Martinborough Waste Water Treatment Plant
Review of Potential Upgrade Technologies.

1: Executive Summary

A review has been undertaken of available technologies to improve the effluent quality from the Martinborough WWTP. From a larger range of possible options, 8 have been chosen for comparison. These are; coagulation, floating treatment wetlands (FTW), soil beds, PETRO, membrane filtration (MF), constructed wetlands, sequential batch reactors, (SBR), membrane bioreactors, (MBR), A weighted numerical rating system has been devised to allow ranking of these alternatives.

The comparison considers; cost, performance, reliability and residuals.

On the basis of the current values and weightings, four of the 8 options are considered to be of similar and preferred ranking; coagulation, FTW's, MBR and constructed wetlands.

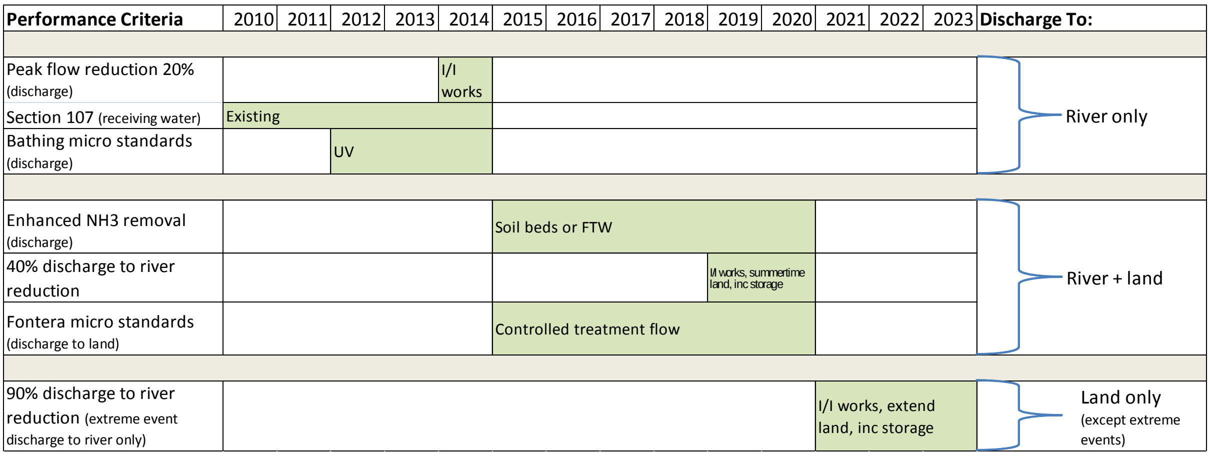
A further option exists, which is simply not to undertake any additional treatment, and instead make progress on inflow and infiltration reduction, land purchase and irrigation system construction.

2 Background and Brief

2.1 Background

The need for the proposed upgrade has come about through the aspirations of sections of the community and other stakeholder groups, to improve the performance of the existing treatment processes, thereby minimising the impact on the receiving waters of the Ruamahanga River, and to work towards an ultimate goal of zero discharge to water.

Forward planning and cost estimates have been produced based on achieving this goal over a 10 to 20 year time frame. Figure 1 below, shows the specific staging and required performance for the waste water treatment system, in order to meet this goal in a nominal 15 year time frame through a series of staged consents. Note that this figure has been produced purely for the purposes of demonstrating the different treatment performance criteria which should be reached at different stages and should not be taken as being a commitment to specific timing for the stages.



Performance Criteria	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Discharge To:
Peak flow reduction 20% (discharge)					I/I works										River only
Section 107 (receiving water)	Existing														
Bathing micro standards (discharge)			UV												
Enhanced NH3 removal (discharge)						Soil beds or FTW									River + land
40% discharge to river reduction										I/I works, summertime land, inc storage					
Fontera micro standards (discharge to land)						Controlled treatment flow									
90% discharge to river reduction (extreme event discharge to river only)												I/I works, extend land, inc storage			Land only (except extreme events)

Figure 1. Indicative performance criteria for staged upgrading ultimately leading to full-time discharge to land.

2.2 Brief

The brief for this report is to satisfy the requirements of clause 8b of the operative discharge to water consent - consent number WAR970079 (30753); specifically

By 10 January 2012 - Submission of a draft Assessment of Environmental Effects (AEE) to the Manager, Environmental Regulation, Wellington Regional Council and key stakeholders. The draft AEE shall cover all aspects identified in 5.4.2 of the Regional Freshwater Plan, and shall specifically include the following matters raised at the meetings on 23 February 2011 and 26 August 2011:

Assessment of a range of options to upgrade the wastewater treatment plant in order to reduce the existing water quality standards (particularly BOD, SS, and ammonia) in terms of their feasibility and costs.

Whilst reporting on a range of options to specifically address the three effluent quality criteria mentioned above is the minimum requirement of this AEE report, these parameters only focus on the short to medium term situation where the discharge is primarily to water. Any treatment upgrades which occurred during this period should also be compatible with the longer-term aspirations of more comprehensive discharge to land and therefore should include consideration of key effluent quality parameters which govern/restrict discharge the land, primarily; microbial levels, nitrogen and phosphorus. Microbial levels specifically should be based on the additional benefits that the treatment method will add to the existing UV treatment technology, which could be either reducing the suspended solids/transmissivity of the feed to the UV plant and/or reducing the microbial levels in the feed to the UV plant.

3 NZ Context

When considering possible upgrades for the Martinborough Waste Water Treatment Plant, it is important to consider the changes in waste water treatment that are occurring throughout New Zealand. A Horizons Regional Council survey[1] was undertaken in 2009 to review the upgrades that

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[1] CPG Ltd, **Horizons Regional Council,** Recent History and Rationale for Wastewater Treatment Plant Upgrades. November 2009

had been implemented in waste water treatment plants in 21 different Territorial Local Authorities (TLAs) from throughout New Zealand. The communities involved were limited to those of between 1000 and 80000 people, in mainly inland locations. The survey was largely made up of Waikato TLAs, but featured an even spread of TLAs from the rest of the country. The results from this report are summarised below.

3.1 Drivers for upgrades

The primary driver for WWTP upgrades was reported as more stringent water quality targets set under new resource consents. This is possibly a reflection of the more specific definitions and lower limits for water quality parameters being introduced as defining section 107 of the Resource Management Act criteria.

Additional drivers for upgrading WWTP's include population increases (requiring upgrades in capacity), public health concerns related to the discharge of effluent into waterways, and cultural values.

In order to meet and satisfy these drivers, specific water quality targets and treatment components were considered and selected. The upgrades to the WWTPs were primarily designed to improve; phosphorus removal, nitrogen removal, organic removal and pathogen removal.

3.2. Discharge Parameters

Under the new consents, the discharge parameter limits were more stringent than in previous consents. This can be seen in tables 1 and 2 below.

	mg/L									
	BOD5 Mean	BOD5 Max	TSS Mean	TSS Max	TN Mean	TN Max	NH3-N Mean	NH3-N Max	TP Mean	TP Max
Pre-Upgrade	48	56	78	92	15	26	20	16	11	12
Post-Upgrade	24	27	43	28	12	22	8	5	2	9

Table 1: Typical chemical parameter - effluent discharge limits pre- and post-upgrade.

	cfu/100mL			
	FC Mean	FC Max	E. coli Mean	E. coli Max
Pre-Upgrade	32000	7500	1000	10000
Post-Upgrade	2000	6000	250	1000

Table 2: Typical biological discharge limits pre- and post-upgrade.

3.3 Pre- and Post-Upgrade technology

Prior to the upgrades, the most common treatment technology used was oxidation ponds. This can be seen in figure 1 below.

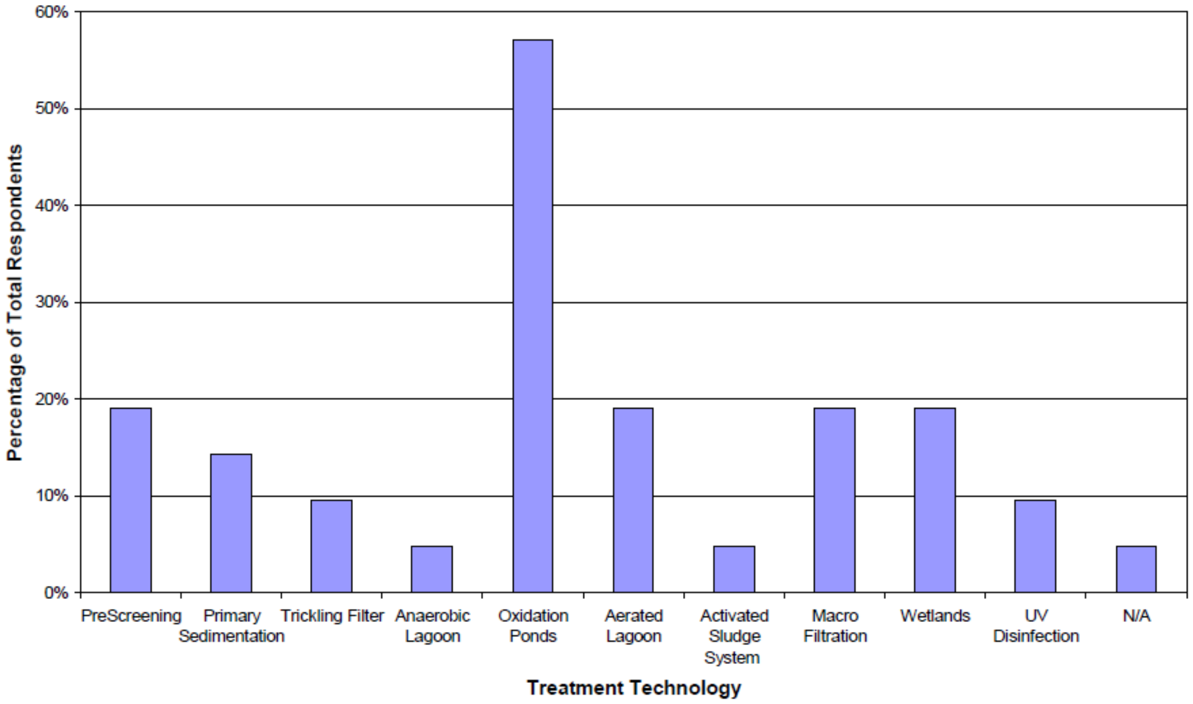


Figure 1: Pre upgrade treatment technology

After treatment was upgraded, activated sludge systems were the most common option favoured, including conventional activated sludge systems, Sequencing Batch Reactors (SBR), and Membrane Bioreactors (MBR). UV disinfection was also widely used. In general, a greater range of more sophisticated technologies were adopted. This is demonstrated in figure 2 below.

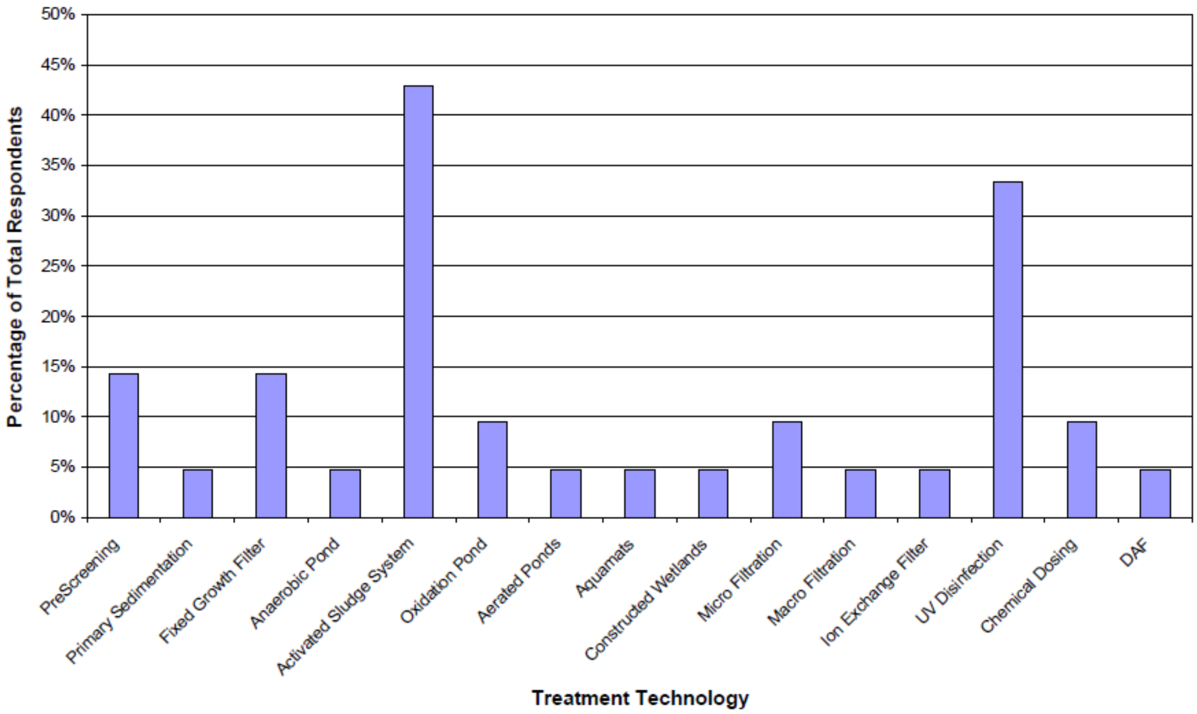


Figure 2: Post-upgrade technology

3.4. Discharge Environment

Prior to the upgrade, the primary discharge environment for treated waste water was to water ways, mainly rivers. Despite the change in treatment technology, the discharge environment remained unchanged in 81% of the cases surveyed. This is likely due to:
(i) Cost;
(ii) Perception of lack of need as current system is adequate;
(iii) The need to maximise use of existing infrastructure;
(iv) The preparedness to accept perceived higher risks of alternatives;
(v) Lack of political will; and
(vi) Cultural issues associated with discharge of human effluent to land.

Of the final discharge systems, about half of those that previously been piped to the ocean, and about half of those that had previously been piped to rivers, had installed a rock filter in the discharge line.

3.5. Combined Land and Water Discharge (CLAWD)

An alternative to waste water discharge to a single environment (usually waterways) is to also discharge to land. In principle, a CLAWD system can provide advantages over and above individual land or water discharges, while reducing the disadvantages of each. The principle is that wastewater is discharged into a river or stream at times of higher flow, but is applied to land at times when stream flow is low. Advantages are:

(i) In dry weather, an irrigation application to land can avoid the stream discharge, when the receiving stream flow is low and its sensitivity to contaminants is greatest.
(ii) WWTP upgrades to provide for pathogen and nutrient reductions may not be needed as critical in-stream parameters are less sensitive during high flow.
(iii) Irrigation of land has the initial benefit of assisting growth of the crops being produced. Irrigation will be most beneficial following limited rain, when stream or rivers are at low flow.
(iv) Irrigation of land with wastewater has the addition benefit of utilising the nutrients it contains, instead of losing those nutrients into a waterway when systems discharge to water. This can reduce the need for expensive imported fertilisers.
(v) Land application is an effective protection mechanism against pathogens, with populations being reduced by 2 logs within the first 10 mm of soil, subject to suitable application rates being used.
(vi) In wet weather the soil may be saturated and irrigation of wastewater could lead to preferential through-flow, ponding or run-off. This would impact on the usability of the land and its productive capacity. In such cases, river or stream discharge will be available as the alternative.
(vii) When the land is too wet to irrigate, in normal circumstances stream flow will be sufficiently high to offer a high degree of dilution to the wastewater; at these higher flow rates the alternative uses of the waterway for recreational and other purposes demanding higher water quality will be less likely to be taking place.
(viii) CLAWD reduces the requirement for reserve wastewater storage that would be necessary to achieve sustainable environmental outcomes from either a high flow stream discharge or a land application alone. The cost of operating a dual discharge system can be offset by the cost savings of not providing for winter storage when irrigation may be suspended.

There are, however, some disadvantages. These include:

(i) Two sets of wastewater discharge infrastructure are required, rather than just to land or just to water. This may be more expensive, depending on storage requirements.
(ii) The system is more complex than a single discharge option, requiring management, decision making, monitoring and accountability to be better than is typically required for a single discharge.
(iii) The complexity of the dual discharge, with the possibility of limited storage being a third routing option for wastewater on any given occasion, increases the scope for operator error to confound the environmental improvement intended to be delivered.

3.6. Costs of Upgrades

In order to evaluate the costs of upgrading WWTPs, the cost per person in the community for a particular component reduction in the waste water was determined. This evaluation can be seen in figure 3 below.

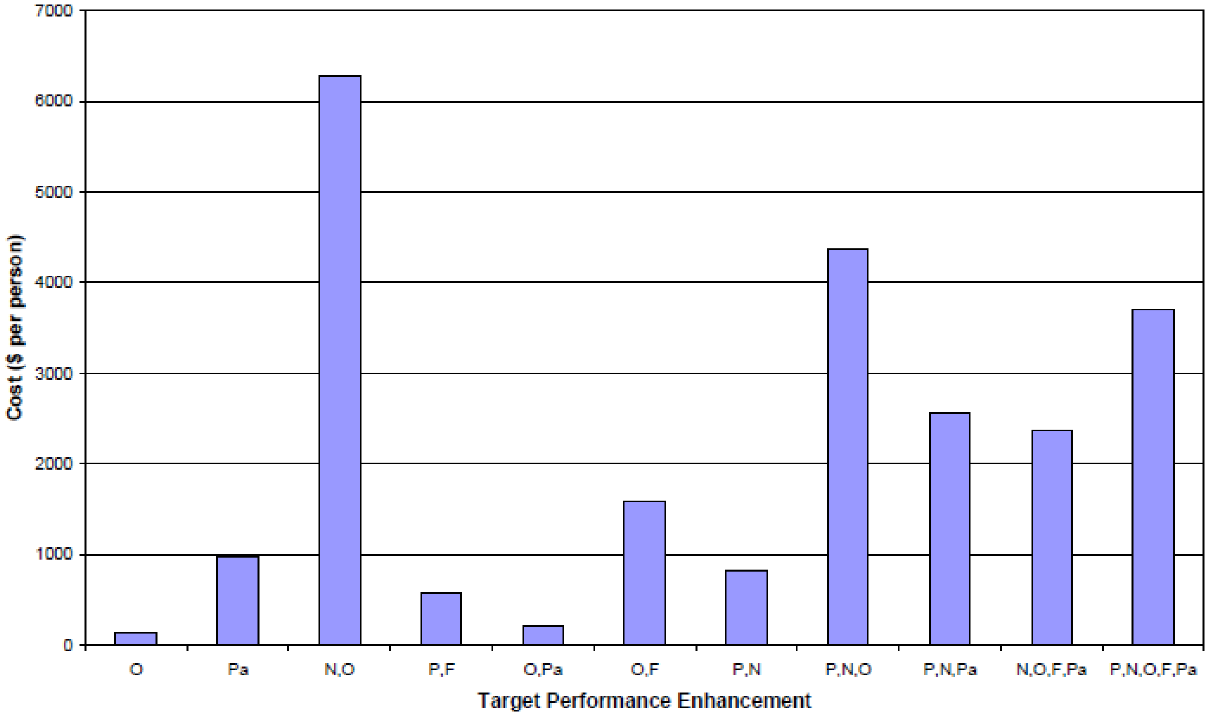


Figure 3: Cost of enhancement of a component per person in the community. Note abbreviations: O – organic, Pa – pathogen, N – nitrogen, P – phosphorus, F – flow

4 Available Technologies

There are a wide range of different types and locations in the process stream for technologies which could be utilised in upgrading wastewater treatment plants such as the Martinborough system. The more appropriate of these are shown in figure 4 below and classified as to where in the process stream they would be located. The figure is colour-coded - those processes marked in green are already installed, those marked in blue have or are being trialled either at Martinborough, Featherston, or Carterton, whilst those marked in brown have been reviewed in section 5 below for the purpose of providing a comparison with alternatives.

