Nutrient composition of dairy effluent ponds

Final report to Subtropical Dairy South-East Queensland Subregional Team

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The Department of Primary Industries and Fisheries (DPI&F) seeks to maximise the economic potential of Queensland's primary industries on a sustainable basis.

This publication has been compiled by Alan Skerman, Theresa Kunde and Caroline Biggs, Delivery.

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Introduction

Over the past five years, Queensland dairy farms have been undergoing expansion and intensification in an attempt to improve efficiency and reduce milk production costs. In many cases, producers have significantly increased herd numbers on the same overall farm area and increased feed production by more intensive use of fertiliser and irrigation. The use of feed pads has also increased, allowing dairy producers to use imported or home grown conserved fodder to supplement grazed crops and pastures.

The intensification of dairy farming systems has resulted in a higher overall nutrient loading across most farms, mainly through increases in effluent production at the dairy, around feed pads, in laneways and in loafing or camping areas. While some farmers still view dairy effluent as a waste product to be disposed of, others are beginning to realise that it is a valuable, nutrient-rich resource.

In the current economic climate, dairy producers need to maximise production benefits from all available resources. They cannot afford to ignore or mismanage dairy effluent. Careful management is, however, required to effectively use the valuable nutrient and water resources in the effluent, while avoiding adverse impacts on the environment (e.g. nutrient runoff into watercourses, leaching of contaminants into groundwater and soil structural damage). Due to the increased community and government interest in environmental and natural resource management issues, effluent management has become an important issue for the industry to proactively address.

As herds expand and dairy manure and wash down volumes increase, effluent treatment and storage ponds are gradually replacing small capacity sumps that have become incapable of handling the increased loadings. Producers are recognising that effluent ponds have several advantages over sump-pump-sprinkler systems—they don’t require daily attention, have the ability to store effluent for extended periods and enable scheduling of effluent irrigation to suit soil, crop and pasture conditions.

There is very little data currently available regarding the nutrient composition of Queensland dairy pond effluent. Without reliable, representative data, farmers are not currently well equipped to effectively manage effluent applications to match crop nutrient requirements. This limits their ability to effectively maximise the organic fertiliser value of the effluent while protecting environmental values. A major objective of this study is to provide baseline data to assist dairy producers in more effectively managing their pond effluent.

During this study, samples from twenty dairy effluent ponds located throughout south-east Queensland were collected and analysed in a laboratory to determine the nutrient and chemical characteristics of the liquid effluent available for irrigation onto crop or pasture. The resulting data has also been used to estimate the economic value of dairy pond effluent as a replacement for inorganic fertilisers.

Additional farm operational data, such the numbers of cows milked, daily wash down volumes, times the cows spend in the dairy and yards, yard areas, pond storage volumes and effluent irrigation methods, were also collected for each of the farms visited. This data has been used to assess the accuracy of the existing DPI&F *Dairy effluent* calculator for predicting pond nutrient content.

Methodology

During May and early June 2005, twenty effluent samples were collected from effluent ponds operating on twenty dairy farms located throughout south-east Queensland. The farms were situated within an area extending from Gympie and Kenilworth in the North, to Beaudesert in the South, Gatton to the West and Beechmont to the East.

A major objective of this project was to collect samples that were representative of the effluent available for irrigation onto land growing crops or pasture. Eleven of the effluent systems sampled in this project employed single ponds, while the remaining nine farms had two pond effluent systems. Because effluent irrigation pumps generally draw water from the ‘final’ (or secondary) pond in multiple pond effluent systems, effluent samples were collected from the second pond for each of the two pond systems.

The effluent samples were collected using a telescopic aluminium sampling pole, as depicted in Figure 1. The pole has a total extended length of approximately 2.5 m. It is fitted with an aluminium sampling bottle holder that is designed to carry a wide-mouthed, one litre polyethylene sampling bottle, secured to the bottle holder using a rubber band. All samples were taken from just below the surface of the pond to avoid collecting any crust material floating on the surface.

Figure 1. Sampling pole used to collect pond effluent samples.

Initially, a composite sample was collected by taking five x one litre samples from five randomly distributed positions around the perimeter of each pond. Each sample was tipped into a twenty litre bucket after collection. The contents of the bucket were thoroughly mixed before a second one-litre, water-washed sample bottle was used to collect the sub-sample to be submitted for chemical analysis.

All samples were kept cool by packing in crushed ice in an insulated cooler. Following return to DPI&F, all samples were removed from the ice and placed in a freezer. Three batches of frozen samples were delivered to the Toowoomba City Council's laboratory at Mt Kynoch, for chemical analysis.

Various data analysis methods were used to examine the variation in effluent characteristics, based on the type of effluent system (single or double pond) and pond loading rate. The economic value of the effluent as a replacement for inorganic fertiliser was also determined for each pond, based on current costs of inorganic fertilisers commonly used by dairy producers.

Key characteristics of the farm effluent systems were measured and recorded during the on-farm sampling visits. The producers were interviewed to enable the recording of relevant operating practices employed on each farm. The effluent system design and farm management data are summarised in Appendix B. This data has been used to assess the accuracy of DPI&F's *Dairy effluent* calculator (Skerman, 2004b) for predicting pond nutrient content.

Minimum sustainable areas (based on nutrient loading) for the irrigation of pond effluent were also determined using DPI&F's *Dairy effluent* calculator. These calculations assumed that the effluent was applied to the most common summer and winter forage and pasture crops indicated by the farmers during on-farm interviews.

The effluent data were also assessed against guidelines for salinity, sodium and chloride concentrations to determine the likelihood of adverse effects on crop growth and soil structure.

Results

Tabulated results of the pond effluent analyses for each of the twenty ponds sampled are provided in Appendix A. Effluent system design and management data for each of the farms where the samples were collected are provided in Appendix B.

Although twenty dairy effluent ponds were sampled during this project, analysis results for two of these ponds were not considered in many of the following data analyses because it was found that the samples were collected from a secondary pond and a turkey's nest storage that had been diluted by the addition of fresh water. In both cases, the farmers were using these storages for mixing effluent with fresh water, pumped from bores on the property, prior to irrigating the 'shandied' effluent onto crop or pasture. The effluent analysis results for the remaining 18 ponds are summarised in Table 1.

Box and whisker plots of the major nutrients and chemical characteristics of the effluent are provided in Figure 2, Figure 3 and Figure 4. In these plots, the boxes enclose the middle 50% of the data while the horizontal line across the box represents the median value (middle value when all data is arranged in ascending or descending order). The bars (whiskers) on the ends of the boxes indicate the maximum and minimum values recorded for each parameter. Box and whisker plots are useful for displaying the variation and range of the recorded data.

Table 1. Summary of effluent analysis results for 18 ponds sampled (excluding results from 2 ponds diluted with fresh water).

Parameter	Units	Min	Max	Average	Median	Standard deviation
Total Kjeldahl Nitrogen (TKN)	mg/L	22	459	167	118	148
Total Phosphorus (Total P)	mg/L	10	85	36	28	22
Potassium(K)	mg/L	3	1,020	274	148	299
Electrical Conductivity (EC)	µS/cm	1,040	9,680	3,904	3,480	2,111
pH		7.2	9.0	7.9	7.7	0.6
Nitrite (NO_2^-)	mg/L NO_2^-	<0.1	12.4	2.3	0.3	5.0
Nitrate (NO_3^-)	mg/L NO_3^-	0.2	6.1	1.2	0.9	1.3
Nitrite Nitrogen ($NO_2^- – N$)	mg/L	<0.03	3.77	0.69	0.08	1.51
Nitrate Nitrogen ($NO_3^- – N$)	mg/L	0.05	1.39	0.28	0.21	0.30
Total Nitrogen (Total N)	mg/L	23	460	167	118	148
Chloride (Cl^-)	mg/L	71	914	234	171	207
Calcium (Ca^{++})	mg/L	36	187	98	99	51
Magnesium (Mg^{++})	mg/L	34	254	103	74	66
Sodium (Na^+)	mg/L	54	748	225	173	168
Sodium Adsorption Ratio (SAR)		1.4	8.9	3.7	3.4	1.9

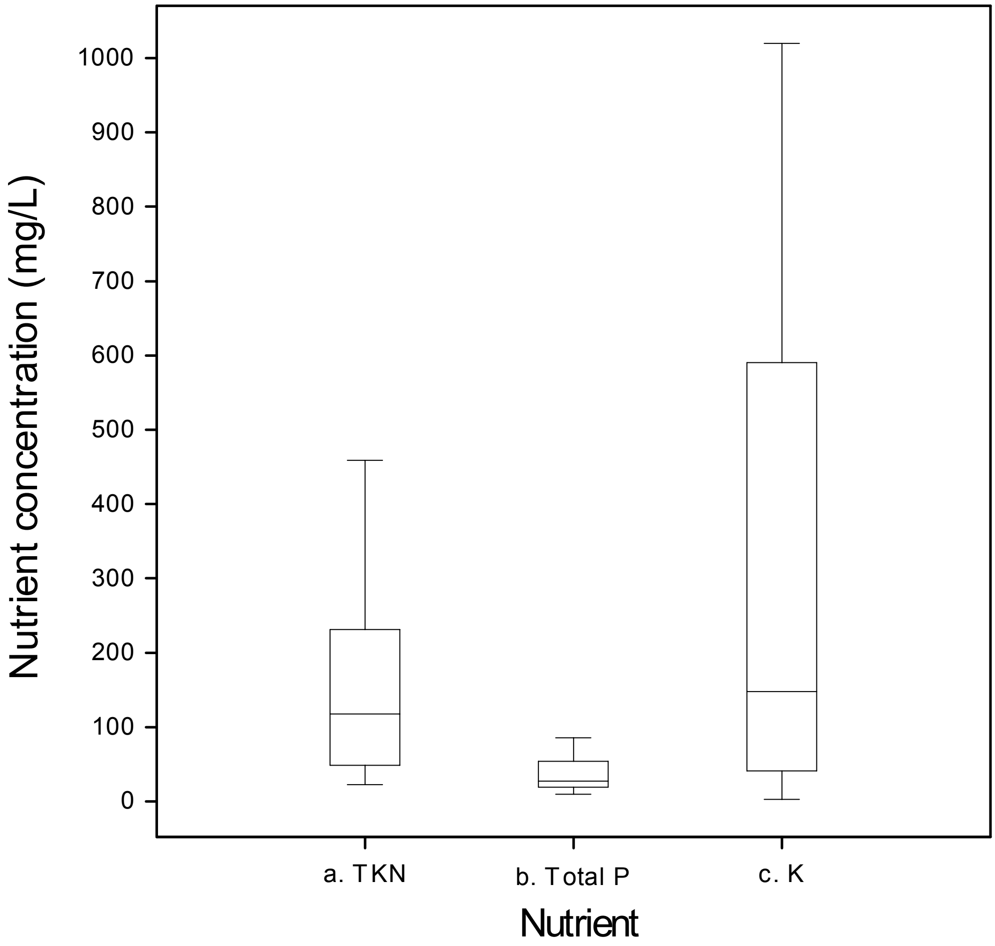

Figure 2. Box and whisker plot for Total Kjeldahl Nitrogen (TKN), Total Phosphorus (Total P) and (c) Potassium (K) concentrations in effluent samples from 18 ponds.

