

# DAIRY FARM EFFLUENT TREATMENT POND PERFORMANCE IN THE WAIKATO REGION: A PRELIMINARY REVIEW OF THE REGIONAL SURVEY

N. Selvarajah, Environment Waikato, P O Box 4010, Hamilton East

## Introduction

In 1994 Environment Waikato introduced rules related to dairy farm effluent management for the Waikato region through the *Dairy Shed Effluent Operative Plan* (Environment Waikato, 1994). The rules are to (a) prohibit discharge of untreated dairy farm effluent to water, (b) permit discharge of effluent onto land provided certain conditions are met, and (c) allow discharge of treated effluent to surface water as a discretionary activity (i.e. an activity that requires a resource consent).

It is acknowledged that although the land application of effluent is now a permitted activity, oxidation ponds are still used as treatment systems by many dairy farmers to discharge effluent into waterways due mainly to practical problems associated with land based systems in certain regions. For example, despite the rapid conversion from dairy farm treatment ponds to irrigation systems in the Waikato region (1800 farms within the last two years) about 40% of dairy farmers (approximately 2400 farms) are still using dairy farm ponds as treatment systems. Operational inconvenience, poor technological transfer and high capital cost related to effluent irrigation management and unsuitable soil or climatic conditions explain the reliance on dairy farm pond systems in New Zealand. Consequently, research related to improving dairy farm discharge quality is considered very useful.

The key condition for the discharge of effluent as a discretionary activity in the Waikato region is that the effluent shall be treated in *either* (a) a two pond or barrier ditch system *or* (b) a system which can be demonstrated by the applicant to be consistently capable of achieving a discharge effluent quality of  $< 100 \text{ g BOD m}^{-3}$  and  $< 100 \text{ g SS m}^{-3}$  to the satisfaction of Environment Waikato.

The above rules were set by Environment Waikato with limited information on pond performance and effluent quality guidelines. It is believed that the current effluent quality standard (i.e.  $100 \text{ g BOD m}^{-3}$ ) could adversely impact surface water quality. However, this target was set considering oxidation pond performance rather than the effects of pond discharges on the receiving environment. There was concern that setting a higher effluent quality standard would have made the majority of pond treatment systems unacceptable as a discretionary activity. It was felt that imposing high effluent quality standards on dairy farmers prior to the discovery of practical ways of enhancing oxidation pond performance would be excessively onerous. Environment Waikato is certain that the ongoing research in this field will soon result in improved effluent discharges. It is preferred that effluent discharge standards consider contaminants such as ammoniacal-N, other nutrients and faecal coliforms - not merely BOD and SS as the current discharge quality standard specifics.

There have been very few surveys performed to monitor dairy farm effluent treatment pond efficiency in New Zealand. Of the surveys performed, Taranaki Regional Council (TRC Technical Report, 1990) and Auckland Regional Council (Grogan, 1990) are noteworthy. These surveys demonstrate that the pond systems constructed and maintained according to the MAF specifications discharge poor quality effluent, often well above  $100 \text{ g BOD m}^{-3}$ . Hickey

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*et al.* (1989) used the data collected by the former Manawatu and Southland Catchment Boards to estimate the potential impact of pond discharges on rivers. They concluded that most river water uses are accommodated provided dilution of these discharges is  $> 250$  fold. It is common knowledge that in many cases such a dilution is not available.

This paper summarises a survey of dairy farm diluent treatment pond performance on selected farms in the Waikato region and determines the existing discharge quality. The pond systems used in this study are all classified as 'good' according to the MAF specifications.

## **Methods**

### *Pond sampling*

Fifteen treatment systems were sampled within the Waipa, Waikato and Matamata-Piako districts for dissolved oxygen (DO), biochemical oxygen demand (BOD), total kjeldahl nitrogen (TKN), ammoniacal-N, nitrate + nitrite-N (NNN), pH, electrical conductivity (EC), suspended solids (SS), faecal coliforms, coliforms, chlorophyll-A, temperature, total organic carbon (TOC), dissolved organic carbon (DOC), total phosphorus (TP), and dissolved reactive phosphorus (DRP). Sampling was initiated during the 1993/94 milking season and carried on until the end of the 1995/96 milking season. Except for the 1995/96 milking season, sampling was performed every two months. The 1995/96 milking season sampling was conducted on a monthly basis.

