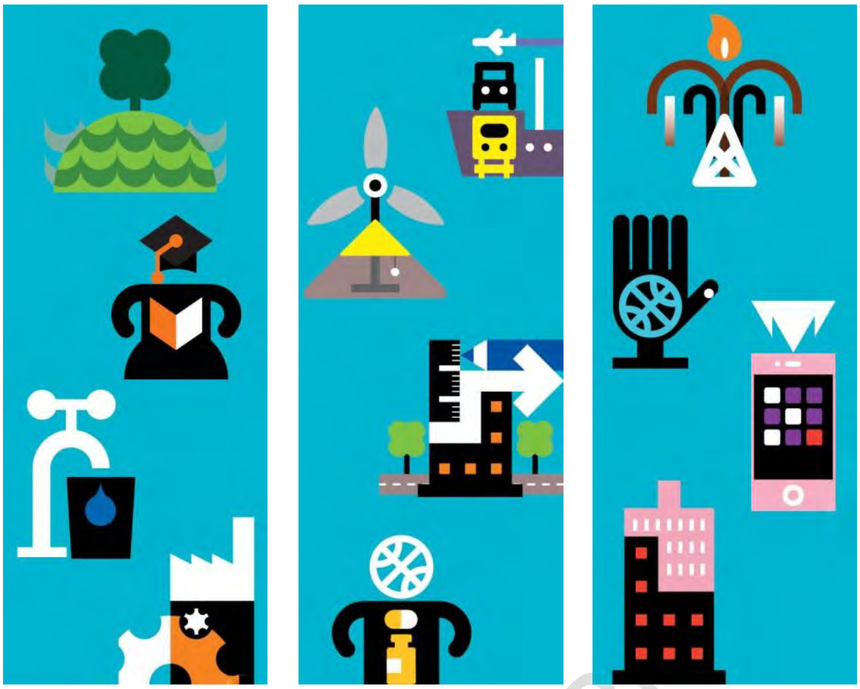

Rotorua Lakes Council

Wastewater Strategy

Version Three: June 2015

Rotorua Lakes Council

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Rotorua Lakes Council

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Issue and revision record

Revision	Date	Originator	Checker	Approver	Description
Revision 1	15 May 15	K Brian	N Dempsey	K Brian	
Revision 2	8 June 15	K Brian			Update and Review
Revision 3	22 June 2015	K Brian	S Couper	S Couper	

Contents

Executive Summary

Overview

As a result of the current land treatment system being decommissioned in 2019 and risks associated with the potential installation of a wet air oxidation (TERAX)process for solids management, Rotorua Lakes Council (RLC) implemented this study to investigate treatment and disposal options for the Rotorua WWTP. The key driver for the investigation is the best for plant option to meet projected nutrient targets of 30tN/yr and 3tP/yr in the discharge.

Design Criteria

Design criteria has been selected from the Terax business case and associated work to represent system inputs (including raw and settled wastewater characteristics) and projected output (effluent quality) requirements. Growth to the input is based on the average daily wastewater flow to the plant increasing from 19 to 23.8 ML/d across the study period. Current final effluent quality data has been considered from the MBR Permeate, Bardenpho effluent and the combine flow. This has shown both processes to be performing as anticipated with the exception being nitrification stability in the MBR with ammonia levels elevated by about 1 mgN/L above what is expected.

Option Selection

Options for evaluation have been developed through considering the best process configurations and/or choice of process to reach the target nitrogen and phosphorus effluent quality requirements. The options analysis revealed the following.

- **Phosphorous removal** - An evaluation around phosphorus removal considered supplemental carbon dosing (in the form of acetate) to enhance bio P removal against dosing of a metal salt (Alum) for phosphorus precipitation. This analysis shows a more favourable OPEX for Alum dosing of approximately $225,000 PA along with better process reliability.

- **Filtration to eliminate particulates** - Filtration was considered to be fundamental to removing particulate nitrogen and phosphorus from the wastewater stream. The removal of this these nutrients in particulate form means that the removal of the soluble nutrient fraction can be lower which will make the plant easier to operate through allowing more variation in the soluble nutrient species. A filtration process can be either incorporated into the secondary biological process (such as MBR) or provided as tertiary treatment, it is reliable and has a relatively low opex and provides a lower risk of failure. Membrane filtration was identified as the most reliable means through its provision of a "physical barrier".
-
- **Nitrogen removal** - A critical evaluation around the nitrogen removal requirements for the biological process considered whether the current secondary (activated sludge) process (either in its current or modified form) can meet the required removal, or if another tertiary stage is required. An overall efficiency of 93% is required to meet the projected effluent quality of 3.5mgN/L. Based on the evidence from a Water Environment Research Foundation study in the US this efficiency is achievable on a 50%ile basis. There is a greater risk with achieving the requirements with TERAX in the process train as this process may increase the level of soluble organic nitrogen.
-
- **Carbon balance** – Ensuring an effective carbon balance is critical for the nitrogen removal process. If the Terax process is not incorporated as part of the WWTP (justification for TERAX is related to minimising supplemental carbon dosing and bio solids disposal costs and outside the scope of this report)then the primary sedimentation system should be removed to improve the carbon balance for biological nitrogen removal.

Process Selection

The process selection considered the options selection/evaluation and developed a process configuration based on incorporating; chemical phosphorus removal, filtration as a given, and the opportunity to by-pass primary sedimentation to enhance the use of the carbon available in the wastewater and minimise ethanol dosing. Bypassing primary sedimentation will significantly increase the solids inventory in the system driving the selection of a process configuration that incorporates filtration into secondary biological treatment (i.e. MBR). This process configuration also allows for the use of the existing Bardenpho reactors and negates the limitations associated with an increased solids load to the existing secondary clarifier's.

The process configuration does not exclude the use of TERAX (in its current form) but the benefits from bypassing the primary sedimentation system would not be realised if TERAX is implemented and the TERAX risks identified remain.

Our process selection considered the nitrogen removal potential for an MLE configuration against and four stage Bardenpho configuration and this analysis identified a four stage Bardenpho configuration with a maximum anoxic fraction of 55% as the most efficient at achieving the nitrogen removal requirements.

An assessment of the solids production shows that this initiative will generate approximately 21M3/d of dewatered sludge (@ 18% TDS) compared to the current 32 M3/d (@ 17% TDS).

