Agricultural Water Management

NSW Department of Primary Industries

Shoalhaven Starches Pty Ltd

SHOALHAVEN STARCHES ETHANOL UPGRADE

FITNESS FOR PURPOSE OF TREATED WASTEWATER

AGRONOMIC INVESTIGATIONS

Prepared for Shoalhaven Starches Pty Ltd

and

Cowman Stoddart Pty Ltd

by

Dr John Murtagh, Roy Lawrie and Glenys Lugg

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SHOALHAVEN STARCHES AGRONOMIC INVESTIGATIONS

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S. GENERAL SUMMARY

The proposed upgrade of the ethanol plant at the Shoalhaven Starches facility at Bomaderry will alter the quality and quantity of wastewater that is used for irrigation on the Environmental Farm. This report examines the potential effect of the changes on the sustainability of the Farm productivity and the risks to the wider environment.

The wastewater that will be used for irrigation will come from the sulphur oxidation basin (2.1 ML/d) and possibly include the retentate from the reverse osmosis plant (up to 1.5 ML/d). The report examines three scenarios where no retentate (total flow of 2.1 ML/d), 50% of the available retentate (total 2.85 ML/d), or all the retentate (total 3.6 ML/d) is used for irrigation.

The expected total dissolved solids (TDS) concentrations in the irrigation water will range from 1.3 g/L (no retentate) to 2.6 g/L (100% retentate). These compare with TDS concentrations of 4.8 g/L before the dryers were installed in 2004 to improve the quality of the wastewater, and 2.1 g/L with the current system. Hence the expected TDS concentrations will straddle the current concentration. There will also be a substantial change in the composition of the irrigation water. The calcium concentration will be much reduced and the bicarbonate and magnesium concentrations will be increased.

The proposed on-site treatment and reuse of some wastewater within the plant will also give a substantial reduction in the volume of wastewater to be used for irrigation, resulting in a corresponding reduction in the TDS load on the Farm to 2.1 – 7.0 t/ha/yr. Based on the past changes in soil salinity with different TDS loads, the anticipated loads will give the following ranges in soil salinity, where the soil salinity in the root zone is expressed in terms of the electrical conductivity of saturated-paste equivalents. The range within each scenario represents the uncertainty attached to the appropriate conversion factor.

- Current 3.2 – 4.8 dS/m;
- Scenario 1, no retentate: 2.9 - 4.3 dS/m;
- Scenario 2, 50% retentate: 3.2 - 4.9 dS/m;
- Scenario 3, 100% retentate: 3.6 – 5.5 dS/m.

These expected levels of soil salinity are expected to have little or no effect on the productivity of grass species, but will reduced the growth of white clover by 25-50%. The expected soil salinities are not much different to the current values and the likely effects agree with current observations of pasture productivity on the Environmental Farm.

The altered composition of the irrigation water will also impact on the nutrient load on the pastures. Nitrogen and potassium will be supplied at sub-optimal levels for plant growth and should be supplemented with fertiliser applications. The wastewater will also supply insufficient phosphorus, calcium and sulphur but these needs can be met from existing soil stores.

A large surplus of magnesium will be supplied to the Farm but the existing levels of calcium will balance these inputs for many years. Given the high magnesium input, It will also be important to apply sufficient potassium fertiliser to balance the cation composition on the soil exchange complex. There is also a possibility that the amount of magnesium in wastewater will be less than the current working value because a smaller amount will be added once the treatment system stabilises. Alternatively, another neutralising agent could be used within the treatment process. These options provide potential remedial actions should the high magnesium inputs start to create problems on the Farm.

From the hydraulic load point of view, a water balance analysis with the reduced flows showed that the existing storages provided more than the required capacity to prevent overtopping and the discharge of wastewater. With all the retentate being used for irrigation, a storage capacity of 636ML was required to prevent overtopping, while 823ML is available.

The irrigation management follows three general principles:

- 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 the irrigated areas of the Environmental Farm.

These principles involve using soil moisture deficits to schedule irrigation. The IRRICALC scheduling program is used to define the broad irrigation needs, and local knowledge and the characteristics of individual paddocks are then used to refine the irrigation scheduling.

S1. General conclusions

The various analyses indicated that all the retentate from the reverse osmosis plant could be used for farm irrigation, and the report outlines potential practical remedial measures that could be used to address increases in soil salinity should they occur. The recommendation regarding the use of retentate is made with the proviso that the soil-salinity study was forced to use empirical analyses based on past experience using wastewater of a different composition to that used to date. If field experience in the future shows an unacceptable increase in soil salinity or an adverse effect on pasture productivity the quantity and or the quality of retentate that is directed towards irrigation may have to be modified.

In this regard, it will be important to conduct careful monitoring of the soil to provide an advance warning of adverse changes in the soil and pasture productivity. Issues that will be important are the soil salinity and the ionic composition of the soil solution, especially the calcium and magnesium concentrations. Better information on the detailed composition of the wastewater that is used for irrigation and annual sampling of a few selected paddocks will also improve the predictive capabilities.

1. INTRODUCTION

In considering the preliminary proposal for the Shoalhaven Starches Ethanol Upgrade, the Department of Environment and Climate Change (DECC) identified the information that was required to complete the assessment of the project. The critical information requirements were included in Attachment A of their report, and included the following items under the ‘Sustainability of Shoalhaven Starches’ effluent irrigation and storage” heading:

- A full water balance that demonstrates a capacity of the project to avoid water pollution;
- A full irrigation management plan for the Environmental Farm, demonstrating the agronomic capacity of the land, soil, crop and climate combination to sustainably assimilate the effluent.
- Use the water balance to demonstrate that there is sufficient storage to prevent pollution of waters when prolonged wet weather prevents irrigation.

The following report addresses these issues. The report was prepared by:

- Dr John Murtagh of Agricultural Water Management;
- Roy Lawrie of NSW Department of Primary Industries;
- Glenys Lugg of Shoalhaven Starches Pty Ltd.

2. LOCAL ENVIRONMENT

The monthly rainfall and evapotranspiration at Nowra are summarised in Table 1, and were based on records from the Bureau of Meteorology. The rainfall records covered 68 years from 1940-2007 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)	90	122	106	96	95	116	55	67	62	90	84	75	1057
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	603mm	977mm	1634mm	2248mm

Points of note are:

- The area receives a moderate rainfall that averages 1057 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 allows 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.

3. WASTEWATER

Three general classes of wastewater have been/will be used for irrigation on the environmental farm:

- Wastewater from the starch production process before June 2004. This flow was heavily limed as part of the odour-control process. The wastewater during this period is termed the pre-dryer wastewater.
- From June 2004, some of the wastewater flow was processed through a DDG dryer to remove solids. It dramatically reduced the COD concentration and less lime was added to the wastewater. This gave the post-dryer wastewater.
- The on-site treatment and reuse of some of the wastewater flow, as part of the ethanol production upgrade, will cause another marked change in composition of the wastewater. In addition, the composition of the irrigation water will depend on the blending of the waste flow from the sulphur oxidation (SO) pond and a proportion of retentate from the RO plant.

