PREFERENTIAL FLOWPATH LAND TREATMENT SYSTEM

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ABSTRACT

New Zealand produces around a billion litres of municipal wastewater per day. (inf-facts-issues-Sep09.pdf, 2009) Currently very little of this effluent is used for farm irrigation, despite declining water resources in many areas. A key obstacle to uptake of treated wastewater is perception. Thus whilst technology is sufficiently advanced to ensure that public health risks are acceptable in a scientific sense, there is a knowledge gap in achieving cultural acceptability.

The research proposes the use of constructed trenches set on a sloping hillside in low permeability soils (clay loam/clay). Trenches are excavated and filled with a local soil of higher permeability (silts and sands) with a reused topsoil covering. The effluent can move only slowly through the surrounding soil (low permeability) and so chooses an easier flowpath through the filtration soil. Whilst some effluent will be lost to ground, the vast majority will follow this *preferential flowpath* down the trench, receiving treatment through a number of mechanisms along the way. The system uses bio-mimicry to replicate the natural processes through which water is purified by the environment in the upper soils layers, and is used as a polishing treatment.

A trial trench was constructed and municipal wastewater passed through the trench over a three-week period. The system was also dose loaded with manufactured MS2 phage to investigate virus removal efficacy. Sampling at entry, intermediate points, and exit of trench indicated a four-log removal of e-coli and MS2 phage, high Biochemical Oxygen Demand removal (82%-98%), and 98% Phosphorus removal.

KEYWORDS

Land treatment, municipal wastewater treatment, phosphorus removal.

1 INTRODUCTION

Sustainable Wairarapa Incorporated received funding from the Agricultural Marketing and Research Development Trust (AGMARDT), Greater Wellington Regional Council, Carterton District Council, Masterton District Council, and South Wairarapa District Council to carry out a land treatment trial based on the Preferential Flowpath Land Treatment System concept.

The trial was carried out in partnership with Carterton District Council, on Council land at the wastewater treatment plant in Dalefield road, Carterton.

The primary purpose of the investigation was to scope the feasibility of contaminant removal from treated municipal wastewater, namely the ‘human elements’ that compromise the use of recycled water by a perception taint. Whilst mechanical removal is relatively straightforward, there is a perceptual difference when ‘natural’ or biological processes are used to effect this removal.

There are many examples of how recycled water perceptually loses its stigma and is viewed as fresh or natural water. Septic tanks, for example, discharge into ground, and the wastewater in its passage through soil into the groundwater and in its passage through land as groundwater, is transformed into water. Whilst the physical and chemical changes to the water are sometimes less reliable than man-made treatment processes, public perception favours this natural process.

This trial therefore attempts bio-mimicry by introducing land treatment as a mechanism for recycled water polishing in a controlled manner.

In other related matters, the storage of treated wastewater for farm irrigation during the summer months is jeopardised by the possibility of algal growth, caused by high nutrient levels. Thus, nutrient removal is also of benefit for farm irrigation when storage is considered.

The system is the intellectual property of EQOnz ltd, and has a patent pending.

1.1 LOCATION

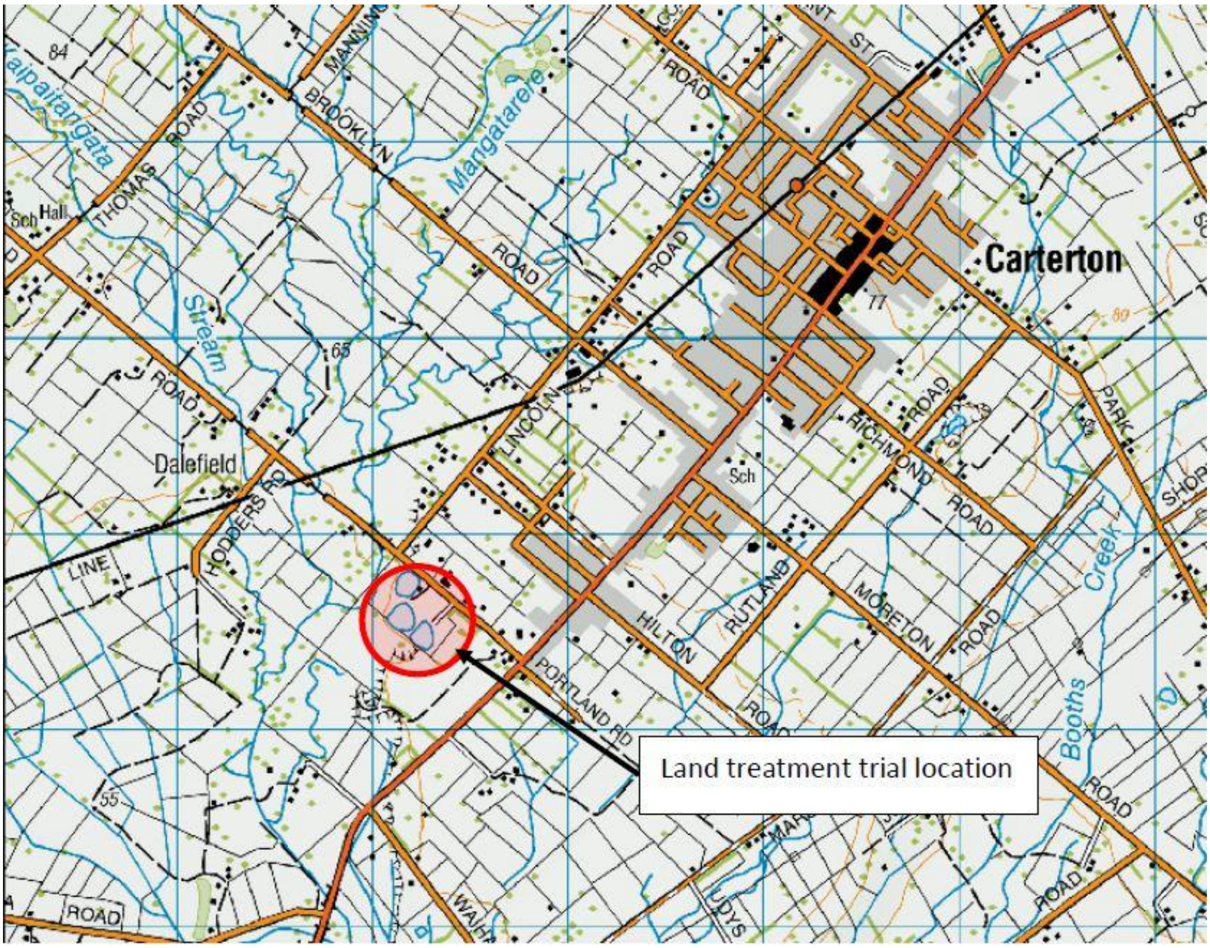


Figure 1 Site Location Plan

The site provided not only a physical space in which to construct the trial trench, but also treated and partially treated municipal wastewater with which to test the efficacy of treatment.