The process has been sized to treat up to the peak wet weather flow through an MBR plant with the system is configured around constructing a separate membrane tank for the modules. Opportunity exists to consider housing the membrane modules in the existing clarifier tanks.

Process Description

A process flow diagram presents the detail around the proposed configuration which consists of; Improves screening, Inter-stage pumping, two secondary treatment trains (existing side stream MBR and new Bardenpho reactors converted into MBR), Alum dosing, Solids management.

Costs

Estimated costs have been developed based on the above process description and include for items that are additional to the current plant and are provided on the same basis as the previous options reports prepared by Mott MacDonald and are presented in the cost summary table below.

Cost summary

Item	Sum (new Membrane Tank)	Sum (reuse clarifiers)
CAPEX Plus Contingency (incl non works costs)	$32,781,841	$30,298,780
OPEX ($/yr) – incl biosolids processing and disposal	$1,754,317	$1,754,317
OPEX per m3 treated	$0.24	$0.24
NPV (to 2035)	$53,784,490	$51,301,429

1 Introduction

Rotorua Lakes Council (RLC) is investigating options for the treatment and disposal of wastewater for Rotorua. This is driven by the existing land treatment system being decommissioned in 2019. In addition RLC has been investigating the use of wet air oxidation (TERAX) for the oxidation and destruction of primary and secondary solids from their wastewater treatment plant (WWTP).

The integration of TERAX into the treatment process has introduced risks associated with residual nitrogen and colour in the WWTP effluent. In addition there are some unknowns around the impact of phosphorus removal chemicals (such as Alum) on the TERAX system. These risks may affect the viability of some or all of the alternatives to land disposal.

This report presents an investigation of the most appropriate technology to meet the long term discharge consent requirements of the treatment plant (assumed to apply at the exit of the current and future treatment process), and how TERAX could be integrated into this solution. Note that the investigation is done on the basis of "best for plant" and does not assume that the TERAX process will be used by default.

1.1 Project Drivers

The driver for the treatment plant for effluent quality is the ability to meet likely future targets of 30tN/yr and 3tP/yr in the discharge from the WWTP. At current average annual flows of approximately 20ML/d, a total nitrogen concentration less than 4.1mgN/L and 0.4mgP/L on average are required. Under future flow conditions of 23.81ML/d these concentrations will reduce to an average of 3.5mgN/L and 0.35mgP/L.

At this time there are no drivers for biosolids quantities or dry solids content, albeit that minimum volumes leaving site are desirable. The ultimate fate of the biosolids is outside the scope of this report, however this is likely to require additional investigation if TERAX is not the best option for management of biosolids.

2 Design Criteria

The design criteria used for this study have been derived from the following sources:

- TERAX business case – in particular the current use of ethanol, estimated future and current bio solids production rate, sludge disposal charges and polymer use for solids dewatering
- Sampling data for the period 29/4/12 to 21/4/15
- Wastewater characteristics (COD fractions etc) have been assumed to be the same as the TERAX business case and investigations – this information may need to be updated with the latest sampling results in the future

The raw and settled wastewater characteristics are summarised in tables 2.1 and 2.2 below:

Table 2.1: Raw Wastewater Characteristics

Parameter	Units	Average
Current Daily Flow	ML/d	19
Future Daily Flow	ML/d	23.81
Total COD	mg/L	450
Filtered COD	mg/L	119
Filtered Flocculated COD	mg/L	63
Total Kjeldahl Nitrogen	mgN/L	49
Ammonia N	mgN/L	32.5
Total Phosphorus	mgP/L	7
Total Suspended Solids	mg/L	280
Volatile Suspended Solids	mg/L	219

Source: TERAX business case

Table 2.2 Settled Wastewater Characteristics

Parameter	Units	Average
Current Daily Flow	ML/d	18.91
Future Daily Flow	ML/d	23.72
Total COD	mg/L	252
Filtered COD	mg/L	119
Filtered Flocculated COD	mg/L	63
Total Kjeldahl Nitrogen	mgN/L	42
Ammonia N	mgN/L	32.5
Total Phosphorus	mgP/L	5.6
Total Suspended Solids	mg/L	112
Volatile Suspended Solids	mg/L	102

Source: TERAX business case

Final effluent quality for the WWTP is recorded in three separate samples:

- MBR Permeate
- Bardenpho Effluent
- Combined

The data used in this study has been sourced from the separate samples for each process (MBR and Bardenpho) such that the performance of each process unit can be analysed separately.

Table 2.3 Bardenpho Effluent Characteristics

Parameter	Units	Average	No of samples
Total COD	mg/L	44	149
Filtered COD	mg/L	16	46
Total Kjeldahl Nitrogen	mgN/L	2.61	95
Ammonia N	mgN/L	0.33	416
Total Phosphorus	mgP/L	3.42	150
Total Suspended Solids	mg/L	23	150
Volatile Suspended Solids	mg/L	19	150
Nitrate +Nitrite	mgN/L	2.04	354
Total Nitrogen	mgN/L	4.65	-
Dissolved Reactive Phosphorus	mgP/L	2.81	150

Source: Site Data 29/5/12 to 21/5/15

The characteristics of the Bardenpho effluent show that this process is achieving very good consistent levels of nitrification and denitrification. Elevated suspended solids and the effect of these on total phosphorus and total nitrogen levels mean that the Bardenpho in its current configuration will not be able to meet the proposed future quality limits.

Table 2.3 MBR Permeate Characteristics

Parameter	Units	Average	No of Samples
Total COD	mg/L	17	257
Total Kjeldahl Nitrogen	mgN/L	1.34	236
Ammonia N	mgN/L	1.24	561
Total Suspended Solids	mg/L	0.7	143
Nitrate +Nitrite	mgN/L	2.43	258
Organic Nitrogen	mgN/L	0.93	255
Total Nitrogen	mgN/L	3.91	235
Dissolved Reactive Phosphorus	mgP/L	1.43	258

Source: Site Data 29/5/12 to 21/5/15

The characteristics of the MBR permeate show that this process is achieving very good consistent levels denitrification, virtually no suspended solids and some phosphorus removal. However the process appears to be unstable with respect to nitrification resulting in total nitrogen levels that are slightly higher than the future targets (3.91mgN/L vs 3.45mgN/L)

3 Option Selection

The selection of the best for plant treatment option has been based on the revised effluent discharge criteria of 30tN/yr and 3tP/yr

Key questions considered are:

What are the best configurations and/or choice of process to reach the target nitrogen and phosphorus concentrations required in the plant final effluent:

3.1.1 Phosphorus Removal

Historic performance of the Bardenpho and more recently the MBR, has shown that good biological nitrogen and phosphorus removal can be achieved with the appropriate levels of carbon dosing. The removal of both nitrogen and phosphorus has not been consistently achieved at the same time.