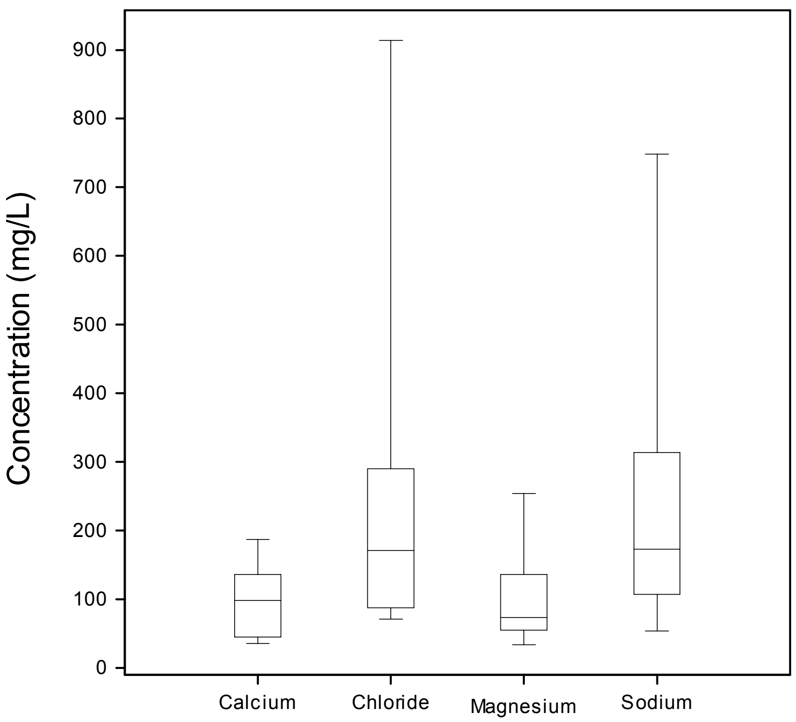

Figure 3. Box and whisker plot for major anion and cation concentrations in 18 pond effluent samples.

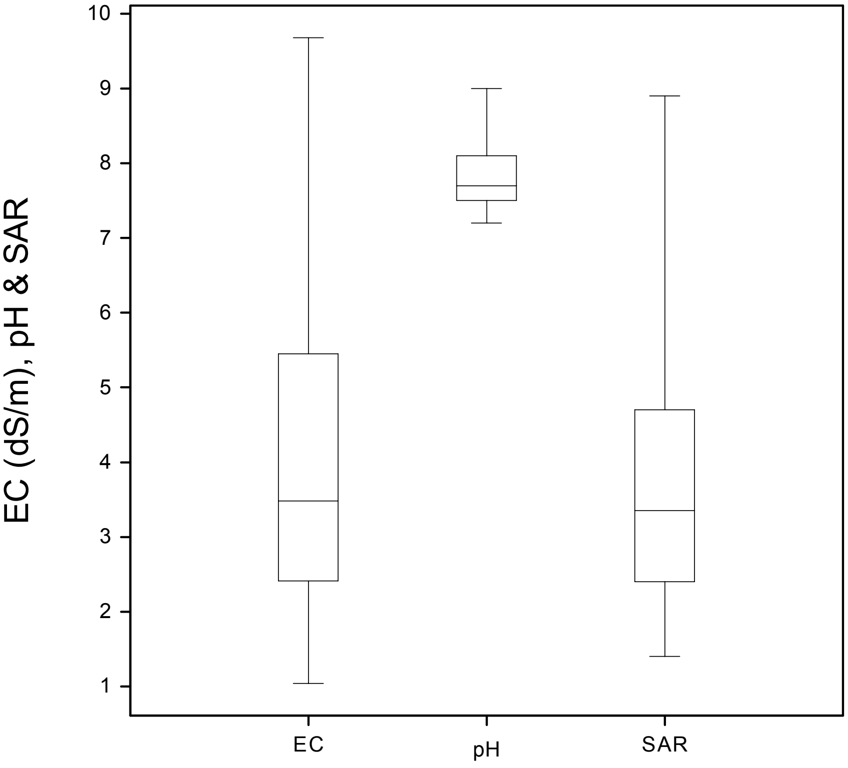

Figure 4. Box and whisker plot for electrical conductivity (EC), pH and sodium adsorption ration (SAR) analysis results for 18 pond effluent samples.

Discussion

Variation in dairy pond effluent characteristics

The pond effluent analysis data collected during this project clearly indicate that the chemical characteristics of the pond effluent vary significantly between farms. This variation is likely to be caused by a combination of the following factors:

(1.) Variations in the constituents of the manure deposited in the dairy and yards, which are influenced by:

- feed components (the species/type and quality of grazed pasture/forage and concentrated or conserved supplements fed to cows)
- feed processing methods
- drinking water quality (bore or surface water)
- animal breed and genetics
- rumen health (e.g. how well rumen micro-flora are performing, the presence of sub-clinical acidosis).

(2.) Variations in the quantities of manure deposited in the washed down areas of the dairy and yards, which are influenced by:

- the number of cows in the herd
- the time the cows spend in the dairy and associated yards
- cow live-weight and feed intake
- the way the herd is managed prior to entry into the yards and during milking.

(3.) Variations in the amounts of water used for washing down the dairy and yards, which are influenced by:

- wash-down methods (hosing, hydrant, flood washing)
- yard slope and shape
- availability of a suitable water supply
- the use of dry scraping of manure from yards, prior to washdown.

(4.) Variations in the amounts of runoff entering the pond system, which are influenced by:

- the area of yards draining into the effluent system
- the presence or absence of guttering to divert roof runoff away from the effluent system
- the presence or absence of a rainwater diverter on the yards
- local climatic characteristics (average annual rainfall)
- seasonal climatic effects.

(5.) Variations in design and management factors, such as:

- the use of stone traps, trafficable solids traps or other types of solids separators
- the use of dry scraping of manure deposited in yards
- the type of pond system (single or double pond)
- bacterial population and activity in the pond, which is also influenced by temperature
- the size of the pond in relation to the loading rate
- the collection of leachate from by-product feed storage bunkers and silage pits
- the amount of sludge accumulated in the pond and the history of pond desludging
- yard washing water quality (e.g. salinity)
- the use of recycled pond effluent for yard washing purposes
- effluent irrigation practices (frequency of irrigation).

Many of the above factors vary considerably between farms. Some of the above factors also vary within the same farm over time, suggesting that effluent quality may be quite variable over time in the same pond.

To get a better understanding of the variation in pond effluent characteristics over time, it would have been desirable to take a series of samples from each pond over a period of several months. Limitations in funding, labour and time, however, constrained the scope of this project to taking single samples from a range of different ponds over a period of a few weeks.

Nevertheless, the pond effluent data collected for this project arguably provide the most comprehensive data set of this type currently available for the sub-tropical dairying region. The data will provide valuable baseline results for use until opportunities arise for further, more comprehensive investigations of pond effluent quality in the region.

Variations in effluent quality due to a number of the above factors are examined in more detail in the following sections.

Single and double pond systems

The effluent chemical analysis data were examined to assess any variation in effluent characteristics between samples collected from single and double pond effluent systems. Figure 5 is a box and whisker plot showing the variation in the major nutrient concentrations between samples collected from all 18 ponds, 11 single ponds and 7 double ponds.

This figure indicates that the median concentrations of major nutrients are all higher for the single pond systems in comparison to the double pond systems. There is also a much greater range of values for the single pond data. This may indicate that there is a greater level of effluent treatment in the double pond systems, resulting in reduced and more consistent nutrient concentrations. Some of the variation in single pond nutrient concentrations may, however, be due to pond loading rates, as discussed in the following section.