The trial trench is located at the eastern end of the site adjacent to the oxidation pond (fig. 2).

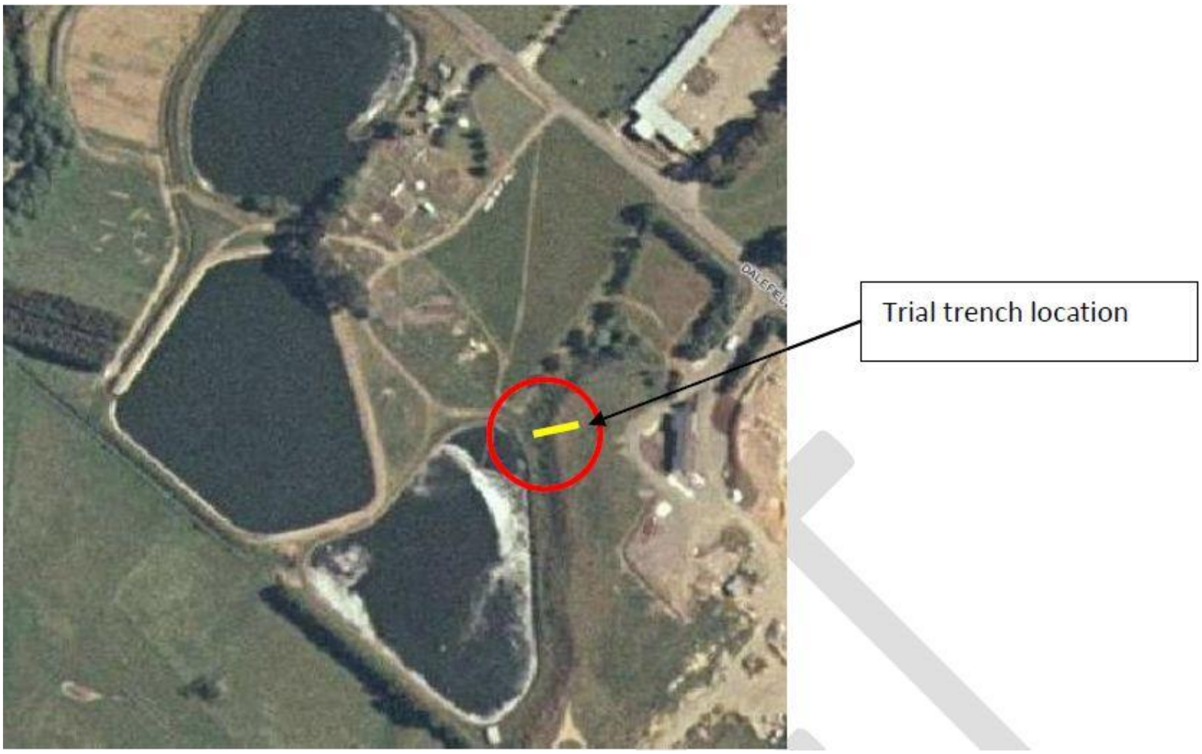


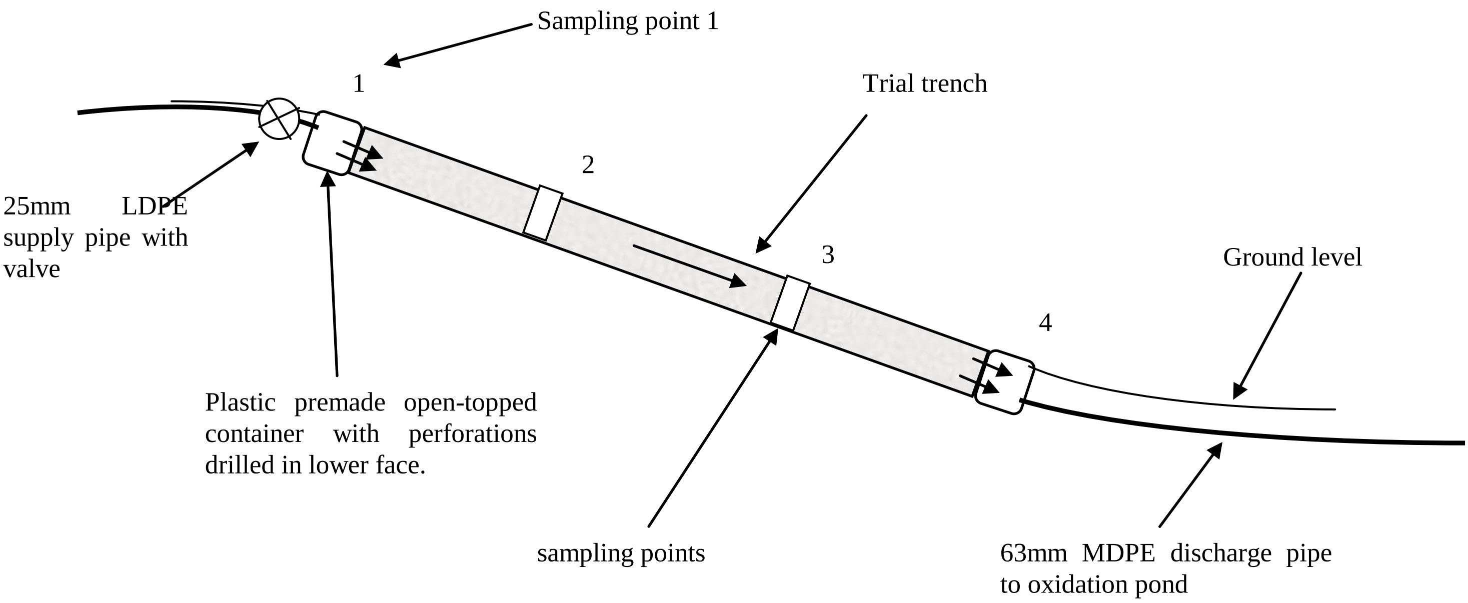
Figure 2 trial trench location

The trench was located to receive effluent from the feed pipe for an effluent dripline area, and from a submersible pump in the primary oxidation pond adjacent.