While it is possible to meet the target concentrations for nitrogen and phosphorus via biological methods, there is competition between denitrification (nitrogen removal) and phosphorus removal for carbon (COD). Typically a COD/TKN ratio of greater than 15:1 is needed to achieve low levels of both nitrogen and phosphorus. The raw wastewater at Rotorua has a C/N ratio of about 11:1 so is not ideal. This restriction is not specific to the type of process. All biological processes rely on a favourable C:N ratio to achieve nitrogen and phosphorus removal so this limitation cannot be overcome by a different type of process.

To overcome the COD limitation additional carbon such as acetic acid could be added to achieve biological phosphorus removal. As this needs to be dosed to the process this would incur an additional OPEX cost. This cost needs to be compared to chemical dosing metal salt to provide phosphorus removal to determine the best option for the WWTP.

Table 3.1 and 3.2 compare the cost of alum versus acetic acid for phosphorus removal based on the performance of the current plant.

Table 3.1: Phosphorus Removal with Acetic Acid Dosing

Parameter	Units	Value	Source
Residual	mgP/L	2.8	Sampling data

Parameter	Units	Value	Source
Phosphorus to remove			table 2.3
Acetate Requirement	kg/kg	10	Henze et al
Mass P to remove (at current ADF)	kg/d	67	
Acetate Dose	kg/d	670	
Acetate Cost	$/kg	$2.92	Orica per IBC
Annual Dosing Cost	$/yr	$714,086	

Source: Insert source text here

Table 3.2: Phosphorus Removal with Alum Dosing

Parameter	Units	Value	Source
Residual Phosphorus to remove	mgP/L	2.8	Sampling data table 2.3
Alum required	kgAlum/kgP	21	Calculation
Mass P to remove (at current ADF)	kg/d	67	
Alum Dose (52% w/w)	L/d	2064	
Alum Cost	$/L	$0.65	Orica
Annual Dosing Cost	$/yr	$489,000	

Source: Insert source text here

The cost of acetic acid dosing is nearly double the cost of alum dosing for the same result (excluding the costs of sludge handling) and there does not appear to be a driver to enhance phosphorus removal via additional carbon dosing.

Given the cost advantage of alum and that the most reliable and controllable means for removing phosphorus is via chemicals (lime, alum or ferric) then a chemical dosing option for phosphorus removal is likely to be the preferred option for the WWTP. Dosing is not process specific and can be added to almost any biological process either in situ or as a separate tertiary stage.

Conclusion: Use chemicals (i.e alum) to remove phosphorus

3.1.2 Filtration

Sampling results for the Bardenpho (as shown in table 2.3) show that there are significant levels of suspended solids in the final effluent from this part of the treatment process. Loss of suspended solids causes several issues with the ability of the WWTP to meet the future nitrogen and phosphorus standards. These include:

- Secondary solids from all biological processes contain phosphorus due to this being an essential nutrient for growth. In a typical secondary process approximately 2% of the effluent volatile suspended solids are related to total phosphorus.
- With chemical dosing for phosphorus removal the phosphorus is bound to a chemical such as aluminium (when alum is dosed). Therefore the solids in the final effluent of a system dosed with alum will have higher percentages of phosphorus, in the order of 3-4%
- Secondary solids from all biological processes also contain nitrogen. This typically ranges from about 7% to 10% by mass.

The performance of the Bardenpho over the last three years has averaged 23mgTSS/L. This represents a phosphorus concentration of approximately 0.5mg/L or a mass discharge of 3.65 tonnes/yr. Alum dosing to reduce this could be as high as 6.7tP/yr. Removal of this residual phosphorus is essential to meeting the proposed limit of 0.3mgP/L.

In terms of nitrogen the discharge of 23mg/L of suspended solids represents between 1.6mgN/L and 2.3mgN/L. If the proposed average concentration of 3.5mgN/L is to be met then removal of these solids is essential.

If the Bardenpho were replaced with any other biological process where gravity settlement is used, the risk of solids loss and elevation of phosphorus and nitrogen concentrations remains. Filtration, either as part of the secondary process or as a tertiary process, is a reliable and relatively low OPEX means of virtually eliminating particulate phosphorus and nitrogen.

Removal of all the particulate nitrogen from the final effluent also means that the reduction of the other components of total nitrogen do not need to be as efficient to achieve the same overall total nitrogen result. This will reduce carbon consumption and more importantly allow more variation in the other nitrogen species.

As a unit process the highest levels of filtration can be achieved via a membrane (see tertiary options study) and it is likely that removing solids to essentially zero can only be achieved with membrane filtration

A membrane provides the most reliable means of filtering as all flows have to pass through a physical barrier to achieve treatment and there is no opportunity for short circuiting or variable pore sizes etc that can be an issue with other filtration devices.

Conclusion: Filtration of the final effluent is essential to reduce or eliminate particulate phosphorus and nitrogen. Membrane filtration will give the highest level of solids removal due to very low pore size of the filter. Removing all particulate nitrogen will reduce the required removal efficiency of other nitrogen species such as nitrate and ammonia

If a membrane is used as final filtration stage in whatever configuration (MBR or tertiary) then this will give lowest particulate N as TSS is always essentially zero.

3.1.3 Nitrogen Removal

One of the key requirements of the WWTP is the ability to remove nitrogen. This can be done in a variety of ways either by fixed film systems (sand or media filters), suspended growth processes (activated sludge) or via newly developed processes such as AMMONOX.

Given that the plant is configured as secondary activated sludge process and is removing nitrogen already, the key questions are:

- Can this type of secondary process (activated sludge) remove enough nitrogen to meet the proposed consent limits or is another (tertiary) stage required?
- How does this compare to other nitrogen removal plants in terms of efficiency?

3.1.3.1 What efficiency of N removal is needed?

The efficiency of the secondary process is an essential element to answering the above question. If sufficient removal efficiency can be obtained in a single stage (sludge) BNR then it is likely that the same type of process that is used at present can be modified to meet the new limits. If a single stage process cannot meet the required efficiency then irrespective of how the secondary process is configured a tertiary stage will be required.

