit. Under these circumstances it is inevitable that there will be some uneven watering and the surface runoff from over-watered areas is accepted as a cost of the full watering.

A different recommendation applies with wastewater irrigation. As it is undesirable to have surface runoff of wastewater during irrigation, a reuse system should leave a residual soil water deficit that remains when the irrigation is completed (DEC 2004). This ensures that all the wastewater enters the soil even if there is some unevenness of watering.

A common strategy is to set the irrigation volume at 5-10mm less than the trigger deficit, thus leaving a 5-10mm soil water deficit after irrigating. A system that applies 5mm of irrigation with a 10mm trigger deficit is termed a 5/10 *irrigation strategy.*

2. Chosen strategy

In practice, the principles relating to the irrigation strategy must be merged with local experience to select the best strategy for each paddock. In doing so, the over-riding requirements are that paddocks are never overwatered and irrigation never causes surface runoff. Other factors that influence the choice of the irrigation strategy are the need to maximise the irrigation volume to draw down the wet weather storages, or on the other hand to share limited water supplies over a number of paddocks.

Often, it will be best to apply just 5-10mm per irrigation to (a) keep wastewater circulating through the irrigation mains, and (b) to limit the mass of organic solids that are applied to the soil during each irrigation. However, this is not a universal requirement.

3. Irrigation scheduling software

Scheduling decisions are confirmed by the irrigation scheduling software program (IRRICALC) which prompts when the next irrigation is due.

The program calculates a daily water balance for various blocks using (a) actual rainfall on the reuse areas, and (b) the mean seasonal evapotranspiration for the various crops, with adjustments for the prevailing weather conditions. The water balance is used to track changes in the soil water content and to indicate when the soil has dried to the trigger deficit and hence irrigation is due.

However, it is recognised that the IRRICALC program cannot account for the finer detail of the hydraulic characteristics within individual blocks. Hence irrigation scheduling will continue to use visual inspections to ensure that the aims are being met and to fine tune the irrigation scheduling provided by the IRRICALC program where necessary.

4. Visual inspection

Visual inspections provide an important adjunct to irrigation scheduling. Since the soil moisture status is correlated with soil strength, the common technique for an experienced irrigation owner is to test the drivability of the area. As the travelling irrigators have similar traction to a vehicle, this simple test using a vehicle is relevant. Advantages are that the run is visually inspected; surface conditions are noted so that the irrigator is neither bogged nor tripped by vegetation.

Paddock suitability is co-ordinated with the irrigation cycle of paddocks.

The pivots are irrigated in sequence so that the line supplying the wastewater is kept in constant use and that down time for each supply line is minimised. Now that the project is using 7 pivots, the watering cycle is kept as consistent as possible so that baling and aeration operations are completed in a logical manner.

5. Limitations to the full utilisation of available irrigation area and irrigators

The main limitation to the ongoing utilisation of the available irrigation area and irrigators is the weather, especially rain. As a consequence, the irrigation volume will fluctuate between years with less being applied during wet seasons. Under these circumstances every attempt will be made to utilise the stored wastewater during the dry months that inevitably occur even in a wet year, but if necessary some wastewater will be carried over in the storages for utilisation in the following year. This eventuality was allowed for in the water-balance modelling and estimation of the required storage capacity.

Another limitation is the run-on of water from outside the property and which can accumulate behind floodgates. The longer drying-out period where this occurs delays the recommencement of irrigation.

Centre pivot installation is dependent upon property shape. Centre pivots have been installed in suitable spaces. Travellers are more mobile and can be positioned to fit into areas that are not circular in shape. Thus they are more versatile for small irregular shaped areas.

A 40 metre boundary has been imposed around all waterways, be it an engineered drain or remnant paleo-channels, and irrigation is not applied within these buffer areas.

The capacity of the irrigation pumps limits the rate at which the stored wastewater can be drawn down during dry weather but this must be balanced against the need to maintain a regular cycle of irrigation to ensure that wastewater is kept circulating through the irrigation mains. On balance, the irrigation pumps are rarely run to capacity because of the need to maintain the regular cycle.