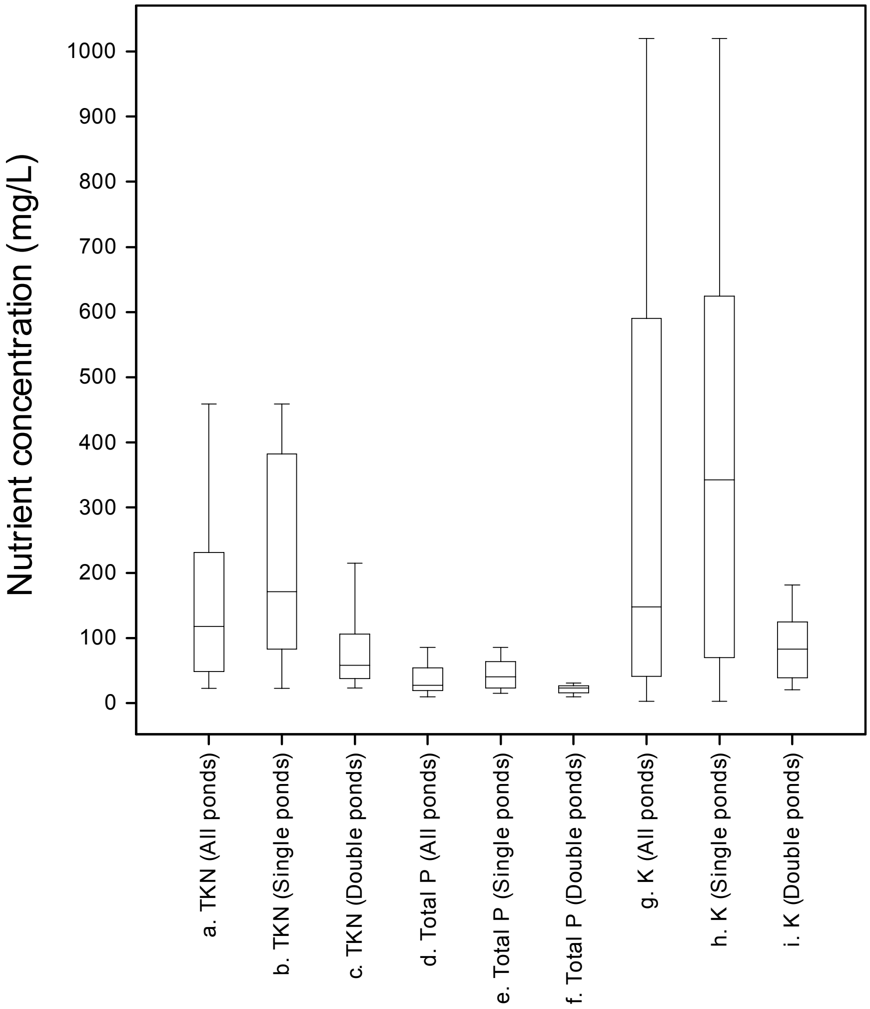

Figure 5. Box and whisker plot comparing Total Kjeldahl Nitrogen (TKN), Total Phosphorus (Total P) and Potassium (K) concentrations in effluent samples collected from 11 single pond and 7 double pond effluent systems.

Pond loading rate

The amount of manure hosed or flushed into the pond system on a daily basis determines the pond loading rate. Other forms of organic matter, such as spilt feed and small amounts of milk, may also contribute to the loading rate.

Ponds should generally be designed to have sufficient capacity to support the bacteria population required to effectively break down (or treat) the manure loading entering the pond. This is commonly referred to as the treatment capacity of the pond. Consequently, farms where large amounts of manure are washed into the pond from the yards and dairy generally require larger pond treatment capacities than farms where the manure loading rate is lower.

The degree of crusting on the pond surface provides an indication of the pond loading rate. If there is a large amount of organic crust floating on the pond surface, this suggests that there is insufficient treatment capacity to effectively break down the manure entering the pond on a daily basis. As crusting becomes thicker and more extensive on highly overloaded ponds, grass may become established on the crust, resulting in floating grass islands. These islands may eventually cover a large proportion of the pond surface. By comparison, ponds with sufficient treatment capacity are relatively clear, with less than 20% crust over the entire pond surface. The presence of gas bubbles erupting from the base of the pond also indicates healthy bacterial breakdown of manure.

In addition to the treatment capacity, ponds also require sufficient capacity to store sludge, which is the solid material that settles out of the liquid effluent during the bacterial decomposition of organic matter in the pond. As sludge accumulates on the floor of a pond, the treatment capacity may be reduced, resulting in less effective breakdown of the manure entering the pond. This effectively increases the loading rate on the remaining treatment capacity of the pond. The resulting variation in pond loading rates may also influence the characteristics of the pond effluent.

Table 2 outlines an assessment of the loading rates on each of the eighteen ponds, based on a comparison of the existing primary pond capacity and the required primary pond capacity (determined using DPI&F's *Dairy pond* calculator, Skerman 2004a); visual assessment of the amount of crusting on the pond surface, and the level of visible sludge accumulation. Generally, visual assessments of ponds can only identify when sludge levels are high.

Figure 6 is a box and whisker plot comparing the major nutrient levels in effluent samples collected from the 8 ponds designated as 'overloaded' and the 10 ponds designated as 'not overloaded' in Table 2.

Table 2. Assessment of degree of overloading of 18 primary effluent ponds, based on comparison of existing pond capacity with required pond volume determined using DPI&F *Dairy pond* calculator, degree of pond surface crusting and observed sludge level.

Sample No	**Existing primary pond capacity** (ML)	**Required primary pond capacity** (ML)	**Existing / required primary pond capacity ratio** (%)	**Surface crusting** (%)	**Observed sludge level**	**Overloaded?**
1	2.4	1.2	204%	0%		No
2	5.6	2.8	200%	0%		No
3	1.7	0.9	187%	50%		No
4	3.8	2.8	136%	0%		No
5	6.0	2.3	259%	3%		No
6	1.0	0.6	167%	50%	High	Yes
7	4.0	1.2	333%	0%		No
8	1.2	1.5	82%	90%	High	Yes
10	1.2	1.0	117%	0%		No
11	1.0	1.3	75%	5%		Yes
12	1.4	4.2	35%	10%	High	Yes
13	0.8	0.9	85%	30%	High	Yes
14	1.8	2.8	63%	40%	High	Yes
16	3.0	3.7	81%	5%		No
17	3.5	1.6	219%	0%		No
18	2.5	5.2	48%	35%	High	Yes
19	8.0	1.3	615%	30%	High	Yes
20	1.5	0.9	170%	0%		No

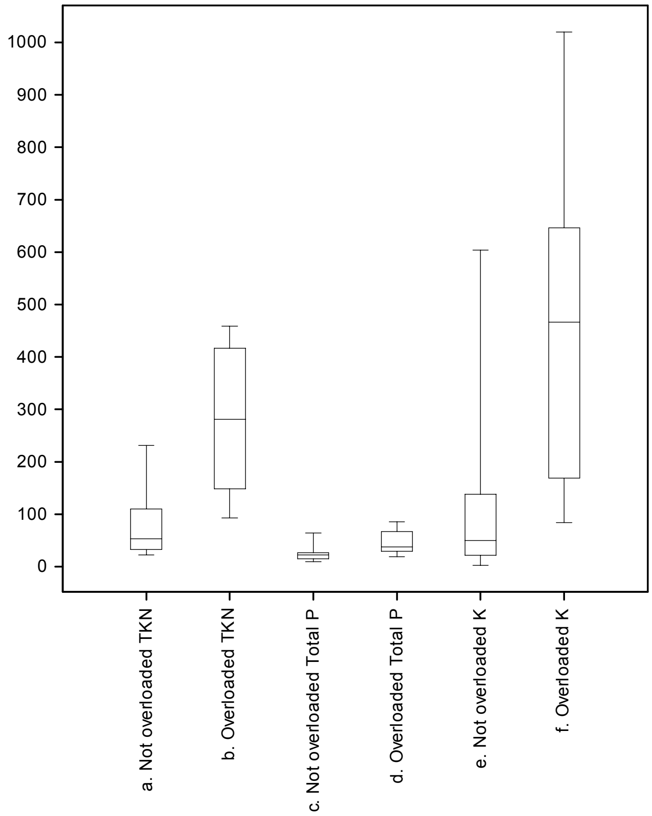

Figure 6. Box and whisker plot comparing Total Kjeldahl Nitrogen (TKN), Total Phosphorus (Total P) and Potassium (K) concentrations in effluent samples from 8 'overloaded' and 10 'not overloaded' ponds, as outlined in Table 2.

Predicting effluent nutrient concentrations using DPI&F *Dairy effluent* calculator

Another major objective of this project was to assess the accuracy of DPI&F's *Dairy effluent* calculator (Skerman, 2004b) for predicting the concentration of major nutrients in pond effluent. These predictions can then be used to determine sustainable areas for the irrigation of effluent onto crop or pasture.

To enable this assessment to be carried out, the effluent system and farm management data outlined in Appendix B were entered in the *Dairy effluent* calculator to estimate major nutrient concentrations in the pond effluent. A comparative summary of the calculator predictions and the measured pond effluent nutrient concentrations is provided in Table 3.

Table 3. Summary of comparisons between measured effluent nutrient concentrations and those predicted by computer modelling using DPI&F's *Dairy effluent* calculator (Skerman, 2004b).

Parameter	**Nutrient concentrations** (mg/L)					
	Nitrogen (N)		**Phosphorus** (P)		**Potassium** (K)	
	Measured	Modelled	Measured	Modelled	Measured	Modelled
Minimum	23	33	10	5	3	69
Maximum	460	394	85	57	1,020	720
Range	438	361	75	52	1,017	651
Average	184	187	36	27	274	349
Median	127	149	28	22	148	283
Standard Deviation	149	124	22	18	299	229

Figure 7 is a box and whisker plot indicating the variation in the range and distribution of the measured effluent nutrient concentrations and values predicted using DPI&F's *Dairy effluent* calculator. Figure 8 is a box and whisker plot providing a similar comparison of TKN and Total P values on a less condensed vertical scale.

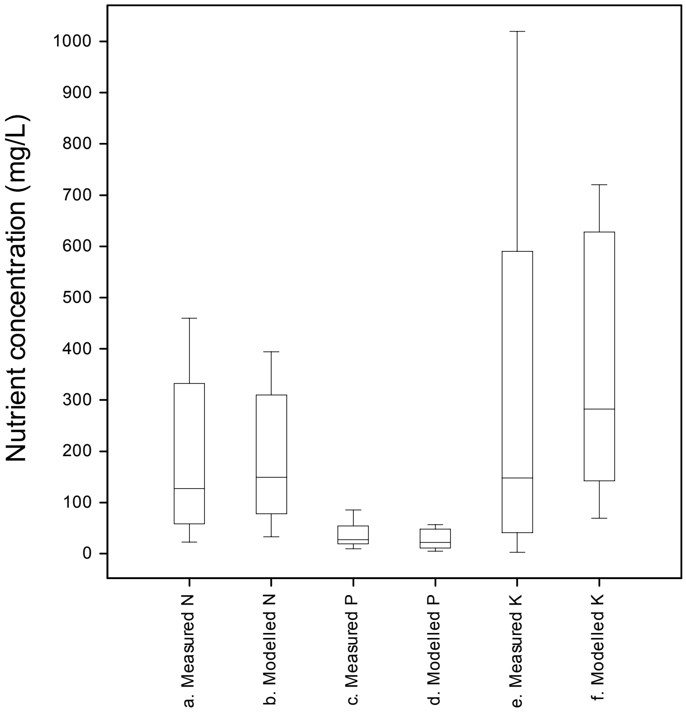

Figure 7. Comparison of measured nutrient concentrations and those determined by modelling using DPI&F's *Dairy effluent* calculator (Skerman, 2004b).