The outlet from the trench returns to the oxidation pond.

2 TRENCH DETAILS

2.1 SCHEMATIC



2.2 SOIL CHARACTERISITICS

In order to make a realistic end product for full scale use, relatively high permeability soils are needed (permeability of around 10m/d and upwards). This requires a sand material. In order to increase the treatment efficacy Environmental Science & Research investigations suggest that incorporation of volcanic soils is beneficial (these have the opposite ionic charge to pathogens) (Pang, Volume 38, July–August 2009). Pumice sand was therefore imported from Taupo as a mixer.

The capacity of soils for effluent renovation is commonly limited by depth to groundwater. In addition, the upper, oxygenated soil layers provide habitat for biological activity not present in deeper soil strata. Research by Environmental Science & Research (Pang, Volume 38, July–August 2009) recorded microbial removal rates through different types of soil, which varied from around 0.3 to 16 log/m (mean), most soils displaying mean removal rates of between 1 and 4 log/m. Typically sandy soils out-performed clayey soils. There are a number of mechanisms that remove pathogens in sand filter systems (Bomo, Stevik, Hovi, & Hanssen, 2004) (Garabedian, 1991).

It is clear that in terms of microbial removal, the longer passage through soil, the better the removal rate, and the greater the proportion of biologically active soil, the better the removal rate.

The desire to re-use recycled water for irrigation requires that water be recaptured after land treatment, and this is not always possible or practicable in naturally occurring soil strata. In-situ soils can also exhibit non homogeneous conditions or macro-pore flowpaths, reducing the efficacy and predictability of treatment.

The above limitations led to the generation of the Preferential Flowpath Land treatment System (PFLTS) (patent pending). This concept utilises an imported high permeability soil confined within a trench in a low-permeability naturally occurring site soil. The water is (relatively) unable to escape through the surrounding impermeable soil, and follows a preferential flowpath through the high permeability soil.

2.3 CONSTRUCTION & TRIAL PERIOD

The trial trench was constructed in early May 2011, and a three week trial period was run from 16th May to 2nd June 2011.

2.3.1 SAMPLING

Timing: Given the soil transmissivity, it was anticipated that there would be a delay between effluent entering the trench and it appearing at the sampling points. An initial timing trial suggested that there was a 2 hour time lag for each 5m so 6 hours overall. This time lag was progressively applied between effluent application and sampling for each sampling point.

Aggregate samples were taken where possible to increase the probability of samples being representative. Sampling was carried out by the Environmental Health Officer for Carterton District Council. Before sampling, each container was labelled with the date and time of sampling, site name, and sampler identification. Nutrient samples were collected in sterile plastic nutrient containers provided by the ELS. Samples were collected by completely submersing the open container in the effluent until the bottle was entirely filled. Bacteria and MS2 phage sampling was conducted using aseptic technique. Each sample was collected in sterile 500ml tinfoil covered glass jars. The samples were sealed leaving an air gap of 20ml, and stored upright a chilly bin containing ice packs. All the samples from the day were refrigerated overnight and sent on the express courier to ELS or Environmental Science & Research the following morning. A completed Chain of Custody document accompanied each set of samples to ELS/ESR.

2.3.2 INFLUENT QUALITY

Different influent qualities were trialled (and hence contaminant concentrations). The experiment had three distinct phases:

a) Current best (final) wastewater treatment plant effluent quality (disk filtration and UV) [week 1]
b) Water taken directly from the primary oxidation pond [week 2].
c) Spiking the final effluent with MS2 phage concentrate to measure the removal efficiency [week 3].

The existing effluent quality was trialled first, as that is the most likely scenario for actual full scale use. E-coli concentrations were low in the influent, and did not adequately test the trench in terms of pathogens; however nutrient and physical parameters were also modelled.

The effluent in all cases is viewed as mediocre quality in terms of that envisaged for a full-scale system, where it is anticipated that further removal of gross solids would be necessary to ensure a suitable trench life expectancy. A passive screening or sand filter may be suitable.

Whilst physical contaminant testing was continued past the first week, the effluent quality on the second week was so poor that it was expected to overload the trench in terms of physical loading. In fact, the results indicate that although there would undoubtedly be long-term implications of applying low quality effluent, in the short-term high contaminant removals are still possible, particularly for Phosphorus.

The physical testing in week 3 was contaminated by soil entering the bottom chamber (washed off from above), and the results have been ignored.

2.3.3 CONTAMINANTS TESTED

CONSTITUENT	NUMBER OF DAYS PER SAMPLING ROUND	LOCATION	TOTAL NUMBER OF SAMPLES	TIMING /SAMPLING ROUNDS	TESTING BY
TOTAL N	4	1,4	24	WEEK 1,2,&3	ESL
TOTAL P	4	1,4	24	WEEK 1,2,&3	ESL
SUSPENDED SOLIDS	4	1,4	24	WEEK 1,2,&3	ESL
DISSOLVED OXYGEN	4	1,4	24	WEEK 1,2,&3	ESL
BOD_5	4	1,4	24	WEEK 1,2,&3	ESL
MS2 PHAGE	4	1, 2, 3, 4	16	WEEK 3	ESR
E-COLI	3	1, 2, 3, 4	21 OVERALL	WEEK 1&2	ESR

Table 1 sampling details

3 COMMISSIONING

The trial trench was commissioned using final Carterton District Council effluent; however, it became apparent on the first day of sampling that this had not been sufficient, as fines and protein type foam were apparent in the sampling ports. It is thought that this is due to the 'settling down' of the particles in the trench fill, finding their physical equilibrium. During this period, finer material is released.