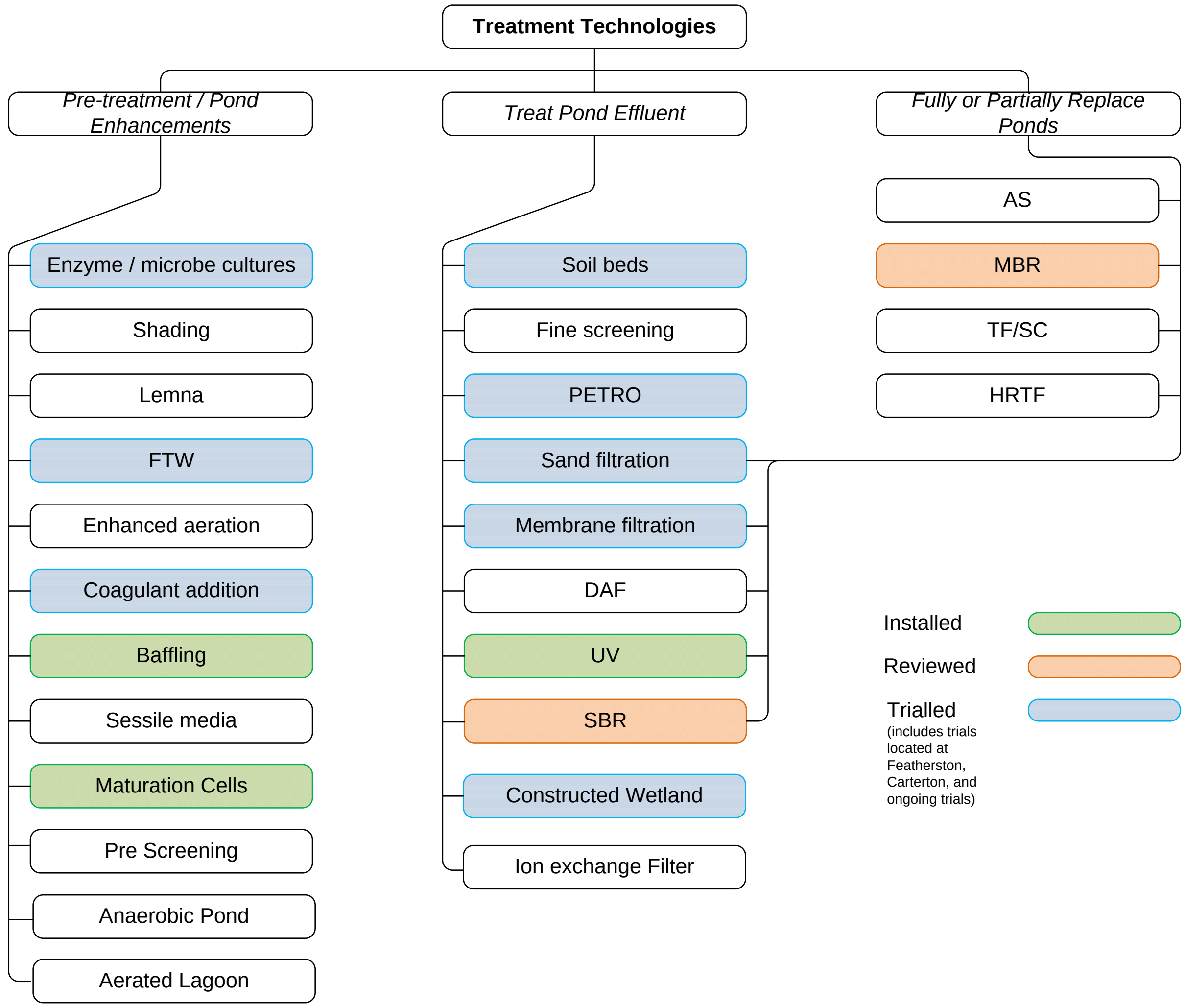


Figure 4. Treatment technologies potentially suited for upgrade of the Martinborough wastewater system

5 Specific Technologies Reviewed and Compared

5.1 Basis for Comparison

The technologies listed in this section are described briefly and compared on the basis of a number of parameters: cost, both capital and operating expressed as net present value over 20 years; performance versus a range of parameters; assessed reliability - is this new technology to be used for the first time, imported technology from overseas still being evaluated for New Zealand conditions, or well established technology with full reliable process warranties; and the disposal of residuals, which although factored into the cost aspect of the assessment also introduce a potential new level of complexity with respect to obtaining further consents.

5.2 Pond Enhancements

The following technologies would be installed prior to the existing ponds.

5.2.1 Enzyme and Microbial Cultures

Enzyme and mixed / enzyme microbial cultures have been used for some time in situations where there are a nuisance build-ups of solids, especially fats, and/or issues with odours in locations such as sewage holding tanks, pumping stations and the like. The concept is by dosing appropriate microbes and/or enzymes into the vessel a preferred culture of specific species will develop whose characteristics are more attuned to attacking the specific problem be it; fat deposits, organics reduction, nitrification, sulphide oxidation, etc. The main theoretical problem in applying this type of technology to an oxidation on system is the large volumes and significant potential for washout of the selected microbes as they are not able to obtain a competitive advantage against the normal flora. This is partly addressed by continual dosing; however the quantity and cost of the material being dosed then may become a significant operating cost.

This technology is included not for comparison at this stage but simply to identify that trials are being undertaken during the first six months of 2012. This is not a technology which is seen as having a high likelihood of success however the manufacturers of this particular product have offered to provide it free of charge for the purposes of trialling and therefore it was felt that on balance the would be more benefits than potential disadvantages from taking advantage of this offer.

5.3.2 Coagulant Addition

Coagulant addition to wastewater is potentially a way of reducing a range of parameters; suspended solids, dissolved organics, and both particulate and soluble phosphorus. The coagulant can simply be added into the wastewater flow entering the pond system and allow flocculation, (the building up of coagulant-based precipitates into small particles of flocculent material which is heavier than water), and sedimentation, (the settling outs of those particles of flocculent material), to occur within the normal hydraulic regime of the ponds, or the coagulant can be added prior to a filter or a filter added after the ponds, in order to remove the finer floc particles.

Again that this technology has been added as bench scale trials have been undertaken on typical samples of the Martinborough wastewater. These trials have been sufficiently detailed to provide indicative dose rates, operating costs, and achievable performance.

The reports from these bench scale trials are included as appendix A to this report. The identified dose rates and operating costs from the bench scale trial reports are also included in the comparison spreadsheet in section 6 below. The testing trialled a natural organic coagulant which has been successful at other plants at removing phosphorus at an acceptable dose rate. For Martinborough however, this was not the case and the natural product would be 3 x the operating cost of aluminium sulphate with an anionic flocculant.

The capital costs for the coagulation option are very low. All that is required is the facility to store dose and adequately mix the appropriate chemicals. Operating costs however are moderate. Performance is patchy and a major drawback is the potential for problems with residuals, either increased sludge volumes in the ponds, or aluminium residual toxicity issues for the pond and / or receiving water biota.

5.3.3 Floating Treatment Wetlands

Floating treatment wetlands are one of the preferred options for in Pond enhancements of the existing performance. A trial wetland was constructed at the Featherston wastewater treatment plant in 2010 and has been monitored for approximately 12 months. Unfortunately this pilot system has not performed as well as other pilot and full-scale systems elsewhere in New Zealand and overseas. In an effort to cure this issue the process suppliers Kauri Park Wetlands revisited the system in late 2011 and reconfigured some baffles. To date with limited post modification results, this work does not seem to have been effective.

Nevertheless the wetlands are producing good results in other full-scale locations and the process suppliers are offering performance warranties.

The advantages with the floating treatment wetlands are; that they could be installed in the existing maturation cells, which would give the ability to achieve four hydraulically separated zones, allowing the different sections to be configured for different performance objectives, they are a passive low energy process, and they can be configured to address a range of performance objectives.

Figure 5 below shows a design plan for the Martinborough system.

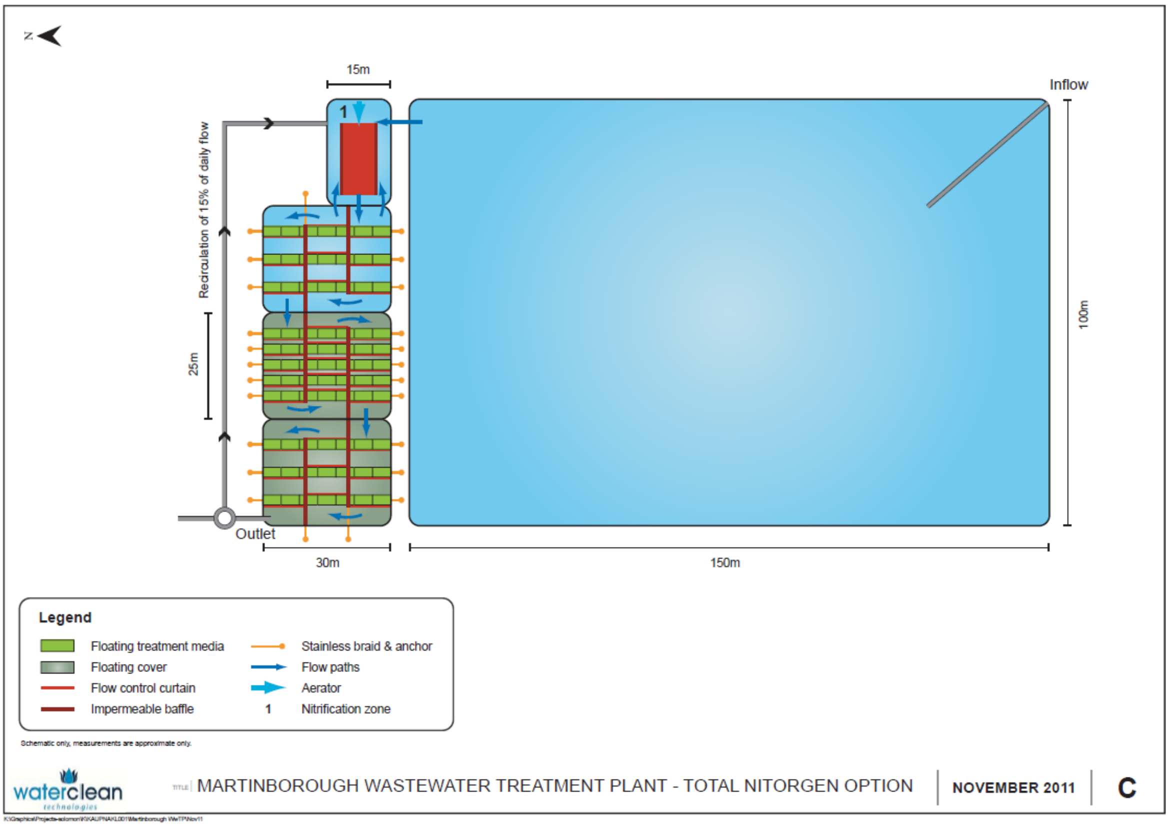


Figure 5, Layout of proposed retrofit of FTW’s to the existing Martinborough maturation Cells.

5.2 Options for Treating Pond Effluent

5.2.1 Soil Beds

The use of horizontal flow soil beds containing specific selected media is a relatively novel concept which is currently being trialled on land adjacent to the Carterton wastewater plant. The South Wairarapa District Council has contributed to the cost of these trials, and the results which are obtained will be transferable to the South Wairarapa sites.

The system works by constructing the soil beds on a specific slope so that the introduced effluent being filtered passes down through the sloping bed under gravity but is distributed relatively evenly through the full depth of the bed. Dosing onto the beds can be by way of a distribution channel or pumped supply with automated valves, and will be intermittent with probably in the order of four doses per day.

Preliminary results from initial trials conducted over an approximately 2 month period showed good levels of removal for: microbes, suspended solids, phosphorous and BOD, as well as moderate removal of total nitrogen and ammonia.

One of the key parameters in establishing the viability of this option will be the life expectancy of the beds. It is expected that phosphorous removal will be the first performance related parameter to fail at which time the soil media will be saturated with absorbed phosphorous. This will then require the soil to be removed and replaced. It is expected that the removed soil possibly after a short holding period will be suitable for discharge to land as a fertiliser. A schematic of how this system could be applied at Martinborough is shown in figure 6 below.

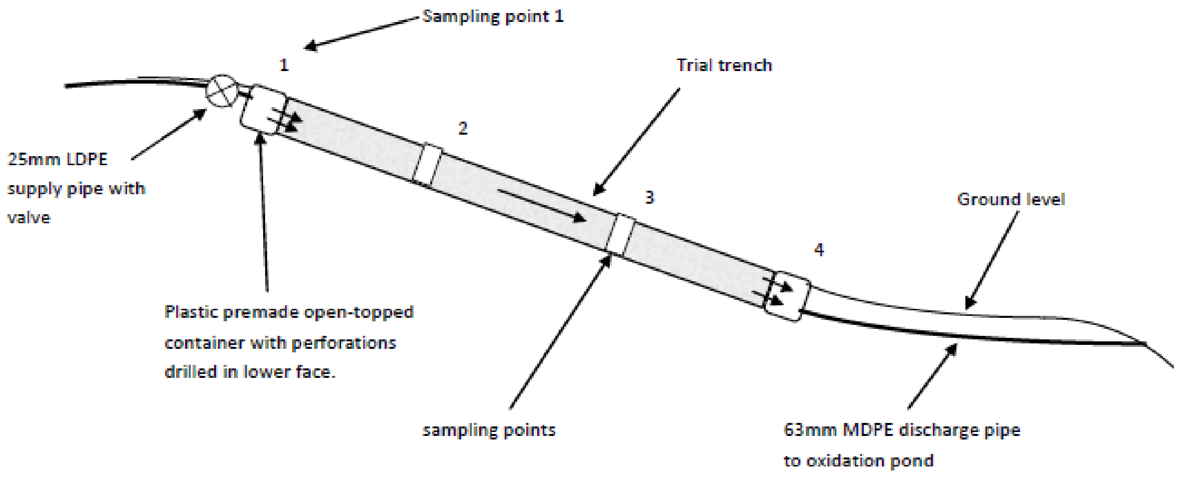


Figure 6. Possible layout of soil bed filtration system for Martinborough.

For more details, refer to the report attached in Appendix 1.

5.2.2 PETRO

The PETRO concept is based on using stabilisation ponds as a first stage of treatment, to tackle the bulk of the organic load.

However, these ponds have a serious drawback in that, while reducing the wastewater organic load, they produce large quantities of microalgae which are difficult to remove from the final effluent, at low cost.

For this reason a polishing facility is used as the secondary stage, in the form of either a rock-trickling filter or an activated sludge process. Under stress, algae autoflocculate and remove themselves through the rock filter or activated sludge process.

The basic flow diagram is presented in Fig. 7 below. The system comprises a deep primary facultative (Aerobic/Anaerobic, Ae/An) pond and one or a number of shallow secondary oxidation ponds as a primary stage of the process removing more than 70% of the incoming organic load. As the secondary stage a biological TF filled with stone medium followed by a humus tank is used. The TF may be substituted with an activated sludge process (ASP). An important feature of the system is recirculation to ensure that the primary anaerobic pond does not constitute an environmental hazard. The recirculation of oxygen-rich water from the secondary oxidation ponds and nitrate-rich humus tank underflow into the primary pond allays obnoxious odours by sulphide oxidation. The design and positioning of the primary pond obviates the hazard of employing open impeller pumps.

This feature constitutes an important maintenance and operational advantage, particularly on small installations. In case of an emergency such as prolonged power failure which prevents pumping, the inflow of raw sewage will pass through the anaerobic pond into the secondary oxidation ponds for temporary storage.
The secondary oxidation ponds are incorporated in the system in a closed side-loop in which the required flow rates can be selected. The functions performed by the PETRO oxidation ponds are the following:

- further reduction of primary pond organic matter effected by the algo-bacterial consortium
- supply of algae- and oxygen-rich water to suppress odours in the primary pond
- reduction of ammonia which otherwise would have to be nitrified downstream
- generation of bicarbonate alkalinity which assists in offsetting the effect of advanced nitrification in the TF
- providing a balancing reservoir for attenuation of the daily and wet weather peak flows
- providing an effective emergency treatment for the primary pond effluent prior to its final discharge should a power failure occur or pumping be interrupted
- providing a satisfactory treatment facility during initial stages of a progressive development program prior to the introduction of a TF (or ASP) as a polishing step.