The advantages of a tertiary stage are that if this were added to the current plant (or another type of single stage process) the combined efficiency of each process stage can be used to meet the quality drivers.

For example if the secondary process is 80% efficient and a tertiary process 60% efficient then the overall efficiency is 92%. For very high efficiency levels it will be more reliable to use this effect of several stages in series.

The sampling data from site shows that the inlet total nitrogen to the WWTP is approximately 50mgN/L. Therefore to meet the new limit of 3.5mgN/L the required efficiency of the process overall is 3.5/50 or 93%.

Can this be reliably achieved in a secondary process?

3.1.3.2 Comparison to other Plants

The Water Environment Research Foundation (WERF) has published several guides and investigations into low nutrient treatment plants and their reliability. For the purposes of this study, we have used the example plants contained in the WEF/WERF "Study Quantifying Nutrient Removal Technology Performance (2011)". This study looks at 22 treatment plants that have the lowest nutrient standards in the US. It looks at the reliability of meeting different effluent qualities in terms of nitrogen and phosphorus and compares these using a range of statistical methods.

The plants most similar to Rotorua are summarised in table 3.3. Each plant is a single sludge process (tertiary filters only), are of a similar scale and have similar nitrogen standards than those proposed for Rotorua.

Table 3.3: Comparison of Nitrogen Removal Plants – Single sludge N removal

Plant	Configuration	Median TN (mg/L)	N Removal
Piscataway, MD (78,000m3/d)	Activated sludge and Tertiary Filters	3.00	86%
Eastern WRF, FL (64,000m3/d)	Bardenpho and tertiary Filters	3.64	90%
Parkway, MD (21,600m3/d)	4 Stage Bardenpho	3.40	88%

Plant	Configuration	Median TN (mg/L)	N Removal
Rotorua WWTP (23,800m3/d)	?	3.50	93%

Source: WERF 2011

The data above illustrates that single sludge plants can achieve similar standards to Rotorua, however it is important to note that these plants are not able to achieve these limits on more than a 50%ile basis. This is important for the setting of limits for the plant as percentile concentrations greater than 50% are likely to mean that additional nitrogen removal stages are required to achieve lower average nitrogen standards.

There is some risk if TERAX were included in the process train that dissolved organic nitrogen would increase thereby increasing the effluent total nitrogen concentration. It is estimated (Mott Mac Donald 2014) that the dissolved organic nitrogen from TERAX may increase effluent total nitrogen by 0.3mgN/L (or 2.6tN/yr). If this increase in organic nitrogen is offset by further nitrate removal then it is possible that a single sludge process will not be suitable

Conclusion: Single sludge BNR plants can achieve the standards required at Rotorua provided limits are set on median or mean concentrations. If greater levels of certainty are required (i.e. 90th or 95th percentiles) additional treatment stages will be essential.

3.2 Carbon Balance

The key to removing nitrogen in a conventional nutrient removal process is the efficient use of organic carbon. Carbon is critical to the removal of nitrate nitrogen that is formed from the oxidation of ammonia. If sufficient carbon is not available to match nitrate generated in the process then incomplete nitrate removal will occur and consequently elevate final effluent nitrogen.

Currently the plant uses ethanol to supplement carbon and one of the primary drivers of considering TERAX was to recover carbon from primary and secondary sludge.

In the current process configuration primary settlement removes carbon (COD) associated with suspended solids. This COD is thickened and then dewatered and removed from site. In this configuration the COD removed in the primary settlement stage is not used for any other purpose in the treatment train. In larger plants, and historically at Rotorua, the primary sludge is mixed with secondary sludge and digested to make gas. This is no longer used at the plant and has not been part of the treatment train for a significant period of time.

The TERAX process has been developed to take primary sludge, ferment it and produce a carbon source for the WWTP. Residual solids are then oxidised in the TERAX "cooker" and the residual liquid (containing the carbon source) is returned to the WWTP.

The TERAX process, in its current form, is only of value to the WWTP if this primary solids stream can be transformed into a carbon source.

Given that without TERAX the primary solids once removed from the WWTP process present no value (in fact a significant cost) to the WWTP, there is no driver to continue removing primary sludge. It is recommended that to minimise OPEX and make the best use of the available carbon that the primary sedimentation system is removed from the process configuration.

In terms of considering the use of TERAX at the WWTP, this is only a valid option in its current form if carbon recovery for nitrogen removal is required (to minimise or eliminate ethanol use) and to reduce the tonnage of bio solids leaving site. If primary solids are not removed in the WWTP then one of the key drivers for TERAX in the Rotorua plant is removed.

4 Process Selection

The option selection analysis discussed above has identified the following:

- From a reliability and OPEX perspective dosing with chemicals such as alum is the best means of phosphorus removal at this WWTP
- Filtering of the final effluent is essential to remove particulate nitrogen and phosphorus
- Nitrogen removal targets of 3.5mgN/L as median or mean can be achieved by a single stage process and tertiary nitrogen removal (denitrification) is not required to meet the proposed limits
- To make maximum use of the available carbon in the wastewater primary sedimentation could be by passed

Given the above there are process configurations that can be considered to identify the best option of the WWTP. If a single stage process can achieve the limits proposed then making the best use of the existing assets on site such as the existing Bardenpho reactor are likely to represent the lowest capital cost.

4.1 Filtration

The unit process of filtration can be added as a separate stage after the existing final clarifiers of the Bardenpho or as a process that is integral to the secondary process such as an MBR. As discussed above the ideal filtration stage from a quality perspective is a membrane filter as this has the lowest pore size compared to most tertiary systems such as sandfilters, disc filters etc.

4.2 Primary Tank Bypass

Bypass of the primary sedimentation system at the plant will increase the carbon applied to the Bardenpho and should decrease or eliminate the need for ethanol dosing. Table 4.1 and Table 4.2 below compare the nitrogen reduction potential of the primary settled and raw wastewater respectively. The calculations have been based on 100% of the flow being treated in the Bardenpho (as currently configured). This is done for illustrating the use of carbon only and assumes no ethanol dosing.