The test results for some parameters were therefore compromised on the first day of sampling.

4 RESULTS

The results are separated into three categories: physical, biological, and appearance.

4.1 PHYSICAL TESTING

For all physical parameters except Dissolved Oxygen, a reduction in the parameter is of environmental benefit. For these parameters a percentage reduction is cited, for Dissolved Oxygen (DO) a percentage increase is cited (i.e. for all parameters a negative percentage indicates degradation).

Dissolved Oxygen

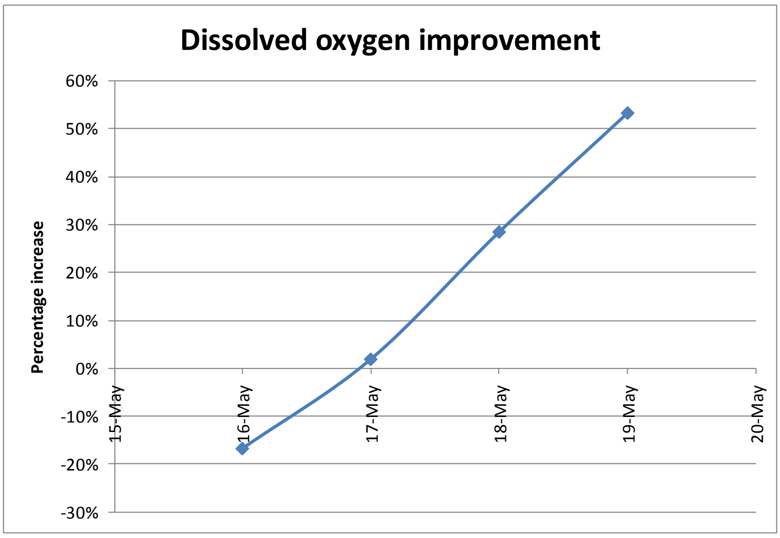


Figure 3 Improvement in dissolved oxygen in passage through the trench. Week 1

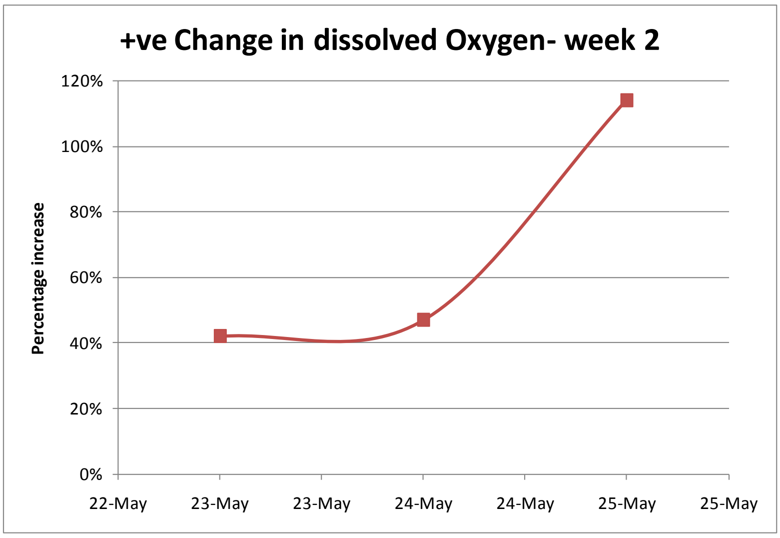


Figure 4 Improvement in dissolved oxygen in passage through the trench. Week 2

It can be seen that an improvement in dissolved oxygen was achieved in passage through the trench.

Suspended Solids and Nitrogen:

The suspended solids removal was good under the normal Carterton District Council effluent, and decreased with the poor quality oxidation pond water. The nitrogen removal rate is clearly dependent on a number of factors (as per the nitrogen cycle) and is a complex issue (fig. 10). Given experience in land application systems elsewhere, cut and carry crops could be used to remove nitrogen. In addition, NIWA has trialled trenches using sawdust as a medium to absorb Nitrogen from effluent, and this is a possibility here.

