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CLEARTECH®: A NEW TECHNOLOGY TO IMPROVE EFFLUENT MANAGEMENT

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Introduction

In response to requests to help dairy farmers improve effluent management and reduce risk-exposure, a joint research project known as the ClearTech® development was undertaken by Lincoln University and Ravensdown Ltd. The aim of the project was to develop a new effluent treatment system that would: (i) reduce the volume of effluent that needed to be irrigated or stored each day; (ii) reduce the risk of contamination of rivers, lakes and groundwater from effluent irrigation; and (iii) reduce water use by recycling water to wash the farm yard safely. A detailed description of the ClearTech® technology has been given by Cameron & Di (2019), and the environmental benefits of applying the treated effluent and the clarified water on to farm land have also been reported by Wang *et al*. (2019) and Chen *et al*. (2019). In order to further determine the effects of applying the treated effluent (TE) on nutrient losses and *E. coli* leaching compared with the untreated farm dairy effluent (FDE) a new lysimeter study was conducted to verify results reported previously. This paper briefly outlines the key features of the ClearTech® system and reports the results from the lysimeter study. For details of the ClearTech® technology, refer to Cameron & Di (2019).

Background

There are environmental concerns about land application of FDE because it can be a non-point source of pollution, creating adverse impacts on water quality (Cameron & Di, 2004; McLeod *et al*., 2014). Land application of farm dairy effluent (FDE) can contaminate, both directly and indirectly, rivers, lakes and groundwater with phosphorus (P) and nitrogen (N), as well as micro-organisms, such as *E. coli.* The New Zealand Dairy Industry recognises these concerns and the first Commitment of the Dairy Industry strategy "Dairy Tomorrow" is that: "We will protect and nurture the environment for future generations" and "Lead efforts to improve the health of our rivers and streams…" (DairyNZ, 2018)

On average about 70 L of effluent is produced per cow per day from the water that is used to wash the farm yard, milking parlour and milking equipment (DairyNZ, 2014). Therefore, the average New Zealand dairy farm with c. 400 cows produces about 28,000 L of FDE per day and, over a typical 270 day milking season, this amounts to more than 7,500,000 L of effluent produced per year.

Farm dairy effluent mostly consists of water, urine, dung, soil, feed, cleaning chemicals and milk. The solids content of FDE is low (c. 0.9%) (Longhurst *et al*., 2000) and the majority of the FDE is water (c. 99%). FDE contains a large number of pathogenic bacteria which can pose a risk to humans if it leaks from soil into water during irrigation of the FDE.