Table 4.1: Dentrification Potential of Primary Settled Wastewater

Parameter	Units	Value	Notes
Total COD	mgCOD/L	252	Site data
Process Sludge Age	days	12	Site Data
Anoxic Fraction	%	33	Existing unaerated fraction
Nitrogen removal potential	mgN/L	12	calculated
Ethanol Saving	L/d	0	Baeline

Table 4.2: Denitrification Potential of Raw Wastewater

Parameter	Units	Value	Notes
Total COD	mgCOD/L	450	Site data
Process Sludge Age	days	12	Site Data
Anoxic Fraction	%	33	Existing unaerated fraction
Nitrogen removal potential	mgN/L	22	calculated
Ethanol Saving	L/d	700	At 20ML/d

The tables above show that in its current configuration the Bardenpho can remove approximately 10 mgN/L more nitrogen with bypass of the primary sedimentation tanks. At 20ML/d this represents a saving of approximately 700L/d of ethanol or $320,000/yr at $1.27/L.

4.3 Carbon Utilisation

As discussed in section 4.2 the use of primary sludge as a carbon source could reduce (not eliminate) the use of ethanol for denitrification and provide a significant OPEX saving. However the major disadvantage of bypassing primary treatment is an increase in the mass of solids entering the secondary process.

If the secondary volume of the plant is taken as fixed (i.e. assuming reuse of the Bardenpho reactor) then the concentration of solids within the process will increase as a result of bypassing primary solids. This is estimated to in the order of 1.2g/L taking the estimated MLSS from 2.8g/L to approximately 4g/L.

As discussed above the Bardenpho clarifiers are currently performing relatively poorly in terms of solids removal with an average of approximately 23mg/L under current flows. In the future with increased average flows and under peak wet weather flows this performance could deteriorate further. Moreover if more solids are added to the process from primary bypass or alum dosing then it is highly likely that the clarifiers will be overloaded.

In terms of option selection this has the following implications:

- Bypass of primary sedimentation is not feasible without increasing clarifier capacity – ground conditions onsite are known to be poor introducing construction risk if new clarifiers are built
- Filtration is considered essential to remove as much particulate phosphorus and nitrogen as possible so this would need to be added to the process in addition to clarifers if the primary tanks were bypassed.
- If primary solids are removed then the plant will rely more heavily on external carbon and this is likely to be a higher operational cost than making best use of the COD in the wastewater.
- TERAX can be used to add carbon back to the process if primary solids are removed, however this has the same risk profile as the options currently being considered and does not mitigate any of the identified risks associated with TERAX.

If filtration is a given in the process, tertiary denitrification is not essential, best use is made of the current Bardenpho reactor and primary sedimentation is bypassed, then the most likely option is to replace the final clarifiers of the Bardenpho and retrofit these with membranes, to form an MBR Process.

An MBR can operate at a much higher mixed liquor concentration than a clarifier based process. Therefore an increase in solids loading on the Bardenpho reactor is not an issue, provided maximum solids loading limits of the membranes is not exceeded.

4.4 Process Configuration

Based on the characteristics of the raw wastewater (assuming primary bypass) the nitrogen removal potential of the plant can be calculated as above (see table 4.2). In addition to the carbon availability a critical factor for determining nitrogen removal potential is the process configuration. There are “standard” process configurations for nitrogen removal these are described below.

4.4.1 MLE Process

The MLE process consists of a single anoxic zone followed by an aerobic zone and solids liquid separation (see figure 4.1). Recycles are taken from the aerobic zone to the anoxic zone and from the clarifier or membrane underflow

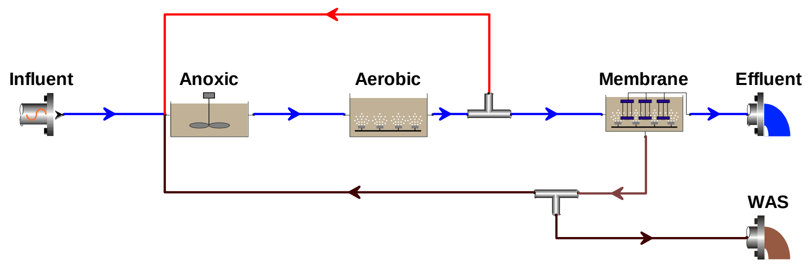


Figure 4.1: MLE Process (with Membrane)

4.4.2 Four Stage Bardenpho

Four stage Bardenpho - this configuration consists of a series of four reactors in an anoxic, aerobic, anoxic aerobic series. This configutarion is very similar to the 5 stage Bardenpho configuraton at the WWTP, with the first anaerobic zone removed (see figure 4.2). Note that the Bardenpho process shown below has the traditional fourth stage (re aeration) replaced by the membrane separation stage.

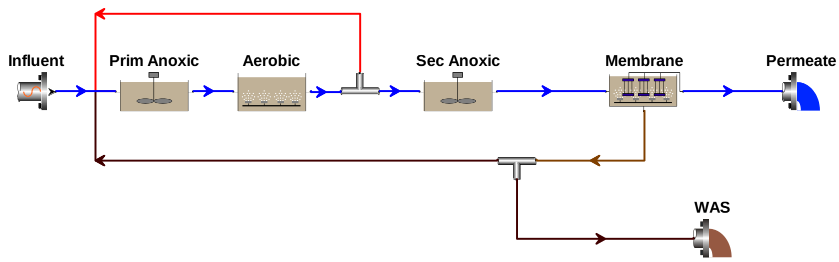
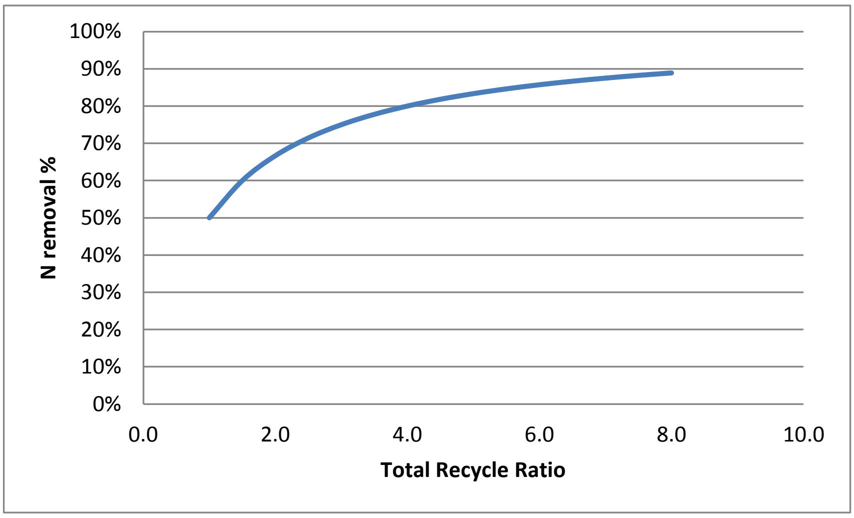