With the implementation of the ethanol upgrade, wastewater flows that will be used for irrigation will come from two sources:

- Some of the discharges from the sulphur oxidation (SO) basin, amounting to an average of 2.1 ML/d. A second discharge stream from the SO basin will direct discharges to a proposed wastewater treatment plant.
- The wastewater treatment plant will produce a clean water flow and a retentate flow that will contain most the water contaminants from the inflow. The retentate flow will average 1.5 ML/d and may be used for irrigation.

The present study considered three options where none, half or all of the retentate was used for irrigation. Thus the total flow to the farm equalled 2.1, 2.85 or 3.6 ML/d.

3.1 Chemical Composition of wastewater

Details of the chemical composition are given in Tables 2 and 3. The composition during the pre-dryer and post-dryer stages was provided in an email from Shoalhaven Starches dated 8 February 2008, except that the calcium concentration was increased to allow for the calcium hydroxide that was added as a neutralising agent to the acidified wastewater.

The pre-dryer wastewater had a very high nitrogen concentration, much of which was in organic forms. Hence the nitrate concentration was less than might be expected on first glance.

The suggested composition after the upgrade was taken from an email from Shoalhaven Starches dated 20 February 2008. It is emphasised that the post-upgrade composition is a tentative estimate. It was based on experiences in other plants and may not translate directly to the proposed upgraded plant.

Two measures were used to quantify the total concentration of soluble components in the wastewater:

TDS: Total dissolved solids; the combined content of all soluble (pass through a 2 µm sieve) inorganic and organic substances. In the following, the TDS was estimated by summing the concentrations of the various ions. This approach will introduce a slight underestimate of the total concentration when minor components are not included.

EC: Electrical conductivity; a measure of the conductivity of a solution that is related to the TDS. Note that the relation between the two depends on the ionic composition. The

EC is often used because of the ease of measurement, and as discussed later it provides the standard expression of soil salinity when considering the effect on plant growth.

Table 2 Some chemical constituents in wastewater from different processes.

Analyte	Unit	Composition of wastewater from:			
		Pre-dryer	Post-dryer	Post-upgrade SO basin	Post-upgrade retentate
pH	pH units	~9	9.1		
TDS	mg/L	4,802	2,090	1,323	4,399
Ca^{++}	mg/L	2,469	1,042	8	24
Mg^{++}	mg/L	97	17	122	470
Na^{+}	mg/L	460	167	85	285
K^{+}	mg/L			12	39
CO_3^{---}	mg/L				
HCO_3^{--}	mg/L			850	2,991
SO_4^{--}	mg/L		384	23	91
Cl^{-}	mg/L	800	230	105	392
NO_3^{-}	mg/L	970	173	60	48
PO_4^{+++}	mg/L	6	77	60	59
Total N	mg/L	35,000	39		41
Total P	mg/L	200	25		112

Much of the magnesium in the post-upgrade wastewater will be introduced when magnesium hydroxide is added to the buffer tank as a pH stabilising agent. Based on experience elsewhere, some uncertainty surrounds the continuing need for the treatment to continue at the suggested level and lower amounts may suffice once the system has stabilised. Also, other alkaline agents (eg soda ash) could be used at this step. The point to be made here is that there is scope to reduce the magnesium inputs should the magnesium concentration in the soil prove to be a problem over time (see later discussion).

The current investigation considered three options, where nil, 50% or 100% of the retentate flow was mixed with the waste flow from the SO pond to provide the irrigation water. The resulting net composition of the irrigation water is given in Table 3.

Table 3 The net chemical composition of the post-upgrade irrigation water, with three proportions of retentate in wastewater blend.

Item	Unit	Proportion of retentate in wastewater blend		
		Nil retentate	50% retentate	100% retentate
		Composition of wastewater blend		
Total flow	ML/d	2.1	2.85	3.6
TDS	mg/L	1,325	2,134	2,606
TDS load *	t/ha/yr	2.1	4.6	7.0
Ca^{++}	mg/L	8	12	15
Mg^{++}	mg/L	122	214	267
Na^{+}	mg/L	85	138	168
K^{+}	mg/L	12	19	23
HCO_3^{--}	mg/L	850	1413	1742
SO_4^{--}	mg/L	23	41	51
Cl^{-}	mg/L	105	181	225
NO_3^{-}	mg/L	60	57	55
PO_4^{+++}	mg/L	60	60	60

* The TDS load was calculated for a total irrigation area of 487ha.

Points of note are:

- The high TDS concentration that increased from 1,325 mg/L with no retentate in irrigation water to 2,606 mg/L with all the retentate in irrigation water;
- The substantial reduction in the calcium concentration relative to the current and past wastewater;
- The increase in the magnesium concentration from 18 mg/L in the post-dryer (current) phase to 85-168 mg/L depending on the wastewater blend;
- The large amount of bicarbonate in the future wastewater;
- The marked reduction in sulphate.

The consequences of using irrigation water with these compositions on the sustainability of the soil and plant growth are discussed in the next section.

4. SOIL SALINITY

The main issue with soil salinity is the addition of solutes to the soil solution that can harm plants through their osmotic effect on water and nutrient uptake. In this context, the identification of the various solutes is important because of their varying ionic strengths and behaviour in the soil solution.

4.1 Past and present soil salinity

The soils on the environmental farm were monitored over many years and the results include measurements of soil salinity down the soil profile. The 1995-2006 results are tabulated in the annual “Environmental Monitoring Reports” prepared by Roy Lawrie and others of the NSW Department of Primary Industries. The 2007 results were obtained directly from Roy Lawrie.

The profile measurements were given as the EC in a 1:5 soil:water mixture and were transformed as follows for purposes of the current investigation:

- The various EC measurements from various depths within the upper 50cm of the soil profile were used to obtain a root-density weighted mean EC (EC_w). In doing so, the 5 measured values over the 50cm range were weighted with a weight of five in the uppermost sample (10cm) ranging to a weight of one at 50cm, which was the lowermost sample that was used. This was done to obtain the effective EC over the major rooting zone, with the greatest weight applying to depths where roots were most dense.

- This gave the EC_w values in Table 4. Since different paddocks were sampled in each year and some had consistently lower EC concentrations than others, paddock-weighted EC_w’s were calculated for each paddock (Table 5 and Figure 1). The weight was the overall mean EC_w divided by the mean for that paddock. It was done to counteract the effect of paddock differences on annual means given the intermittent sampling.

Note that the paddock weighting was done to obtain better estimates of annual means, and only the annual means should be used for direct interpretation.