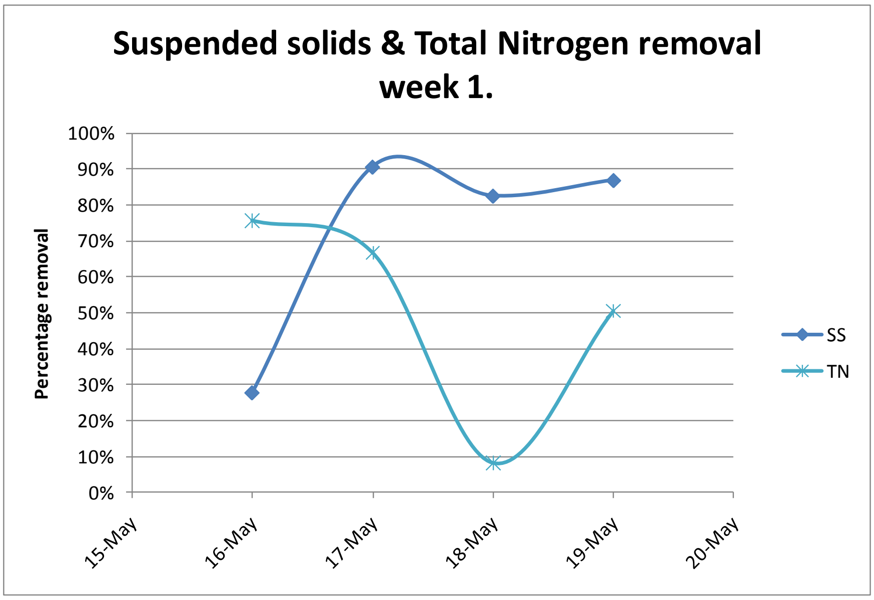


Figure 5 Suspended solids and Nitrogen removal rates week 1

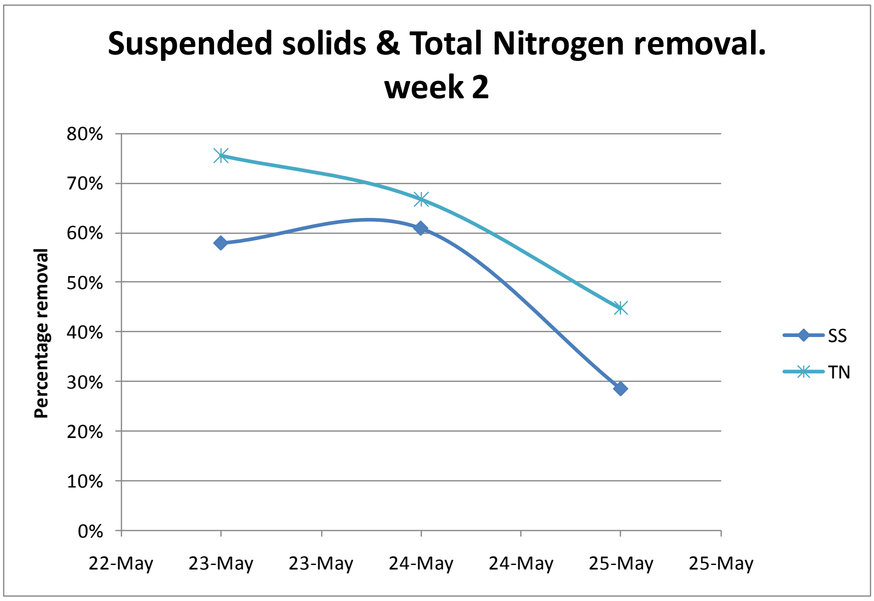


Figure 6 Suspended solids and Nitrogen removal rates week 2

Phosphorus and Biochemical Oxygen Demand:

The Phosphorus removal was significantly higher than anticipated, and remained high for the duration of the trial. Biochemical Oxygen Demand removal appears related to the influent quality, but was also relatively high.

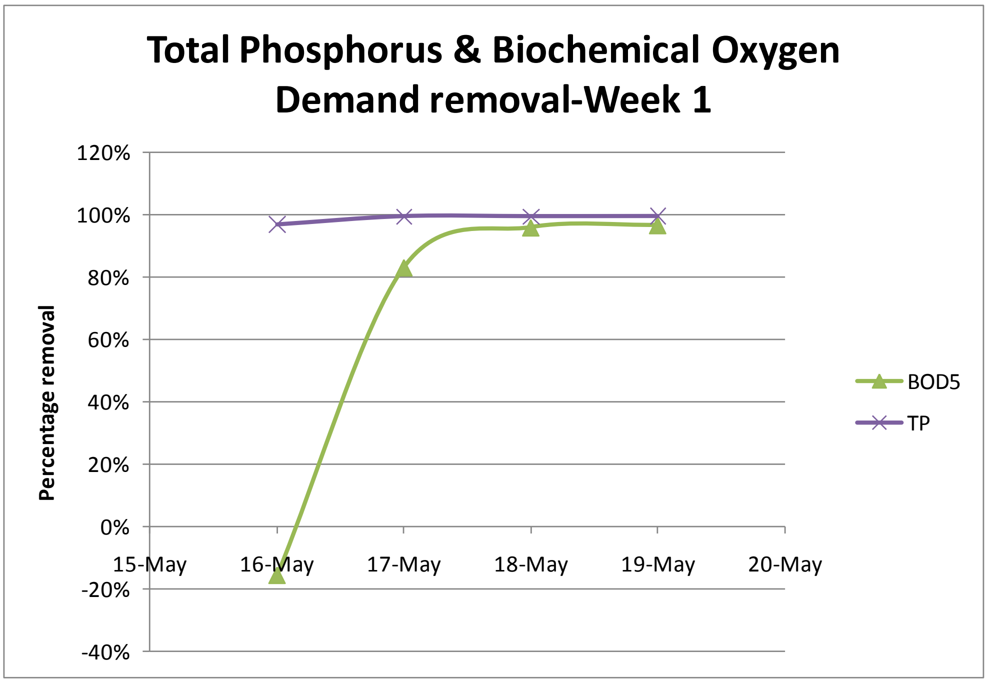


Figure 7 Total Phosphorus and Biochemical Oxygen Demand removal. Week 1

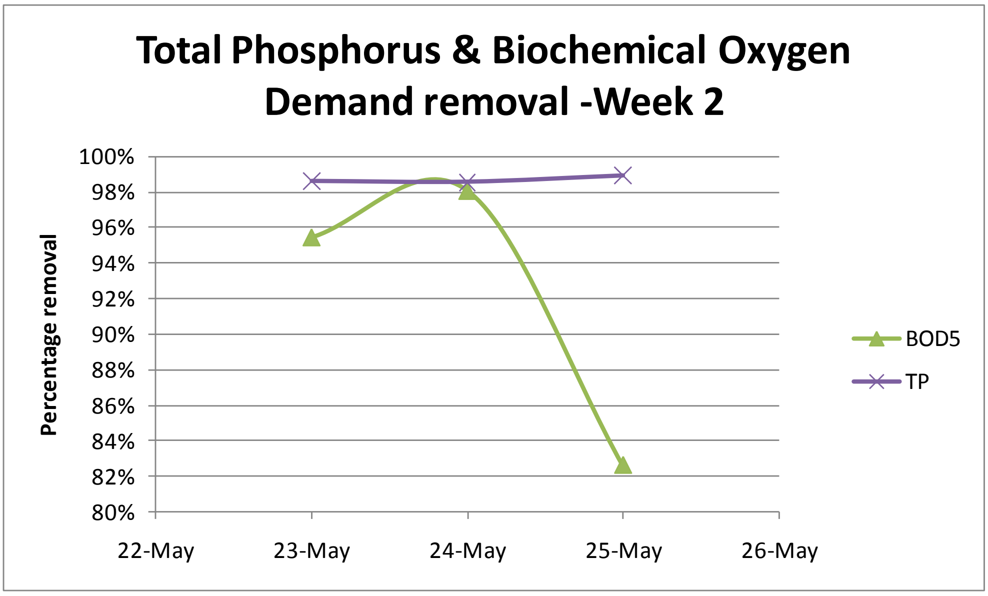


Figure 8 Total Phosphorus and Biochemical Oxygen Demand removal. Week 2

4.2 PATHOGEN TESTING

The trial, in terms of pathogen, investigated e-coli removal (week 1&2) and virus removal (week 3). Suitable e-coli concentrations were obtained by using primary oxidation pond effluent. An MS2 phage was propagated by Environmental Science & Research in Christchurch, and mixed into a dosing tank at the head of the trench (fig. 14).

