ROTORUA WASTEWATER TREATMENT PLANT UPGRADE: PROJECT DRIVERS AND DESIGN APPROACH

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ABSTRACT

In 2008 the Rotorua District Council (RDC) identified that the capacity of the final clarifiers in the secondary treatment process at the Rotorua wastewater treatment plant (RWWTP) were limiting treatment capacity. Treatment of additional flows from the soon to be reticulated Eastern Area Catchments and solids loss due to overloading needed to be addressed.

A project was implemented for the planning of a new (third) clarifier and associated infrastructure. In addition, the capacity of the whole plant (including all solids and liquids streams) was assessed to determine which processes would require upgrade/expansion to meet the projected population to 2050.

The capacity study identified (assuming the existing Bardenpho process was retained for current and future flows) that to provide redundancy and process capacity that the Bardenpho would need to be extended and a fourth clarifier would need to be added before 2050.

The RWWTP is built on an area that is influenced by geothermal activity and by the water level of Lake Rotorua. The ground conditions are therefore challenging for the founding of large water retaining structures such as clarifiers (the additional clarifiers would be in the order of 3000m^3 each). To overcome these conditions preloading and/or piling of the structures would be required. This presented both a construction/design risk and a program risk in terms of the time required for pre load (greater than 12 months) for a new clarifier.

A refined investigation was undertaken to find the most appropriate solution for the plant expansion taking into account geotechnical conditions, space restrictions, existing infrastructure, continuity of operations, whole of life and capital costs. The solution selected was to retrofit one of the three existing, disused, reactor clarifier tanks on site into a membrane bioreactor plant to be operated in a side stream to the existing Bardenpho reactor.

This solution will deliver an overall increase in capacity from a current average flow of 17ML/d to 24ML/d, providing sufficient capacity to allow for the projected growth of the catchment for the next 30 years as well as providing immediate redundancy for operations staff to conduct maintenance on the existing clarifiers. This MBR will be the first in New Zealand to use GE hollow fibre membranes (for an MBR application) and will be New Zealand's largest municipal MBR, with a peak capacity of 11ML/d.

This paper presents the methodology of the capacity study, the selection of the membrane type and the configuration of the membrane bioreactor.

KEYWORDS

Clarifiers, MBR, Bardenpho, Rotorua

1 INTRODUCTION

The Rotorua Wastewater Treatment Plant (WWTP) is located at Te Ngae Road, Rotorua. The plant currently serves approximately 60,000 people including a significant tourist population.

The treatment plant has undergone a number of upgrades since it was originally constructed in 1973, the most significant of these being the conversion of the treatment process to a Bardenpho configuration and the consenting of the Whakarewarewa Effluent Disposal Scheme in 1989. When constructed, the plant was New Zealand’s first biological nutrient removal process and integrated land disposal system. The process was among the first in the world to use an integrated prefermenter for the generation of volatile fatty acids for phosphorus removal and the first major municipal land based wastewater irrigation system for the management of nitrogen and phosphorus in New Zealand.

The plant and land disposal system have a discharge consent based upon the mass of nutrients returned to Lake Rotoua via the Pueranga stream. The current consent allows for the discharge of 30,000kgN/yr and 3,000kgP/yr.

In the last decade there have been significant issues with the water quality of the Rotorua Lakes, and in the last 3-5 years there have been significant algal blooms within some of the Lakes. Restrictions have been placed on contact *recreation*, particularly over summer.

To mitigate the effects of onsite wastewater treatment systems on Lake water quality, some of the outlying areas of the Rotorua District have been reticulated to prevent nitrogen, phosphorus and bacteriological contamination. Wastewater from all of the newly sewered communities (with the exception of Rotoma, Rotoihi, Rotoehu) will be returned to the Rotorua WWTP for treatment.

Flows from the newly sewered areas (Rotorua Lakeside Communities Sewerage Scheme Programme), combined with population growth will increase the future load on the plant with the result that parts of the existing treatment process could become overloaded in the future, requiring additional process capacity. In addition to growth with one treatment plant serving the majority of the District, the maintenance of equipment, plant redundancy and down time are critical issues for the Rotorua District Council to consider.

2 BACKGROUND

Secondary treatment at the Rotorua Treatment Plant consists of activated sludge, based upon the five stage Bardenpho process for the removal of nitrogen and phosphorus. A schematic of the treatment process is shown in Figure 1.