Table 4 The root-density weighted EC concentrations (EC_w) 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_w (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
Paddock mean	0.42	0.86	1.18	0.75	1.48	1.33	1.00

Table 5 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_w (dS/m)			
1995		1.05		0.85	0.46		0.79
1996			1.01				1.01
1997							
1998			1.01				1.01
1999	0.34	0.82		0.87	0.97	0.82	0.76
2000				1.17	0.90		1.03
2001	1.33					0.72	1.02
2002		1.09	1.00				1.05
2003				1.57	1.51		1.54
2004	1.68					1.54	1.61
2005		1.05	0.99				1.02
2006				0.56	1.17		0.87
2007	0.67					0.93	0.80

* The paddock weight was the overall mean EC_w (1.00 dS/m) divided by the mean EC_w for each paddock given in Table 1.

Paddock 21 had the lowest EC_w while paddocks 130 and 140 had the highest. Many factors could contribute to these differences including differences in soil hydraulic properties, elevation, watertable influence and irrigation volumes. Given that the main emphasis of the current investigation was to examine the annual change in EC with the changing quality of the wastewater to estimate future trends, it was beyond the scope of the investigation to delve into these issues. Also a commentary on the soil EC measurements is provided in the annual monitoring reports.

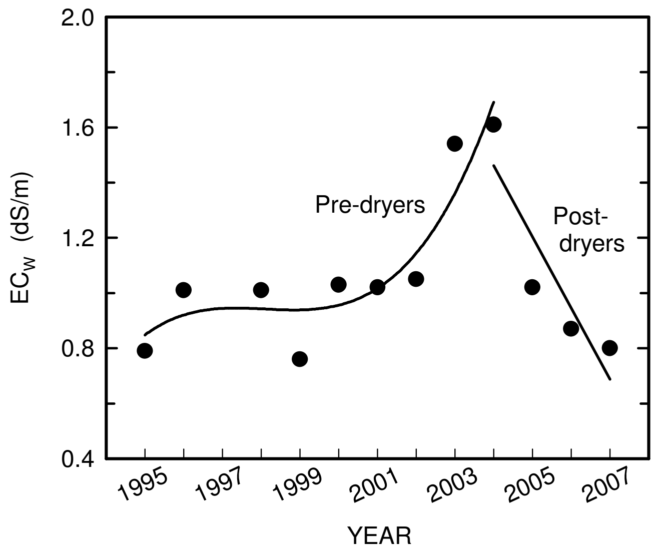

Figure 1 The time trend in the root-density weighted EC concentrations

The results show:

- High EC_w values throughout the period.
- Markedly higher values in 2003-2004.
- An increase in the EC_w from 1995 to 2003-2004 (pre-dryer phase), and a decline to half the peak value three years later in 2007 (post-dryer phase).
- Some annual variation, with lower values in 1995 and 1999.

Before the introduction of the DDG dryers, there was a slow increase in the EC_w until 2002, followed by a large increase during the next two years. It was not clear why the sudden increase occurred. The dryers were introduced in November 2003 but their impact on the quality of the irrigation water was delayed until much of the stored and heavily-limed wastewater was used. Hence the 2004 results were placed in the pre-dryer phase. Thereafter the EC_w declined and was attributed to the considerable decline in the wastewater TDS (Table 2).

One explanation for the high EC_w in 2003-2004 is that the heavily limed wastewater simply maintained the relatively high EC_w until 2002 and that some separate effect caused the subsequent added increase. One suggestion is that the separate effect came from the addition of settled solids from the bottom of dams to the irrigation water during these years. However the possible effect could not be verified by the chemical testing and hence was not allowed for in the estimation of the TDS loads.

The various Environmental Monitoring Reports showed inconsistent patterns in the change in soil salinity with depth, and suggested that the different patterns may be related to soil type and elevation. One consistent result was that whenever the soil EC in the uppermost sample (10cm) exceeded 2 dS/m the soil salinity always declined with depth. This was taken to indicate that the highest soil EC's were caused by recent salt applications.

4.1.1 Factors affecting soil salinity

This section describes attempts to relate the measured EC_w values to various driving factors (independent variables) in order to understand why the soil salinity varied between years and in doing so obtain a relation that could be used to predict future salinity after the upgrade.

Various driving factors were investigated and some of the relationships that were tested are graphed in Figure 2.

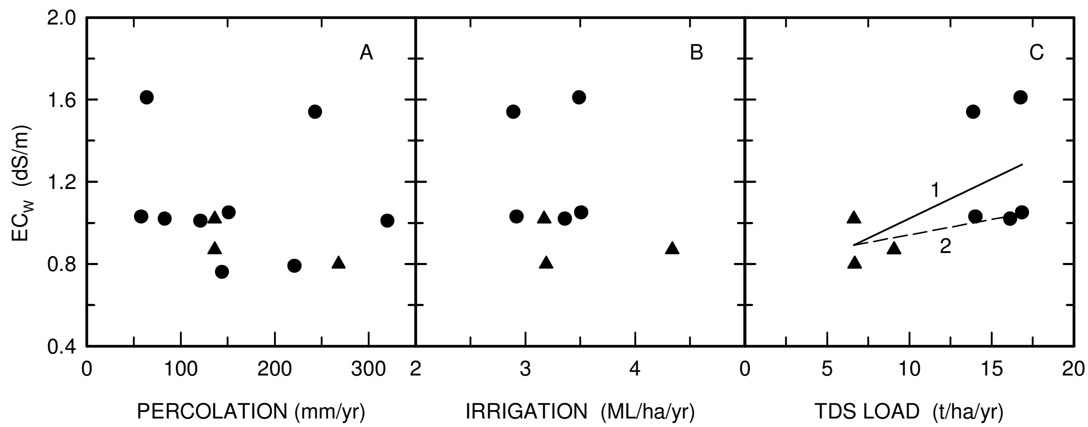

Figure 2   The relation between the mean annual EC_w between 1995 and 2007 and the corresponding annual percolation (A), irrigation volume (B), and TDS load (C). The circles and triangles indicate years when pre-dryer and post-dryer wastewater was used respectively.

None of the relations properly explained the high EC_w in 2003 and 2004, and as discussed below arguments can be developed to either include or exclude these values when developing a predictor relation.

The lack of a relation with percolation (Figure 2A) places the soil salinity in a different class to the common situation where the salinity is dominated by the soluble and mobile sodium and chloride ions. Under such conditions, and in contrast to the experience on the Environmental Farm, the leaching of these ions causes a decline EC_w when there is high rainfall and a high rate of percolation. The message that was drawn from the result was that the usual approach to examining soil salinity does not apply in this case.

Similarly the irrigation volume alone did not explain the variation in soil salinity, but the combination of irrigation volume and TDS concentration (the TDS load) was more successful. Especially note that the two high values were placed at the high end of the range in TDS load in Figure 2C. Regression analysis was used to fit the two lines shown in Figure 2C using the EC_w as the dependent variable and the TDS load as the independent variables. The two high values were included when estimating line 1, but were excluded for line 2.