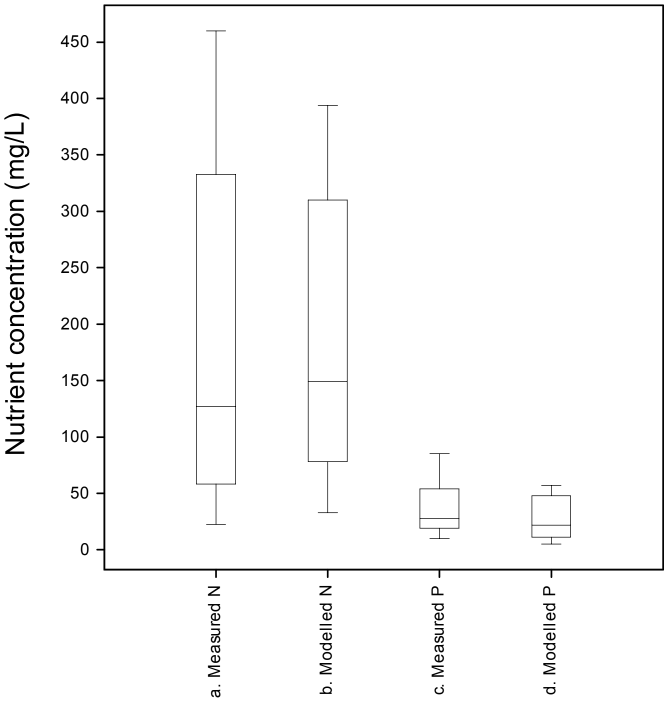

Figure 8. Comparison of measured nitrogen (TKN) and phosphorus (Total P) concentrations with those determined by modelling using DPI&F's *Dairy effluent* calculator (Skerman, 2004b).

Graphs showing the correlation between the measured effluent nutrient concentrations and the modelled values (derived using DPI&F's *Dairy effluent* calculator) are provided in Figure 9, Figure 10 and Figure 11.

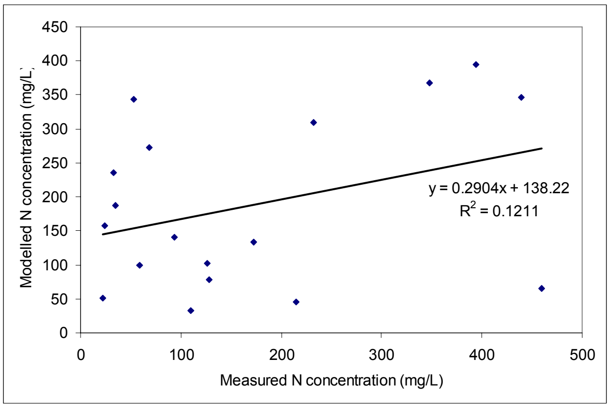

Figure 9. Modelled versus measured effluent TKN concentrations.

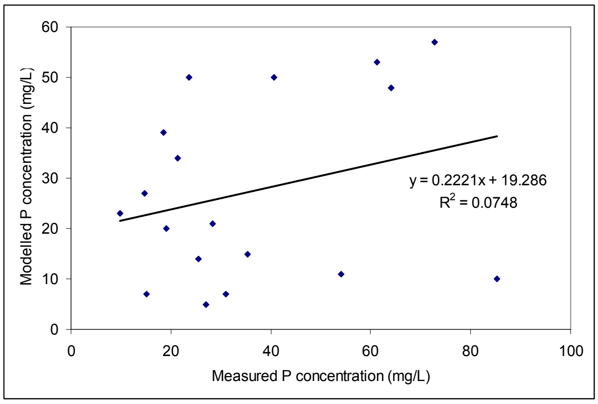

Figure 10. Modelled versus measured effluent Total P concentrations.

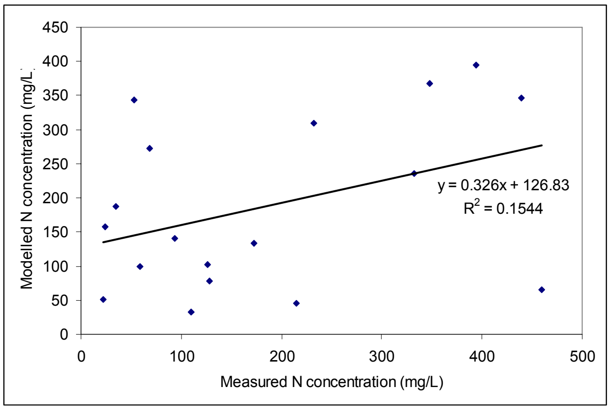

Figure 11. Modelled versus measured effluent Potassium (K) concentrations.

Figure 9, Figure 10 and Figure 11 indicate relatively poor correlations between the effluent nutrient concentrations predicted using DPI&F's *Dairy effluent* calculator, and those determined by sampling and analysis of pond effluent. In these graphs, close correlation between the predicted and measured values would be indicated by a trend line starting near the origin (0, 0), and having a slope close to unity, with data points closely clustered along the line. The R^2 (coefficient of determination) value would also approach unity.

These figures suggest that DPI&F's *Dairy effluent* calculator does not provide accurate predictions of individual pond effluent nutrient concentrations. This, however, is not surprising given the large number of factors that can potentially affect effluent chemical characteristics, as outlined previously in this discussion. For instance, it may be possible that the calculator provides reasonably accurate predictions of average effluent quality over an extended time period, whereas the measured values only provided a 'snap shot' in time.

While the calculator may be a poor predictor of effluent quality in individual farm ponds, Table 3, Figure 7 and Figure 8 suggest that the average and range of predictions agree reasonably closely with the measured values. For example, the predicted values for N, P and K are respectively 2% higher, 25% lower and 27% higher than the measured values. Furthermore, the range of measured values is also greater than that of the values predicted using the calculator. This suggests that the calculator does not adequately account for all the possible variables that exist in a 'real life' farm effluent system.

To achieve more accurate nutrient concentration predictions, the incorporation of additional data inputs would significantly increase the complexity of the model. This may severely detract from its relative simplicity and convenience, affecting its usefulness for many users.

Fertiliser replacement value of pond effluent

The major economic benefit of good effluent management is the ability to use effluent to replace inorganic fertiliser use. While effluent contains a range of potentially beneficial minor nutrients such as calcium and magnesium, it contains significant amounts of the major nutrients nitrogen (N), phosphorus (P) and potassium (K) required for productive pasture and crop growth. Based on the average pond effluent nutrient concentrations measured in this project, 1 ML of effluent contains 167 kg of N, 36 kg of P and 274 kg of K.

DPI&F's *Dairy effluent* calculator (Skerman, 2004b) estimates the potential saving in fertiliser costs, by determining the tonnage of three common fertilisers required to supply equivalent quantities of the major nutrients. Table 4 lists the three fertilisers used in estimating the cost savings, along with their nutrient contents and current supply costs.

Table 4. Fertiliser costing data used for determining the fertiliser replacement value of dairy pond effluent. Fertiliser costs obtained from *Bowdler English and Wehl*, Toowoomba, June 2005.

Major nutrient	Fertiliser	Major nutrient %	Cost per tonne
Nitrogen (N)	Urea	46%	$450 / t
Phosphorus (P)	Super Phosphate	8.8%	$407 / t
Potassium (K)	Muriate of Potash	50%	$495.50 / t

Table 5 lists the measured nutrient concentrations for each of the ponds sampled, along with the estimated average annual effluent irrigation volume, individual nutrient fertiliser replacement values and the total annual value. There is a wide variation in the estimated fertiliser replacement values, ranging from a minimum of $256 to $5209 per year, with an average value of $2036 per year. This variation reflects the variations in effluent nutrient content and estimated average annual effluent irrigation volumes.

It should be noted that the available effluent would have to be managed carefully to achieve the savings outlined in Table 5. Effluent is not a balanced fertiliser with identical proportions of nutrients to pasture or crop uptake. Consequently, application rates should be based on supplying the limiting nutrient, generally resulting in a shortfall in other nutrients. To gain maximum economic benefit from effluent irrigation, application of additional inorganic fertiliser is likely to be required to supplement the effluent nutrients.

Table 5. Estimated average annual effluent irrigation volume and annual fertiliser replacement value of pond effluent for each of the 18 ponds sampled.

Sample No	**Measured effluent nutrient concentrations** (mg/L)			**Av Ann Eff Irrig**	**Fertiliser replacement value** ($/yr)			**Total Value**
	N	**P**	**K**	(ML/yr)	**N**	**P**	**K**	($/yr)
1	24	10	32	2.8	$76	$96	$83	$256
2	53	24	83	4.1	$247	$338	$316	$900
3	110	27	20	2.1	$262	$197	$40	$499
4	68	19	22	3.2	$253	$210	$67	$530
5	232	64	41	3.0	$813	$686	$117	$1,616
6	93	19	85	1.8	$194	$122	$144	$460
7	128	54	3	2.4	$348	$450	$6	$804
8	348	61	631	1.2	$477	$257	$706	$1,440
10	34	15	58	2.8	$109	$143	$151	$403
11	460	85	590	3.2	$1,707	$968	$1,786	$4,460
12	126	35	157	8.6	$1,250	$1,071	$1,271	$3,591
13	215	31	181	9.5	$2,348	$1,035	$1,613	$4,997
14	172	28	343	5.4	$1,068	$539	$1,738	$3,345
16	33	21	604	4.2	$161	$317	$2,402	$2,880
17	23	15	257	3.9	$101	$209	$945	$1,255
18	394	73	662	3.9	$1,775	$1,001	$2,433	$5,209
19	439	41	1,020	1.7	$855	$242	$1,620	$2,717
20	58	26	138	4.5	$300	$402	$579	$1,280
Minimum	23	10	3	1.2	$76	$96	$6	$256
Maximum	460	85	1,020	9.5	$2,348	$1,071	$2,433	$5,209
Average	167	36	274	3.8	$686	$460	$890	$2,036
Median	118	28	148	3.2	$324	$327	$642	$1,360

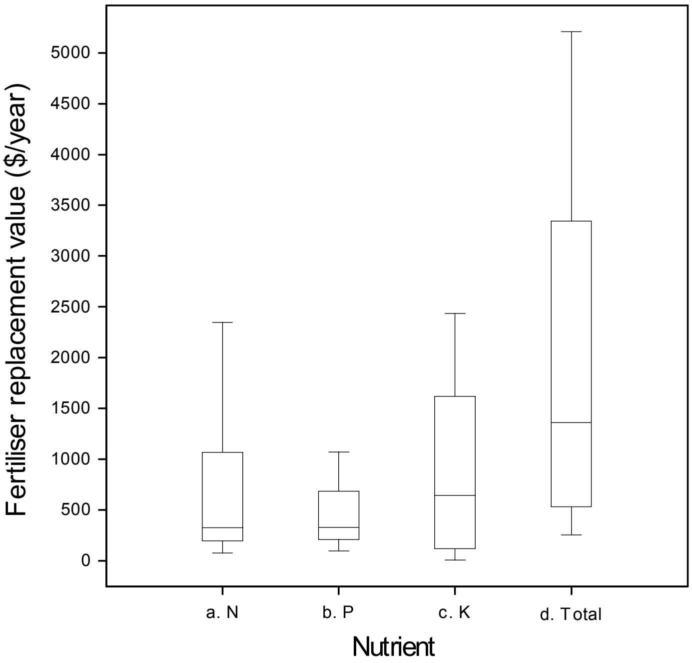

Figure 12. Estimated annual fertiliser replacement value of pond effluent for each major nutrient and in total.