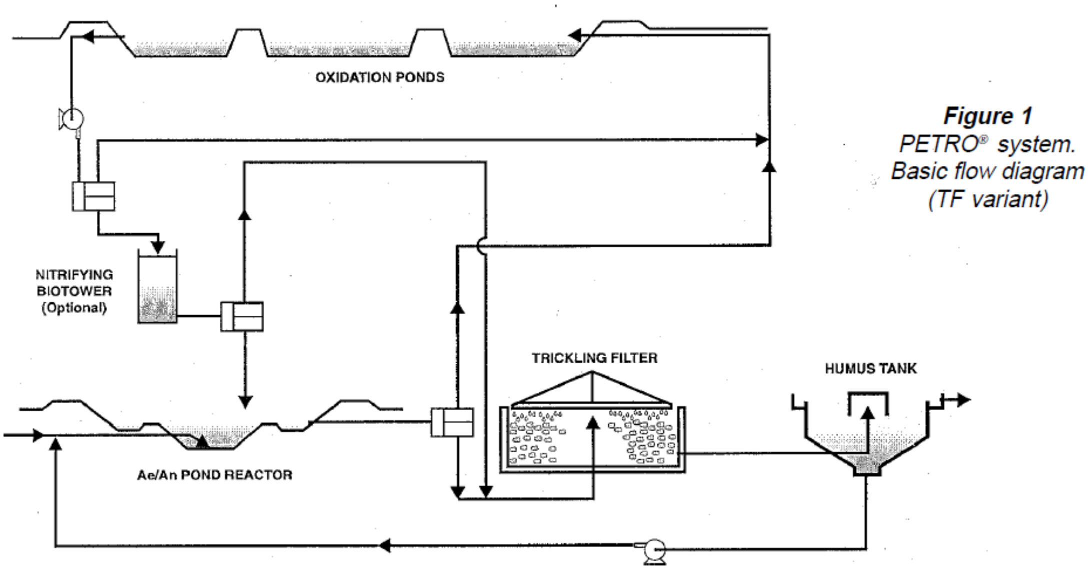


Figure 1
PETRO® system.
Basic flow diagram
(TF variant)

Figure 7, PETRO process.

A recent variation of the process, developed in Turkey has been to remove the anaerobic pond in favour of simply mixing raw wastewater with pond effluent into the TF. This is an attractive option as it would save having to construct a separate anaerobic pond.

5.2.3 Sand Filtration

Sand bed filters work by providing the particulate solids with many opportunities to be captured on the surface of a sand grain. As fluid flows through the porous sand along a tortuous route, the particulates come close to sand grains. They can be captured by one of several mechanisms:

- Direct collision

- Van der Waals or London force attraction
- Surface charge attraction
- Diffusion.

In addition, particulate solids can be prevented from being captured by surface charge repulsion if the surface charge of the sand is of the same sign (positive or negative) as that of the particulate solid. Furthermore, it is possible to dislodge captured particulates although they may be re-captured at a greater depth within the bed. Finally, a sand grain that is already contaminated with particulate solids may become more attractive or repel addition particulate solids. This can occur if by adhering to the sand grain the particulate loses surface charge and becomes attractive to additional particulates or the opposite and surface charge is retained repelling further particulates from the sand grain.

In some applications it is necessary to pre-treat the effluent flowing into a sand bed to ensure that the particulate solids can be captured. This can be achieved by one of several methods:

- Adjusting the surface charge on the particles and the sand by changing the pH
- Coagulation – adding small, highly charged cations (aluminium 3+ or calcium 2+ are usually used)
- Flocculation – adding small amounts of charge polymer chains which either form a bridge between the particulate solids (making them bigger) or between the particulate solids and the sand.

Operating regimes

Sand filters can be operated either with upward flowing fluids or downward flowing fluids, the latter more commonly used. For downward flowing devices the fluid can flow under pressure or by gravity alone. Pressure sand bed filters tend to be used in industrial applications and often referred to as rapid sand bed filters. Gravity fed units are used in water purification especially drinking water and these filters have found wide use in developing countries (slow sand filters).

Overall, there are several categories of sand bed filter (See appendix 3 for diagrams):

1. rapid (gravity) sand filters
2. rapid (pressure) sand bed filters
3. upflow sand filters
4. slow sand filters

Uses in water treatment

All four categories are used extensively in the water industry throughout the world. The first two and third in the list above require the use of flocculant chemicals to work effectively whilst slow sand filters can produce very high quality water free from pathogens, taste and odour without the need for chemical aids.

Passing flocculated water through a rapid gravity sand filter strains out the floc and the particles trapped within it reducing numbers of bacteria and removing most of the solids. The medium of the filter is sand of varying grades. Where taste and odour may be a problem (organoleptic impacts), the sand filter may include a layer of activated carbon to remove such taste and odour.

Sand filters become clogged with floc after a period in use and they are then backwashed or pressure washed to remove the floc. This backwash water is run into settling tanks so that the floc can settle out and it is then disposed of as waste material. The supernatant water is then run back into the treatment process or disposed off as a waste-water stream. In some countries the sludge may be used as a soil conditioner. Inadequate filter maintenance has been the cause of occasional drinking water contamination.

Sand filters are occasionally used in the treatment of sewage as a final polishing stage. In these filters the sand traps residual suspended material and bacteria and provides a physical matrix for bacterial decomposition of nitrogenous material, including ammonia and nitrates, into nitrogen gas.

5.2.4 Membrane Filtration

Membrane filtration uses a semi-impermeable membrane to separate materials according to their physical and chemical properties when a pressure differential is applied across the membrane. They are classified by the size of the membrane pore size and the size of the particles removed.

The membrane plant is configured as follows:

- Modules that comprise thousands of hollow porous fibres, each 2 millimetres diameter and 2 metres long, bundled together are installed on a frame to make a cassette; and
- Cassettes are immersed vertically in rectangular tanks (refer Figure 8) to form a train

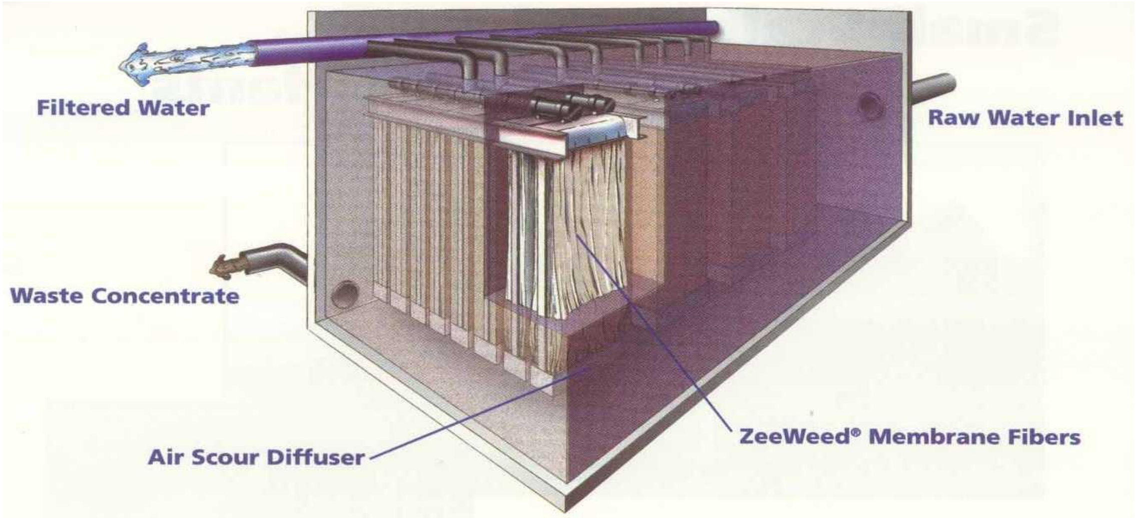


Figure 8 Membrane Schematic

The fibres consist of a woven inner core for strength and durability with the membrane film applied to the exterior. The nominal membrane pore size is 0.035 micron, the absolute pore size 0.1 micron. These inhibit the passage of protozoa and bacteria and most viruses to the filtered water. The range of materials these membranes will remove is shown in Figure 9.

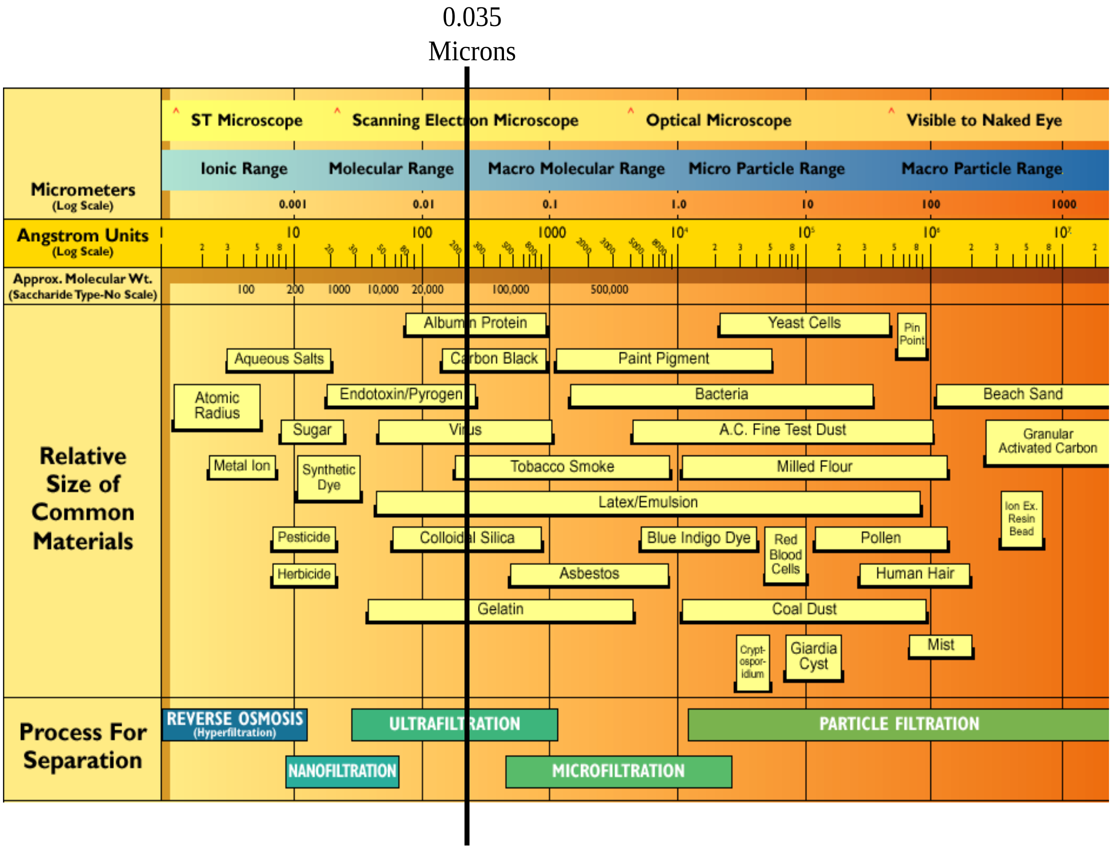


Figure 9 Filtration Spectrum

Each train has a dedicated low pressure permeate pump to draw the water out through the fibres under vacuum. Flow through each membrane is controlled by a variable speed drive on the permeate pump, with the set point determined by the incoming flow.

Aeration of the cassettes is done to agitate the fibres to reduce the rate at which solids accumulate on the membrane surfaces. At intervals a reverse flow (backpulse) is applied to the membranes for a short period to dislodge any accumulated solids from the membrane surface. Dirty water that accumulates in a membrane tank is removed and returned to the start of the treatment process.

Trials of new membranes have confirmed the following removal rates:

Micro-organism	Removal rate
Giardia	> 5 log
Cryptosporidium	> 4 log
E-coli	> 8 log
Viruses	> 4 log

Zenon membranes have obtained an ETV Statement to verify the performance of the membranes. The average removal rate for particles in the 3 – 15 μm size range was greater than 4.0 log for both test periods and the membrane integrity testing comprising of air pressure-hold test, particle counting and turbidity monitoring, was suitable for the detection of a compromised membrane fibre.

There is a gradual buildup of material on the membrane surfaces that cannot be removed by the aeration and backpulse process. When this occurs the affected tank is removed from service and chemically cleaned with either sodium hypochlorite or citric acid. These chemicals are then neutralised and discharged prior to returning the membrane to service.

For more details refer to the report in Appendix 2.

5.2.5 UV Light

Ultraviolet (UV) light can be used instead of chlorine, iodine, or other chemicals in disinfection of wastewater. Because no chemicals are used, the treated water has no adverse effect on organisms that later consume it, as may be the case with other methods. UV radiation causes damage to the genetic structure of bacteria, viruses, and other pathogens, making them incapable of reproduction. The key disadvantages of UV disinfection are the need for frequent lamp maintenance and replacement and the need for a highly treated effluent to ensure that the target microorganisms are not shielded from the UV radiation (i.e., any solids present in the treated effluent may protect microorganisms from the UV light). In the United Kingdom, UV light is becoming the most common means of disinfection because of the concerns about the impacts of chlorine in chlorinating residual organics in the wastewater and in chlorinating organics in the receiving water.

5.2.6 Constructed Wetland

Natural wetlands act as a biofilter, removing sediments and pollutants such as heavy metals from the water, and constructed wetlands can be designed to emulate these features.

General contaminants removal

Physical, chemical, and biological processes combine in wetlands to remove contaminants from wastewater. Theoretically, wastewater treatment within a constructed wetland occurs as it passes through the wetland medium and the plant rhizosphere. A thin film around each root hair is aerobic due to the leakage of oxygen from the rhizomes, roots, and rootlets. Aerobic and anaerobic micro-organisms facilitate decomposition of organic matter. Microbial nitrification and subsequent denitrification releases nitrogen as gas to the atmosphere. Phosphorus is coprecipitated with iron, aluminium, and calcium compounds located in the root-bed medium. Suspended solids filter out as they settle in the water column in surface flow wetlands or are physically filtered out by the medium within subsurface flow wetland cells. Harmful bacteria and viruses are reduced by filtration and adsorption by biofilms on the rock media in subsurface flow and vertical flow systems.

Specific contaminants removal

Domestic sewage - ammonia

In a review of 19 surface flow wetlands it was found that nearly all reduced total nitrogen. A review of both surface flow and subsurface flow wetlands concluded that effluent nitrate concentration is dependent on maintaining anoxic conditions within the wetland so that denitrification can occur and that subsurface flow wetlands were superior to surface flow wetlands for nitrate removal. The 20 surface flow wetlands reviewed reported effluent nitrate levels below 5 mg/L; the 12 subsurface flow wetlands reviewed reported effluent nitrate ranging from <1 to < 10 mg/L. Results obtained from the Niagara-On-The-Lake vertical flow systems show a significant reduction in both total nitrogen and ammonia (> 97%) when primary treated effluent was applied at a rate of 60L/m^2/day. Calculations showed that over 50% of the total nitrogen going into the system was converted to nitrogen gas. Effective removal of nitrate from the sewage lagoon influent was dependent on medium type used within the vertical cell as well as water table level within the cell.

Domestic sewage - phosphorus

Adsorption to binding sites within sediments was the major phosphorus removal mechanism in the surface flow constructed wetland system at Port Perry, Ontario. Release of phosphorus from the sediments occurred when anaerobic conditions prevailed. The lowest wetland effluent phosphorus levels occurred when oxygen levels of the overlying water column were above 1.0 mg / L. Removal efficiencies for total phosphorus were 54-59% with mean effluent levels of 0.38 mg P/L. Wetland effluent phosphorus concentration was higher than influent levels during the winter months.

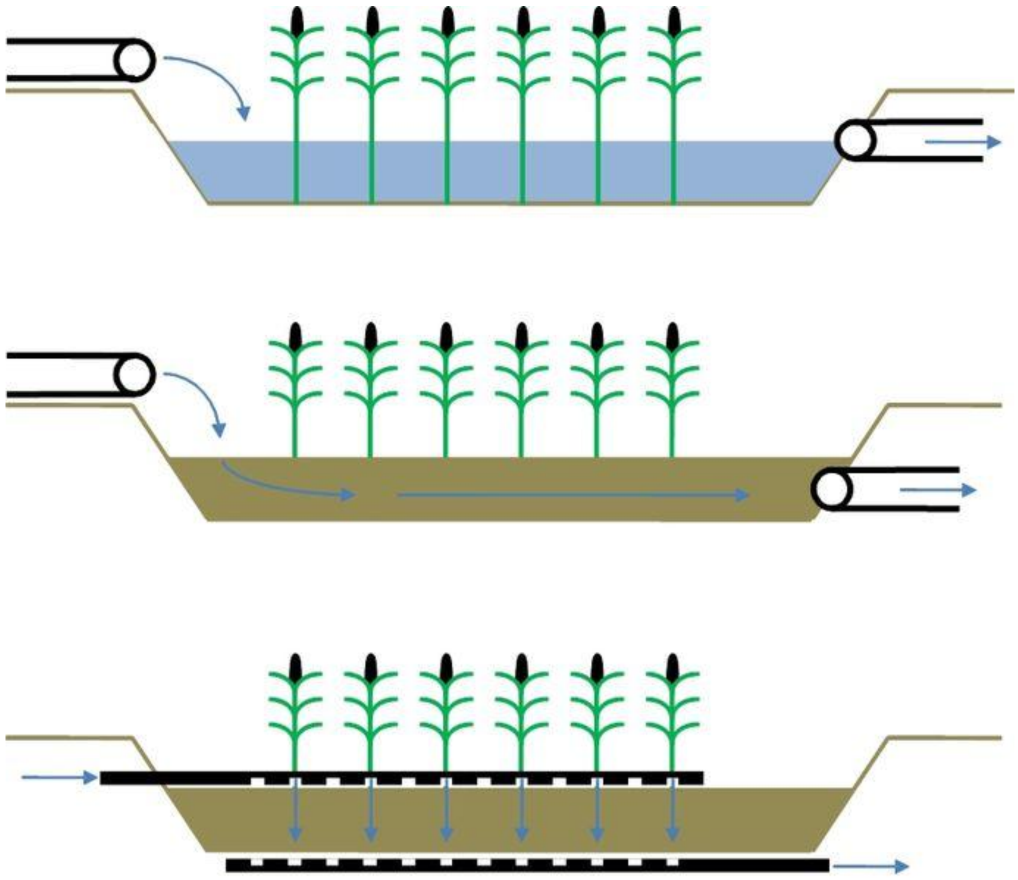
The phosphorus removed in a VF wetland in Australia over a short term was stored in the following wetland components in order of decreasing importance: substratum> macrophyte >biofilm, but over the long term phosphorus storage was located in macrophyte> substratum>biofilm components. Medium iron-oxide adsorption provides additional removal for some years.