Of the 15 treatment systems, 12 were two-pond systems, two were barrier ditches and one was a three-pond system. Samples were collected from the outflow pipe of the first and second pond of the two-pond systems, second and third ditch of the barrier ditch system and from the first and last ponds of the three-pond system during the morning, generally, following washing of the milking area. Temperature, EC and DO were measured in the field. Samples were not collected when there was no discharge from the systems. Under such conditions, the preliminary analysis of samples collected immediately adjacent to the discharge structure produced meaningless results.

### *Raw effluent sampling*

Raw effluent was collected for the 1995/96 milking season from nine selected dairy farms in the Waikato region. Raw diluent samples were collected for a different project characterising the effluent for pasture irrigation. These farms were selected because they had effluent tankers to collect effluent from the milking parlour. Samples were collected in the morning on a monthly basis following sufficient stirring using a portable pump. Ideally, for the purpose of this paper raw effluent should have been collected from the farms used for pond sample collection. One of the major problems associated with raw effluent sampling is the collection of a representative sample between the milking parlour and the first pond or ditch. Timing of sampling is critical since different washing practices may have a significant impact on the effluent quality.

## **Results and discussion**

It must be noted that although data were collected for 'anaerobic' and 'aerobic' compartments of the pond systems, this paper focuses only on the effluent quality of the 'aerobic'

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compartments. This is because from an environmental effects viewpoint the ‘aerobic’ compartments have a more direct impact on the receiving waters than that of the ‘anaerobic’ compartments.

### *Effluent quality variation between sites*

Figure 1 shows the distributions and variability of selected key parameters for all sites for the *final* pond or ditch of the treatment systems. Variation both within individual ponds with time, and among the ponds contributed to the total variability of individual parameters in the combined data set. Variability cannot generally be attributed to sampling time as all samples were collected within 2.5 hours on each sampling run. On average, the three-pond system (site M, Figure 1) has outperformed the barrier ditches and two-pond systems in terms of discharge quality. Since only one three-pond system was monitored in this study, any conclusion derived with regard to three-pond system should be treated with caution.

There is considerable variation in effluent quality within the two-pond sites (sites A-L, Figure 1). Some sites consistently yielded high quality effluent (e.g. sites A, C, K and H) whilst others had poor quality effluent (e.g. sites, B, F and G). The reasons for this can only be explained with a knowledge of the pasture, milking parlour and pond management histories. This will be addressed when a comprehensive review is undertaken.

The quality of effluent from the outflow structures of ponds and barrier ditches is summarised in Table 1. Generally, the overall performance of the pond systems is considered as satisfactory. These systems satisfactorily treat most effluent constituents effectively considering the lower capital cost and maintenance required for pond management.

**Table 1. Median quality of raw effluent and treated effluent discharged between ponds and ditches and to surface water**

Variable	Units	Raw	Pond 1	Pond 2	Pond 3	Ditch 1	Ditch 3
		n=53	n=180	n=140	n=7	n=14	n=21
Temperature	°C	n.m.	18	16	16	18	16
pH	pH units	8.6	7.4	7.9	7.7	7.7	7.6
Conductivity	mS m <sup>-1</sup>	261	260	171	117	323	174
DO	g m <sup>-3</sup>	n.m.	1.5	4.0	2.7	1.3	4.1
BOD <sub>5</sub>	g m <sup>-3</sup>	n.m.	160	83	36	160	63
SS	g m <sup>-3</sup>	4780	430	220	69	350	125
NH <sub>4</sub> -N	g m <sup>-3</sup>	130	150	69	42	170	80
NNN-N	g m <sup>-3</sup>	n.m.	0.05	0.44	0.82	0.05	0.04
TKN	g m <sup>-3</sup>	355	190	91	55	233	95
DRP	g m <sup>-3</sup>	6.6	8.5	5.7	3.9	9.3	7.9
TP	g m <sup>-3</sup>	49.1	29.7	20.0	9.4	50.0	22
DOC	g m <sup>-3</sup>	369	115	68	45	161	100
TOC	g m <sup>-3</sup>	567	176	87	54	241	105
Coliforms	n/100 ml.	n.m.	1.1 x 10 <sup>6</sup>	2.5 x 10 <sup>5</sup>	6.3 x 10 <sup>4</sup>	2.4 x 10 <sup>6</sup>	2.3 x 10 <sup>5</sup>
Faecal coliforms	n/100 mL	n.m.	5.4 x 10 <sup>5</sup>	3.5 x 10 <sup>5</sup>	3.4 x 10 <sup>4</sup>	7.0 x 10 <sup>5</sup>	5.1 x 10 <sup>4</sup>