Minimum effluent irrigation area

It is important for farmers to know the area over which they should aim to irrigate their dairy effluent. The effluent irrigation system (pump and irrigator or sprinkler) must be capable of applying effluent over this area within the required time frame.

DPI&F officers generally utilise DPI&F's *Dairy effluent* calculator (Skerman, 2004b) when making recommendations to farmers regarding effluent irrigation areas. These recommendations are generally based on balancing total nitrogen (N) applications with pasture or crop uptake, and balancing total phosphorus (P) applications so that they do not exceed pasture or crop uptake, in addition to 'safe' storage of P within the soil profile. The soil P storage allowance incorporated in the calculator depends on the soil type and is based on the phosphorus sorption method developed by Redding (2000).

Because potassium (K) is not known to have negative impacts on the environment, recommended minimum effluent irrigation areas are not generally based on achieving a balance for potassium uptake. However, high soil potassium levels can inhibit magnesium uptake by pasture, potentially resulting in grass tetany (hypomagnesaemia) in grazing stock. This condition does not appear to be a widespread problem in Queensland, however, as a precaution, high potassium application rates should be avoided over extended periods.

Table 6 and Figure 13 indicate that the average minimum effluent irrigation areas determined using DPI&F's *Dairy effluent* calculator are similar, regardless of whether the calculations are based on the measured or estimated effluent nutrient concentrations. Although, similarly to the effluent nutrient contents, the range of values is larger using the measured nutrient concentrations.

The calculator results presented in Table 6 and Figure 13 were based on applying the pond effluent onto irrigated tropical grass, yielding 10 t DM (dry matter) per ha, over the summer growing season, and ryegrass, yielding 11 t DM (dry matter) per ha, over the winter season. It was assumed that the paddocks were grazed throughout the year. This effluent irrigation area pasture/crop production combination was the most common scenario employed by producers interviewed during the project, as recorded in Appendix B.

Table 6. Comparison of minimum effluent irrigation areas determined using DPI&F Dairy effluent calculator, based on measured effluent nutrient concentrations and those estimated using the calculator.

Sample No	**Minimum effluent irrigation area (ha)**	
	Based on measured effluent quality	Based on effluent quality estimated using DPI&F *Dairy effluent* calculator
Minimum	0.7	0.6
Maximum	5.9	4.2
Range	5.2	3.6
Average	2.3	2.2
Median	1.8	2.0

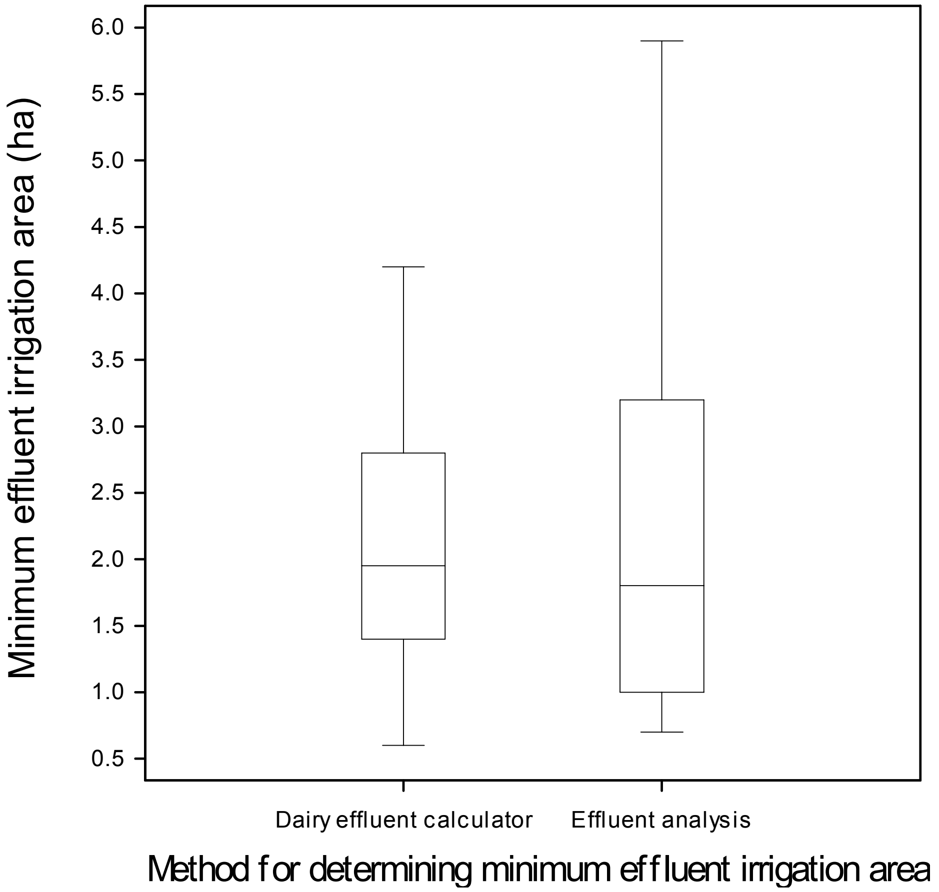

Figure 13. Minimum effluent irrigation areas determined from effluent pond analysis results and by calculation using DPI&F's *Dairy effluent* calculator (Skerman, 2004b).

Effects of effluent salinity, sodium and chloride

Table 7 provides a summary of the electrical conductivity (EC), sodium adsorption ratio (SAR), sodium (Na) and chloride (Cl) concentrations in 18 pond effluent samples, excluding the two pond samples that had been diluted with fresh water. These three chemical characteristics of effluent can impact on crop growth and soil structure in an inter-related manner.

Table 7. Summary of electrical conductivity (EC), sodium adsorption ratio (SAR), sodium (Na) and chloride (Cl) concentrations in 18 pond effluent samples.

Sample No	EC (dS/m)	SAR	Na (mg/L)	Cl (mg/L)
Min	1.0	1.4	54	71
Max	9.7	8.9	748	914
Range	8.6	7.5	694	843
Average	3.9	3.7	225	234
Median	3.5	3.4	173	171
Standard deviation	2.1	1.9	168	207

Electrical conductivity (EC) is a measure of the salinity of water. Table 8 indicates the salinity rating of each of the effluent pond samples, based on the standards in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000). This table indicates that the majority of samples have a medium to high salinity rating, with four samples in the very high category and one in the extreme category. This table includes samples 9 and 15 which were diluted with fresh water, thereby lowering the EC.

Table 8. Irrigation water salinity ratings for pond effluent samples, based on electrical conductivity (Australian and New Zealand Guidelines for Fresh and Marine Water Quality, ANZECC and ARMCANZ, 2000)

EC (dS/m)	Water salinity rating	Plant suitability	Sample numbers	No of samples
< 0.65	Very low	Sensitive crops	9*	1
0.65 — 1.3	Low	Moderately sensitive crops	10	1
1.3 — 2.9	Medium	Moderately tolerant crops	1, 3, 13, 15*, 17, 20	6
2.9 — 5.2	High	Tolerant crops	2, 4, 5, 7, 12, 14, 16	7
5.2 — 8.1	Very high	Very tolerant crops	6, 8, 11, 18	4
> 8.1	Extreme	Generally too saline	19	1

* Samples 9 and 15 were collected from ponds that had been diluted with fresh water prior to sampling.

Table 8 suggests that seventeen of the twenty samples are only suitable for irrigation onto ‘moderately’ to ‘very tolerant crops’, however, a more comprehensive assessment of the suitability of effluent for irrigation on a particular crop requires consideration of the soil characteristics, climate and irrigation management. The SALF (salt and leaching fraction) computer model (Carlin and Brebber, 1993) can be used to provide a more comprehensive assessment of the suitability of effluent for irrigation onto particular crops and pastures. This model was used by Skerman (2000) to derive the graphs in Figure 14 and Figure 15, which indicate the recommended maximum annual effluent irrigation applications resulting in limited yield reductions in low and medium salt tolerant plants respectively, growing on a black vertosol (black cracking clay) soil.

These graphs can be used as follows: The average annual rainfall throughout south-east Queensland dairy farming areas is generally greater than 750 mm. The average effluent EC recorded in this project was 3.9 dS/m. Using the lowest EC curve (5 dS/m) provided in Figure 14, the maximum recommended depth of effluent irrigation on low salt tolerant plants is approximately 220 mm/yr (2.2 ML/ha). Applications in excess of this amount could be expected to result in yield reductions greater than 10% in low salinity tolerant plants. Common dairy farming pasture and crop species that are categorised as having low salinity tolerance include rose clover, white clover, maize and paspalum.

Figure 15 suggests that even the highest salinity effluent recorded in this project (10 dS/m) could be applied at high rates (in excess of 600 mm/year) to medium salt tolerant plants.