A comparison of phosphorus removal efficiency of two large-scale, surface flow wetland systems in Australia which had a gravel substratum to laboratory phosphorus adsorption indicated that for the first two months of wetland operation, the mean phosphorus removal efficiency of system 1 and 2 was 38% and 22%, respectively. Over the first year a decline in removal efficiencies occurred. During the second year of operation more phosphorus came out than was put in. This release was attributed to the saturation of phosphorus binding sites. Close agreement was found between the phosphorus adsorption capacity of the gravel as determined in the laboratory and the adsorption capacity recorded in the field.

The phosphorus adsorption capacity of a subsurface flow constructed wetland system containing a predominantly quartz gravel in the laboratory using the Langmuir adsorption isotherm was 25 mg P/g gravel. Close agreement between calculated and realized phosphorus adsorption was found. The poor adsorption capacity of the quartz gravel implied that plant uptake and subsequent harvesting were the major phosphorus removal mechanism.

Metals removal

Constructed wetlands have been used extensively for the removal of dissolved metals and metalloids. Although these contaminants are prevalent in mine drainage, they are also found in stormwater, landfill leachate and other sources (e.g., leachate or FDG washwater at coal-fired power plants), for which treatment wetlands have been constructed for mines, and other applications.



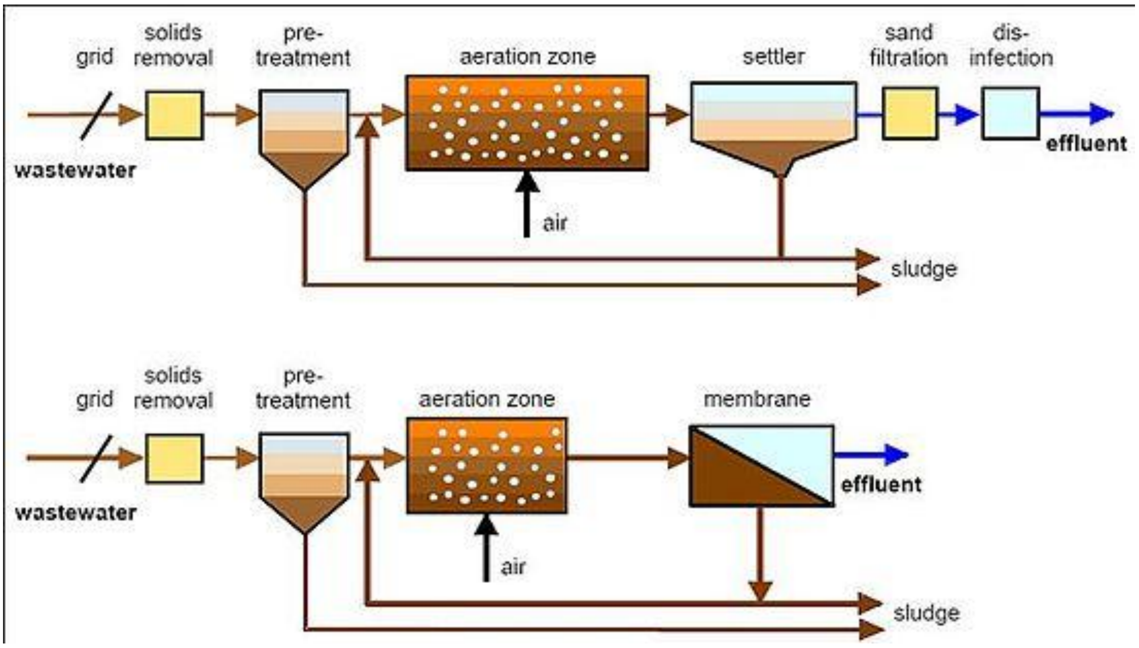
The 3 treatment set-ups mostly employed in combined treatment ponds

5.3 Options for Fully or Partially Replacing the Existing Ponds

5.3.1 Membrane Bioreactor

Membrane bioreactors (MBR) combine activated sludge treatment with a membrane liquid-solid separation process. The membrane component uses low pressure microfiltration or ultrafiltration membranes and eliminates the need for clarification and tertiary filtration. The membranes are typically immersed in the aeration tank; however, some applications utilize a separate membrane tank. One of the key benefits of an MBR system is that it effectively overcomes the limitations associated with poor settling of sludge in conventional activated sludge (CAS) processes. The technology permits bioreactor operation with considerably higher mixed liquor suspended solids (MLSS) concentration than CAS systems, which are limited by sludge settling. The process is typically operated at MLSS in the range of 8,000–12,000 mg/L, while CAS are operated in the range of 2,000–3,000 mg/L. The elevated biomass concentration in the MBR process allows for very effective removal of both soluble and particulate biodegradable materials at higher loading rates. Thus increased sludge retention times, usually exceeding 15 days, ensure complete nitrification even in extremely cold weather.

The cost of building and operating an MBR is usually higher than conventional wastewater treatment. Membrane filters can be blinded with grease or abraded by suspended grit and lack a clarifier's flexibility to pass peak flows. The technology has become increasingly popular for reliably pretreated waste streams and has gained wider acceptance where infiltration and inflow have been controlled, however, and the life-cycle costs have been steadily decreasing. The small footprint of MBR systems, and the high quality effluent produced, make them particularly useful for water reuse applications



5.3.2 SBR

Sequencing batch reactors (SBR), or sequential batch reactors, are industrial processing tanks for the treatment of wastewater. SBR reactors treat waste water such as sewage or output from anaerobic digesters or mechanical biological treatment facilities in batches. Oxygen is bubbled through the waste water to reduce biochemical oxygen demand (BOD) and chemical oxygen demand (COD) to make suitable for discharge into sewers or for use on land.

While there are several configurations of SBRs the basic process is similar. The installation consists of at least two identically equipped tanks with a common inlet, which can be switched between them. The tanks have a “flow through” system, with raw wastewater (influent) coming in at one end and treated water (effluent) flowing out the other. While one tank is in settle/decant mode the other is aerating and filling. At the inlet is a section of the tank known as the bio-selector. This consists of a series of walls or baffles which direct the flow either from side to side of the tank or under and over consecutive baffles. This helps to mix the incoming Influent and the returned activated sludge, beginning the biological digestion process before the liquor enters the main part of the tank.

There are five stages to treatment:

1. Fill

2. React

3. Settle

4. Decant

5. Idle

Aeration of the mixed liquor is performed during the first two stages by the use of fixed or floating mechanical pumps or by transferring air into fine bubble diffusers fixed to the floor of the tank. During this period the inlet valve to the tank is open and a returned activated sludge pump takes mixed liquid and solids (mixed liquor) from the outlet end of the tank to the inlet. This “seeds” the incoming sewage with live bacteria.

Removal of Constituents

Aeration times vary according to the plant size and the composition/quantity of the incoming liquor, but are typically 60 – 90 minutes. The addition of oxygen to the liquor encourages the multiplication of aerobic bacteria and they consume the nutrients. This process encourages the conversion of nitrogen from its reduced ammonia form to oxidized nitrite and nitrate forms, a process known as nitrification.

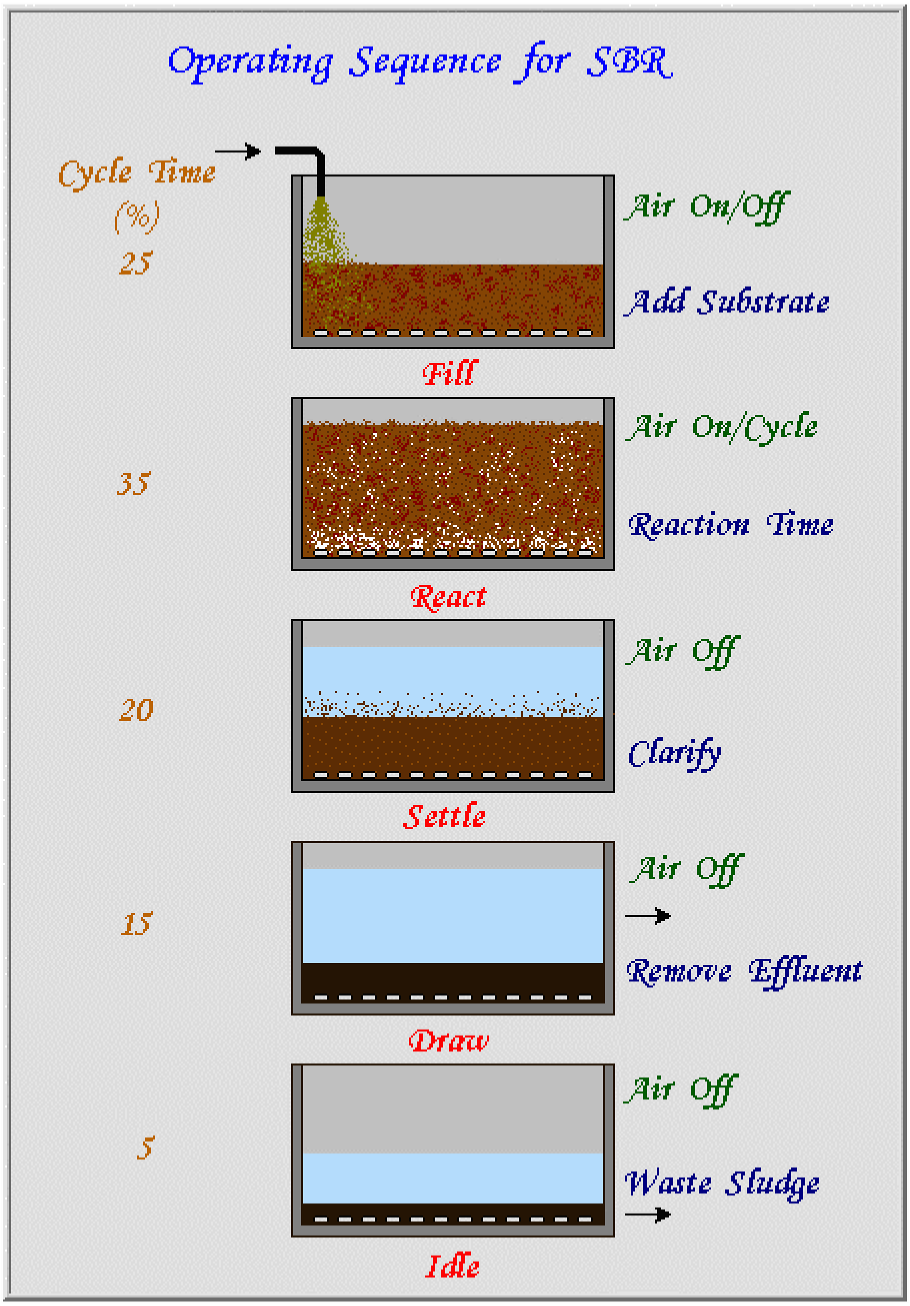
To remove phosphorus compounds from the liquor aluminium sulfate (alum) is often added during this period. It reacts to form non-soluble compounds, which settle into the sludge in the next stage.

The settling stage is usually the same length in time as the aeration. During this stage the sludge formed by the bacteria is allowed to settle to the bottom of the tank. The aerobic bacteria continue to multiply until the dissolved oxygen is all but used up. Conditions in the tank, especially near the bottom are now more suitable for the anaerobic bacteria to flourish. Many of these, and some of the bacteria which would prefer an oxygen environment, now start to use oxidized nitrogen instead of oxygen gas(as an alternate terminal electron acceptor) and convert the nitrogen to a gaseous state, as nitrogen oxides or, ideally, dinitrogen gas. This is known as denitrification.

As the bacteria multiply and die, the sludge within the tank increases over time and a waste activated sludge pump removes some of the sludge during the settle stage to a digester for further treatment. The quantity or “age” of sludge within the tank is closely monitored, as this can have a marked effect on the treatment process.

The sludge is allowed to settle until clear water is on the top 20%-30% of the tank contents.

The decanting stage most commonly involves the slow lowering of a scoop or “trough” into the basin. This has a piped connection to a lagoon where the final effluent is stored for disposal to a wetland, tree growing lot, ocean outfall, or to be further treated for use on parks, golf courses etc.



6 Comparison of Options and Recommendations

6.1 Comparison of Options

The eight options identified in section 5 above are now compared. The basis for comparison and weighting for each criterion is as indicated in table five below.

Assessment Criteria	Weighting
Costs	50

Performance	30
Reliability	10
Residuals	10

Table 5: Assessment criteria and weighting for evaluation of options

Cost estimates are based on specific quotations/calculations for Martinborough; (coagulation, FTW's,), estimates based on Martinborough specific parameters; soil beds, PETRO, Membrane Filtration, Constructed Wetlands, or prices for similar sized plants elsewhere; SBR, MBR.

Option	Coagulation	Floating Treatment Wetlands	Soil Beds	PETRO	Membrane Filtration	Sequential Batch Reactor	Constructed Wetland	Membrane Bioreactor
capital costs	$30,000	$427,725	$300,000	$1,000,000	$300,000	$350,000	$250,000	$420,000
operating costs	$25,000	$10,000	$50,000	$20,000	$75,000	$20,000	$10,000	$50,000
NPV	$275,450	$525,905	$790,900	$1,196,360	$1,036,350	$546,360	$348,180	$910,900
Rating	39.3	29.5	19.1	3.3	9.6	28.7	36.4	14.5

Table 6, Cost estimates; capital, operation, and 20 year NPV.

For performance, the key criteria; BOD, SS, and NH4-N are rated the highest, however, other performance criteria; micro, P and N, metals and emerging contaminants are also rated, albeit with lower weighting.

Performance	Weighting	Coagulation	Floating Treatment Wetlands	Soil Beds	PETRO	Membrane Filtration	Sequential Batch Reactor	Constructed Wetland	Membrane Bioreactor
BOD	6	4	4	5	3	5	3	2	5
SS	6	4	4	5	3	6	3	2	5
NH3	7	1	5	5	4	2	6	3	6
Micro	3	1.5	2	2.5	1.7	3	1	2	3
P	3	2.5	0.5	2.5	0.4	1	1.5	0.5	1.5
N	3	0.5	0.5	1	0.8	1	1.5	0.5	1.5
Metals	1	0	0.2	0.8	0.2	0.8	0.2	0.5	0.8
Emerging contaminants	1	0.1	0.3	0.2	0.1	0.2	0.1	0.7	0.4
Total	30	13.6	16.5	22	13.2	19	16.3	11.2	23.2

Table 7, Treatment performance for the options against a range of criteria.

Reliability is based on the proven nature of the treatment process and whether performance warranties are or are likely to be provided, so, for example, the soil bed and PETRO options, which are relatively unproven receive a 3, constructed wetlands a 6 as they are unlikely to come with a process warranty, and

Well established / proprietary treatment processes such as MF and MBR an 8. Ability to cope with higher flows is also included in this characteristic.

	Coagulation	Floating Treatment Wetlands	Soil Beds	PETRO	Membrane Filtration	Sequential Batch Reactor	Constructed Wetland	Membrane Bioreactor
Reliability	8	8	3	3	8	7	6	8

Table 8, Assessed reliability of the various options.

The final characteristic is residuals. As council currently has no avenue for disposal of significant quantities of sludge, (other than via the municipal solid waste stream), a process which produces significant residuals offers not only an additional cost but also a potential degree of difficulty. For this characteristic coagulation is rated the worst as there would be significant qualities of aluminium sulphate based sludge. At best this would contribute to the rate of sludge accumulation in the ponds, and at the worst it may cause reentrainment of sludge, a falling off in effluent quality, and / or toxicity issues for pond and receiving water bioate due to high soluble aluminium residuals.

By comparison, processes incorporating fixed or suspended growth; PETRO, SBR, and MBR, would provide some issues with biological sludge generation and disposal, MF backwash is normally flushed back to the source pond with relatively minor implications for feed quality, constructed wetlands and FTW's experience slow build up of sludges. Soil beds are rated lowly although it is entirely possible that the spent soil, saturated as it would be with phosphorus, would actually have some value or at least be able to be disposed of at cost.

	Coagulation	Floating Treatment Wetlands	Soil Beds	PETRO	Membrane Filtration	Sequential Batch Reactor	Constructed Wetland	Membrane Bioreactor
Residuals	1	8	2	4	5	4	7	6

Table 9 Residuals.

Table 10 below summates all these rankings and gives an overall score. The higher the score the more suitable the option.

Option	Coagulation	Floating Treatment Wetlands	Soil Beds	PETRO	Membrane Filtration	Sequential Batch Reactor	Constructed Wetland	Membrane Bioreactor
Costs	39.3	29.5	19.1	3.3	9.6	28.7	36.4	14.5
Performance	13.6	16.5	22.0	13.2	19.0	16.3	11.2	23.2
Reliability	8.0	8.0	3.0	3.0	8.0	7.0	6.0	8.0
Residuals	1.0	8.0	2.0	4.0	5.0	4.0	7.0	6.0
Total	61.9	62.0	46.1	23.5	41.6	56.0	60.6	51.7

Table 10, Weighted rating for the 8 options.

6.2 Recommendations

Although the ratings in the tables above are calculated and reported to the nearest 0.1 value, some of the specific numbers derived have been somewhat subjectively arrived at. Therefore, the ratings should not be considered absolute but rather indicative values. Further changes in the ranking bias may also come from a more detailed assessment of the current impacts of the discharge on the Ruamahanga River and the relative importance of different contaminants, for example, ammoniacal nitrogen may be found to be the most significant impact and therefore warrant changing the weighting for ammonia reduction.
On the basis of the current values and weightings, however, four of the 8 options are considered to be of similar and preferred ranking; coagulation, FTW's, MBR and constructed wetlands.

A further option exists, which is simply not to undertake any additional treatment, and instead make progress on inflow and infiltration reduction, land purchase and irrigation system construction.