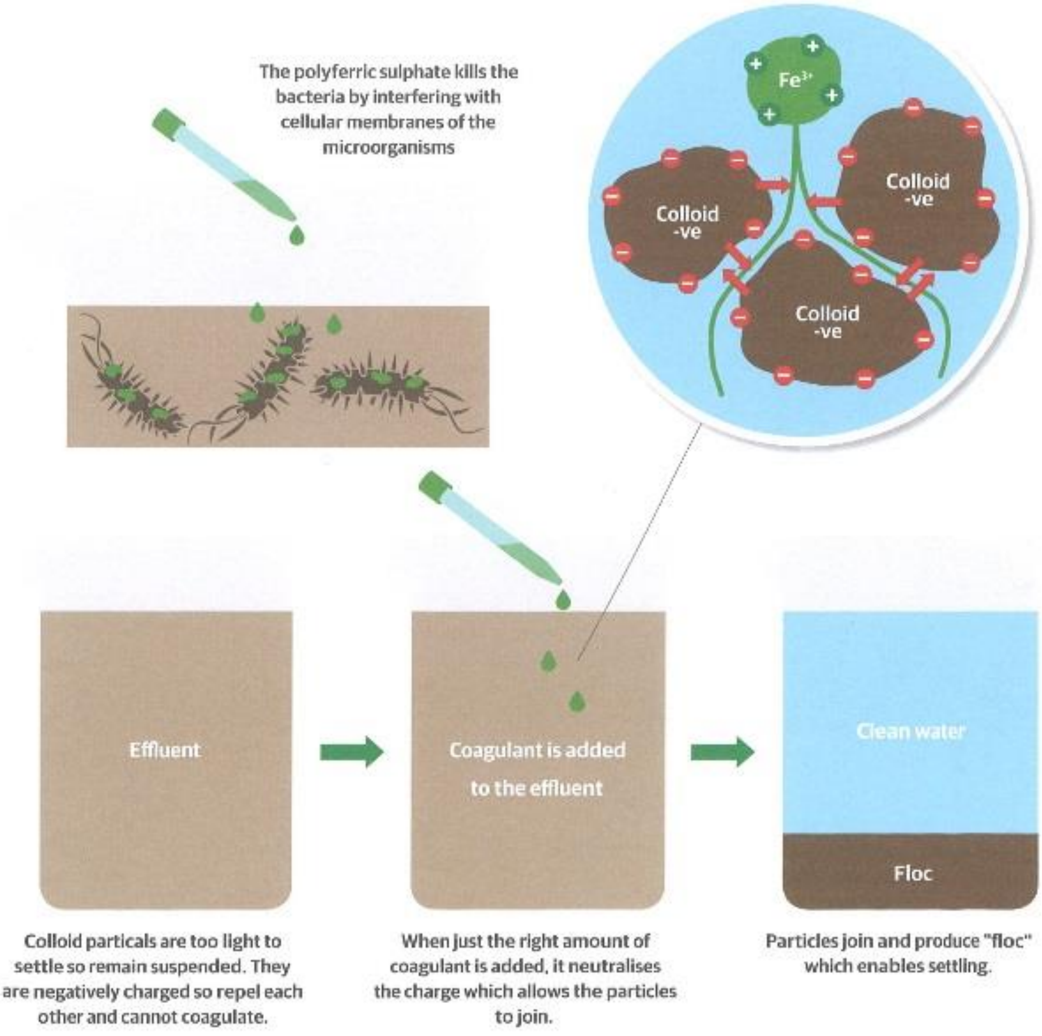
ClearTech® effluent treatment system

The new system for treating FDE (ClearTech®) is based on established engineering processes that are used in municipal water and waste water treatment plants around the world (Cameron & Di, 2019).

Coagulation

The primary treatment process involves ‘coagulation and flocculation’ which is used to remove fine colloidal material (e.g. soil, dung, organic matter) from the effluent and produce clarified water. The fine colloidal particles in effluent are not heavy enough themselves to settle out of water under gravity. The colloidal particles are also negatively charged so they repel each other causing them to remain in suspension. The addition of a coagulant to the effluent neutralises the negative electrical charges on the surfaces of colloids allowing the particles to form into ‘flocs’ that have sufficient mass to settle out of the water under gravity (Figure 1). The coagulant can also create a mechanism called ‘sweep floc’ which enhances the process and helps stick the colloids together.

Figure 1. Coagulation and flocculation mechanisms treat the effluent, clarify the water and kill the bugs.



The polyferric sulphate kills the bacteria by interfering with cellular membranes of the microorganisms

Colloid particals are too light to settle so remain suspended. They are negatively charged so repel each other and cannot coagulate.

When just the right amount of coagulant is added, it neutralises the charge which allows the particles to join.

Particles join and produce "floc" which enables settling.

Polyferric Sulphate

Multiple types of coagulant are used in the treatment of drinking water and wastewater however our research found that polyferric sulphate (PFS) was a very effective coagulant for use in treating FDE. Health studies have shown that drinking water treated with polyferric sulphate is safe for human consumption (Hendrich *et al*., 2001). In addition, ferric sulphate is approved by the US Food and Drug Administration (FDA) as a food additive and is also affirmed as 'generally recognised as safe' (GRAS) for human consumption by the FDA (FDA, 2017). Iron is an essential dietary element and ferric sulphate is used to increase the iron content of, and add flavour, to food (FDA, 2017).

Pilot Plants

Multiple pilot plants have been modelled, constructed and/or tested with the latest plant being a 30,000 litre sequencing batch reactor (SBR) placed on Lincoln University Dairy Farm (LUDF).

Initial runs of the SBR at LUDF treated 26,000 L of FDE per run, producing approximately 15,000 L of clarified water each time, leaving a reduced volume of effluent (11,000 L) needing to be stored or irrigated. This reduction in the volume of effluent to be stored (i.e. from 26,000 L down to 11,000 L) could more than double the number of days of effluent storage capacity available in the pond. The volume of clarified water produced (15,000 L) was greater than the average volume of water (c. 7000 L) required each milking to wash the farm yard on an average New Zealand dairy farm milking 400 cows (Cameron & Di, 2019).