As previously noted, Figure 14 and Figure 15 are based on a black cracking clay soil, common in some dairy farming districts. The maximum recommended application rates are likely to be higher for more freely draining soils such as loams and sandy loams, and lower for high sodium clay soils and duplex soils with low permeability sub-soils.

In most cases, the maximum recommended annual effluent application rate determined from Figure 14 (based on salinity considerations) exceeds the maximum rate determined based on nutrient (N & P) loadings, as outlined in Table 5 and Table 6 (3.8 ML over 2.3 ha = 1.65 ML/ha = 165 mm). Consequently, provided effluent applications are based on nutrient loadings, crop and pasture growth is unlikely to be adversely affected by effluent salinity for most soil / crop combinations.

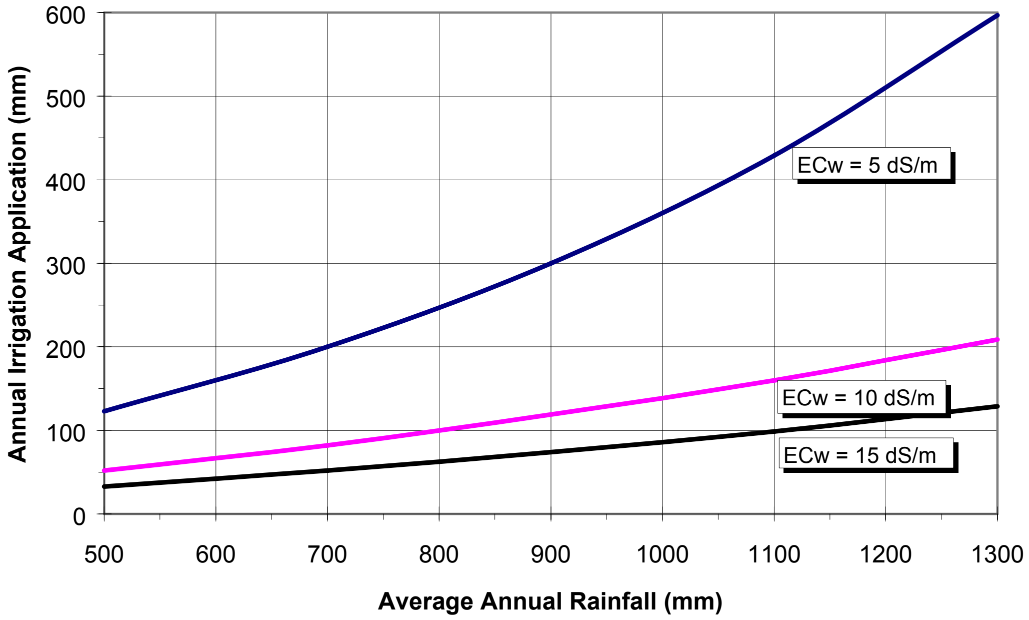

Figure 14. Maximum annual irrigation applications for up to a 10% yield reduction in low salt tolerance plants (threshold ECse = 1.9 dS/m) growing on a black vertosol (black cracking clay) soil (reproduced from Skerman, 2000).

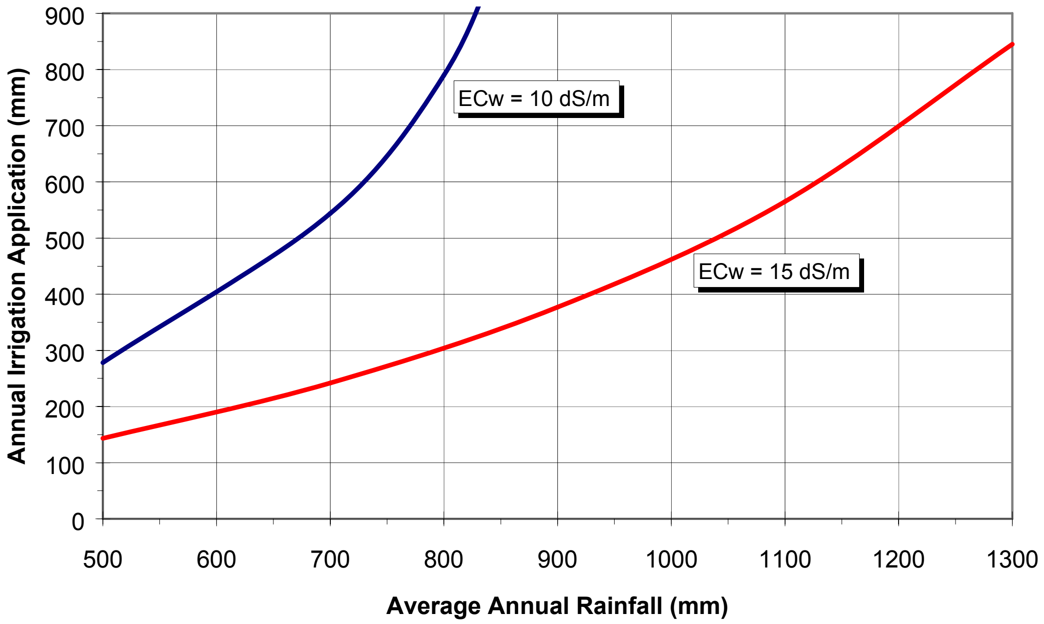

Figure 15. Maximum annual irrigation applications for up to a 10% yield reduction in medium salt tolerance plants (threshold ECse = 4.5 dS/m) growing on a black vertosol (black cracking clay) soil (reproduced from Skerman, 2000).

The above assessment focused solely on the effects of salinity on plant growth. However, the combination of salinity and sodicity can also have adverse effects on soil structure and permeability. The sodium adsorption ratio (SAR) provides a measure of the effluent sodicity. High sodium levels impair soil quality by increasing soil dispersibility, reducing water entry, making cultivation and good seed bed preparation more difficult, and reducing soil profile water availability.

Figure 16 provides some general relationships between effluent EC and SAR for predicting soil structural stability, as published by ANZECC, 2000. The EC and SAR values for the 18 pond effluent samples collected in this project (excluding the two diluted samples) have been plotted on this graph. The plotting positions of each of the pond effluent samples lie within the 'stable soil structure' area of the graph, indicating that irrigation of the pond effluent is unlikely to have an adverse effect on soil structure.

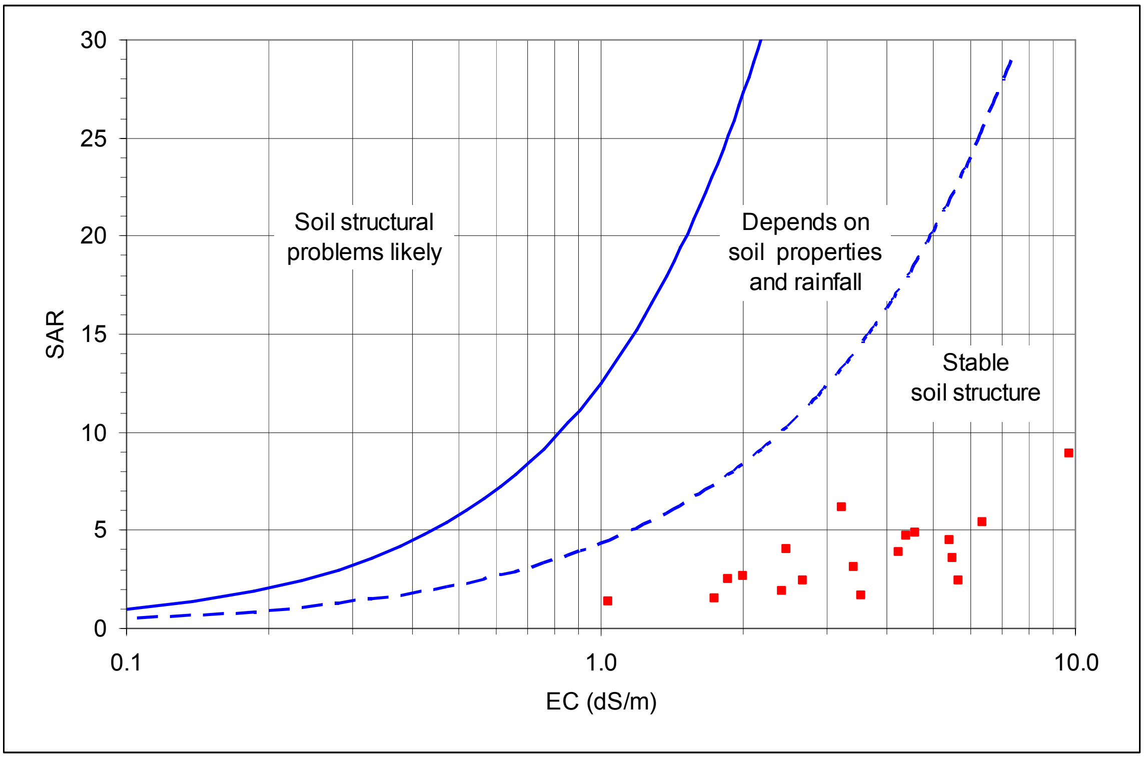

Figure 16. Relationship between sodium adsorption ratio (SAR) and electrical conductivity (EC) of irrigation water for prediction of soil structural stability (adapted from DNR 1997; as published in ANZECC, 2000. Note that 1 dS/m = 1000 µS/cm,). The 18 pond effluent samples from this project are plotted as red squares.

ANZECC (2000) provides some further figures indicating irrigation water chloride and sodium concentrations and SAR values likely to cause crop foliar damage and other adverse impacts. These figures are reproduced below.

Three of the effluent samples have chloride concentrations greater than 350 mg/L. Based on Table 9.2.12, this effluent may cause foliar damage if applied to moderately tolerant crops, such as barley, maize, lucerne and sorghum. Furthermore, six of the samples had sodium concentrations greater than 230 mg/L, indicating that this effluent may cause foliar damage to moderately tolerant crops. However, only one sample had an SAR greater than 8, indicating that this effluent may cause stunted growth in sensitive plants.

The following tables are reproduced from the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC, 2000).