Two explanations can be advanced for the significance of the two high EC_w values in the relation between the TDS load and EC_w (Figure 2C):

- The high values during 2003-04 were part of the general pattern of changes in EC_w during the per-dryer phase, and hence line 1 in Figure 2C best illustrates the trend for TDS load effects on EC_w.
- The high values are outliers that represent a separate but unexplained effect. If so, line 2 best illustrates the TDS load effect.

Both explanations accept that the TDS loads during the pre-dryer and post-dryer phases acted similarly on EC_w even though their composition varied somewhat (Table 2). The main compositional difference was the higher calcium concentration in the pre-dryer wastewater. However, given the dominance of calcium ions in the soil by the time post-dryer wastewater was used for irrigation, calcium related reactions in the soil and their effect on the EC_w would apply equally to both phases. Hence, a common relation between the TDS load and EC_w in both phases was accepted.

Given the lack of an explanation for the high EC_w values in 2003-2004, line 1 which included them, was used as the basis for estimating future trends in EC_w depending on the TDS load. Note that the relation can only be used as a predictor in situations with generally high EC_w values.

4.2 Future changes in soil salinity

The relation between TDS load and EC_w that was derived above (line 1, Figure 2C) was used to estimate the possible changes when post-upgrade wastewater was used for irrigation. It is recognised that the following is a somewhat empirical analysis but past experience on the environmental farm has shown that pasture production will continue under TDS loads that would be unacceptable under other circumstances. The key to explaining the environmental farm experience almost certainly lies with the chemical composition of the wastewater and soil solution but the processes that could occur in the soil are only partly understood. Hence the analysis built on field experience over past years.

The expected TDS concentration in the post-upgrade wastewater will be 1,325 – 2,606 mg/L, depending on the proportion of retentate in irrigation water (Table 3). With the expected irrigation volume, this will result in a TDS load of:

- 2.1 t/ha/yr with no retentate in irrigation water;
- 4.6 t/ha/yr with 50% retentate;
- 7.0 t/ha/yr with 100% retentate.

Fitting these loads to line 1 in Figure 2C gave expected EC_w of:

- 0.72 dS/m with no retentate;
- 0.81 dS/m with 50% retentate;
- 0.91 dS/m with 100% retentate.

If the slope of line 1 in Figure 2C was projected downwards, it passed above, rather than through the origin. This indicates that the effect of the annual load of soluble salts on EC_w was somewhat counterbalanced by reactions within the soil that removed salts from the soil solution when the EC_w was at a high level. In this regard, the precipitation of calcium compounds would be important, but there would also be some absorption by plants, net adsorption to soil, and leaching. As a result, the potential effect of the high TDS load was markedly ameliorated. Furthermore, since the post-upgrade TDS loads will be in the same general range or less, they should not cause a deterioration in pasture productivity on the environmental farm, at least in the short term while the chemical composition of the soil solution is similar.

Relevant issues in this regard are:

- If no retentate was included in the irrigation water, the TDS load of 2.1 t/ha/yr would be much less than past experience and could produce a decline in soil salinity;
- Even with 100% retentate in the irrigation water the TDS load of 7 t/ha/yr will be less than half the load during the pre-dryer phase;
- The calcium concentrations will be important;
- The post-upgrade irrigation water will contain a high proportion of bicarbonate ions. Given the existing high calcium concentration in the soil, some of the bicarbonate will precipitate out of the soil solution. Also, the conductivity factor of bicarbonate ions is only 19-39% of the factors for the more common cations in soil. Both effects will tend to reduce the EC_w;

The expected effects of other ions including magnesium on plant nutrition and growth are discussed elsewhere.

The above projections rely heavily on the presence of surplus calcium ions in the soil solution to promote precipitation. In this regard, it will be very important that the soil salinity and calcium concentrations be monitored on an ongoing basis to both test the above projections and to indicate longer term trends in soil salinity.

4.3 Soil salinity and plant growth

In order to estimate the effect of EC_w on plant growth it is necessary to convert this value, which applies to a 1:5 soil:water mix, to the equivalent in a more concentrated solution (soil paste) that plants would experience in soil. The EC in a soil paste is abbreviated as ECE. If the soil solution was dominated by the soluble sodium and chloride ions, a conversion factor of 10 (with a sandy clay loam soil) would be used but a smaller factor applies with the expected composition where precipitation will be enhanced at higher concentrations.

In the absence of information on the composition of the soil solution, conversion factors of 4 and 6 were used in the following discussion. These roughly apply to soil solutions where the concentration of all salts in proportion to just the chloride salts, as quantified by the ratio of $EC_{1:5}$ to the EC due to chlorides, is between 100 to one and 10 to one respectively. The corresponding expected ECEs with conversion factors of 4 and 6 are:

- 3.2 – 4.8 dS/m current (2007);
- 2.9 – 4.3 dS/m with post-upgrade irrigation using no retentate;
- 3.2 – 4.9 dS/m with post-upgrade irrigation using 50% retentate;
- 3.6 – 5.5 dS/m with post-upgrade irrigation using 100% retentate.

A general point is that the expected ECEs, post-upgrade, will be slightly less than current values when no retentate is used for irrigation, and slightly greater when all the retentate is used.

The EPA Guidelines (2004) indicate that the productivity of ryegrass will not be affected by an ECE up to 5.6 dS/m, and that it will decline by 10% at 6.9 dS/m. White clover, which is less tolerant, will suffer about a 25-48% reduction in productivity with 100% retentate, depending on which conversion factor is appropriate. Other publications indicate that kikuyu will suffer just a 2-8% reduction in productivity.

Two points can be made about these conclusions:
- The projected effects fit field experience where grass pastures have remained productive, but white clover has a limited presence;
- The current and projected ECEs are approaching the upper limit for good productivity by pasture grasses.

Recent monitoring reports (Environmental Farm: 2005 and 2006 Environmental Monitoring Reports by R Lawrie and S Eldridge) have noted that that soil aggregate stability is satisfactory. There is a low risk that this situation will change with the post-upgrade wastewater, but ongoing monitoring will be essential especially if 100% retentate is used for irrigation, given the sodium and chloride concentrations in the retentate.

The expected ECEs were based on the projected TDS concentrations, which are in the high range, and an irrigation volume which averaged out at a relatively low 1.6-2.7 ML/ha/yr depending of the proportion of retentate that is used for irrigation. Should either of these increase substantially, the pasture productivity could suffer from the consequent increase in ECE.

4.4 Recommendation

Based on just the salinity study at this stage , wastewater with 100% retentate could be used for irrigation on the environmental farm. This recommendation is made with the proviso that the study was forced to use empirical analyses based on past experience using wastewater of a different composition. If field experience shows an unacceptable increase in soil salinity or an adverse effect on pasture productivity the quantity of retentate may have to be modified.

Adverse changes will occur gradually and careful monitoring of the soil will provide an advance warning. Issues that will be important are the soil salinity and the ionic composition of the soil solution, especially calcium concentration. Better information on the detailed composition of the wastewater that is used for irrigation, and annual soil and pasture sampling of a few selected paddocks will also improve the predictive capabilities.