Figure 9 Header tank for dose loading of viruses

This allowed a known volume and hence the virus concentration could be established such that it was at an appropriate level for testing. Virus concentrations were at a level 20-250 times that that could be expected in raw sewage from a contaminated community (Metcalf & Eddy, 2003).

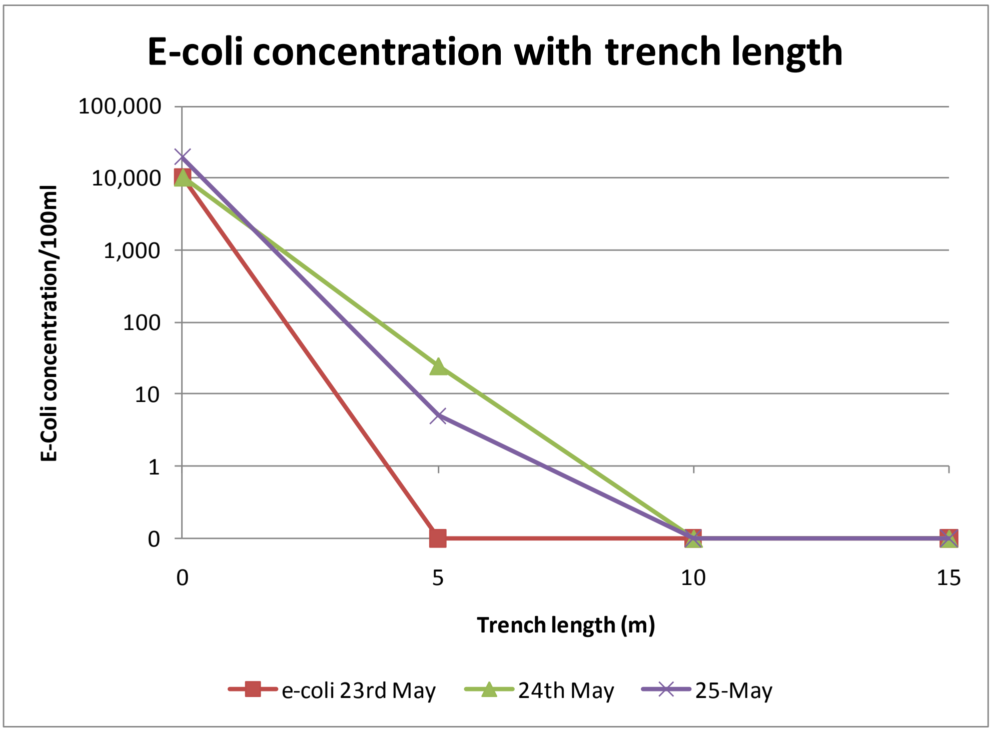


Figure 10 E-coli Concentration with trench length (oxidation pond effluent)

Note: The e-coli test results should strictly be recorded as Most Probable Number <1, but for ease of presentation have been shown as zero.