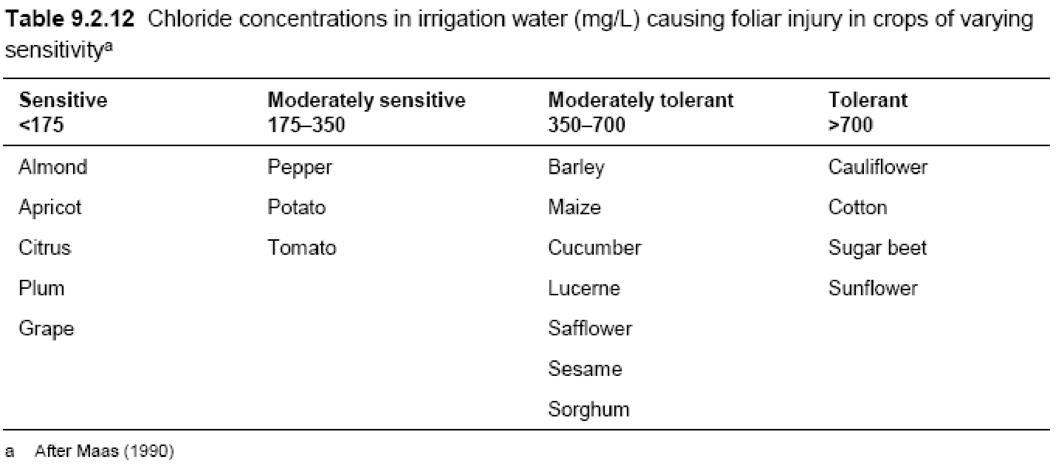

Table 9.2.12 Chloride concentrations in irrigation water (mg/L) causing foliar injury in crops of varying sensitivity[a]

Sensitive **<175**	**Moderately sensitive** **175–350**	**Moderately tolerant** **350–700**	**Tolerant** **>700**
Almond	Pepper	Barley	Cauliflower
Apricot	Potato	Maize	Cotton
Citrus	Tomato	Cucumber	Sugar beet
Plum		Lucerne	Sunflower
Grape		Safflower	
		Sesame	
		Sorghum	

a After Maas (1990)

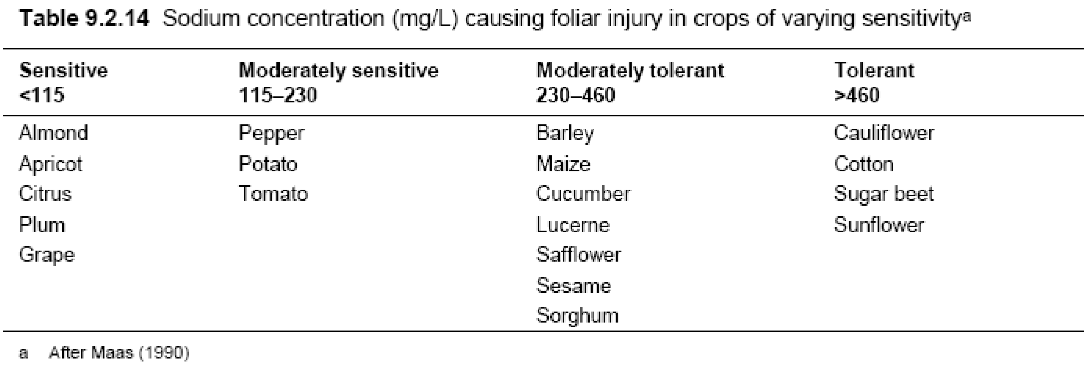

Table 9.2.14 Sodium concentration (mg/L) causing foliar injury in crops of varying sensitivity[a]

Sensitive **<115**	**Moderately sensitive** **115–230**	**Moderately tolerant** **230–460**	**Tolerant** **>460**
Almond	Pepper	Barley	Cauliflower
Apricot	Potato	Maize	Cotton
Citrus	Tomato	Cucumber	Sugar beet
Plum		Lucerne	Sunflower
Grape		Safflower	
		Sesame	
		Sorghum	

a After Maas (1990)

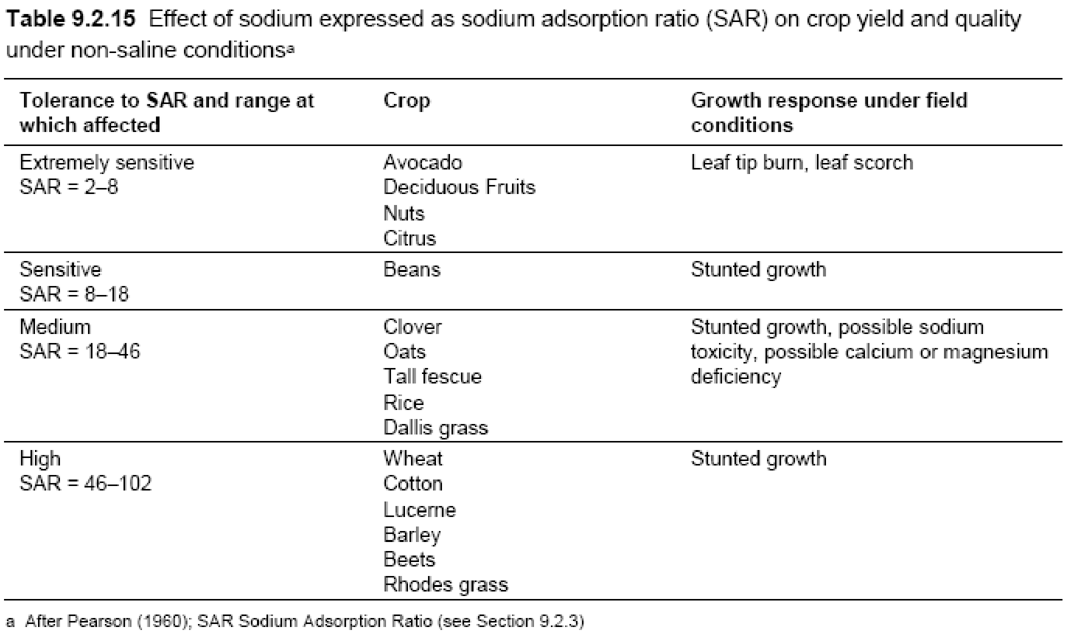

Table 9.2.15 Effect of sodium expressed as sodium adsorption ratio (SAR) on crop yield and quality under non-saline conditions[a]

Tolerance to SAR and range at which affected	**Crop**	**Growth response under field conditions**
Extremely sensitive SAR = 2–8	Avocado Deciduous Fruits Nuts Citrus	Leaf tip burn, leaf scorch
Sensitive SAR = 8–18	Beans	Stunted growth
Medium SAR = 18–46	Clover Oats Tall fescue Rice Dallis grass	Stunted growth, possible sodium toxicity, possible calcium or magnesium deficiency
High SAR = 46–102	Wheat Cotton Lucerne Barley Beets Rhodes grass	Stunted growth

a After Pearson (1960); SAR Sodium Adsorption Ratio (see Section 9.2.3)

Conclusions

The chemical characteristics of the pond effluent were highly variable. The many factors contributing to this variability are outlined in this report. The average values of the major nutrient concentrations for N, P and K were 167, 36 and 274 mg/L respectively.

There were considerable differences in effluent characteristics between samples collected from the 11 single and 7 double pond systems. In general, the range of major nutrient concentrations was considerably wider for single ponds than for double ponds. This may indicate a greater degree of effluent treatment in the double pond systems, resulting in reduced and more consistent nutrient levels. However, some of the variation may reflect the major differences in pond loading rates.

The pond loading rates were assessed by comparing estimated pond volumes with recommended volumes determined using DPI&F's *Dairy pond* calculator (Skerman, 2005a). The degree of crusting on the pond surface and the presence of any visible sludge accumulation were also taken into account in assessing the pond loading rate. In general, overloaded ponds had significantly higher nutrient concentrations and a much wider range of values in comparison to ponds that were not overloaded.

DPI&F's *Dairy effluent* calculator (Skerman, 2005b) performed relatively poorly at predicting individual pond effluent nutrient concentrations, however, the calculator predictions were generally within the range of measured values and the average values were reasonably similar. This reinforces the suggestion that the calculator cannot adequately account for the many variables that can affect nutrient concentrations. It should be noted, however, that the measured values represent a 'snap shot' in time and that long term average values for a particular pond may differ significantly from the single effluent analysis results obtained for each pond in this project.

The fertiliser replacement value of the pond effluent was estimated with DPI&F's *Dairy effluent* calculator, assuming the available effluent is used to replace applications of three inorganic fertilisers (urea, super phosphate and muriate of potash) commonly used by dairy producers. Based on the effluent data from eighteen of the sampled ponds, the annual value of the pond effluent ranged from $256 to $5209, with an average value of $2036 per year. These estimates provide a significant incentive for producers to carefully manage effluent irrigation to maximise the nutrient value.

The measured effluent nutrient concentrations were entered into DPI&F's *Dairy effluent* calculator to determine minimum recommended effluent irrigation areas, based on applying the pond effluent to grazed tropical pasture and ryegrass. The minimum recommended effluent irrigation areas ranged from 0.7 to 5.9 ha, with an average of 2.3 ha. The calculator suggested a similar average effluent irrigation area when predicted nutrient concentrations were used in place of the measured values.

Based on the ANZECC water quality guidelines (2000), the majority of effluent samples had a medium to high salinity rating, with five samples in the very high to extreme categories. However, graphs produced using the SALF model (Carlin and Brebber, 1993) taking into account average annual rainfall and soil characteristics, suggest that relatively high effluent application rates should be possible, without adversely affecting production of low salt tolerant plants, for most effluent/soil type combinations.

A further analysis accounting for the combined effect of salinity (EC) and sodium adsorption ratio (SAR) suggested that none of the effluent samples were expected to have any adverse effects on soil structure or permeability.

Based on the ANZECC water quality guidelines (2000), the chloride and sodium levels in some of the samples could be expected to cause foliar damage in moderately sensitive crops. Dilution of the effluent with fresh water and careful irrigation management could assist in alleviating potential problems. Dairy farmers should avoid applying effluent to pasture and crop species that are sensitive to sodium, chloride and salinity.