Other sections of the report consider other issues related to the irrigation with wastewater, and again those findings do not rule out the use of 100% of the retentate for irrigation.

5. PLANT NUTRITION

This chapter examines the nutrient levels on the Environmental Farm, considering both the past use of wastewater and the future use where the wastewater will contain varying proportions of retentate.

5.1 Wastewater characteristics

Table 6 Wastewater characteristics based on two sources of information (labelled 1 & 2 within the Table).

Option	N	P	K	S	Ca	Mg
1a	57	26	?	31.2*32/96	19.5	30.4
2a	44	20	11	23*32/96	5	3 (+121.3)
1b	209	96	?	38.2	71.6	111.6
2b	262	119	65.4	45.4	29.7	17.8 (+722)
3b	116	53	29	20	13	7.9 (+722)

(a) mg/l
(b) kg/ha per year and assumes irrigation area is 497 ha.

The various elemental loads in wastewater (Table 6) were calculated with three alternative wastewater flow rates:
1 = "combined flow" of 5ML/day taken from fax from Shoalhaven Starches dated 11/2/08
2 = "total effluent" flow of 8.1 ML/day
3 = total effluent for irrigation of 3.6 ML/day

Comments on Table

There is reasonable agreement between the option 1 and option 2 estimates for N, P, S (and K?). However the Ca and Mg loads are less with option 2 relative to option 1, but this will have little effect because

- the soil is loaded with calcium, and
- the magnesium input is going to be much bigger.

Both options 1 and 2 gave higher loads than option 3.

The option 2 values were used for the following calculations, which included three scenarios.

Scenario 1
The farm gets all of the retentate: (this calculation is based on **2b** in the table).

Scenario 2
The farm gets half of the retentate: this will be calculated by subtracting 50% of the retentate nutrients from **2b** in the table.

Scenario 3

The farm gets none of the retentate: this will be calculated by subtracting all of the retentate nutrients from the **2b** figures.

5.1.1 Retentate Calculations – Volume and Loading Rates

1.5 ML/day over 497 ha = 1.1 ML/ha yearly

Table 7 Nutrients in the wastewater

		N	P	K	S	Ca	Mg
1	mg/L	180*14/62	352*31/95	36	138*32/96	20	470
2	kg/ha/year	44.7	126	39.6	50.6	22	517
3	kg/ha/year	22.4	63	19.8	25.3	11	259

1 = from flow sheet 7/2/08
2 = annual loading (per ha)
3 = 50% of annual loading (per ha)

5.2 Nutrient uptake by Irrigated Ryegrass

Using the recent tissue analysis from Pivot 2 (Bay 5) (NSW DPI Report No. R07-00615-F-V3), (note this is real data; not something from a textbook) and yield of pasture harvested (ie 60-68 bales/ha, 500kg per bale, 50% moisture), then in one year the pasture will take up the following amounts (kg/ha)

Table 8 Nutrient uptake by pasture (kg/ha/yr).

N	P	K	S	Ca	Mg
497	71.4	662	36.5	84.8	25.7

Compare this with the 3 scenarios in Table 9 that provides the projected annual nutrient balances.

Table 9 Nutrient inputs (kg/ha/yr) for scenarios 1, 2 and 3.

Scenario	N	P	K	S	Ca	Mg
1	262	119	65.4	45.6	29.7	740
2	262-22.4 =239.6	119-63 =56	65.4-19.8 =45.6	45.6-25.3 =20.3	29.7-11 =18.7	740-259 =481
3	262-44.7 =217.3	119-126 =0	65.4-39.6 =25.8	45.6-50.6 =0	29.7-22 =7.7	740-517 =223

Scenario 1 (All retentate goes to the Farm)

N deficit; 497 – 262 = 235 kg/ha N fertiliser needed
P surplus; small, around 47 kg/ha – retention by soil
K large deficit; about 600 kg/ha of K fertiliser needed after 1-2 years
S small surplus; 10 kg/ha either retained as CaSO4 or lost to groundwater
Ca small deficit; huge store already in soil
Mg big surplus; over 700 kg/ha will be retained by soil profile as exchangeable Mg, displacing other cations from topsoil, then other lower horizons. Plant nutrition could be disturbed after say 5 years.

Scenario 2 (Half the retentate goes to the Farm)

N deficit; 260 kg/ha N fertiliser needed
P deficit; 15 kg/ha but huge store already in soil
K big deficit; 615 kg/ha K fertiliser needed
S small deficit; 10 kg/ha can be obtained from soil
Ca deficit; 65 kg/ha can be obtained from soil for many years
Mg big surplus; 455 kg/ha and while soil degradation likely it could take 10 years

Scenario 3 (No retentate goes to the Farm)

N deficit; 280kg/ha N fertiliser needed
P deficit; 70 kg/ha but huge store already in soil
K big deficit; 61 kg/ha K fertiliser needed
S deficit; 10 kg/ha which can probably come from soil store
Ca deficit; 77 kg/ha which can come from soil for many years
Mg big surplus; about 200 kg/ha but due to high Ca and K levels will not lead to soil degradation or nutrient imbalances if K fertiliser is added for at least 20 years.

5.2.1 Soil Nutrient Levels Ca, Mg and K

Previous irrigation practices have greatly increased the soil nutrient levels since irrigation commenced. Annual monitoring of surface soils and testing down the profile every three years has provided the following data.

Table 10 Exchangeable Cations [cmol(+)/kg] - mostly plant available

	Ca	Mg	K	
1	21 to 60	3 to 6	1.2 to 3	cmol(+)/kg
2	40	4	2	cmol(+)/kg
3	12800	640	1040	kg/ha
4	-55	+716	-597	kg/ha

1 Range of exchangeable cation concentrations in surface soils (0-10 cm depth)
2 Typical figure in many paddocks
3 Estimated available nutrient content, kg/ha, 0-10 cm.
4 Annual deficit or surplus as projected for Scenario 1

Under **Scenario 1** (all retentate going to irrigation), soil potassium levels will be depleted in less than 2 years, unless potassium fertiliser is applied.

Rising magnesium levels will depress potassium uptake by the irrigated pastures unless potassium fertiliser is applied, probably after 1 year.

After 3 years the exchangeable calcium/magnesium ratio, currently favourable for plant growth will start to fall below 2:1, potentially reducing growth. After 8 years the topsoil will become dominated by exchangeable magnesium, increasing the risk of soil structural degradation unless calcium is added (as lime or gypsum, or as calcium nitrate fertiliser).

These changes will be delayed if the paddocks are cultivated, incorporating the surface soil into the subsurface layers (to 20 or 30 cm).