The increase in the number of days of effluent storage could help reduce the risk of effluent breaches due to the pond not filling so quickly. It could also enable the farmer to have a greater opportunity to apply the effluent at a time that avoids the risk of surface ponding occurring. Increasing the number of days of pond storage could potentially reduce the risk of nitrogen leaching, by delaying effluent application until spring when plant uptake of nitrogen is higher.

Turbidity

Initial runs of the SBR significantly reduced the average turbidity from 2947 of the untreated FDE down to 16 nephelometric turbidity units (NTU) (representing a reduction of 99.5%) (Cameron & Di, 2019).

E.coli

Earlier large tank studies (Cameron & Di, 2019) showed a significant reduction in *E.coli* concentration from an average of 247,718 coliform units (cfu) per 100 mL in the untreated FDE down to 55 cfu per 100 mL in the clarified water (representing a 99.98% reduction). This occurs because the coagulant kills the bacteria by breaking the cellular membrane around the microorganism. In addition, the 'sweep floc' mechanism also captures the microorganisms from the effluent liquid and traps them inside the floc.

E. coli numbers in the treated effluent at the bottom of the tank were also reduced by up to 91%. This makes the treated effluent much safer to irrigate because it is less likely to cause leaching of microorganisms into rivers, lakes and groundwater.

Other Parameters

The following table (Table 1) shows the average parameter values for untreated farm dairy effluent, clarified water and treated effluent produced by treatment of the FDE with PFS in the large tank studies.

Table 1. Average parameter values for untreated FDE, clarified water and treated effluent (adapted from Cameron & Di, 2019). Statistically significant differences between untreated farm dairy effluent and the clarified water or the treated effluent are shown at $p < 0.001$ as ***; $p < 0.01$ as **; $p < 0.05$ as * and no significant difference as NS.

	Untreated Farm Dairy Effluent	**Clarified Water**	**Treated Effluent**	**Difference between Untreated Farm Dairy Effluent and Clarified Water**	**Difference between Untreated Farm Dairy Effluent and Treated Effluent**
	Mean	**Mean**	**Mean**	**Significance**	**Significance**
Turbidity (NTU)	2214	17	6361	***	***
E. coli (cfu 100ml^{-1})	247718	55	22816	***	*
Total-N (g m^{-3})	200	87	447	***	***
NH_4-N (g m^{-3})	56	43	55	*	NS
Total-P (g m^{-3})	35.27	0.44	111.80	***	***
DRP (g m^{-3})	9.68	0.02	0.03	***	***
K (g m^{-3})	198	182	195	*	NS
S (g m^{-3})	28.20	224.97	320.97	***	***
pH	7.89	5.35	5.24	***	***
Solids (g m^{-3})	3173	24	8961	***	***
Water (%)	99.7	100.0	99.1	***	***

Pasture Field Trial

Pasture field trials were conducted to test if there were any differences in plant production or plant chemical composition when clarified water or treated effluent was applied when compared to standard untreated effluent (Cameron & Di, 2019).

Importantly, the results showed that there was no significant difference in the amount of pasture dry matter produced by the application of clarified water or treated effluent compared to the untreated effluent over the experimental period (1 year). There were also no significant differences between the annual average plant concentrations of N, P, K, Ca or Na between the untreated FDE and the clarified water or treated effluent plots (Cameron & Di, 2019).

Lysimeter study

The lysimeter study was conducted at Lincoln University, Canterbury, New Zealand (43º 38′ 52″ S, 172º 28′ 07″ E), where the annual average temperature is 11.5°C and the annual rainfall is 630 mm.

The soil used was a Balmoral stony silt loam (Typic Dystrudept, USDA) collected from Lincoln University's Ashley Dene Research and Development Station situated near Springston on the Canterbury Plains, New Zealand (NZGD2000: 43º 38′ 42″ S, 172º 20′ 33″ E). The soil texture in the first 15 cm was a moderately permeable, well drained silt loam, but the soil profile became increasingly stony below this depth with ~50% of the soil volume occupied by stones by 30 cm depth, and the remaining volume interspersed with fine-to-coarse sands. The lysimeters contained pasture consisting of perennial ryegrass (*Lolium perenne* L., cultivar Grasslands Nui) and 10%-20% white clover (*Trifolium repens* L., cultivar Grasslands Huia).