The analysis results obtained through this project provide valuable baseline data to assist in promoting better effluent management, however, the wide variability between the results for individual farms means that it is not possible to make general assumptions about effluent characteristics across all farms in south-east Queensland. Ideally, it would be desirable to carry out further longer term studies of pond effluent characteristics, taking, for example, monthly samples over a period of several months, from perhaps two or three ponds that are designed and managed according to best practice. This data would provide a better indication of the variation of effluent characteristics within individual ponds. Because some of the variation between ponds examined in this project appears to be due to overloading, by concentrating further studies on ponds that are not overloaded, some of this variation may be eliminated.

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Appendix A – Effluent analysis results

Table 9. Pond effluent analysis results for all 20 ponds.

Sample No			1	2	3	4	5	6	7	8	9 *	10
Total Kjeldahl Nitrogen	TKN	mg/L	24	49	110	68	231	93	128	348	3	34
Total Phosphorus	Total P	mg/L	10	24	27	19	64	19	54	61	3	15
Potassium	K	mg/L	32	83	20	22	41	85	3	631	7	58
Electrical Conductivity	EC	μS/cm	2,000	4,600	2,460	4,410	4,240	5,510	3,230	5,660	246	1,040
pH	pH		8.7	8.5	8.1	7.6	7.4	8.0	7.6	7.3	8.4	9.0
Nitrite	NO_2^-	mg/L NO_2^-	0.4	12.4	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1
Nitrate	NO_3^-	mg/L NO_3^-	0.9	2.0	1.3	1.0	6.1	1.2	1.6	0.2	0.8	0.9
Nitrite Nitrogen	$NO_2^- – N$	mg/L	0.12	3.77	0.07	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	0.04
Nitrate Nitrogen	$NO_3^- – N$	mg/L	0.21	0.46	0.30	0.22	1.39	0.26	0.37	0.05	0.18	0.21
Total Nitrogen	Total N	mg/L	24	53	110	68	232	93	128	348	3	34
Chloride	Cl^-	mg/L	149	421	117	449	182	914	290	250	15	79
Calcium	Ca^{++}	mg/L	36	41	40	179	114	187	87	150	15	45
Magnesium	Mg^{++}	mg/L	54	127	58	190	125	254	66	153	9	42
Sodium	Na^+	mg/L	109	280	169	377	251	326	314	177	12	54
Sodium Adsorption Ratio	SAR		2.7	4.9	4.0	4.7	3.9	3.6	6.2	2.4	0.6	1.4

Sample No			11	12	13	14	15 *	16	17	18	19	20
Total Kjeldahl Nitrogen	TKN	mg/L	459	126	215	171	10	33	22	394	439	58
Total Phosphorus	Total P	mg/L	85	35	31	28	8	21	15	73	41	26
Potassium	K	mg/L	590	157	181	343	66	604	257	662	1,020	138
Electrical Conductivity	EC	μS/cm	6,370	2,670	1,740	3,540	1,370	3,420	1,850	5,450	9,680	2,410
pH	pH		7.6	7.3	8.1	7.2	8.9	9.0	7.9	7.5	7.6	7.8
Nitrite	NO_2^-	mg/L NO_2^-	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1
Nitrate	NO_3^-	mg/L NO_3^-	1.3	0.9	0.4	0.9	0.4	0.3	0.4	0.4	0.4	1.8
Nitrite Nitrogen	$NO_2^- – N$	mg/L	0.08	<0.03	<0.03	<0.03	<0.03	<0.03	<0.3	<0.3	<0.3	0.04
Nitrate Nitrogen	$NO_3^- – N$	mg/L	0.29	0.21	0.08	0.21	0.09	0.06	0.09	0.09	0.08	0.41
Total Nitrogen	Total N	mg/L	460	126	215	172	10	33	23	394	439	58
Chloride	Cl^-	mg/L	269	160	71	90	189	183	85	88	344	78
Calcium	Ca^{++}	mg/L	136	96	65	101	76	45	46	105	172	124
Magnesium	Mg^{++}	mg/L	136	55	34	62	51	87	45	80	224	68
Sodium	Na^+	mg/L	373	118	61	88	91	155	100	249	748	107
Sodium Adsorption Ratio	SAR		5.4	2.4	1.5	1.7	2.0	3.1	2.5	4.5	8.9	1.9

* Samples 9 and 15 were collected from ponds that had been diluted by the addition of fresh water. Consequently, they are not representative of normal effluent characteristics.

Appendix B – Farm design and management data

Table 10. Design and management data for the farms where effluent samples 1 to 10 were collected.

Sample No		1	2	3	4	5	6	7	8	9 *	10
Farm locality		Gatton	Harrisville	Peak Crsg	Beaudesert	Lowood	Rosevale	Beaudesert	Beaudesert	Beaudesert	Beaudesert
Number of cows	cows	130	380	250	200	380	100	100	85	125	100
Milk production	L/cow/day	20	7000	16	19	26	18	21	19	15	17
Average cow liveweight	kg	600	580	550	640	600	500	550	500	550	450
Time spent in yards	hours/day	3	2.5	0.25	3	2.25	2	1.25	3.5	2	3.5
Daily washdown volume	L/day	10000	11000	18000	8000	6000	1600	4500	4000	6000	5500
Recycling %	%								75		
Effluent irrigation shandying %	%					50				1	5
Rainwater diversion devices		guttering		External runoff collected		guttering					
Flushed/hosed concrete area	m^2	370	413	500	200	468	350	162	830	175	
Scraped concrete area	m^2										
Scraped earth area	m^2			620							
Pre-treatment system		Stone trap		Solids trap		Solids trap	Stone trap			Grate	
Number of effluent ponds		2	2	2	1	1	2	1	1	2	2
Primary pond storage volume	ML	2.35	5.6	1.7	3.8	6	1	4	1.23	1.5	1.2
Secondary pond storage volume	ML	2.35	4.2	1.7			1.5			2	0.8
Age of ponds	years	4	10	24	7	2.5	4	5	7	8	7
Time since last pond desludging	years		3	2		Due soon	1	0.5			
Average effluent irrigation frequency	weeks			2		12			1	0.25	
Effluent irrigation method		Proposed travelling irrigator		Travelling irrigator		Travelling irrigator	Pipe	Pump into turkey's nest	Pipe	Travelling irrigator & easy shift	Easy shift
Effluent irrigation area soil type		Blenheim gilgai	Brown clay	Cyrus cracking clay	Black self mulching	Heavy black, forest ridge	Clay	White clay, sandstone	Clay	Alluvial to volcanic (black and chocolate)	Black
Effluent area crop/pasture type (summer)		Native pasture		Sorghum, lucerne, maize	Tropical pasture	Callide rhodes grass	Native pasture	Kikuyu	Kikuyu	Kikuyu, callide rhodes grass	Callide rhodes grass
Effluent area crop/pasture type (winter)		Native pasture	Rye, clover, oats	Rye, oats, lucerne	Temperate pasture	Rye	Temperate pasture	Rye, clover	Rye grass	Rye grass	Rye grass
Observations		Ponds functioning well	Ponds functioning well, 2nd pond may need emptying soon	1st pond very crusted (50%)	Pond functioning well	Clean pond, only small amount of crusting (3%)	1st pond loaded, acting like solids trap, No crusting in 2nd pond	No crusting	Pond 90% crusted, needs cleaning, Samples taken from flood wash system	Samples taken from turkey's nest used to shandy effluent for irrigation	Very clean pond, system working well

Table 11. Design and management data for the farms where effluent samples 11 to 20 were collected.

Sample No		11	12	13	14	15 *	16	17	18	19	20
Farm locality		Beaudesert	Toogoolawah	Conondale	Kenilworth	Kenilworth	Gympie	Gympie	Beechmont	Rosevale	Harrisville
Number of cows	cows	190	400	195	290		170	120	350	160	120
Milk production	L/cow/day	21	17	19	15		22	18	32	20	16
Average cow liveweight	kg	650	450	580	450		550	550	600	580	500
Time spent in yards	hours/day	1	1.5	1.5	2.25		4	1	3	2.5	2.5
Daily washdown volume	L/day	7000	30000	31500	13 500		9000	7000	1800	1600	13500
Recycling %	%										
Effluent irrigation shandying %	%				Unknown						
Rainwater diversion devices				Disused yard diverter				guttering			
Flushed/hosed concrete area	m^2	540	846	450	450		225	100	320	54	500
Scraped concrete area	m^2						500	75		54	
Scraped earth area	m^2	600	6000	900				75		10	
Pre-treatment system		Solids trap		Solids trap	Solids trap						
Number of effluent ponds	ponds	1	1	2	1		1	1	1	1	2
Primary pond storage volume	ML	1	1.44	0.75	1.75		3	3.5	2.5	8	1.5
Secondary pond storage volume	ML			2.5							2
Age of ponds	years	1	7	20	4		4	2	10	4	2
Time since last pond desludging	years	4	3	3					0.75	2	
Average effluent irrigation frequency	weeks	1	0.5	16			annually		12	0.3	4
Effluent irrigation method		Travelling irrigator	Open hose	Solid set with centrifugal pump	Travelling irrigator		Travelling irrigator	Travelling irrigator	Easy shift / yardmaster chopper pump	Travelling irrigator	Hand shift
Effluent irrigation area soil type		Sandy loam	Forest	Heavy clay loam	Clay loam, shale		Loam	Loamy	Red loam	Clay	Clay loam
Effluent area crop/pasture type (summer)		Lucerne	Rhodes grass	Kikuyu	Kikuyu		Kikuyu	Kikuyu	Kikuyu	Kikuyu	Kikuyu
Effluent area crop/pasture type (winter)		Rye grass	Rye grass	Rye grass	Rye grass, plantain		Rye grass	Rye grass	Rye grass	Rye grass	Rye grass
Observations		Pond starting to crust 5%	Sample taken from sump used for irrigation, pond, 10% crusted with grass congestion	Primary pond crusted 30%, needs cleaning	Pond hjighly loaded, with grass islands and crushing to about 40%	Primary pond loaded 15% grass, sample collected from diluted 2nd pond	Pond clean, some crusting around edges	Pond clean	Pond receives stored feed leachate (silage, pineapple), 25% grass islands, 10% crusted	Pond was 30% crusted with grass islands, needs desludging	Ponds functioning well

* Samples 9 and 15 were collected from ponds that had been diluted by the addition of fresh water. Consequently, they are not representative of normal effluent characteristics.