Figure 4.2: Four Stage Bardenpho with Membrane

The advantage of the four stage Bardenpho over an MLE is nitrogen removal efficiency. Figure 4.3 below shows the relationship between the nitrogen removal efficiency and recycle ratio for an MLE process. As shown on the figure this configuration is limited to about 90% nitrogen removal with a recycle rate of up to 8 times the influent flow. Even at this very high recycle rate this configuration will not be able to remove enough nitrogen to meet the standard required for the Rotorua WWTP. With a four stage Bardenpho the limitations associated with one anoxic zone are removed and removal efficiencies of >90% are possible.

Figure 4.3: Nitrogen Removal Efficiency of Two Stage Process



In addition to the process configuration the unaerated fraction of the process with respect to the aerated fraction determines its nitrogen removal potential. As a rule of thumb a maximum anoxic mass fraction of 50-55% can be used before nitrification becomes unstable. With a maximum anoxic fraction of 55% the denitrification potential of the process is increased therefore minimising the use of ethanol. Table 4.3 shows the denitrfication potential of a four stage bardenpho at a mass fraction of 55%. This represents the configuration with the maximum nitrate removal that can be achieved with the raw wastewater without carbon addition.

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Table 4.3: Denitrification Potential of Raw Wastewater at 55% Mass Fraction

Parameter	Units	Value	Notes
Total COD	mgCOD/L	450	Site data
Process Sludge Age	days	12	Site Data
Anoxic Fraction	%	55	Existing unaerated fraction
Temperature (min)	C	20	calculated
Nitrogen removal potential	mgN/L	33	At 20ML/d

Four Stage Bardenpho is the most Efficient Configuration to meet the required Nitrogen Standards with an anoxic fraction of 55%.

4.5 Ethanol Use

With an anoxic mass fraction of 55% the WWTP, configured as four stage Bardenpho, has the potential to remove approximately 33mgN/L without carbon addition. Table 4.4 summarises the required nitrogen concentrations required to meet the proposed consent limits. Based on these nitrogen standards there is a significant shortfall in the amount of nitrogen that can be removed without additional carbon. It is estimated at future flows of 23.8ML/d that approximately 600L/d of ethanol is required. This compares with an estimated ethanol consumption of 1900L/d projected for the current plant configuration (source: TERAX business case)

Table 4.4: Average Effluent Nitrogen Concentrations – Future Flows

Parameter	Units	Value	Notes
Effluent Ammonia	mgN/L	0.5	Based on Mean of combined current effluent
Soluble organic Nitrogen	mgN/L	1.25	Mean of MBR Organic N
Particulate Nitrogen	mgN/L	0	Assumed
Nitrate/Nitrite Required	mgN/L	1.75	Required to Meet limits
Nitrate/Nitrite with no carbon dosing	mgN/L	6.2	Calculated
Ethanol Dose	L/d	600	Calculated

Source: Insert source text here

Conclusion: Ethanol dosing is required to meet future standards. In the proposed plant configuration this is estimated to be 600L/d

4.6 Solids Production

Solids production in the plant currently arises from two sources namely primary and secondary sludges. Waste activated sludge is thickened in a DAF and combined with primary sludge and dewatered (belt press). The resulting cake solids concentration from the existing belt presses is approximately 17%. Table 4.5 aqnd 4.6 summarise the solids production for the current process configuration and for the suggested process configuration at current flows of 20ML/d.

For the purposes of comparison we have assumed that the current dewatering system would be replaced with duty standby centrifuges operating for a maximum of 6 hours per day and would increase cake solids to approximately 18%DS

Table 4.5: Sludge Production rates

Parameter	Units	Value	Heading Right
Primary Solids Mass	kg/d	3190	Data
Waste Activated Sludge Mass	kg/d	2280	Data
Total solids to Dewater	kg/d	5470	
Cake Dry Solids %	%	17	Data
Cake Volume for Disposal	m^3/d	32	Data

Source: Insert source text here

Table 4.6: Sludge Production Rates - Proposed Configuration

Parameter	Units	Value	Heading Right
Waste Activated Sludge Mass	kg/d	3430	Data
Alum Sludge	kg/d	320	Tertiary Options Study
Total Solids to Dewater	kg/d	3750	
Cake Dry Solids	%	18	Assumed Centrifuge

Parameter	Units	Value	Heading Right
Cake Volume for Disposal	m^3/d	21	Data

Conclusion: Solids production is projected to be approximately 21m3/d including for solids associated with alum dosing. This compares to approximately 32m3/d under the current configuration.

4.7 Membrane Details

For the purposes of this study we have based the sizing and costs of the membrane system on GE ZeeWeed 500D membranes. These are the same product that was used for the side stream MBR currently used onsite.

The membrane capacity has been based upon treating 100% of the peak wet weather flow. This is reported as 850L/s in the Tertiary Options study and previous capacity study reports.

The membrane system has been sized to fit in a separate structure outside of the existing tanks and clarifiers such that the system can be built off line. We have not at this stage considered the fitting out of the existing clarifiers as we are unsure how this would be done while keeping the plant live. It is worth considering how this might be achieved if MBR is considered the preferred option as this represents significant costs savings to use existing structures.

The membrane selection details are summarised in table 4.7. The table is based on the following assumptions:

- Average through put of side stream MBR of 7ML/d
- Peak day flow to plant 40ML/d
- Peak day flow to side stream MBR 7ML/d
- Peak hour flow of side steam plant 470m3/hr
- Peak instantaneous flow to plant 850L/s
- Peak flow duration <1hr
- Standard GE Zeeweed 500D Membranes
- Minimum temperature of 18C

Table 4.7: Insert Table Title here

Flow Condition	Flowrate to new MBR	Flux Rate (L/m2/hr)	No of Cassettes
Average Day (future less side stream MBR)	17ML/d	24.7	16
Peak Day	33ML/d	37.5	28
Peak Hour	850L/s	43.5	36

Source: Insert source text here

We have assumed that the membranes will be arranged in four "trains" similar to the side stream plant. Based on the above table each train would have 9 cassettes making a total of 36. To allow the side stream plant to be offline for maintenance we have allowed a total of 10 cassettes per train arranged in a four trains, each having a peak instantaneous flow capacity of 200L/s. This gives a flow capacity of 800L/s with 4 trains online and 600L/s at n-1. If the instantaneous capacity of the side stream plant is considered (8 cassettes) the total flow capacity of the plant would be 960L/s.