7 Appendices

7.1 Appendix 1 – Report on Soil Beds by Andy Duncan

Carterton District Council /Sustainable Wairarapa Incorporated Land treatment trial

1. Background

The study involves construction of a trial system and testing the performance of the system in terms of contaminant removal. The system involves filtering effluent through a known media on an inclined slope. The concept is that a trench is excavated in low permeability natural soil, and filled with a higher permeability selected soil. Treated wastewater applied at the top of the slope finds the easiest route down, and hence follows a *preferential flowpath* through the more permeable material. A number of criteria are used to obtain the best treatment as the water flows down the trench.

The first trench was constructed and loaded with effluent over a three week period with: final quality effluent from the Carterton District Council wastewater treatment plant, primary oxidation pond effluent, final quality effluent dose loaded with 5x10^{9} MS2 viruses each day.

Sampling was carried out by Vanessa Vermeulen, the Environmental Health officer for Carterton District Council, and samples analysed for physical properties at ELS laboratories, and for biological (pathogen) properties at Environmental Science & Research in Christchurch.

Samples were taken from the trench inlet, two intermediate sampling points, and trench outlet.

Samples were aggregated where possible because of the time period over which the flow occurs.

The trial trench is located at the eastern end of the site adjacent to the oxidation pond (fig. 1).

Figure 1 trial trench location

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

The outlet from the trench will return to the oxidation pond.

2. Schematic

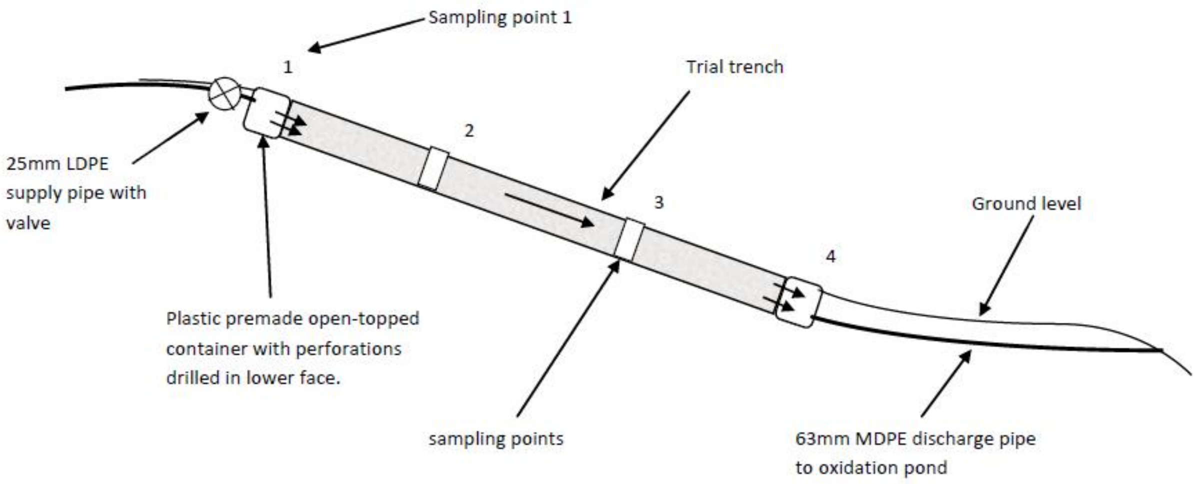


Figure 2 cross section of trench

3. Influent quality

The trial had different influent qualities (and hence contaminant concentrations). The experiment has three phases, and the proposal was to sample:

a) Current best (final) wastewater treatment plant effluent quality (disk filtration and UV)

b) Use water directly from the oxidation pond.

c) This part of the experiment involved spiking the final effluent with MS2 phage (virus) concentrate to measure the removal efficiency.


Preferential Flowpath Land
Treatment System trial site

4. Results

Laboratory results indicate high removal rates for Biochemical Oxygen Demand, suspended solids, very high removal rates for phosphorus, and variable removal rates for nitrogen. Dissolved oxygen increased through the trench. On the first day of testing, it was clear that the trench had not been sufficiently commissioned, as there were fines etc still being washed from the settling fill material. High removal rates were observed for both bacteria and viruses.

Concentrations in g/m³

Week 1	**SS**	**DO**	**BOD5**	**TP**	**TN**
Average in	31.3	8.6	12.0	6.4	18.4
Average out	9.3	10.0	4.3	0.07	9.1

Week 2	**SS**	**DO**	**BOD5**	**TP**	**TN**
Average in	23.3	6.2	23.7	6.1	20.7
Average out	12.3	9.9	1.8	0.08	7.9

Pathogens:

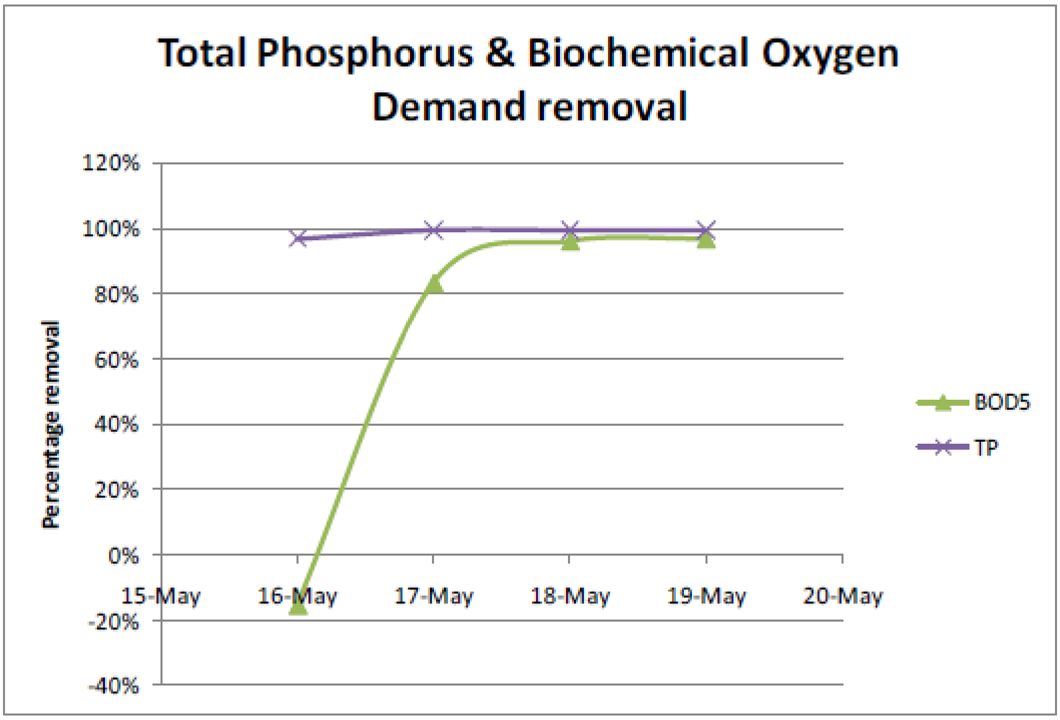
E-Coli.

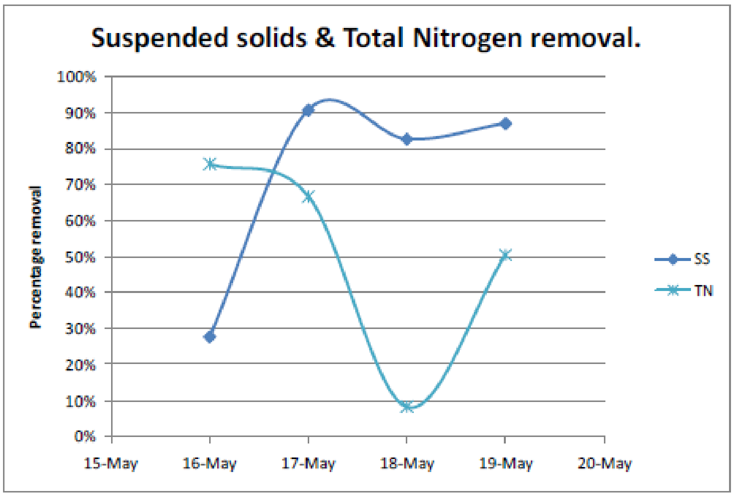
Average in:	13,596
Average out:	<1

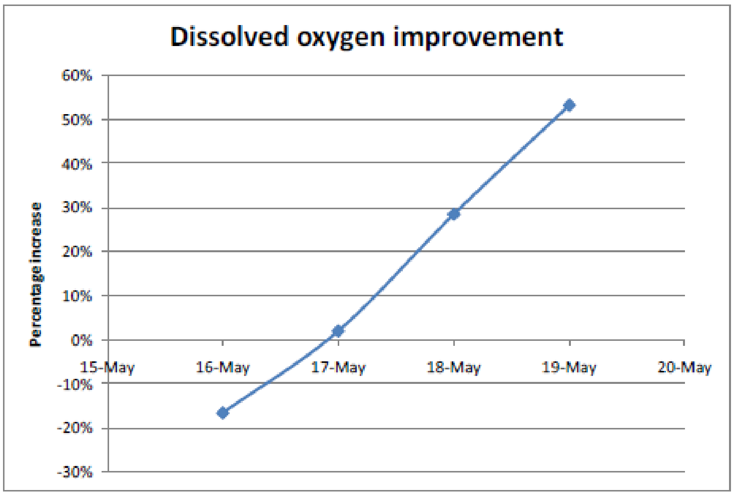
MS2 Phage.

Average in:	199,250
Average out:	40

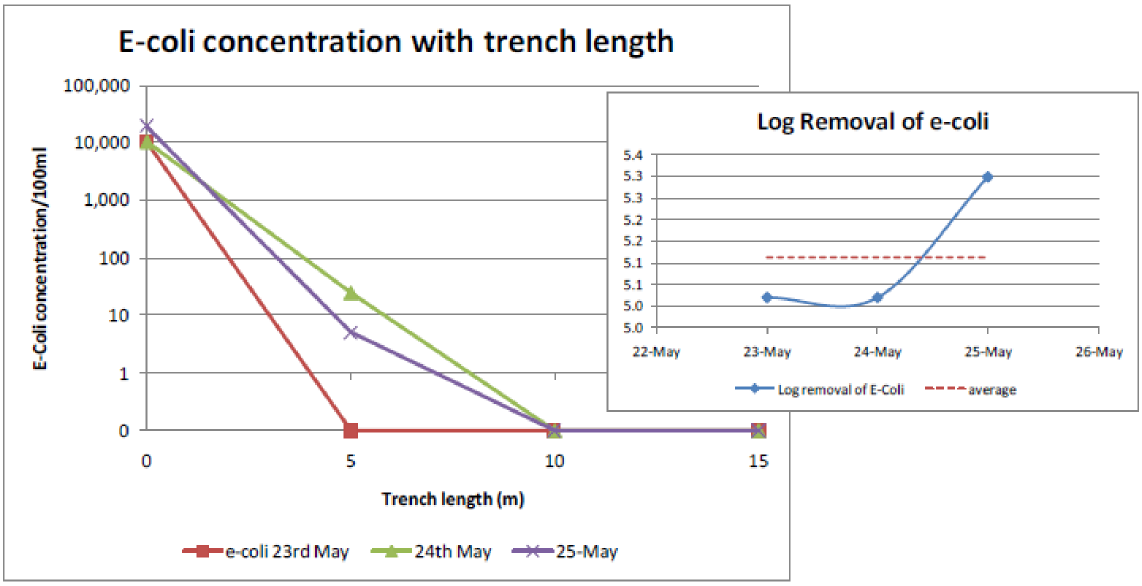
Results week 1:



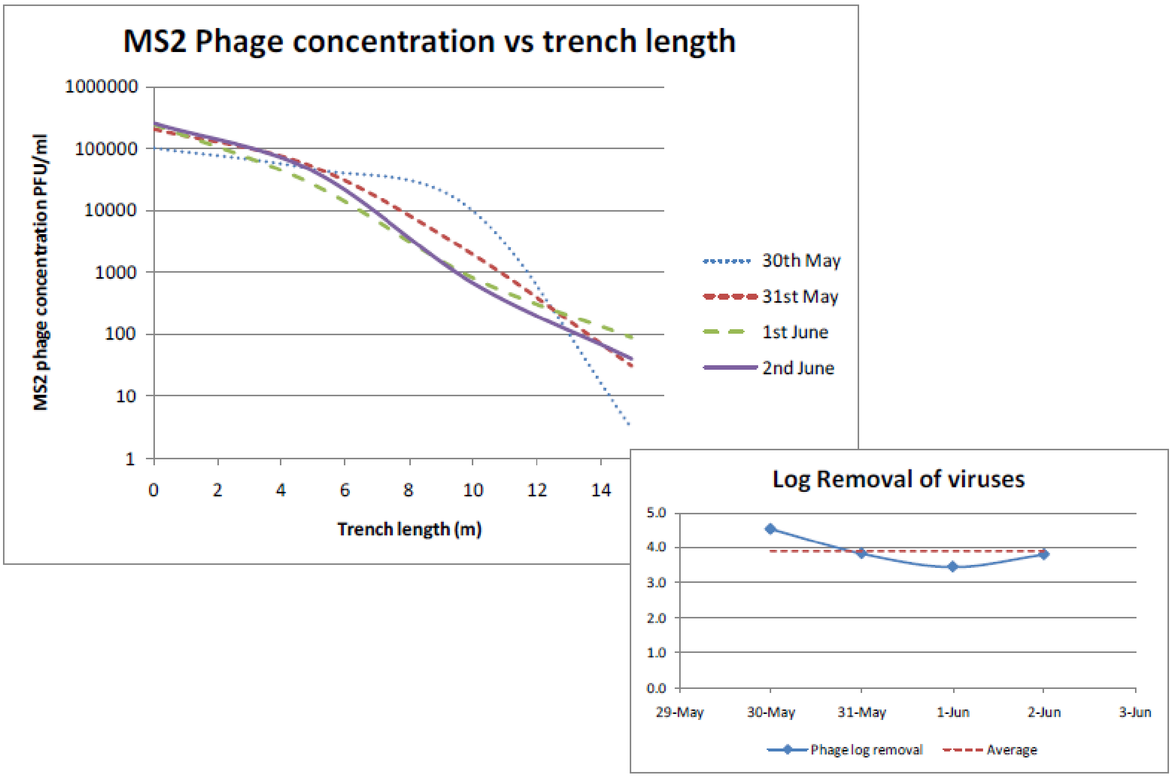


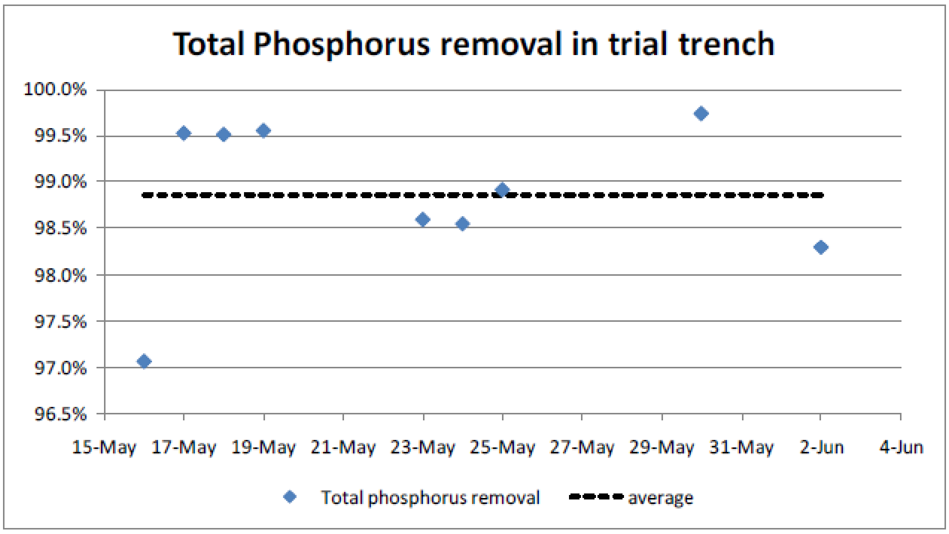


Results week 2:



Results week 3:





7.2 – Appendix 2: Canadian Pacific Limited Proposal on Membrane Filtration for the Carterton Wastewater Treatment Plant

19 December 2007

New Zealand Environmental Technologies Ltd
PO Box 40 339
Upper Hutt, Wellington

Attention Mr Stu Clark

CARTERTON DISTRICT COUNCIL
MEMBRANE, ULTRA FILTRATION, WASTEWATER TREATMENT PLANT

Dear Stu,

The prices listed below are for estimating purposes only and include the manufacture delivery and commissioning of the CPL WWTP situated on a suitable hard stand on site.
This has been prepared in haste, so not all of your questions have been addressed and there will be refinements that can be made as we look at the scheme in more detail.

No allowance has been made for any electrical or pipe work outside of the plant

1. To design, fabricate and supply and install to site an 8 cassette membrane plant for the tertiary treatment of oxidation pond effluent, up to 2,500 m^3/day.

   $909,000 + GST

2. To carry out regular clean in place and service of membranes.

   $48,500 per annum + GST

Thank you for the opportunity to be of assistance.

Yours truly

Peter Leitch BE (civil)
Managing Director

Proposal

The Ultrafiltration system offered by CPL is a 2 train, 8 cassette membrane system, designed to produce a flow of 2500 m^3/d.

Warranty

The CPL plant is offered with a 5 year replacement warranty on the membranes.
The warranty shall cover:

- The integrity of the membranes and the ability to provide the quality of TSS, BOD and Ecoli of the discharge water specified in the tender document and based on the influent quality data supplied in the tender document.
- Nutrient removal is expressly excluded.
- Materials and workmanship
- Performance design

Technical Information

General Description

The Canadian Pacific Ltd (CPL) proposal is a membrane filtration plant, using Zenon 500C cassettes recovered from the Waikato Water Treatment Plant (WTP) at Tuakau. The Waikato WTP was commissioned in 2002 and underwent a capacity upgrade in 2005. In this upgrade the plant operating capacity was increased by retrofitting the WTP with Zenon 500D membrane cassettes. As the existing Zenon 500C cassettes became surplus to use, CPL has purchased the cassettes and stored them for use specifically in wastewater treatment applications.

Membrane filtration uses a semi-impermeable membrane to separate materials according to their physical and chemical properties when a pressure differential is applied across the membrane. They are classified by the size of the membrane pore size and the size of the particles removed.