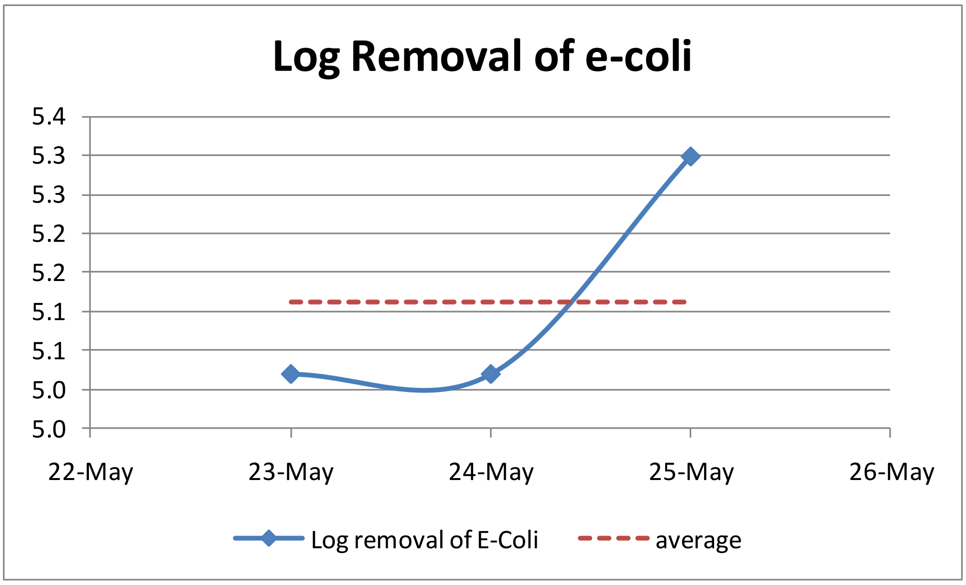


Figure 11 log removal of e-coli

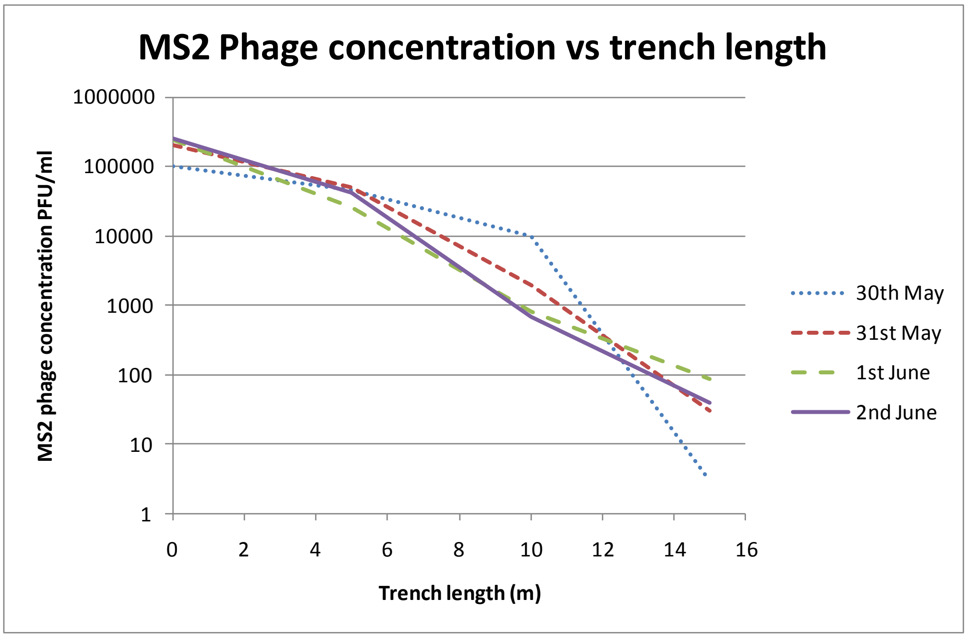


Figure 12 Virus (MS2 phage) removal

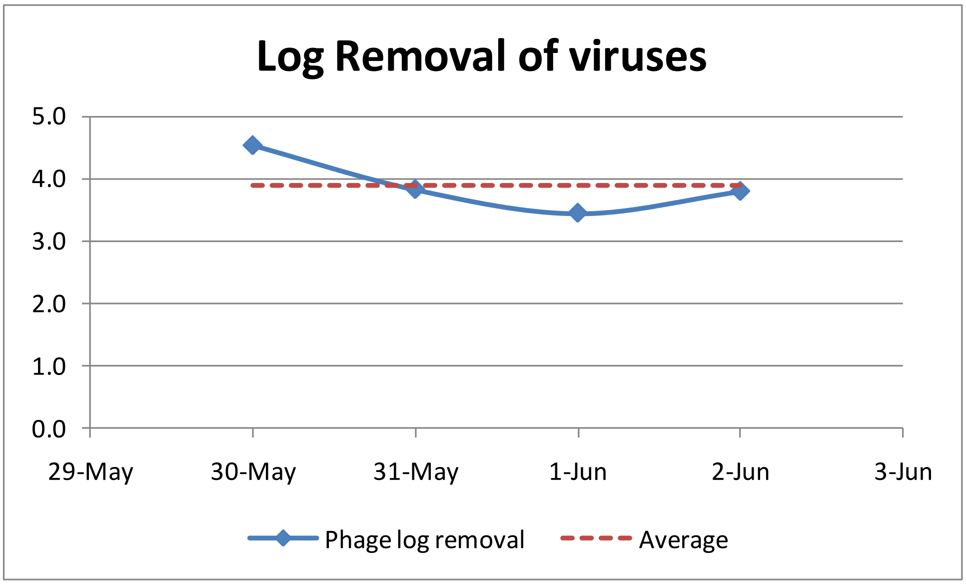


Figure 13 Log removal of viruses

4.3 APPEARANCE

The resultant recycled water was clear, colourless, devoid of any visible solids, and had no odour (fig. 19).

Figure 14 Recycled water (left) and influent (right) samples

5 DISCUSSION

The trial objective was to provide a proof-of-concept and engage the community in terms of the perception of land treatment as a method of providing socially acceptable recycled water.

Ra Smith of Ngati Kahungunu ki Wairarapa was commissioned to provide an Iwi perspective on the perception of wastewater treatment and how the Preferential Flowpath Land Treatment System performed in this role (Smith. R, 2011). The results are encouraging, and tend to support the hypothesis that if contaminants in the water are removed to such an extent that the origin of the water cannot be deduced, a new classification of 'recycled water' is formed, as distinguishable from 'treated wastewater'. This creates significantly more opportunities for water reuse.

The trial was for a relatively short duration, and it is still unknown how the system would perform on a long-term basis. Following the trial results, Carterton District Council has agreed to instigate further monitoring to assess whether the system could be used as part of its long-term treatment solution. This monitoring will provide greater certainty on the longevity and efficacy of the system, and take it from proof-of-concept to full-scale implementation stage.

It has been agreed with Carterton District Council that the trenches remain (i.e. do not get de-commissioned), and that they are available for further testing in terms of other contaminants. Of particular interest is the performance in terms of emerging contaminants such as hormones. Environmental Science & Research have expressed interest in involvement in this, and there may be significant Public good in carrying out such studies. The current study therefore has flow-on benefits outside of the results of the study.

In wastewater treatment terms, a 4-log reduction in pathogens is a significant goal. Because of the likely influent concentrations, it generally reduces pathogen counts to acceptable risk levels for human contact. The reductions indicated in this trial suggest that as a polishing treatment (i.e. there are a number of treatment mechanisms beforehand that are likely to reduce contaminant levels), both bacterial and viral pathogens could be completely removed from the water. Once again, the consistent removal over time needs to be proven, however the removal mechanisms believed to occur suggest that removal efficacy should continue unabated.

Although the study was focussed on the removal of human elements, physical parameters were also measured, and indicated some significant improvement in water quality. Of particular interest was the removal of Phosphorus which, at around 98%-99%, is considerably higher than might be expected. The main benefits of this are:

- Recycled water stored for future farm irrigation is significantly less at risk of toxic algal blooms if the nutrient levels are reduced in the magnitude observed in the trial.
- There is a possibility of adapting the system for use in the treatment of dairy shed effluent.
- It increases the possibility of treating municipal wastewater to a standard at which discharges to water may be considered satisfactory.

This research features as a significant addition to the Sustainable Wairarapa Incorporated Recycled Water Farm Irrigation Feasibility Study (Sustainable Wairarapa Incorporated, 2011)

Soils have a finite capacity for adsorption of Phosphorus, and following the trial results Landcare Research were engaged to carry out Phosphate Sorption Curves – laboratory tests that give an indication of the capacity of the soil to retain Phosphates. The aim was to predict the longevity of the trenches (the point at which trench fill material would need to be replaced). This is the primary factor in the operational cost of the trenches, and hence the system viability when Phosphorus removal is required. The results and analysis indicated that further knowledge of the mechanism of Phosphorus removal is needed to enable prediction of trench longevity, and in practice, field verification is needed.