n.m.: not measured

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### *Seasonal variations*

Time series analysis of results for each parameter for pond and ditch discharges to the environment showed considerable seasonal variation. Generally, greater levels of chemical, physical and biological constituents of the effluent were detected during the spring and summer (data not presented here). Ammoniacal-N, EC, TP, and temperature showed the biggest seasonal variation, with up to a 2-fold median increase during October to March, generally peaking in December-January. The data range typically remained constant for these parameters. Total kjeldahl nitrogen, DOC, TOC, BOD, SS and DRP, exhibited moderate seasonal variation with the median values increasing by 1.25-2 fold. The range of results for these parameters typically became wider and more variable from October to March. Faecal coliforms have no statistically significant seasonal variation, although a slight increase is apparent between October and March.

### *Effluent characteristics of the final pond or ditch*

#### *BOD and SS*

The BOD (median of  $36 \text{ g m}^{-3}$ ) and SS (median of  $69 \text{ g m}^{-3}$ ) levels of the third pond discharge fall well below the current Environment Waikato discharge quality requirement (i.e.  $< 100 \text{ g m}^{-3}$ ). In comparison, the second pond discharge of the two-pond system had a median level of  $83 \text{ g BOD m}^{-3}$  and  $220 \text{ g SS m}^{-3}$ . This is surprising since it is generally assumed that there is a strong link between SS and BOD. Similarly, the discharge from the last ditch of the barrier ditch system contained  $63 \text{ g BOD m}^{-3}$  and  $125 \text{ g SS m}^{-3}$ . In terms of BOD and SS removal, three-pond > barrier ditch > two-pond.

#### *NH<sub>3</sub> and NH<sub>4</sub>*

Most dissolved constituents of the discharge appear to be greater in the ditch discharge compared with the two and three-pond systems. Ammoniacal-N levels are greater in the last ditch (median of  $80 \text{ g N m}^{-3}$ ) compared to three-pond (median of  $42 \text{ g N m}^{-3}$ ) and two-pond ( $69 \text{ g N m}^{-3}$ ) system discharges. It must be noted that in receiving waters ammoniacal-N plays three roles; (a) un-dissociated or unionised ammonia (i.e.  $\text{NH}_3$ ) is toxic to fish (b) both  $\text{NH}_3\text{-N}$  and  $\text{NH}_4\text{-N}$  (collectively referred to as ammoniacal-N) are available for aquatic plants and bacteria and (c) since  $\text{NH}_4\text{-N}$  is the most reduced form of N, a large amount of oxygen is required during the nitrification process to generate  $\text{NO}_3\text{-N}$  the most oxidised form of N.

Ammonia ( $\text{NH}_3$ ) levels in effluent or receiving waters vary according to the pH and temperature. In comparison, pH influences  $\text{NH}_3$  levels more than temperature (i.e. an increase in pH increases the level of  $\text{NH}_3$ ). Surface water or effluent samples obtained for  $\text{NH}_3$  toxicity without temperature and pH measurements are meaningless. If temperature, pH and ammoniacal-N levels are known,  $\text{NH}_3$  levels can be determined using a chart or equation. The pH of the respective discharges were 7.6 for ditch, 7.9 for two-pond and 7.7 for three-pond. The temperature for all three systems was  $16^\circ\text{C}$ . Using this information it has been estimated that the  $\text{NH}_3\text{-N}$  levels were  $1.9 \text{ g m}^{-3}$  (two-pond),  $0.4 \text{ g m}^{-3}$  (three-pond) and  $0.7 \text{ g m}^{-3}$  (ditch). Thus although the ditch system had a high ammoniacal-N level ( $80 \text{ g m}^{-3}$ ) due to a lower pH the ditch system had a low  $\text{NH}_3\text{-N}$  level compared to the two-pond system. Nevertheless, according to the ANZECC water quality guidelines all the three system discharges will require sufficient dilution in the receiving waters to minimise the toxicity to fish (ANZECC, 1992).