Four trains of 10 cassettes have been used to cost the plant

4.8 TERAX

The inclusion of TERAX (in its current form) into the process proposed in this study has a number of implications. These are:

- TERAX relies on the availability of primary sludge for fermentation to release short chain fatty acids to supplement ethanol. While some of these compounds are made in the oxidation stage of the process if primary sludge is not produced then ethanol offset will be diminished
- The TERAX liquor, after oxidation, is treated with lime to elevate pH for subsequent air stripping. Calcium ions are a significant issue with membrane systems and can lead to inorganic (calcium phosphate) fouling. This fouling can lead to large reductions in membrane trough put (flux). Calcium could be replaced by sodium hydroxide or similar, however these chemicals are very much more expensive than lime
- The effect of Alum on the TERAX reactor is not known (at the time of writing) hence there is a risk that chemical scaling etc could occur if alum sludge were treated in TERAX.
- TERAX is likely to produce colour as a by-product of oxidation. While this will not cause any effects on the membranes themselves

a downstream process may be required to remove colour if this is an issue with the treated wastewater discharge

- TERAX may produce dissolved organic nitrogen during thermal oxidation. This is estimated to be 0.3mgN/L. To offset this effect it will be necessary to remove additional nitrogen, most likely in the form of nitrate. There is a risk that a single sludge process may struggle to meet to remove this additional nitrate, although additional ethanol may mitigate this.

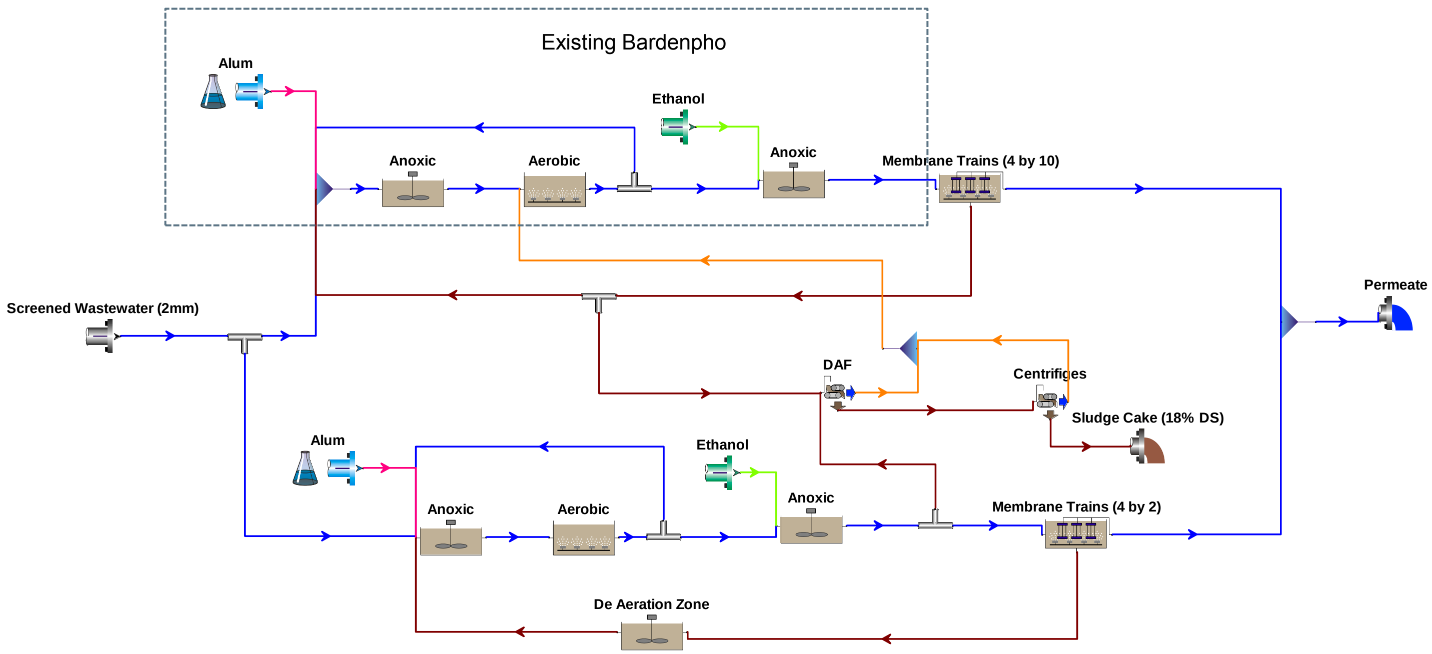
The inclusion of TERAX in its current form is therefore unlikely to be economic or practical with the proposed membrane based process developed in this study. There may however be a place for TEARX with this process as a solids destruction technology provided that the whole of life cost is significantly better than other means of disposal (landfill or vermicomposting).

5 Process Description

A process flow diagram of the full MBR Process is shown in figure 6.1. This consists of:

- Improved inlet screening – 2mm has been selected for costing. Screens could be added either to the existing inlet works or as a separate structure adjacent to the Bardenpho. For the purposes of this study we have assumed that two screens (duty/standby each with 850L/s capacity) would be installed at the head works of the plant
- Interstage pumping – at this stage we have assumed that the raw lift pumps and primary lift pumps would be retained and reused. There is some loss of efficiency with this approach (two sets of pumps in series) but this is considered minimal compared to the cost of a new raw wastewater pumpstation
- Secondary Treatment Train 1 – the side stream MBR would be retained. However given that the flow would be only raw wastewater we have assumed this would be down rated to an average daily flow of 5ML/d
- Secondary Treatment Train 2 – this would consist of the existing Bardenpho structure (7700m^3 volume) in the same configuration as at present. RAS from the MBR would be returned to the zone B3 and internal recycle to zone B5. To improve denitrification potential we have assumed that the primary anoxic zone would be extended to include cells B8 to B11. The secondary anoxic zone would be moved from cells A3 and A4 to B1 & B2, with the remained of the process being aerated.
- Membrane train 2 – from the Bardenpho MLSS would flow by gravity to a new membrane tank located behind the existing (disused) lime silo. The configuration of this tank would include a feed channel and RAS pumpstation. A dedicated membrane MCC and blower building (inl blowers) has been included in the concept design. For the purposes of this study we have assumed a four train layout each with space for 10 membrane cassettes. At average flow only two of the four trains are required to be fully operational. Under peak flows all four trains could be used or a combination of these and the side stream units
- Alum dosing to both MBR's has been included
- Solids Management – as there are no primary sedimentation tanks in the proposed configuration these would be redundant, but could be used for flow balancing. WAS from the side steam and main MBR's would be thickened via the existing DAF and dewatered via centrifuges. These have been sized on a throughput of 20m3/hr (each) and 6hrs operation 7 days per week.