In March 2017, twenty undisturbed soil monolith lysimeters (0.5 m diameter, 0.7 m depth) were collected using standard protocols and procedures (Cameron *et al*., 1992). The lysimeters were transported to Lincoln University's Field Research Centre next to the Lincoln University campus, and were installed in a purpose-built field trench, with the surface of the lysimeters at the same level as the surrounding field; thus ensuring that the lysimeters were exposed to the same environmental conditions as the rest of the field. Plastic tubing was connected to the base of each lysimeter and fed into a 10-L container for leachate collection.

Fresh FDE was collected from Lincoln University dairy farm after milking in the morning of the treatment application day. The coagulant (polyferric sulphate, Cameron & Di 2019) was added to the fresh FDE to flocculate the solids in the effluent. After about 30-60 minutes, the FDE separated into two layers: (i) upper clarified water (CW) for recycling and (ii) the lower treated effluent (TE) which had a higher concentration of solids. Subsamples of each effluent type were taken for analyses as described in Cameron & Di (2019).

Four treatments were established in a randomized block design with four replicates and the treatments applied on 23rd May 2018. Three types of effluents: (i) standard effluent (FDE), (ii) treated effluent (TE), and (iii) a mixture of TE and clarified water that had been recycled (M), were applied at the maximum rate of 24 mm allowed under local regulations. The correct volume of effluent was poured directly and uniformly onto the entire surface area of the lysimeters, with the same volume of water applied to the control.

The grass was cut periodically to simulate typical grazing practice, and weeds were removed by hand.

Leachate was collected from the lysimeters whenever there was 200 mL in the drainage vessel or weekly. Subsamples were collected to determine the concentration of *E. coli*., total phosphorus (TP), dissolved reactive phosphate (DRP), NO_3^--N, and NH_4^+-N (as described in Cameron & Di 2019). The amounts of *E. coli*, phosphorus and nitrogen leached from the lysimeters were calculated by multiplying the volume of leachate with the concentrations at each sampling time. Total mineral N leaching loss represents the combined leaching losses of NO_3^--N and NH_4^+-N.

Effect of effluents on *E. coli* leaching losses

After the first treatment, *E. coli* breakthrough curves for the FDE, TE and M peaked at 2,389, 193, and 141 cfu 100 mL^{-1}, respectively, which occurred between 10-20 mm drainage (Figure 2).

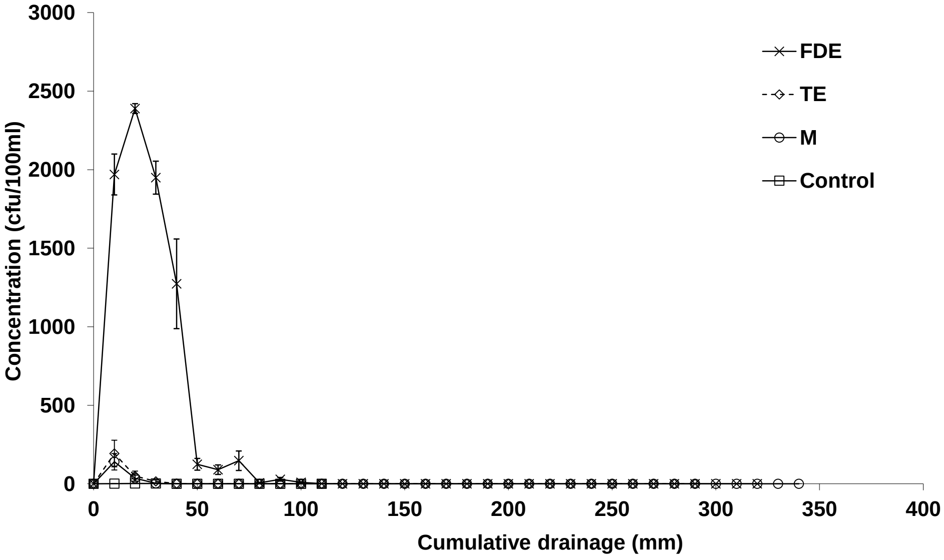


Figure 2. Average leachate *E. coli* concentrations in drainage water from the lysimeters

Total leaching losses of *E. coli* were significantly ($P<0.05$) lower from the TE (1.4×10^{9} cfu ha^{-1} *E. coli*) and M (1.2×10^{9} cfu ha^{-1} of *E. coli)* treated lysimeters compared to the losses from the untreated FDE lysimeters (4.25×10^{10} cfu ha^{-1} of *E. coli*) (Table 2).