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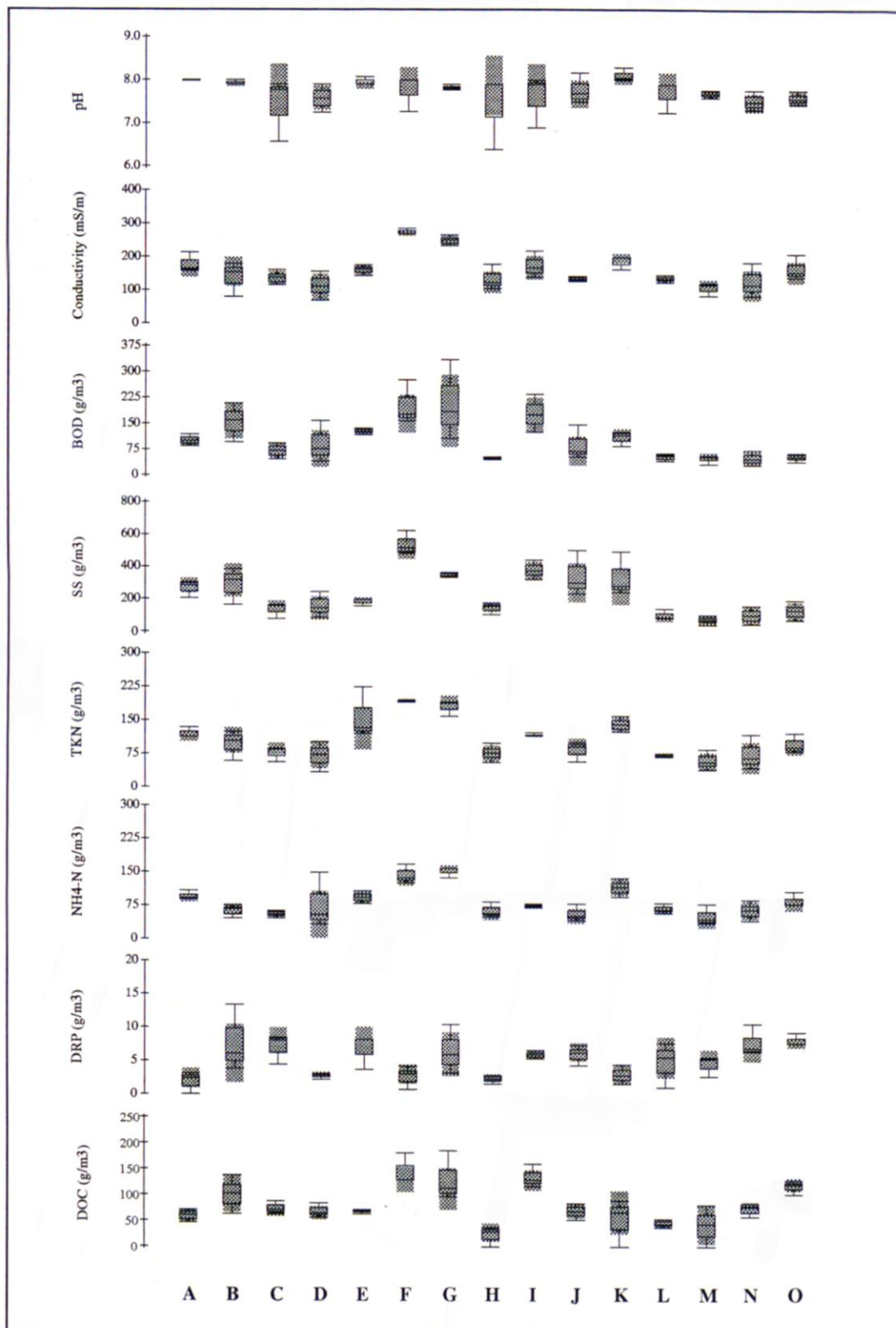