It also appears feasible that when the trench fill reaches Phosphorus holding capacity, it could be removed, air dried, and sold as a fertiliser product. It would be high in Phosphorus and Nitrogen, and in an easy form for incorporation in soils. It is envisaged that as world Phosphorus supplies decline and prices increase, this will become more attractive.

6 CONCLUSIONS

The trial established that the land treatment system has significant potential as a polishing treatment for municipal wastewater.

The system has the capacity for total removal of human pathogens from traditionally treated municipal wastewater. Phosphorus removal rates are of the same magnitude as those that could be expected from specialized nutrient removal plants, and indeed exceeded those from coagulant dosing trials run at Carterton during the same period.

Initial indications are that there is a perceptual difference between the recycled water produced by the trench and that produced by the wastewater treatment works.

It is unknown whether the longevity of the trenches (in terms of Phosphorus removal) is sufficient to make the system economically viable for municipal wastewater treatment. The long-term efficacy of the system in terms of pathogen removal is also unknown.

The seed funding provided by AGMARDT has allowed this research to take place.

Further research is required to validate the results of the trial:

- Long-term (6-month to 1 year) sampling of water to confirm treatment efficacy and longevity.
- Investigation of potential to treat other wastewater i.e. dairy shed effluent.
- Sociological assessment of the system in terms of the perception improvements offered by the system.

ACKNOWLEDGEMENTS

The research was made possible by assistance from AGMARDT, Carterton District Council, Greater Wellington Regional Council, Masterton District Council, and South Wairarapa District Council by contributing to the study funding.

Special recognition is given to the many staff at Carterton District Council who by their physical help and unwavering support have made a challenging undertaking easy.

In addition, the input of Environmental Science & Research staff, notably Jacqui Horswell, Liping Pang, and Louise Weaver has been invaluable.

Last, but not least, the Sustainable Wairarapa Incorporated project team that gave guidance, direction, and impetus to take this study on in addition to their commitments for the Farm Irrigation Feasibility Study.

REFERENCES

1. Bomo, A.-M., Stevik, T. K., Hovi, I., & Hanssen, a. J. (2004). *Bacterial Removal and Protozoan Grazing in Biological Sand Filters.*

2. Garabedian, S. P. (1991). *Use of Colloid Filtration Theory in Modeling Movement of Bacteria through a Contaminated Sandy Aquifer.* Published in Environmental Science & Technology, January 1991, pp. 178-185, by the American Chemical Society.

3. *inf-facts-issues-Sep09.pdf.* (2009). Retrieved February 2011, from National Infrastructure plan: http://www.infrastructure.govt.nz/plan/ifi/25.htm

4. Metcalf, & Eddy. (2003). *Wastewater Engineering, treatment and reuse.* McGraw Hill.

5. Pang. (Volume 38, July–August 2009). Microbial Removal Rates in Subsurface Media Estimated From Published Studies of Field Experiments and Large Intact Soil Cores. *Journal of Environmental Quality* .

6. Sustainable Wairarapa Incorporated. (2011). *Recycled Water Farm Irrigation Feasibility Study .*

7. World Health Organisation. (2006). *Guidelines for the safe use of wastewater, excreta and greywater. Volume 2: Wastewater use in agriculture.*

8. Rawiri Smith (2011) Cultural Perspective for the Research of the Effluent Process - A Wairarapa Perspective

Other references:

9. Review of latest available evidence on potential transmission of avian influenza (H5N1) through water and sewage and ways to reduce the risks to human health. WHO/SDE/WSH/06.1 2006

10. Technologies and Costs Document for the Final Long Term 2 Enhanced Surface Water Treatment Rule and Final Stage 2 Disinfectants and Disinfection Byproducts Rule. Office of Water (4606-M) EPA 815-R-05-013 December 2005 www.epa.gov/safewater

11. Regionalizing Potential for Microbial Bypass Flow through New Zealand Soils. Malcolm McLeod,* Jackie Aislabie, Janine Ryburn, and Alexandra McGill. Landcare Research. Published in J. Environ. Qual. 37:1959–1967 (2008). doi:10.2134/jeq2007.0572 Received 29 Oct. 2007.

12. Water Treatment and Pathogen Control Process Efficiency in Achieving Safe Drinking Water. Published on behalf of the World Health Organization by IWA Publishing, Alliance House, 12 Caxton Street, London SW1H 0QS, UK
13. Active slag filters—simple and sustainable phosphorus removal from wastewater using steel industry byproduct C. Pratt and A. Shilton. IWA Publishing
14. World Phosphate Production: Overview and Prospects L. CISSE and T. MRABET
World Phosphate Institute, 3, Rue Abdelkader Al Mazini, 20001 Casablanca, Morocco

15. HOW CAN WE ENHANCE PHOSPHORUS REMOVAL IN CONSTRUCTED FARM WETLANDS?
Deborah J. Ballantine and Chris C. Tanner NIWA, PO BOX 11115, Hillcrest, Hamilton
16. Farm dairy effluent treatment Steve CouperA,C, Michael TanA, Robert LeiB
AWT New Zealand Ltd, PO Box 109-601, Auckland B Scion, Private Bag 3020, Rotorua
Corresponding author. Email: steve.couper@awtwater.com

17. Clarification of Clean-Bed Filtration models. B.E.Logan, D.G.Jewett, R.G.Arnold, E.J.Bouwer & C.R.O'Melia. Journal of Environmental Engineering Vol 121, No. 12, December 1995

18. Design, Set-Up, and Operation of a Pilot Scale Intermittent Sand Filter -Septic Tank System
to Evaluate the Effects of Sand Dep'th and Infiltration Rate on Filter Treatment Efficiency
A Thesis Presented in Partial Fulfillment of the Requirements for the Degree of Master of Science in the Graduate School of The ui.io State University By James Albert Peeples, B.S.