Table 2. Average amounts of leaching loss over the experimental period. Means with different letters with-in the same column indicates significant difference (*P<0.05*).

	E. coli **(cfu ha^{-1})**		**P Loss (kg P ha^{-1})**				**N Loss (kg N ha^{-1})**	
			Total-P		**DRP**		**NO_3-N**	
FDE	4.25E+10	a	0.93	a	0.085	a	1.23	a
TE	1.41E+09	b	0.18	b	0.010	b	0.87	a
M	1.20E+09	b	0.15	b	0.010	b	1.31	a
Control	3.87E+07	c	0.11	b	0.011	b	1.59	a

Effect of effluents on phosphorus leaching losses

Total phosphorus (TP) concentrations increased significantly after the FDE treatment, reaching peak concentrations of 3.18 mg P L^{-1} (Figure 3). This peak concentration is well above those in the TE and the M treatments which had a total P concentration of 0.41 mg P L^{-1} and 0.17 mg P L^{-1} , respectively (Figure 3).

The TP leaching loss was significantly (P<0.05) lower from the TE lysimeters (0.18 kg P ha^{-1}) and the M lysimeters (0.15 kg P ha^{-1}) compared to the FDE lysimeters (0.93 kg P ha^{-1}) (Table 2). There was no significant difference in TP leaching losses amongst the TE, M and the control treatments.

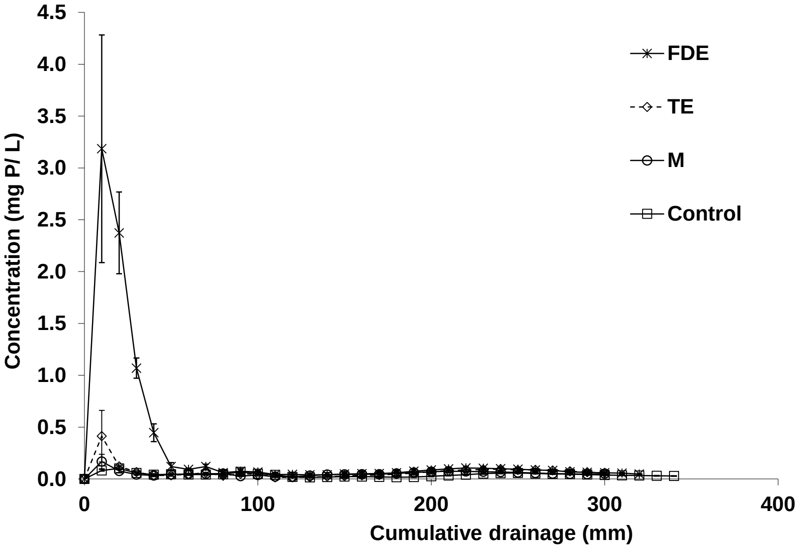


Figure 3. Average leachate total-P concentrations in drainage water from the lysimeters

The DRP leaching breakthrough curve showed a higher peak concentration from the FDE treatment (0.39 mg P/L) compared to those from the other effluent treatments; which were very low and not significantly different to the control values (< 0.01 mg P/L) (Figure 4). The total amounts of DRP leaching loss from the TE and M lysimeters (< 0.01 kg P ha^{-1}) were significantly lower than that from the FDE lysimeters (0.086 kg P ha^{-1}) (Table 2). There were no significant differences in the DRP leaching losses among the TE, M and the control treatments (P<0.05) (Table 2).