Figure 1. Comparison of effluent characteristics of aerobic ponds for two-pond (A-L), three-pond (M), and ditch systems (N-O). The box indicates the interquartile range (IQR), the bar the median value, and 'whiskers' =  $1.5 \times \text{IQR}$ . Shaded portion indicate 95% confidence interval for comparing medians.

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Using  $0.02 \text{ g m}^{-3}$  as a safe level for  $\text{NH}_3$ , the dilution required for two-pond discharge is 95 fold compared to 20 fold for three-pond and 35 fold for ditch discharges.

Using a conversion factor of 4.33 it has been estimated that the oxygen demand resulting from ammoniacal-N is  $346 \text{ g m}^{-3}$  for barrier ditch,  $298 \text{ g m}^{-3}$  for two-pond and  $182 \text{ g m}^{-3}$  for three-pond systems. Thus combined with the BOD will result in a net oxygen demand of  $409 \text{ g m}^{-3}$  for ditch,  $381 \text{ g m}^{-3}$  for two-pond and  $218 \text{ g m}^{-3}$  for three-pond systems. Thus although the ditch discharge required less dilution than the two-pond system to reduce  $\text{NH}_3$ , the dilution required to minimise net oxygen demand is greater than that for the two-pond system. This finding illustrates that whilst greater dilution is required to minimise fish toxicity from two-pond discharge, less dilution is required to minimise net oxygen demand.

#### *Other dissolved constituents*

The levels of DRP and DOC were found to be greater in the ditch discharge ( $\text{DRP} = 7.9 \text{ g m}^{-3}$ ,  $\text{DOC} = 100 \text{ g m}^{-3}$ ) compared to the three-pond ( $\text{DRP} = 3.9 \text{ g m}^{-3}$ ;  $\text{DOC} = 45 \text{ g m}^{-3}$ ) and two-pond ( $\text{DRP} = 5.7 \text{ g m}^{-3}$ ;  $\text{DOC} = 68 \text{ g m}^{-3}$ ) system discharges. This difference is comparable with ammoniacal-N. It is noted that the three-pond discharge carries less dissolved ions ( $\text{EC} = 117 \text{ mS m}^{-1}$ ) than the other two systems. Despite lower levels of DRP and ammoniacal-N in the two-pond discharge compared with the ditch system, both of these systems have similar levels of ions ( $\approx 170 \text{ mS m}^{-1}$ ). Since other ions such as potassium and sulphate were not monitored it is difficult to infer the reason for the similarity in EC for the two-pond and ditch system.

The NNN (nitrate + nitrite-N) level was  $< 1 \text{ g m}^{-3}$  in all three discharges. The immediate inference from this observation is that there was insufficient dissolved oxygen available to oxidise  $\text{NH}_4\text{-N}$  to  $\text{NO}_3\text{-N}$  form. Dissolved oxygen levels were initially measured due to their potential usage to describe certain biochemical reactions in the pond systems. However, it was noticed that the DO levels could be influenced substantially by the presence or absence of sunlight and chlorophyll, particularly in the top few centimetres of the effluent ponds despite the oxygen demand exerted by effluent bacteria due to high  $\text{NH}_4\text{-N}$  and BOD levels. Consequently, DO level monitoring was discontinued during the early part of the investigation.

The second pond of the two-pond system is generally referred to as an aerobic pond and is shallow (1.1 m depth) compared with its anaerobic (3.6 m depth) counterpart. Thus it is expected that the second pond will be more oxygenated. The few DO data points obtained indicate that there is oxygen available for the nitrification process (approximately  $4 \text{ g m}^{-3}$  for the two-pond and ditch systems and  $2.7 \text{ g m}^{-3}$  for the three-pond system). However, there was little or no  $\text{NO}_3\text{-N}$  found in the effluent discharge. It was suspected that nitrification could occur in effluent ponds, however, due to the high levels of DOC and heterotrophic activity,  $\text{NO}_3\text{-N}$  could be rapidly denitrified.