The membrane plant is configured as follows:

- Modules that comprise thousands of hollow porous fibres, each 2 millimetres diameter and 2 metres long, bundled together are installed on a frame to make a cassette; and
- Cassettes are immersed vertically in rectangular tanks (refer Figure 1) to form a train

There are two trains of ZW500C membranes (four cassettes per train, 26 modules per cassette).

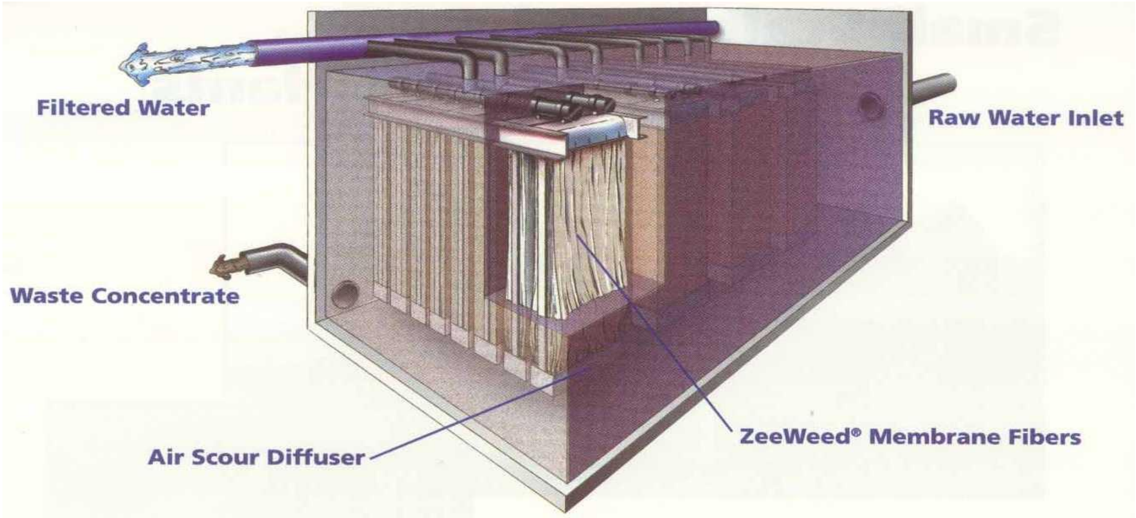


Figure 1 Membrane Schematic

The fibres consist of a woven inner core for strength and durability with the membrane film applied to the exterior. The nominal membrane pore size is 0.035 micron, the absolute pore size 0.1 micron. These inhibit the passage of protozoa and bacteria and most viruses to the filtered water. The range of materials these membranes will remove is shown in Figure 2.

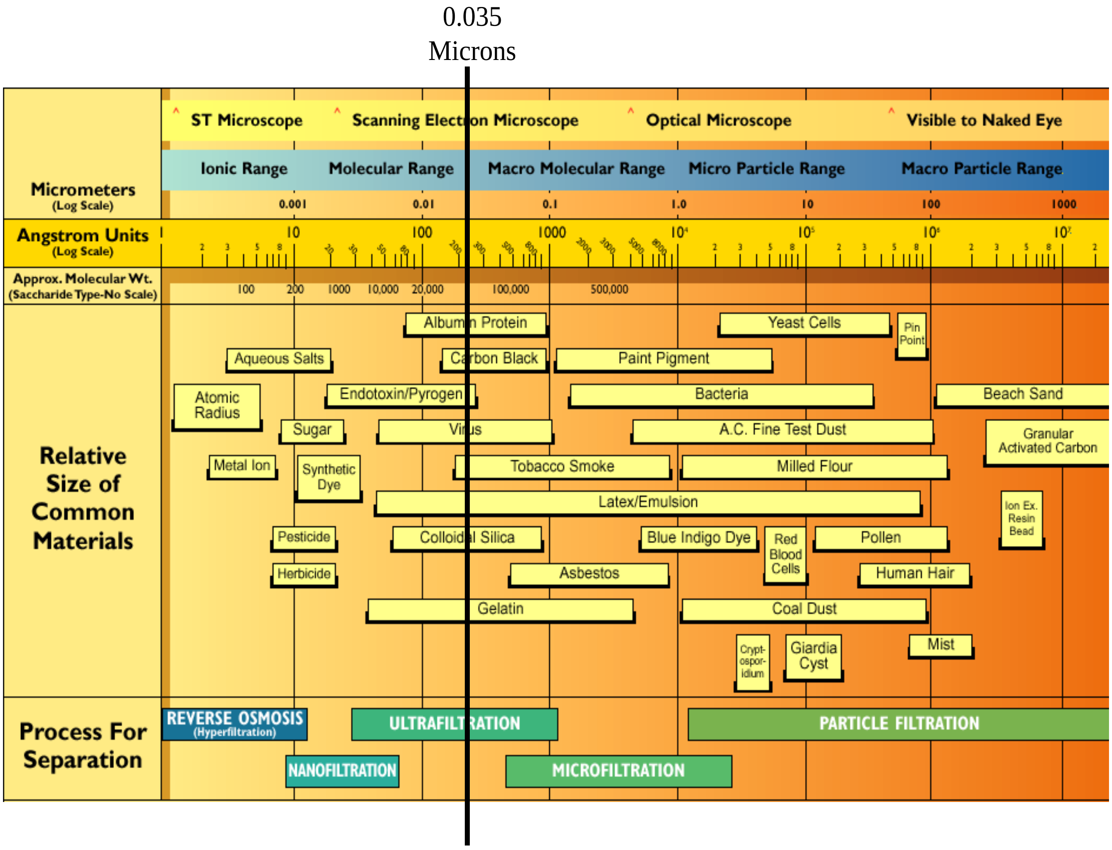


Figure 2 Filtration Spectrum

Each train has a dedicated low pressure permeate pump to draw the water out through the fibres under vacuum. For the ZW500C cassettes water is drawn through the top of the fibre. Flow through each membrane is controlled by a variable speed drive on the permeate pump, with the set point determined by the incoming flow.

Aeration of the cassettes is done to agitate the fibres to reduce the rate at which solids accumulate on the membrane surfaces. At intervals a reverse flow (backpulse) is applied to the membranes for a short period to dislodge any accumulated solids from the membrane surface. Dirty water that accumulates in a membrane tank is removed and returned to the start of the treatment process.

Trials of new membranes have confirmed the following removal rates:

Micro-organism	Removal rate
Giardia	> 5 log
Cryptosporidium	> 4 log
E-coli	> 8 log
Viruses	> 4 log

Zenon membranes have obtained an ETV Statement to verify the performance of the membranes. The average removal rate for particles in the 3 – 15 µm size range was greater than 4.0 log for both test periods and the membrane integrity testing comprising of air pressure-hold test, particle counting and turbidity monitoring, was suitable for the detection of a compromised membrane fibre.

There is a gradual buildup of material on the membrane surfaces that cannot be removed by the aeration and backpulse process. When this occurs the affected tank is removed from service and chemically cleaned with either sodium hypochlorite or citric acid. These chemicals are then neutralised and discharged prior to returning the membrane to service.

Annual Rates of Consumption

Electricity
The permeate pump and blower are expected to consume 35 – 45 units per hour

Membrane Cleaning
Annual cost of cleaning membranes in place is (materials and labour) $48,500 per annum

Replacement Membranes
The cost of replacement for new 500C membrane cassettes, at 2007 prices, is CAD30,000 per cassette.

Flow Variations

The CPL plant is supplied with an on-board PLC with touch screen control panel. This makes the plant extremely flexible and easily controlled. Plant flow can be set to operate in several modes depending on the operators requirements to match the other components of the treatment plant. The operator can change between operating regimes via the touch screen.

- Level Control
- Ultrasonic level sensors are included for pond/sump level monitoring to allow the plant to be operated on pond levels

- Timer Control
- The plant can be programmed to start / stop via the on- board timer.

- Manual Control
- The automatic features can be overridden and the plant can be operated manually.

Local Agents

The CPL plant proposed is manufactured in Auckland, NZ. Current stocks of “Waikato” cassettes are expected to be depleted over the next 12-18 months, at which new membranes will be sourced direct from Zenon in Canada. The “Waikato” cassettes are a standard Zenon membrane configuration.

CPL have been involved with the Waikato WTP plant since commissioning and have undertaken all upgrade and repair works at the plant since. CPL personnel, with guidance and support from Zenon’s Technical Support Department, have developed the skills specifically required for successful membrane work.

An ongoing support service of membrane cleaning and maintenance is offered by CPL.

Previous NZ Installations

Thames Coromandel District Council – Hahei WWTP

Contact David James
07 868 0322
Details 600 m^3/day

Sampling Results 21 December 2006 to 11 June 2007

Parameter	**Inlet**		**Outlet**		**Unit**
	Average	95th percentile	Average	95th percentile	
Carbonaceous BOD_5	50.3	86	3.8	10.7	mg/L
Enterococci	3027	11905	5	10	cfu/100 mL
SS	108	188.8	2.3	26.8	mg/L

Table 3 Hahei MF Plant Inlet and Outlet Average and 95th Percentile

Matamata Piako District Council
Contact Phil Smith
07 884 0060
Details 900 m^3/day trial plant (May 06 – Sept 06

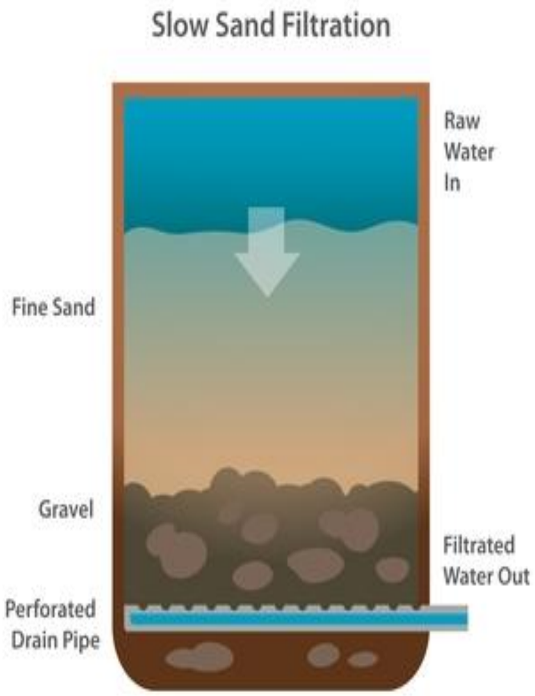
Parameter	Inlet		Outlet		Unit
	Average	90th percentile	Average	90th percentile	
Carbonaceous BOD_5	25.2	43.2	1.2		mg/L
Faecal Coliforms	8211	13000	2.4		cfu/100 mL
SS	76.7	120.0	3.1		mg/L

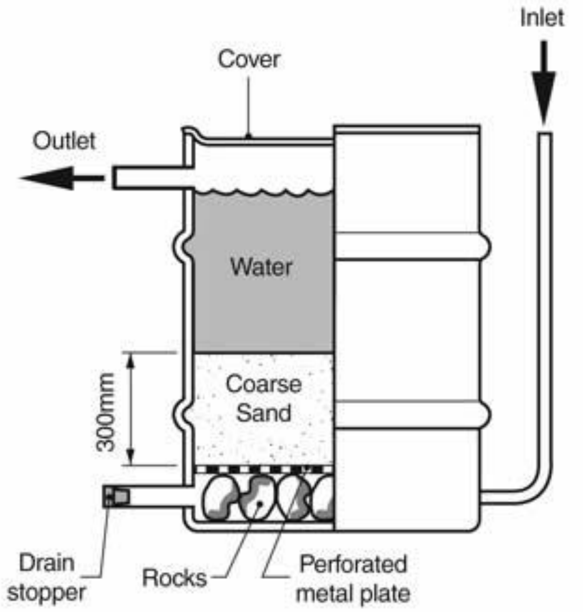
Table 4 Matamata MF Plant Inlet and Outlet Average and 90th Percentile

Material Specifications

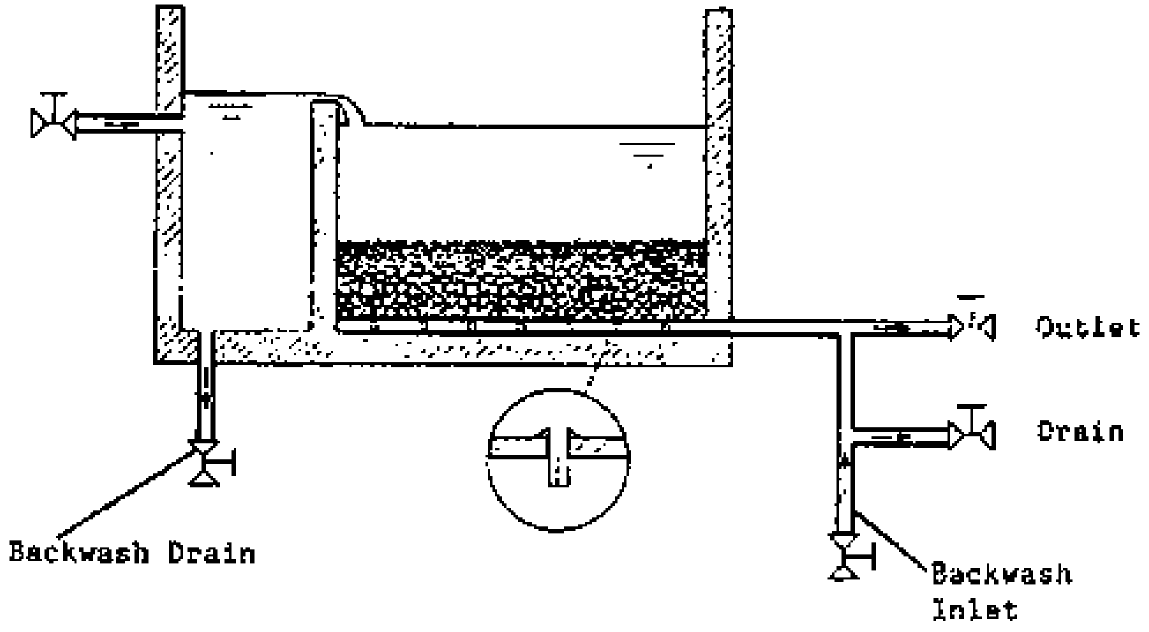
Plant Construction	2 only 8.4m long x 2.5m wide Tanks
Piping	316 Stainless pipe, flanges, nuts and bolts uPVC sch 80 Dosing Lines
Membranes	Zenon 500C ultra filtration membranes (Recovered from Waikato Water Treatment Plant)
Power Requirements	Three phase, 60 amp
Consumption	35 – 45 units / hr @ 2500 m^3/day flow (24 hr flow rate)
PLC	Keyence KV 1000 with touch screen controller
Recovery Washes	Discharge water from the recovery cleans is planned to be returned to the ponds.