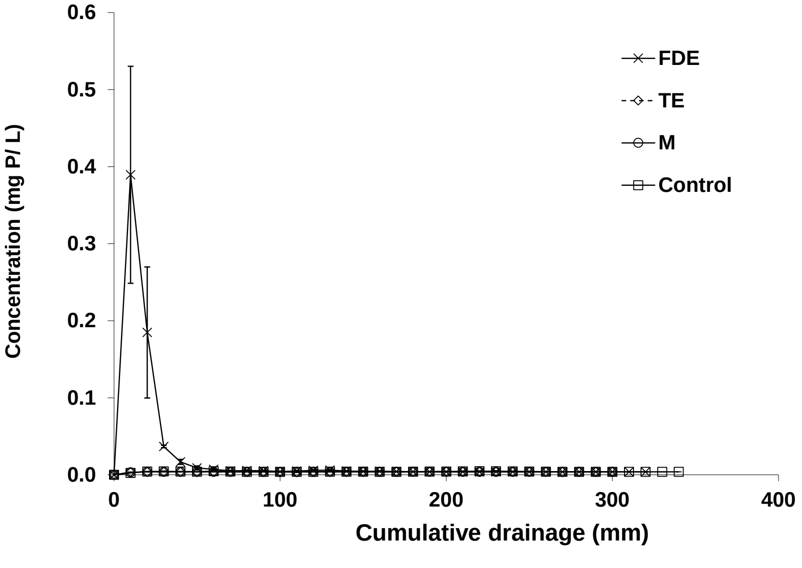


Figure 4. Average leachate DRP concentrations in drainage water from the lysimeters

Effect of effluents on nitrogen leaching losses

There were no significant differences in NO_3^--N concentrations among the different treatments (Figure 5) and no significant differences between the total amounts of NO_3^--N leached from the different treatments (Table 2). The concentrations and amounts of N leached were small compared to those that occur from animal urine patches (Di & Cameron, 2002a,b; Cameron & Di, 2004).

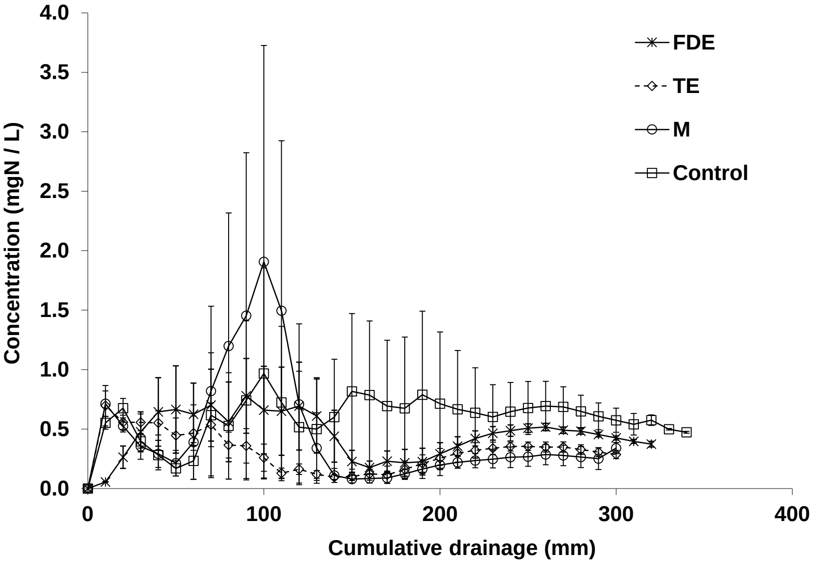


Figure 5. Average leachate nitrate-N concentrations in drainage water from the lysimeters

Discussion of results from lysimeter study

Results from this field lysimeter study support the findings reported in our earlier paper (Wang et al. 2019) that land application of ClearTech® treated effluent (TE) or the TE plus recycled clarified water (M treatment) can significantly reduce the leaching loss of *E. coli*, total phosphorus (TP), and dissolved reactive phosphorus (DRP), compared with leaching losses from land application of untreated original FDE. The reductions in *E. coli* leaching losses were equivalent to 97% for both the TE and the M treatments. The reductions in TP leaching losses were equivalent to 81% and 84% for the TE and M treatments, respectively. The reductions in DRP leaching losses were 88% for both the TE and M treatments.

These reductions in *E. coli*, TP and DRP leaching losses represent significant environmental benefits that would be gained by treating the FDE using the latest effluent treatment technology before land application.

Summary

The key opportunities/benefits of this new method of treating farm dairy effluent are:

- Reduced water use at the farm dairy through recycling water to wash the yard saving water and cost.

- Increased number of days of storage in existing pond. This could reduce the risk of a consent breach, improve timing of effluent application to reduce environmental impacts, and could help meet FEP audit requirements for effluent storage.
- Reduced risk of *E. coli* and phosphate pollution of water from land application of ClearTech® treated effluent and clarified water; compared to land application of untreated FDE.
- Reduced time shifting the effluent irrigator that could result in fewer runs of the irrigator and thus free up staff time for other duties.

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