5.2.2 Soil Nutrient Levels – N, P and S

Nitrogen

The availability of these nutrients is largely controlled by the action of soil micro-organisms on the store of organic matter. The total amount of these nutrients is very large, due to the surplus built up under previous irrigation practices. Under Scenario 1, there will be a decrease of nitrogen levels, which will probably require supplementation with nitrogen fertilisers especially in spring when pastures are growing rapidly.
It is not possible to estimate accurately how much is needed, but the soil and plant tissue testing can guide applications in future years.

Phosphorus

Soil phosphorus levels, both total and available, are high in the topsoil but decrease in the subsurface layers. There will be a small annual surplus (47 kg/ha) under Scenario 1.

Soil phosphorus sorption levels are falling in the surface soils, due to the very high additions of P in previous years, but remain elevated in the subsoils. These deeper layers are highly acidic and contain elevated concentrations of exchangeable aluminium which boosts retention of phosphorus, reducing plant uptake and leaching. Monitoring of soil profiles for phosphorus sorption will indicate if downward P movement will indicate is excessive. (ie beyond the rootzone).

Levels of available (ie mobile) phosphorus remain very low in irrigated subsoils after many years of receiving heavy phosphorus applications, mostly because of high P retention in the surface. Annual testing of surface soils shows that the P sorption of the 100mm to 200 mm depth remains higher than the 0-100mm depth (in 30 paddocks over the last 3 years). The difference mainly arises because sorption is reduced by these P levels.

Sulphur

There will be small sulphur surplus under Scenario 1. Sulphur is likely to be retained in the soil as gypsum (calcium sulphate) due to the very high calcium levels. The content of sulphate (and total sulphur) was high in most soils prior to irrigation.

Detailed testing in 1996 of 36 profiles prior to the development of the centre pivot irrigation system, showed total S levels were high; in the topsoils due to elevated organic matter contents, and in the subsoils due to the presence of acid sulphate soil layers. Levels of 0.1 or 0.2% total S are common. This is equivalent to 4000kg/ha in the top 30 cm or over 13000kg/ha in the top metre of the profile (@ 0.1% S).

Many decades of irrigation are needed if these high background levels are to increase significantly, or to have any influence on groundwater sulphate levels.

Note that there is considerable variation in nutrient levels across the farm, due to the differences in the history of previous irrigation. Paddocks with the longest history of use will be more able to withstand the changed wastewater characteristics than those that received less wastewater in the past.

5.3 Recommendations for Management Plan

Scenario 1

- Monitor soil properties in irrigated paddocks in top 30 cm of profile (to guide management, especially use of fertilisers and irrigation regime).
- Apply nitrogen fertiliser after each cut of forage; about 100 kg N/ha at least twice in the first year, more in later years
- Apply potassium fertiliser after each cut (preferably as potassium nitrate, depending on cost, potassium chloride is second preference) at least 250 kg K /ha in first year, rising to 500kg K/ha after 3 years; soil monitoring data to be used as a guide here.
- Investigate use of lower rates of magnesium hydroxide in the wastewater treatment process
- Consider applying a leaching irrigation, if rainfall is low, to move excess magnesium out of the topsoil to the lower horizons.

Scenario 2 and Scenario 3

- Monitor soil properties annually in irrigated paddocks in top 30 cm of the profile.
- Apply nitrogen fertiliser after each cut of forage at 100 kg N/ha t least 3 times a year.
- Apply potassium fertiliser after each cut (preferably as nitrate); rate depends on soil test level, but may need 300 kg K/ha in first year and will increase to 400 kg K/ha after 3 years.

6. WATER BALANCE ANALYSES

The operating agreement requires all wastewater to be either re-used within the plant or used for farm irrigation. Hence, there must be no discharges of wastewater to the Shoalhaven River. In this regard, wet weather storages are used to hold surplus wastewater during periods of wet weather when the soil is too wet to irrigate.

Previous investigations estimated the wet-weather storage requirements with a wastewater flow of 4.6 ML/d. The present study examined the adequacy of the proposed storage arrangements with a flow of 2.1 – 3.6 ML/d depending on the proportion of retentate that is directed to farm irrigation. The aim was to establish whether there was sufficient storage to prevent discharges under a range of rainfall conditions as represented by the historical rainfall at Nowra. As such, the emphasis in this section is on the hydraulic components on the proposed reuse system, in contrast to the chemical aspects that are discussed elsewhere.

To do this, the H2OB water balance model was used to estimate the day to day change in the soil moisture level under varying degrees of wetness and hence when it was dry enough to irrigate. It did that by solving the water balance each day during the 68 years of rainfall records that were used in the analyses. The inflow of wastewater was then balanced against the outflow to irrigation, with the storages providing a buffering capacity.

Values of key variables were as follows, with more details and broad capabilities of the H2OB model being described in Appendix 1.

- Wastewater flow of 2.1 ML/d with no retentate used for irrigation, increasing to 3.6 ML/d with 100% reuse of retentate for irrigation;
- Pasture irrigation with 238ha under centre pivots and 276ha with travelling irrigators; a total area of 514ha;
- Total available storage of 823ML.

6.1 Water balance results

Mean annual results are given in Table 11.

Table 11 The reuse and irrigation volume with different proportions of retentate in the wastewater used for irrigation.

Proportion of retentate (%)	Wastewater flow (ML/d)	Required storage (ML)	Reuse (%)	Irrigation (ML/yr)
0	2.1	401	100	727
50	2.85	504	100	1004
100	3.6	636	100	1274

There was 100% reuse and no river discharges under all rainfall sequences in the historical record, provided the storage capacity was 401-636 ML, depending on the wastewater flow. As the available storage capacity will be 823ML the 100% reuse was easily obtained.

The difference between the annual irrigation volume of 727 – 1274 ML/yr and the annual wastewater flow of 767 – 1315 ML/yr was accounted for by the net evaporation from the storages.

The pattern of monthly irrigation in months of different wetness are shown in Figure 3.

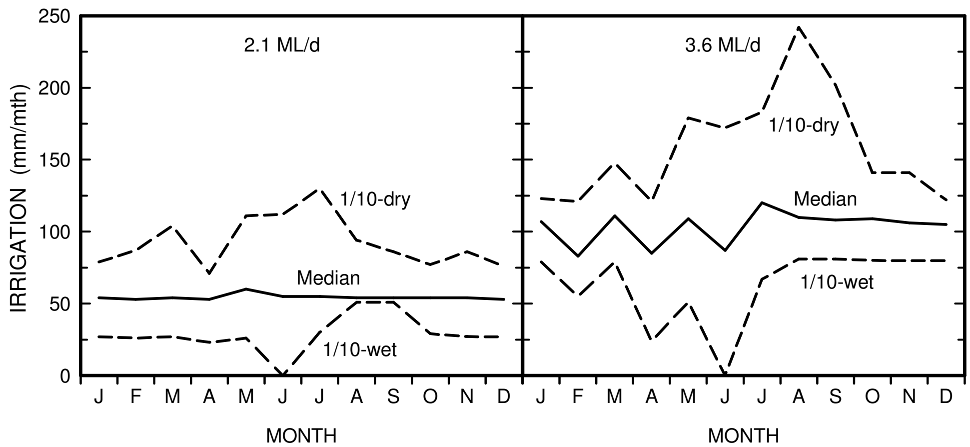

Figure 3 The monthly irrigation volumes in dry, medium and wet months.