Nitrifiers ( $\text{NH}_4$ -oxidisers and  $\text{NO}_2$ -oxidisers) are autotrophic bacteria that use mineral-N ( $\text{NH}_4$  and  $\text{NO}_2$ ). DO and dissolved inorganic-C for their metabolism unlike heterotrophic bacteria which depend on dissolved organic-C: nitrifiers oxidise  $\text{NH}_4 \rightarrow \text{NO}_2 \rightarrow \text{NO}_3$ . The presence of these bacteria in effluent may indicate that there is a potential for nitrification. Five second pond samples were selected randomly and analysed for  $\text{NH}_4$ -oxidisers by Sarathchandra and Burch (1995) using a most probable number (MPN) method described by Sarathchandra (1979). Ammonium-oxidisers were selected as indicators for nitrifiers because  $\text{NH}_4$ -oxidisers

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are considered to be more sensitive to surrounding environmental changes than NO<sub>2</sub>-oxidisers. The bacteria count ranged from  $0.7 \times 10^2$  to  $3.5 \times 10^5$  counts mL<sup>-1</sup>. Sarathchandra and Burch (1995) indicated that in soil environments a population count of  $1 \times 10^4$  is insignificant (i.e. no significant NH<sub>4</sub> oxidation). However, in liquid environments, due to unrestricted movement, a similar number could be considered as significant. Further work is required to confirm the extent of nitrification in the second pond.

One of the important observations made during this study was the frequency of discharges from treatment ponds. It was noticed that during summer several ponds failed to yield discharges. Generally it is assumed that since evaporation rates exceed the influent rates, no discharge results. A simple estimate of water balance will indicate that the daily influent amount should exceed the evaporation rate in the Waikato region. For example, an influent amount of 10 m<sup>3</sup> for a 200 cow herd will result in a 9 mm d<sup>-1</sup> increase in pond effluent (assuming a total pond area of 1100 m<sup>2</sup>). This increase is substantially greater than maximum daily summer evaporation rates (7 mm d<sup>-1</sup>) in the Waikato region and hence a discharge should result. This indicates that the pond systems in the Waikato region leak a considerable amount of effluent into the ground. A recent preliminary pond seepage study commissioned by Environment Waikato showed that a single "discharging" anaerobic pond in the Hinuera area leaks about 1 m<sup>3</sup> effluent d<sup>-1</sup> (an average seepage of 3.3 mm d<sup>-1</sup>) (Ray *et al.*, 1995). The general perception of the wider community is that discharges from dairy farm effluent treatment ponds have adverse effects on the receiving waters. Although this is the case for many areas in New Zealand, from an environmental viewpoint it could be argued that pond seepage minimises surface water quality degradation during the low flow periods. Low flow periods are particularly sensitive to contamination due to the low assimilation capacity of surface waters during these conditions.

## Conclusions

Preliminary review of the regional pond performance survey indicated that in general a three pond system can achieve better quality effluent than two-pond and barrier ditch systems.

On average all three types of systems monitored complied with the Environment Waikato BOD level requirement (BOD level should be < 100 g m<sup>-3</sup>). However, the two-pond and barrier ditch systems failed to comply with the SS requirement (SS level should be < 100 g m<sup>-3</sup>).

Since high ammoniacal-N levels are discharged into waterways a high level of dilution is required on all three types of systems to minimise fish toxicity. The dilution required is greater for two-pond discharges due to the alkaline nature of the discharge.

It is suspected that the effluent environment in the final ponds is conducive for nitrification. However, NO<sub>3</sub>-N produced could be rapidly denitrified due to the high level of DOC and heterotrophic bacteria.

Many pond systems in the Waikato region have little or no discharge during the summer season. Although high effluent evaporation losses minimise summer discharges, the major reason for no discharge is likely to be due to pond seepage. This observation is considered as positive from the surface water quality viewpoint due to the low assimilation capacity of surface water for contaminants during summer season.

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