Figure 5.1: Full MBR Option: Process Flow Diagram



6 Costs

Capital and Operation costs for the proposed MBR are summarised below. These costs include only the items that are in addition to the current plant and are on the same basis as the previous options reports prepared by Mott MacDonald. Full operation and CAPEX estimates are included in appendix 1.

Table 6.1: Summary of Capital Costs, Operational Costs and NPV

Item	Sum (new membrane tank)	Sum (reuse clarifiers)
Total CAPEX	$21,149,575	$19,547,600
Non Works Costs	$6,344,872	$5,862,805
Contingency	$5,287,394	$4,886,900
CAPEX Plus Contingency (incl non works costs)	$32,781,841	$30,298,780
Additional OPEX ($/yr) – incl biosolids processing and disposal	$1,754,317	$1,754,317
OPEX per day	$4,806	$4,806
OPEX per m3 treated	$0.24	$0.24
NPV (to 2035)	$53,784,490	$51,301,429

Appendices

Appendix A. CAPEX and OPEX SUMMARY

Job Name:	ROTORUA FEASIBILITY INVESTIGATION		
Job No.	345068		
Client:	RDC		
Currency:	NZD	*Revision:*	0
Prepared by:	TRM	*Date:*	14/05/2015
Checked by:	KB	*Date:*	14/05/2015

FULL MBR + DEWATERING

Level of Accuracy: ± 25%

Item	Description	Unit	QTY	Rate	Estimate
1.0	**PRELIMINARY AND GENERAL**				**$ 2,758,000**
2.0	**CIVIL & STRUCTURAL**				**$ 6,041,475**
	Inlet screens channel	LS	1	$ 750,000	$ 750,000
	Tank (Distribution, MBR, RAS & Permeate)	LS	1	$3,590,475	$ 3,590,475
	Building (Blower, equipment & control)	LS	1	$1,260,000	$ 1,260,000
	Access roads, temporary & sitewide works	LS	1	$ 441,000	$ 441,000
3.0	**MECHANICAL**				**$ 10,557,600**
	Inlet screens	LS	1	$ 730,000	$ 730,000
	MBR feed	LS	1	$ 450,000	$ 450,000
	Membrane package	LS	1	$5,520,000	$ 5,520,000
	RAS	LS	1	$ 445,000	$ 445,000
	Permeate discharge	LS	1	$ 995,000	$ 995,000
	Scum removal	LS	1	$ 250,000	$ 250,000
	Aeration	LS	1	$ 750,000	$ 750,000
	Utilities	LS	1	$ 675,000	$ 675,000
	Dewatering	LS	1	$ 742,600	$ 742,600
4.0	**ELECTRICAL**				**$ 1,792,500**
	Instrumentation				$ 1,792,500
	Installation				inc
	Engineering				inc
	Site Costs				inc
	PLC and SCADA				inc
	Total Works Costs				**21,149,575**
	Non Works Costs				
	Contingency	%	25		**$ 5,287,394**
	Professional Fees	%	15		**$ 3,172,436**
	Other Non Works Costs	%	15		**$ 3,172,436**
	Total Cost				**$ 32,781,841**

NOTES

The above costs do not include GST and are a best estimate at the time of pricing. No allowance has been made for inflation, currency and commodity fluctuations and other factors unknown at the time. These costs have been prepared for the Project & Client listed above based on the project described to us and its extent is limited to the scope of work agreed between the client and Mott MacDonald. No responsibility is accepted by Mott MacDonald or its directors, servants, staff or employees for the accuracy of information provided by third parties and/or the use of any part of these costs in any other context or for any other purposes. These costs do not include the following services which cannot be quantified at this time; Geotechnical Investigations, Surveying, Feasibility Studies & Fast Tracking.

FULL MBR + DEWATERING - OPEX Estimate					
1	**Electricity**				**$91,581.29**
1.01	Membrane Aeration	kWh	630366	0.11	$69,340.26
1.02	RAS Pump Station	kWh	161290	0.11	$17,741.92
1.03	Centrifuges	kWh	95813	0.11	$10,539.43
	MBR Option				
1.04	Decomission Belt Presses	kWh	-54912	0.11	-$6,040.32
2	**Chemicals**				**$735,540.11**
2.01	Ethanol (existing)	L	361922	$1.22	$441,544.84
2.02	Polymer (Existing solids stream)	kg	9450	$7.90	$74,655.00
	MBR Option (Extras)				
2.02	Sodium Hypo	L	14865	$1.10	$16,351.50
2.03	Citric Acid	L	9935	$2.10	$20,863.50
2.04	Alum	L	564941	$0.65	$367,211.86
2.05	Polymer	kg	898	$7.90	$7,090.25
2.06	Ethanol	L	-157522	$1.22	-$192,176.84
3	**Solids Disposal**				**$562,100.00**
3.01	Biosolids	t	9765	$88.00	$859,320.00
	MBR Option				
3.02	Biosolids	t	3378	$88.00	-$297,220.00
4	**MBR**				**$153,600.00**
4.01	Membrane replacement (Bard after yr 5)	no/yr	96	$1,600.00	$153,600.00
5	**Operation and Maintenace**				**$211,495.75**
5.03	Additional Maintenance	%CAPEX	1%	$21,149,575	$211,495.75
	Total Annual OPEX				$1,754,317.15

Date of Estimate:	8-Jun-15
Estimate Prepared By:	K Brian
Reviewed by	N Dempsey