7.3 – Appendix 3: Sand filtration diagrams

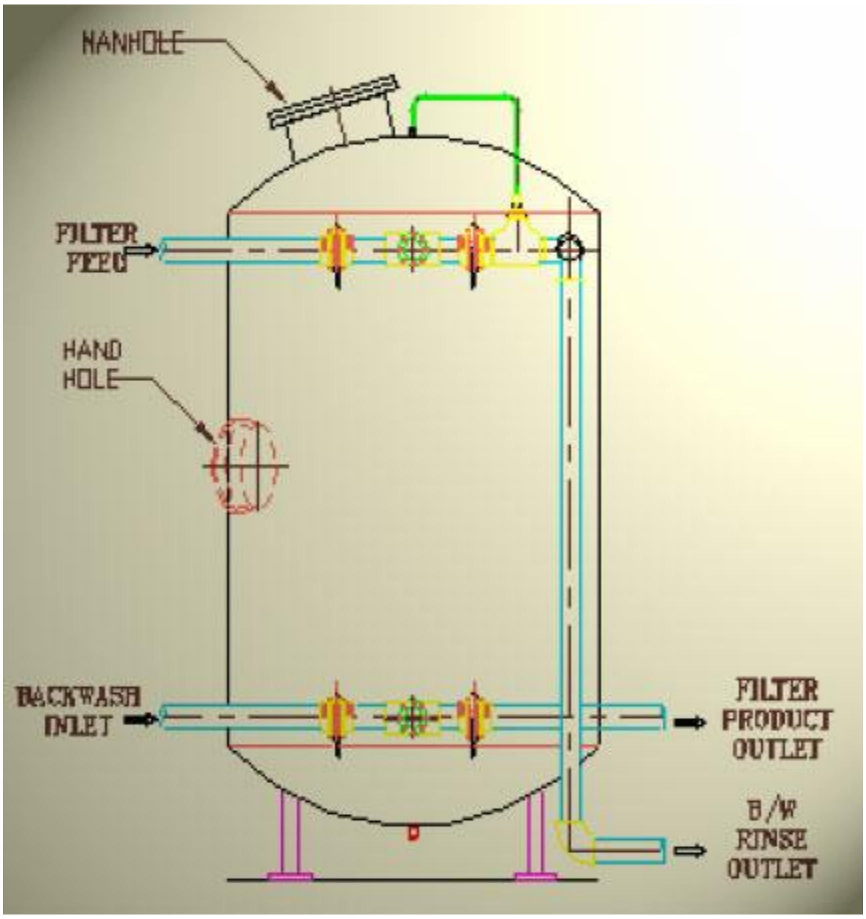




Upflow Sand Filter

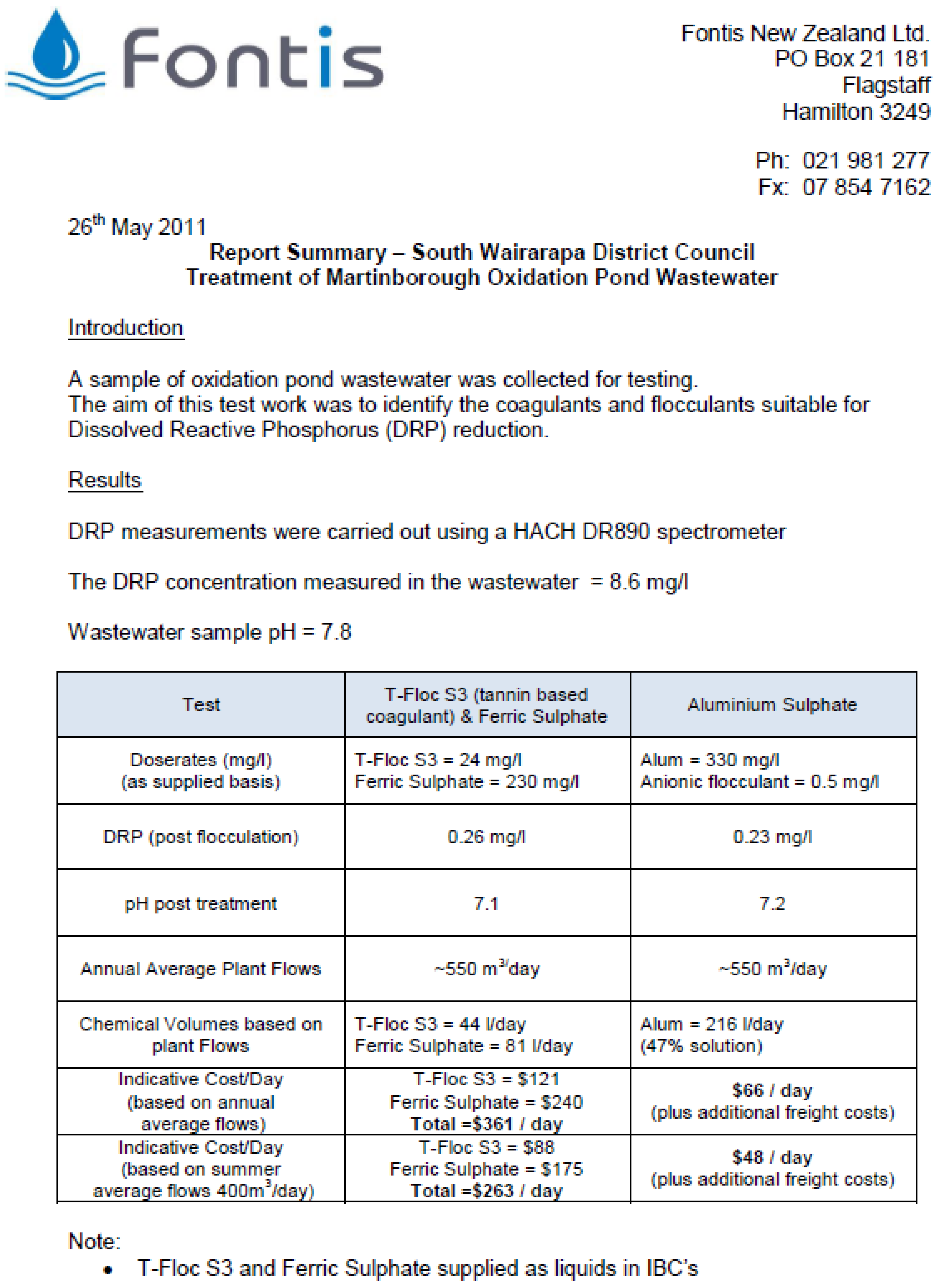


Rapid gravity sand filter



Rapid Pressure Sand Filter

7.4 – Appendix 4: Fontis Report on Martinborough WWTP



Fontis New Zealand Ltd.
PO Box 21 181
Flagstaff
Hamilton 3249

Ph: 021 981 277
Fx: 07 854 7162

26th May 2011

Report Summary – South Wairarapa District Council
Treatment of Martinborough Oxidation Pond Wastewater

Introduction

A sample of oxidation pond wastewater was collected for testing.
The aim of this test work was to identify the coagulants and flocculants suitable for Dissolved Reactive Phosphorus (DRP) reduction.

Results

DRP measurements were carried out using a HACH DR890 spectrometer

The DRP concentration measured in the wastewater = 8.6 mg/l

Wastewater sample pH = 7.8

Test	T-Floc S3 (tannin based coagulant) & Ferric Sulphate	Aluminium Sulphate
Doserates (mg/l) (as supplied basis)	T-Floc S3 = 24 mg/l Ferric Sulphate = 230 mg/l	Alum = 330 mg/l Anionic flocculant = 0.5 mg/l
DRP (post flocculation)	0.26 mg/l	0.23 mg/l
pH post treatment	7.1	7.2
Annual Average Plant Flows	~550 m^{3}/day	~550 m^3/day
Chemical Volumes based on plant Flows	T-Floc S3 = 44 l/day Ferric Sulphate = 81 l/day	Alum = 216 l/day (47% solution)
Indicative Cost/Day (based on annual average flows)	T-Floc S3 = $121 Ferric Sulphate = $240 **Total =$361 / day**	**$66 / day** (plus additional freight costs)
Indicative Cost/Day (based on summer average flows 400m^3/day)	T-Floc S3 = $88 Ferric Sulphate = $175 **Total =$263 / day**	**$48 / day** (plus additional freight costs)

Note:
- T-Floc S3 and Ferric Sulphate supplied as liquids in IBC's

- Aluminium Sulphate supplied in 25kg bags ex store Auckland + freight costs.

Conclusions

- Both the T-Floc S3/Ferric Sulphate and Aluminium Sulphate treatment systems effectively reduce the DRP to very low levels.

- Aluminium sulphate is the lowest cost option for DRP reduction at this plant.

- A low dose of 0.5 mg/l anionic flocculant can enhance the floc size and improve either floatation or settling of the formed floc.

Discussion

- The implementation of coagulants at this plant can effectively reduce the DRP concentration to comply with local body regulations. Considerable quantities of sludge would be generated through a coagulation/flocculation process that must be managed.

  If dosing of coagulants were carried out into a pond significant quantities of sludge will accumulate and at some point will require removal. The removal of sludge and subsequent dewatering could be an expensive exercise. The build-up of sludge in a pond may reduce the hydraulic retention time leading to a decrease in pond performance. The sludge may be at risk of becoming anaerobic and possibly produce a toxic environment for bacteria which may also lead to decreased pond performance. There may be additional risk of flocculated sludge escaping the pond into receiving waters.

  From experience at other WWTP's in New Zealand, alum sludge is very difficult to dewater and consumes high volumes of dewatering flocculants compared with other sludges, for example, WAS, digested and primary sludges. It is anticipated the Tannin / Ferric based sludge would be considerably easier to dewater, requiring less flocculant doserates compared with alum, and be more acceptable for disposal than alum based sludges.

  Perhaps the best mechanism for coagulant implementation is to dose to a clarifier or DAF where the solids can be collected, dewatered and disposed of appropriately. These are decisions which require careful consideration.

If you have any questions or queries regarding this report, please do not hesitate to contact me anytime.

Rob Petch – Fontis NZ Ltd

7.5 – Appendix 5: PETRO Article

PETRO® system: A low-tech approach to the removal of waste-water organics (incorporating effective removal of micro-algae by the trickling filter)

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Abstract

The system offering low-tech low-cost treatment of municipal sewage is described. It is based on a ponding process followed by a trickling filter (TF). Micro-algae produced in stabilization ponds are removed in the TF. It is suggested that micro-algae contribute to biofilm production and organic load reduction in the TF.

Introduction

The name PETRO® is a proprietory name which is an acronym of the concept title **P**ond **E**nhanced **TR**eatment and **O**peration. The system sets out to make maximum use of anaerobic biodegradation followed by aerobic degradation in oxidation ponds prior to the polishing stage in a secondary unit. As the name implies the efficiency of a secondary biological treatment unit (a trickling filter (TF) or an activated sludge process) is enhanced by a series of waste stabilisation ponds which is an effective primary stage for the removal of most of the organic material.

The system consists of a line-up of a number of well-known and reliable unit processes. The units are positioned in such a way that the shortcomings of the individual components are avoided and advantages of the constituent components are used to the best effect.

The system is aimed at employment in the current SA situation as it is particularly applicable in developing countries. This situation dictates that a waste-water treatment system must:

- produce an effluent of a superior quality suitable for discharge into a watercourse;
- be a low-capital cost facility with low operational costs;
- be simple in operation;
- lend itself for progressive upgrading;
- perform well despite of lack of human skills and other restrictions, typical of a developing country environment.

Low-tech systems are of increasing importance in the context of the world-wide situation. A former IAWQ president PGrau has questioned whether world problems of water quality can be solved by "a high-technology and expensive treatment plants" approach (Grau, 1994). A viable solution is a promotion of the "GNP appropriate technology", i.e. a technology appropriate for countries with a low Gross National Product.

The PETRO® system is an example of such "GNP appropriate technology". It is a conceptually innovative process which has been tested on a large scale for more than a decade.

The system was developed in successive stages from a series of oxidation ponds which are indigenous to South Africa. The innovative concept of high-rate recirculation of algae and oxygen-rich effluent from an oxidation pond back to primary pond was described by Abbott (1963) and is still widely used.

However, as the effluents from most oxidation ponds do not comply with the statutary effluent requirements for return to a public stream an exemption has to be granted whenever ponds are to be used. The granting of exemption is only considered in instances where less than 800 $k\ell \cdot d^{-1}$ of sewage is to be treated and where there is little prospect of growth (Meiring et al., 1968).

The advantages of a pond system were so obvious that efforts were made to overcome the shortcomings. A major approach was to try and upgrade the effluent quality. In an attempt to achieve this goal Vosloo (1973) linked a biological filter and humus tank downstream of the oxidation ponds. The process was not effective as algae passed through the biological TF undetained.

The initial design by one of the authors for upgrading the quality of the final oxidation pond effluent in Kanyamazane (Mpumalanga) in 1974 was based on the same premise. However, certain changes were introduced in the design. These changes were of an experimental nature and aimed at supplying primary pond effluent as a source of organic nutrients for TF biofilm in an attempt to enhance the ability of the slime microbial consortium to remove algae, or alternatively, to avoid the prolific growth of algae due to by-passing the secondary oxidation ponds. The process was taken a step further when at Letlhabile (North-West Province) another PETRO® full-scale plant was built 1982. The Letlhabile Sewage Works was specifically designed as an installation requiring minimum skilled attention but producing an acceptable effluent even if a prolonged power failure should occur. Information obtained from operating the Kanyamazane facility was applied and the PETRO® concept was formulated (Meiring, 1992).

The PETRO® concept constitutes an integrated pond system incorporating a facultative stabilisation pond and oxidation ponds interlinked by high-rate interpond recirculation in a peculiar line-up. In a hybrid arrangement it also involves a secondary facility such as a TF.

The operational advantages, low cost and effluent quality achieved consistently for more than a decade prompted a Water Research Commission-funded project to explain the nature of the biological phenomena involved in order to establish informed procedures for optimising the PETRO system.

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TABLE 1
OPERATION PARAMETERS OF THE PETRO TF PLANTS

PETRO plant	Population served	Hydraulic load ($M\ell.d^{-1}$)	Organic load (kg COD.d^{-1})	Number of TFs	TF volume (m^3)
Kanyamazane	50 000	7	4150	2	4162
Letlhabile	30 000	1.6	1000	2	3200
Elliot	13 000*	0.8	660	2	656

* - design population 20 000

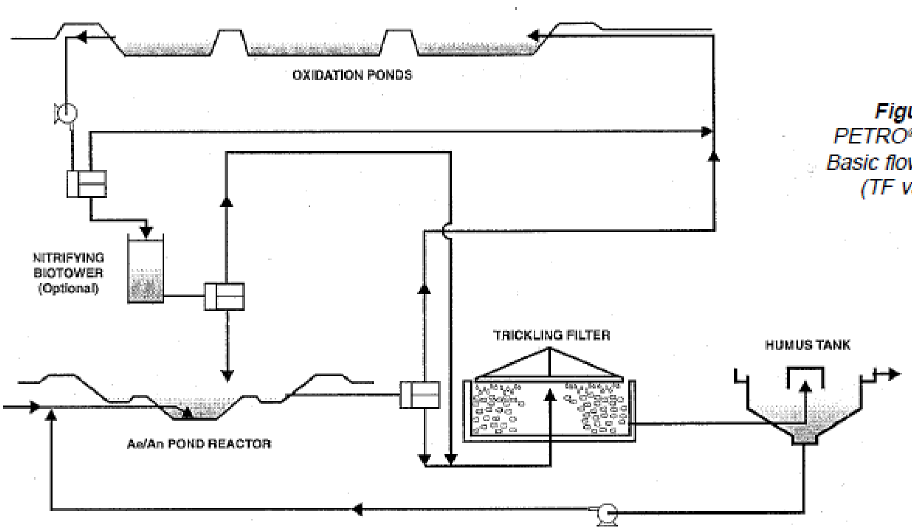

Figure 1
PETRO® system.
Basic flow diagram
(TF variant)

Materials and methods

Three full-scale PETRO® installations were studied: the municipal sewage works in Kanyamazane (Mpumalanga), Letlhabile (North-West Province) and Elliot (Eastern Cape). An inefficient system of oxidation ponds in Elliot was upgraded according to the PETRO concept in July 1994.

Current operation parameters for the plants are given in Table 1.

The system operation parameters (TKN, ammonia, nitrate, VSS, VDS) and chlorophyll *a* concentration were determined according to the *Standard Methods* (1989).

The TF biofilm was collected at a depth of 1 m below the surface. An amount of the biofilm was measured gravimetrically and expressed in kg of dry biofilm per m^3 of the rock medium.

The systems were studied at different seasons (summer-autumn 1994: average T_{water} =23°C and 20°C; winters 1994 and 1995: average T_{water} =15°C and 13°C, for Kanyamazane and Letlhabile, respectively).

Results and discussion

Description of the PETRO system

The basic flow diagram is presented in Fig. 1. The system comprises a deep primary facultative (Aerobic/Anaerobic, Ae/An) pond and one or a number of shallow secondary oxidation ponds as a primary stage of the process removing more than 70% of the incoming organic load. As the secondary stage a biological TF filled with stone medium followed by a humus tank is used. The TF may be substituted with an activated sludge process (ASP).

An important feature of the system is recirculation to ensure that the primary anaerobic pond does not constitute an environmental hazard. The recirculation of oxygen-rich water from the secondary oxidation ponds and nitrate-rich humus tank underflow into the primary pond allays obnoxious odours by sulphide oxidation. The design and positioning of the primary pond obviates the hazard of employing open impeller pumps. This feature constitutes an important maintenance and operational advantage, particularly on small installations. In case of an emergency such as prolonged power failure which prevents pumping, the inflow of raw sewage will pass through the anaerobic pond into the secondary oxidation ponds for temporary storage.

The secondary oxidation ponds are incorporated in the system in a closed side-loop in which the required flow rates can be selected. The functions performed by the PETRO® oxidation ponds are the following:

- further reduction of primary pond organic matter effected by the algo-bacterial consortium

TABLE 2
TYPICAL PERFORMANCE CRITERIA OF PETRO® SYSTEM (KANYAMAZANE, WINTER 1995)

Parameter, mg ℓ$^{-1}$	Raw sewage	Primary pond	TF inflow	TF outflow	HT outflow	Overall removal, %
COD	556	371	149	97	45	92
TKN	67	48	16	5	2	97
NH_4^+-N	25	33	9	2	1	96
NO_3^--N	-	5	6	17	21	-
VSS	80	63	21	29	3	96
VDS	111	81	23	17	8	93

- supply of algae- and oxygen-rich water to suppress odours in the primary pond
- reduction of ammonia which otherwise would have to be nitrified downstream
- generation of bicarbonate alkalinity which assists in offsetting the effect of advanced nitrification in the TF
- providing a balancing reservoir for attenuation of the daily and wet weather peak flows
- providing an effective emergency treatment for the primary pond effluent prior to its final discharge should a power failure occur or pumping be interrupted
- providing a satisfactory treatment facility during initial stages of a progressive development program prior to the introduction of a TF (or ASP) as a polishing step.

The micro-algae make a significant synergistic contribution to successful effluent treatment in oxidation ponds (Abeliovich, 1986; Oswald, 1988; Rose et al, 1992). Algae producing oxygen thus facilitate organics breakdown by bacteria and other components of the microbial consortium. Carbon dioxide and low molecular organics consumed by algae result in a photosynthetic conversion of a substantial portion of the organic load into algal biomass (Abeliovich and Weisman, 1978). COD of the final effluent may be high with a large contribution by algal biomass in the form of filterable solids. Removal is problematic with a potential for nuisance in the form of secondary pollution by algal wastes and decay products (De Pauw and Solomoni, 1991).

Conventional TFs, among other options including in-line activated sludge reactors, when evaluated, have been found unable to remove algae from well-stabilized oxidation pond water (Vosloo, 1973; Meiring,1993; Meiring and Hoffmann, 1994).

The performance of a TF in general depends not only on soluble organics removal but to a greater extent on the ability of the secondary clarifier to separate the volatile suspended solids sloughed off from the TF medium (Bruce and Hawkes, 1983). It is even acknowledged that the inferior performance of the TFs in comparison to the ASP was due to the poor efficiency of the TF to produce settleable material or the downstream clarifier to effect its sedimentation (Anon., 1990). One of the major recent trends in the field of TF applications is to ensure effective flocculation in the TF and downstream by enhanced slime production (Parker et al., 1990).

Typical operational parameters of the PETRO® system are reported in Table 2. While the integrated PETRO® oxidation ponds effect a substantial organic load removal (>70%), the TF and humus tank (HT) achieve a substantial result in terms of polishing oxidation pond effluent and particularly in reduction of VSS, TKN and ammonia. The latter is converted to nitrate in the TF.

TABLE 3
VOLATILE SOLIDS REDUCTION IN THE TRICKLING FILTER-HUMUS TANK SECTION OF THE PETRO® SYSTEM (KANYAMAZANE, WINTER 1995; LETLHABILE, AUTUMN, 1994)

Parameter	Reduction in the TF, %	Reduction in the HT, %	Overall reduction, %
KANYAMAZANE			
Volatile suspended solids	0	90	86
Volatile dissolved solids	26	53	35
LETLHABILE			
Volatile suspended solids	0	82	78
Volatile dissolved solids	41	64	76

The PETRO® TF and humus tank are essential algae-removing components of the system removing 35 to 76% of the volatile dissolved solids (Table 3).

No reduction of the mass of volatile suspended solids (VSS) appears to occur in the PETRO® TF. On the contrary, VSS increase in the TF outflow compared to the influent but passage of organics through the PETRO® TF considerably enhances their settleability. Flocculation of organics including algal residue is a most important function of the PETRO® TF.