With no retentate use, the daily wastewater flow of 2.1 ML/d equates to about 64 ML/mth. Under median conditions, the irrigation volume was slightly less than the wastewater flow indicating that some would be stored until drier than median conditions permitted more irrigation. Note also than even under very dry (1/10-dry) conditions the highest irrigation volume occurred in July, indicating that a shortage of water held back the irrigation volumes during the warmer months.

When all the retentate was used, the increased flow supplied about 110 ML/mth. About the same amount was used under median conditions, and increased only under drier conditions when some water was available from the storages, especially during the cooler months.

These results illustrate how the pasture will be underwatered during many months that are drier than average.

The main conclusion is that the existing storage capacity is more than sufficient to provide wet-weather storage and thus avoid discharges to the river.

7. IRRIGATION MANAGEMENT PLAN

7.1 Summary

The Irrigation Management Plan addresses the impact of future irrigation activities at the Environmental Farm (EF). Included are soil effects, water quality, storage and recycling.

Irrigation scheduling at the site was reviewed in 2003 investigating the current and other available methods. Existing procedures developed specifically for the wastewater infrastructure were determined to be the most appropriate. The quality of the wastewater improved post 2004 so that irrigation and soil properties were improved.

Further analysis of the irrigation data since then, has defined other important characteristics such as a frequency distribution of irrigation volume and pumping capacity upgrades.

Rainfall variation is the dominant limitation to the continuously operating business which is dependent upon beneficial irrigation. Hence the irrigation scheme depends heavily on the provision of adequate wet weather storage capacity to prevent discharges during wet weather.

By entering into the next stage of water treatment and recovery, the Company will move to a less weather dependant factory-operating status; will recover water for factory and agricultural reuse; will generate biogas for cleaner production and will minimise offensive odours.

7.2 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 hydraulic propelled 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. Also site specific instruments are reliant upon the siting of equipment in a representative area of the paddock.

7.3 Irrigation Scheduling and Practices

The initial training in the 1980’s for the irrigators employed by the Company was the soil moisture deficit technique. This approach is to be enhanced by the use of the IRRICALC program giving a combination of meteorological data and visual inspection of paddocks to control irrigation.

Comprehensive records are kept of the irrigation volumes that are applied to all paddocks. An analysis of irrigation records since January 2003 has also confirmed the irrigation intervals for each paddock which is related to soil type.

Three irrigation scheduling techniques were re-evaluated in 2005. They were current practice, use of the “IrriCalc” irrigation-scheduling software, and evaporation deficit calculations. The exercise revealed that the experience of the personnel 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.

However, the time involved with potential re-siting, breakdowns and verification monitoring disadvantaged the efficiency of the operation. Ultimately the quality of the wastewater itself eliminated the commercially available techniques as specific practices had to be devised for the wastewater operation. The site specific evaporation deficit data was useful as a backup.

Simple probe and physical inspection of each area could not be replaced by systems that are reliant upon assumptions of homogeneity of soil within a paddock. Experienced scientific modellers have a verification process commonly known as “ground-truthing” and pre-irrigation inspections are that.

While there are various aids to assist with irrigation scheduling, it is more important that the irrigation area is inspected on a regular basis by experienced operators.

Further details with respect to irrigation scheduling and operation for wastewater are outlined in Appendix 2.

The Company feels that this system of irrigation management is the best way to effectively utilise the wastewater across the farm whilst avoiding the potential for environmental harm.

Standard Operating Procedures (SOP) are being reviewed as machinery descriptions are too specific. A more generic text will be substituted.

7.4 Review of Irrigation Limitations

Since 2005, several major factors have had an effect upon the irrigation operation.

- The condensate dominated wastewater has approximately 1% solids (including the lime adjustment).
- The soil monitoring program since this change has recorded a stabilisation and subsequent decreases for several important parameters.

Limitations for the existing irrigation area are similar to the 2005 report. Coastal weather patterns are variable and even during the last three drought years, the effective irrigation period is reduced by a quarter. See Figure 4.

Rainfall variation is the dominant limitation to the continuously operating business which is dependent upon beneficial irrigation. Hence the irrigation scheme depends heavily on the provision of adequate wet weather storage capacity to prevent discharges during wet weather.

Irrigation data collated and presented annually to the DECC, has been analysed to demonstrate this. A frequency distribution chart of rounded daily volumes was generated for similar periods for the last 3 years.

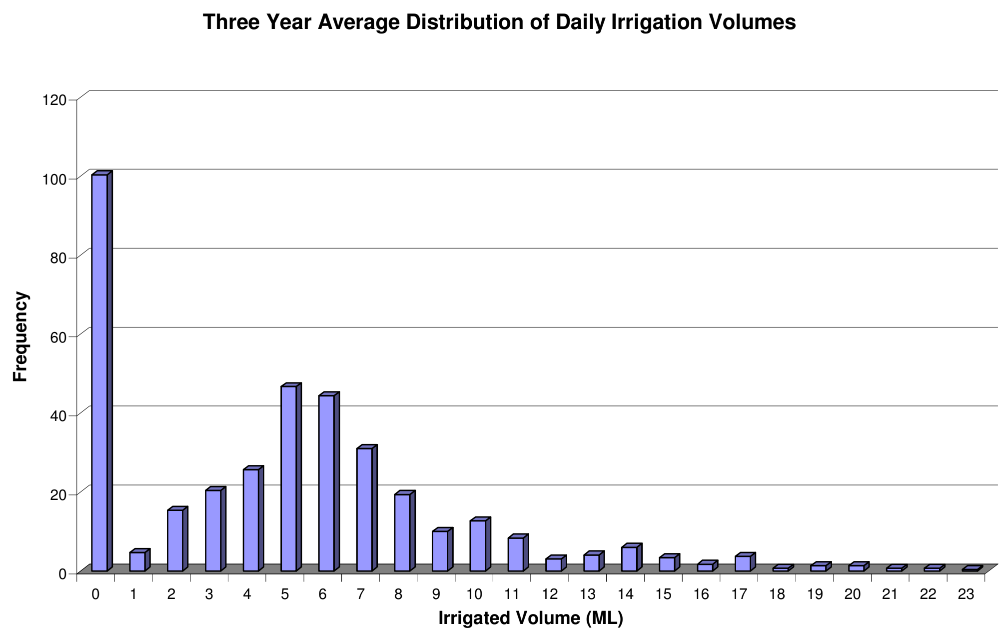

Figure 4 Average Distribution of Daily Irrigation Volumes for the last 3 years.

To obtain a summary of the existing irrigation practices, the data was then averaged to reveal the following important points.

- Zero irrigation volumes exist for 100 days per year
- The effective irrigation year is 265 days
- The effective median irrigation volume is 5 ML per day
- Irrigation hours vary according to soil moisture and weather patterns
- Irrigations larger than 20 ML per day occur only 3 times per year.

APPENDIX 1. Water budget methods and parameters

A major issue in water budget analyses is to estimate when recycled water can be used for irrigation. This is done by using a water balance model to estimate day-to-day changes in the soil water content according to the historical rainfall record, and initiating irrigation when the soil had dried to the trigger deficit as set by the irrigation strategy.

The analyses were done with the H2OB Soil Water Balance Model, version 2.6.

Operating basis for H2OB water balance model

The H2OB water balance model uses two continuity models to balance water inputs against water outputs for both the wastewater supply and the soil/plant system.

Wet-weather-storage water balance

RECYCLED WATER + DAM-RAIN = IRRIGATION + DAM-EVAP + EXCESS + ΔDAM

Recycled water :
Specified as a daily flow

Dam-rain:
Equals volume of rain that falls on storage.

Irrigation:
Uses deficit irrigation. Deficit remaining after irrigation set at 10mm.
Irrigation strategy can be varied.

Dam-evap:
Evaporation from storage. Equated to potential evaporation rate from a free-water surface. No loss if storage is empty.

Excess:
Equals the volume of wastewater that is discharged when the storage is full.

ΔDam:
Balancing term in continuity equation. Equals changes in stored volume.

Irrigation-area water balance

RAIN + IRRIGATION = EVAPOTRANSPIRATION + SURFACE RUNOFF + PERCOLATION + ΔSW

Rain:
Daily rainfall taken from long-term historical records.

Evapotranspiration:

Best available estimate of local evapotranspiration.
Crop factor used to estimate potential evapotranspiration (Et) for a given crop.
Actual Et declines as soil dries, with function determined by crop type.
Intercepted water on canopy preferentially evaporated, at a rate that equals the reference-crop, potential rate of evapotranspiration with low growing crops, and at higher rates with well-ventilated crops, eg trees.

ΔSW:

Balancing term in continuity equation. Represents the changes in soil water content.

Infiltration, redistribution, runoff and percolation:

Most calculations done on a daily basis, infiltration and some runoff calculated 6-hourly using published models of infiltration.
The saturated hydraulic conductivity (Ksat) is estimated from soil texture and likely soil compaction.

Steps in the calculations were:

- Surface runoff calculated from rainfall volume, slope and surface conditions using the US Soil Conservation Service curve number procedure. Only important on steeper land.
- Daily rain split into two equal lots, and each is assumed to fall over 6 hours, with a 6-hour dry period between. This is done because following functions work better on short time steps.
- Distance that wetting front will move in 6 hours is estimated, and subject to the wetting rate not exceeding the infiltration rate, the soil is allowed to fill to saturation to the depth of the wetting front. Surplus rain is allocated to runoff.
- The infiltration rate is determined by sorptivity, and the Ksat of the transmission zone.
- Water redistributes through the soil at a rate that equals the hydraulic conductivity at a nominal suction of 10cm. Only the water held between saturation and field capacity will redistribute.
- A low-conductivity layer can cause water to accumulate as a perched water table.
- Interflow is estimated from Ksat, the hydraulic head and wetting front. It is usually very small on flat reuse areas.

The point of these calculations is to solve the model to estimate the new soil water content. The soil water content is then used to determine when the next irrigation is due.

<u>Parameter values</u>

INPUT DATA

(a) Recycled water flow

- 2.1 ML/d with no retentate used for irrigation;
- 2.85 ML/d with 50% retentate used for irrigation;
- 3.6 ML/d with 100% retentate used for irrigation.

(b) Crops

- Perennial pasture.

(c) Rainfall & evaporation

The monthly rainfall and evapotranspiration at Nowra were based on records from the Bureau of Meteorology. The rainfall records covered 68 years from 1940-2007 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.

Mean monthly rainfall and potential evapotranspiration.

Month	J	F	M	A	M	J	J	A	S	O	N	D	Yr
Rain (mm/mth)	90	122	106	96	95	116	55	67	62	90	84	75	1057
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	603mm	977mm	1634mm	2248mm

(d) Soil properties

Generalised properties of the soil were:

	Horiz.	Depth (cm)	Texture	K_{sat} (mm/d)	WHC (mm)
Pasture	A	0 - 50	Fine sandy clay loam	118	64
	B	50 - 100	Fine sandy loam	120	73

K_{sat} = saturated hydraulic conductivity

WHC = total available water holding capacity within profile depth

(e) Irrigation

- Centre pivots: Each watering applied 10mm when the soil had dried to a 20mm soil water deficit. This is referred to as a 10/20 irrigation strategy. Application efficiency of 85%.
- Travelling irrigators: 20/30 irrigation strategy with an application efficiency of 80%.

APPENDIX 2 Irrigation Scheduling

Current irrigation scheduling techniques

Paddock assessment is by physically inspecting the paddocks. As soil moisture status is correlated with soil strength, the common technique for any 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.

An evaporation pan was initiated and has been maintained since September 2003. This tool is used as a verification step against experience. It also allows a numerical value to be assigned to a qualitative assessment. A simple meteorological balance can be performed to validate decisions to cease or restart irrigation activities.

Soil moisture deficit strategy

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. 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.*

Improved irrigation scheduling techniques

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 EF.

These aims translate into using the prevailing weather conditions to schedule irrigation, and to use a small irrigation volume. The current scheduling techniques were confirmed by the irrigation scheduling software program (IRRICALC) to prompt when the next irrigation is due. Using the chosen 5/10 irrigation strategy within the program will accommodate the need to use small irrigation volumes.

The program calculates a daily water balance for various blocks using (a) actual rainfall on the reuse areas, and (b) the mean seasonal evapo-transpiration 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 on 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.

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.

Options for scheduling to meet with adopted soil moisture deficit strategy that meet the environmental performance criteria

It is proposed to use a 5/10 irrigation strategy for all irrigation. This is an unusual strategy for field irrigation because the small application volume of just 5mm increases costs. Normally an amount of about 20mm is applied to justify the cost of setting up the irrigator and as a result the trigger deficit must also be greater, say 25-30mm.

The cost of applying just 5mm per irrigation is accepted by the Company to (a) keep wastewater circulating through the irrigation mains, and (b) limiting the mass of organic solids that are applied to the soil during each irrigation.

The 5/10 strategy also has other benefits in that the use of the 10mm trigger deficit ensures that the soil is dry enough to absorb up to twice the volume that is applied, and application rate is much less than the infiltration capacity of the surface soil.

Although confirmation would be required, it is quite likely that the irrigation volume could be increased to 10mm without overloading the soil from either a hydraulic or organic loading point of view. In other words, the irrigation management is designed to operate on a conservative basis.