An enhanced flocculation in the PETRO® TF leads to an effective humus tank performance as up to 82 to 90% of incoming VSS sediment is removed in the PETRO® humus tank.

Many factors contribute towards the remarkable performance of the PETRO® system which do not apply in a conventional system. Consequently, whereas the current SA design criteria for a conventional TF would indicate a requirement of a 1 m³ filter medium for every 4 to 5 persons served by the waste treatment facility, this number can be increased by a factor of more than 2 when using the PETRO® system.

Microflora of the PETRO® system

An investigation of microflora in three full-scale systems was undertaken. Typical data are presented in Table 4. All components of the PETRO® system containing micro-algae were surveyed. These include a primary pond, secondary ponds, TF influent combining primary pond and secondary pond effluents, TF and HT effluents.

A comparison of the systems has shown that the total amount of micro-algae is substantially greater in the Kanyamazane system than in both the Letlhabile and Elliot systems. Chlorophyll concentrations in the Kanyamazane TF influent is more than 7 times higher compared to Letlhabile in summer-autumn period (799 and 102 $\mu g \cdot \ell^{-1}$, respectively) and 2 to 7 times higher than in Elliot at different seasons. A winter algal concentration in Elliot was deceptively high (451$\mu g \cdot \ell^{-1}$) due to residual algae generated prior to conversion. At that time the oxidation ponds received raw sewage which resulted in a higher nutrient input and subsequent algal bloom.

Algal numbers in the oxidation pond effluent decrease somewhat in winter apparently due to the lower light intensity and temperature. Chlorophyll *a* concentration dropped twofold in Kanyamazane.

The green algae Chlorophyta and Euglenophyta were numerically by far the predominant chlorophyll-containing organisms. Chlorophyta were represented by *Chlorella* spp., *Scenedesmus obliquus, S. quadricauda* and residual *Volvox* spp. Cells of *Chlorella* spp. were found in much greater numbers than those of the other species. Cells were both free and in clumps as these produced mucilages consisting of exopolysaccharides (EPS). The majority of algal cells in the primary pond and the TF influent were freely dispersed (in Kanyamazane: 85% and 80%, respectively; in Letlhabile: 60 and 70%, respectively; in Elliot: 76 and 65 %, respectively). The rest of the cells were entrapped in an EPS mucilage. The percentage of entrapped algae increased dramatically after the TF (up to 98%). The entrapment appears to facilitate downstream removal as humus attains a high settling characteristic.

Euglenophyta were represented by several species including *Euglena* spp., *Lepocinclis* spp., *Phacus pyrum* and *P. pleuronectes*. The vast majority of *Euglenophyta* were *Phacus* spp., motile and non-motile (due to aging and entrapment). These were found throughout the system down to the HT effluent. Most of the Euglenophyta cells were also found entrapped in a mucilagenous substance. The percentage of the free organisms varies greatly in different components of the system. Approximately 5 to 15% (and 11 to 16%) of the total number of Euglenophyta in the TF effluent (and final effluent) were free cells while the percentage was much higher in the primary and secondary ponds: 69 to 82 and 60 to 80%, respectively.

Diatom algae (Bacillariophyta) were represented by a number of species both unicellular (*Nitzschia* spp.) and filamentous (*Synedra* spp.) and did not constitute a substantial part of the algal consortium.

Thus all studied PETRO® systems were characterised by surprisingly uniform algal microflora. The dominant species include green alga *Chlorella* spp., euglenoid *Phacus* spp. and to a considerably lesser extent diatom *Nitzschia* spp. and green alga *Scenedesmus* spp.

A substantial number of *Protozoa* spp. were observed in the system. Only holozoic feeders capable of ingesting algal cells were counted. These belong to classes Ciliata and Rhizopoda. Stalked ciliates (*Vorticella* spp.) dominated in the oxidation ponds and downstream. Amoeboid organisms were found only in the TF and downstream.

Relatively low numbers of protozoa containing unicellular algae were found prior to the TF. A much greater ratio of *number of algae-containing protozoa : total number of protozoa* for the TF effluent compared to that of the TF influent was observed in all systems. While the ratio prior to the TF was not more than 0.03, the ratio increased after the TF to at least 0.6 in every system. It suggests that most of grazing activity of protozoa is concentrated in the TF.

The same phenomenon was observed for rotifers. Rotifers, both stalked and free-swimming, were found in the TF and downstream. Many contained unicellular algae and even larger euglenoid organisms (12 to 100% of total rotifer population depending on the particular system).

The presence of live algae in a TF increases the importance of the predation phenomenon. Numbers of protozoa and rotifers appear to increase with an increase of algal concentration.

Rotifers, as much as protozoa, are known to have a very high potential to eliminate algae. It has been estimated that one rotifer *Brachionus calyciflorus* can ingest about 2 000 *Chlorella* cells per hour (Seaman et al.,1986).

An increased concentration of particulate organic matter in the form of chlorophyll-containing organisms requires substantially higher activity of protozoa and rotifers as grazers on algal biomass. Being larger than algae these forms would increase settleability of the TF effluent.

Low numbers of fungal hyphae were observed in the oxidation ponds and the TF. Substantially lower numbers of hyphae were present in the Kanyamazane TF compared to those in a conventional TF.

Nematodes were found in the TF and downstream. No chlorophyll-containing organisms were detected inside the nematodes although some contained brown algae-like structures.

Overall, it is evident that an efficient removal of the algal and protozoal components of effluent VSS is effected on passing through the PETRO® TF and humus tank.

These results are corroborated by the data obtained by Oellermann et al. (1994).

Algal removal in the PETRO TF and biofilm development

A principal difference between the PETRO® and conventional trickling filters is that the former receives an organic load a substantial portion of which is in a form of live algal biomass. The presence of algae in the inflowing wastewater appears to have important consequences for the TF operation (Meiring, 1992).

Five PETRO® TFs have been investigated during different seasons. The higher-rate TF in Kanyamazane (receiving 75% of total load) was compared to the lower-rate TF (25% of load). The Kanyamazane system was compared to the Letlhabile system with the higher-rate TF receiving 67% of total load and the lower-rate TF (33%). The percentage supplementation of the PETRO TF influent with primary effluent varied between the two systems with 12% supplementation at Kanyamazane and 58% in the Letlhabile system. The data are reported in Table 5.

The results show that a high supplementation rate does not correlate with specific biofilm productivity, neither does the

TABLE 4
TYPICAL PARAMETERS OF REMOVAL OF ALGAL AND OTHER COMPONENTS OF MICROBIOLOGICAL CONSORTIUM IN THE PETRO SYSTEM REPRESENTED AS CELL COUNTS

Parameter, cells.mℓ^{-1}	TF inflow	TF outflow	HT overflow	Overall removal, %
Chlorophyta	3.5×10^5	2.3×10^4	9.1×10^3	97
Euglenophyta	4.6×10^4	1.9×10^3	2.2×10^2	99
Protozoa total	1700	450	80	96
Protozoa with algae inside	49	280	0	100
Rotifers total	0	170	0	100
Rotifers with algae	0	20	0	100
Chlorophyll *a* (μg.ℓ^{-1})	799	168	40	95

loading rate to individual filters. The results indicate higher biofilm productivity at both lower supplementation and loading rates. Compared to this parameter biofilm mass, however, does appear to be influenced by the quantity of COD loaded to the TF and the supplementation rates employed. The total biofilm mass appears to correlate with increased levels of algal biomass (chorophyll *a*) fed to the TF.

The biofilm mass in a conventional TF is known to substantially increase in winter due to temperature-induced lower levels of biological oxidation by bacteria and fungi (Hawkes, 1983). In contrast, the biofilm mass decreases in the PETRO® TF 1.6 and 2.4 times for the higher- and lower-rate Kanyamazane TF, respectively. A correlation of the decrease with a seasonal twofold drop of algal concentration in the TF inflow suggests other mechanisms controlling biofilm production.

Biofilm of the conventional TF is dominated by bacteria and/ or fungi which are the major producers of the slime known to consist of exopolysaccharides (EPS) (Mack et al., 1975). EPS impart viscosity to a biofilm thus enhancing immobilisation of microbial consortium and preventing its wash-off. The role of micro-algae in this case is limited to the marginal development on the surface of the TF which is exposed to the light (Wolowski, 1989).

However, large number of algal species were shown to function heterotrophically in the dark (Neilson and Levin, 1974; Abeliovich and Weisman, 1978; Day et al.,1991; Pearson et al., 1987) and continue to produce chlorophyll (Diakoff and Scheibe, 1975). Many micro-algae were also reported to produce slime including massive quantities of EPS under both light and dark conditions (Ramus, 1980; Kroen and Rayburn, 1984). Excellent flocculating properties of the algal EPS were demonstrated (Avnimelech and Troeger, 1982).

These features of micro-algae in conjunction with the data reported strongly suggest that micro-algae may play a much more important role in the PETRO® TF compared to a conventional TF. Their active growth appears to extend below the surface of the filter. Micro-algae entrapped in the TF may contribute to the removal of volatile dissolved solids (VDS) and to an increase in volatile suspended solids (VSS) by production of EPS (Table 3) thus enhancing flocculating properties of humus sloughed off. This may determine excellent performance of the TF as a polishing stage and ensure sparkling quality of effluent (Meiring et al., 1994).

Conversion of the Elliot Sewage Works into the PETRO system

The original Elliot Sewage Works built in 1974 consisted of two relatively large oxidation ponds (2.5 and 0.9 ha) followed by the TF which was designed for the removal of algae. The TF and therefore the original system as a whole failed to perform satisfactorily due to a low level of algal removal (50 to 60%).

The conversion of the Elliot system to function as a PETRO® system in 1994 offered an opportunity to study the changes in performance parameters, biofilm production and the TF microbial consortium.

A primary pond reactor preceding the oxidation ponds was built and a supplement of primary pond water to the TF inflow provided.

Poor algal removal in the Elliot TF during the early period of the PETRO® operation was apparently due to insufficient development of a biofilm consortium (Table 5 to 6). High algal concentration in the oxidation ponds 1 month after conversion could be a consequence of increased nutrient loads since, prior to conversion, raw sewage was originally supplied to the oxidation ponds as the system did not include an anaerobic primary pond. A period of imbalanced operation followed when the primary pond was in a start-up period. The development of the TF biofilm mass increased over time and was independent of loading rate while efficiency of algal removal was directly dependent on the mass of biofilm present.

Seven months of the PETRO® operation led to a significant overall improvement in performance parameters (Table 6) and particularly in the removal of algae which has reached 79% suggesting that the algae-removing TF consortium is in a process of development. In retrospect, a poor development of the biofilm and its consortium, and as a result an inferior performance of the plant prior to conversion, appears to be due to a lack of supplementation of organic matter to the TF facilitating development of a heterotrophic microbial consortium (Meiring and Hoffmann, 1994).

TABLE 5
COMPARISON OF BIOFILM PRODUCTIVITY AT DIFFERENT SUPPLEMENTATION, COD AND ALGAL LOADING RATES (CHLOROPHYLL *A* IN THE INFLUENT) APPLIED TO THE TRICKLING FILTER OF THREE PETRO® SYSTEMS

Trickling filter	Specific loading rate[1]	Biofilm mass (kg·m^{-3})	Specific biofilm productivity[2]	Algal concentration[3]	VSS removal in TF+HT, %
			KANYAMAZANE		
Higher-rate TF	133	1.19	9.0	599	89
Lower-rate TF	45	0.69	15.3	200	69
			LETLHABILE		
Higher-rate TF	99	0.64	6.5	81	78
Lower-rate TF	25	0.12	8.4	21	-
			ELLIOT		
1 month operation	148[4]	0.15	1.0	225	24
7 months operation	74	0.44	6.0	90	80

[1] - in g COD·m^{-3}·d^{-1};
[2] - in g biofilm produced from 1 g of COD loaded per day;
[3] - chlorophyll *a*, in µg·ℓ^{-1};
[4] - high loading rate was due to an ineffective operation of upstream ponds.

TABLE 6
PERFORMANCE OF THE ELLIOT PETRO SYSTEM 1 MONTH AND 7 MONTHS AFTER THE START-UP

Parameter, mg·ℓ^{-1}	Raw sewage	Anaerobic pond outflow	TF inflow	TF outflow	HT overflow	Overall removal,%
			1 month operation			
COD	486	315	301	189	150	69
TKN	76	63	59	50	48	-
NH_3^+-N	53	29	45	41	39	-
VSS	101	89	68	48	52	42
VDS	213	184	156	120	103	44
Chlorophyll *a*, µg·ℓ^{-1}	-	74	451	360	383	15
			7 month operation			
COD	828	293	150	102	75	90
TKN	69	58	40	19	14	80
NH_3-N	36	41	20	4	2	95
NO_3-N	<1	<1	2	29	32	-
VSS	250	91	50	62	10	96
VDS	106	113	83	30	31	71
Chlorophyll *a*, µg·ℓ^{-1}	-	16	180	79	38	79

TABLE 7
IMPROVEMENT OF THE FINAL EFFLUENT QUALITY IN THE NEWCASTLE TF PLANT AFTER THE CONVERSION

Parameter mg/ℓ	Prior to conversion	After the PETRO retrofit
COD (raw inflow)	514	625
COD (clarifier overflow)	56	46
COD (final effluent)	55	34
NH_4^+-N (raw inflow)	23	17
NH_4^+-N (clarifier overflow)	4	2
NH_4^+-N (final effluent)	0.6	1
NO_3^--N (raw inflow)	0.3	0.8
NO_3^--N (clarifier overflow)	22	18
NO_3^--N (final effluent)	13	16
SS (raw inflow)	300	300
SS (clarifier overflow)	10	8
SS (final effluent)	6	0

The PETRO® system is ideal for a stage-wise development and capital investment can be done accordingly. To upgrade an existing pond the system has much to offer. Where the necessary land is available, the annual cost of providing and running a PETRO® system can be appreciably less than 50 % of that of a conventional system producing an effluent of a similar quality. In instances where existing TF plants require upgrading, the potential benefits of converting them into the PETRO® linked to a pond system should be considered.

Retrofitting Newcastle TF plant

Retrofit of Ngagane Sewage Purification Works (Newcastle, KwaZulu-Natal) is a typical example of a cost-efficient upgrading of the works with a concomitant doubling of the flow. Original works operated until 1996 and received municipal sewage with an industrial component (12.5 Mℓ/d). It consisted of three anaerobic digesters preceded by two primary sedimentation tanks. In parallel settled sewage was treated by four TFs filled with furnace slag followed by three clarifiers which discharged effluent into three maturation ponds. Works had to be extended due to a flow increase up to 25 Mℓ/d. Instead of building another series of four TFs and clarifiers a PETRO® retrofit was chosen. A ponding system consisting of two primary and three secondary ponds was constructed at a cost of one new TF to tackle the bulk of organic load (>70%). Two new clarifiers were built to account for an increased hydraulic load. Another feasible option alternative to the PETRO was the construction of four TFs with four clarifiers preceded by two new digesters with two primary tanks.

Overall cost savings amounted to nearly 40% since PETRO® retrofit cost R 800 000 per 1 Mℓ extention while new TF plant would cost R 1 300 000 per 1 Mℓ. Furthermore, due to the PETRO® retrofit redundant anaerobic digesters, primary sedimentation tanks and sludge drying beds could be used to treat additional abattoir flow. Most notably apart from the fact that the system was capable of treating a double load with the same number of TFs, the retrofit also resulted in a marked increase of final effluent quality (Table 7).

Conclusions

The study reported here confirmed previous observations concerning the functioning of the PETRO® system (Meiring, 1993; Meiring and Oellermann, 1993). The system offers an efficient method of low-tech and low-cost treatment of municipal sewage which has been demonstrated in three full-scale plants for more than a decade.

The system incorporates a stage of effective removal of micro-algae from the oxidation pond water. The key element of the algae removal is the PETRO® TF. Unlike the conventional TF polishing systems, the algal biomass is now retained in the biofilm. The humus fraction produced has a high settling characteristic. It is recovered in the humus tank and a final effluent of a sparkling clarity is produced.

The results obtained suggest a much greater importance of micro-algae in the PETRO® TF compared to a conventional TF. Algal biomass appears to contribute to both biofilm production and an organic load reduction in the TF.

The operation of the system relies on the estabishment of a heterotrophic biofilm on the filter medium effected by supplementation of the TF oxidation pond feed with a nutrient- containing component of the partially treated effluent. The supply of primary pond effluent to the TF inflow is a prerequisite for development of an effective algae-removing biofilm consortium comprising algae, bacteria, fungi, protozoa and metazoa. Protozoa and rotifers grazing on algae in the TF also substantially contributes to the algal removal.

A thorough understanding of the nature of the biological phenomena involved is required in order to optimise the process and extend its field of application.

Trickling filters in general being reliable and simple in operation are classified as “appropriate” technology perfectly suitable to serve developing communities. Nevertheless designers regularly shy away because of their high initial cost. As far as capital cost is concerned the PETRO® system has brought about a dramatic change. Affordability has once again become an attractive feature. A substantial reduction of the volumetric requirements of the TF and sludge drying beds, omission of the primary sedimentation tanks and digesters significantly reduces the construction cost. Low power consumption, simplicity of operation, low manpower requirements and minimum mechanical equipment requirements facilitating phase-wise construction, result in a reduced maintenance expenditure. Overall, the PETRO® system is versatile and site-specific and can be employed in a number of flexible modes.

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7.6 – Appendix 6: Summary Flow Data for Martinborough WWTP

ASSET DATA	
Catchment population (2006 census)	1,326
TDWF - Theoretical dry weather flow (@ 250 L/cap/d) (m3/d)	332
DWF - Measured dry weather flow (average of lowest three months) (m3/d)	446
WWF - Measured wet weather flow (average of highest three months) (m3/d)	686
PWWF - Peak wet weather flow (peak day) (m3/d)	2821
AADF - Average annual daily flow (m3/d)	539
Dilution factor at DWF and average river/stream flow over that period	7259
Dilution factor at AADF and annual average river/stream flow	12227
WWF multiplier - (WWF/TDWF)	2.2
PWWF multiplier - (PWWF/TDWF)	8.5
Surface area of ponds (m2)	19400
Assumed average depth of ponds (m)	1.4
Pond volume (m3)	27160
Retention time - AADF (days)	50
Retention time - WWF (days)	40
Retention time - peak flow (days)	10