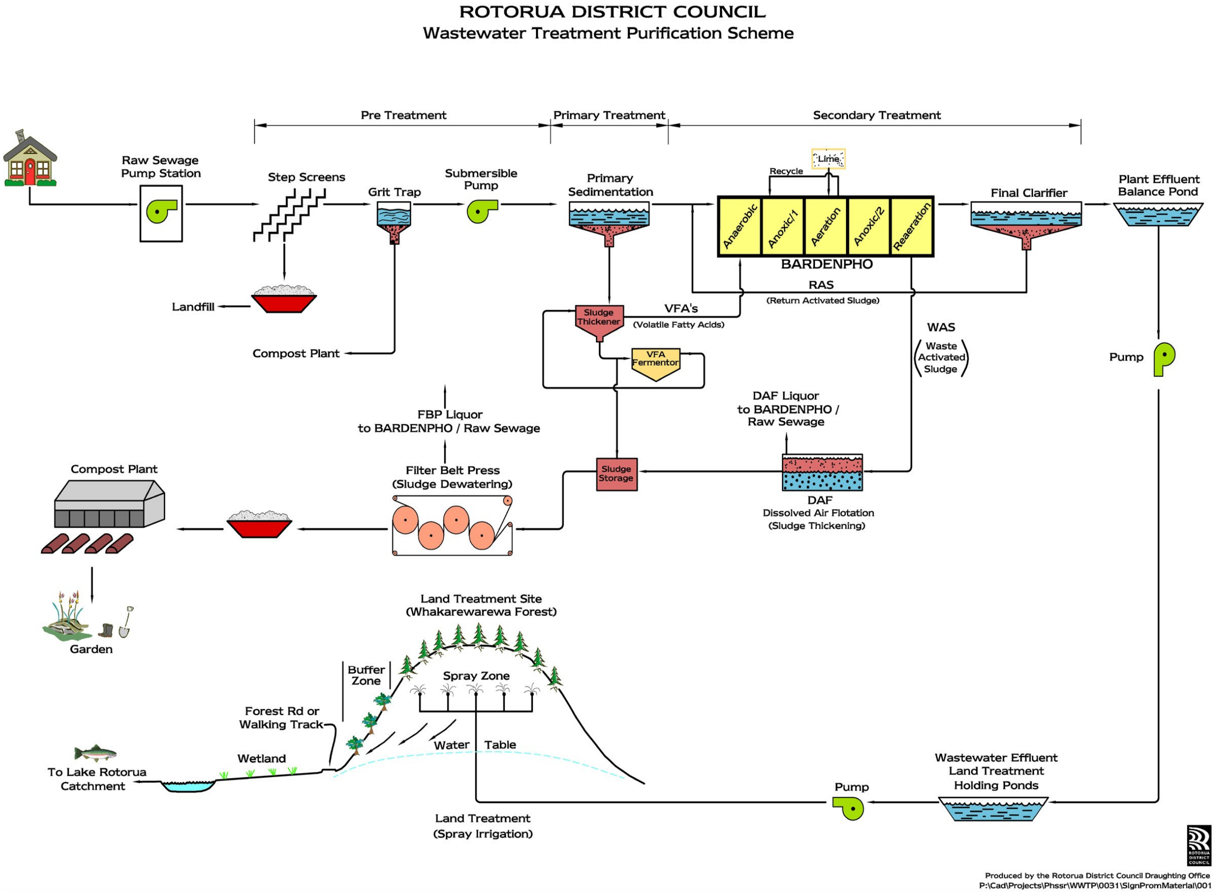

Figure 1 – Process Schematic of the Existing Plant

The final stage of the Bardenpho is clarification, and this is currently undertaken in two 30m diameter 4.5 metre deep clarifiers. These have been in service since the Bardenpho was commissioned. The condition of the scraper mechanisms, scraper bridges and general state of repair of the clarifier internals is not known and this presents a maintenance and level of service risk to Council. Should a clarifier fail there is insufficient clarifier capacity to treat average wastewater flows.

3 PROJECT IDENTIFICATION

The treatment plant site (as shown in Figure 2) borders onto the Sulphur Bay geothermal area and is in relatively close proximity to Lake Rotorua.

Figure 2: – Plant Aerial Photograph

Ground water levels are close to the ground surface (about 0.5m below) and are influenced by the level of Lake Rotorua. The soil stratum consists of a number of ash and sand/pumice layers, interspersed by organic deposits. To mitigate the risk of ground settlement, preloading of up to 12 months duration and/or piling have been used previously to construct large structures such as the clarifiers and Bardenpho reactor.

Preloading of the ground involves placing a mass of soil onto the proposed founding area that is similar to the weight of the final structure and measuring the settlement rate over time. Once the settlement rate drops below a certain amount per time the soil can be removed and the site used for construction.

The Bardenpho expansion undertaken in 2004 left an area of pre load in the intended position of a third clarifier to prepare the ground for construction. This was not positioned in the exact location of the proposed structure and had not been surveyed over time so it was not possible to determine if the ground had settled sufficiently to avoid settlement.

3.1 POTENTIAL SOLUTION

To address potential capacity issues due to growth and connection of the new areas of the District and the risk of clarifier failure the construction of a new final clarifier was proposed. Based on the ground conditions construction of a third clarifier poses the following risks to RDC:

- Uncertainty over location of preload, meaning that this may need to be moved (time)
- Unknown settlement rate of existing preload and uncertainly about how long the preload needed to be in place (time)
- Variable soil structure – significant extra time and cost if unknown ground conditions were found during construction (cost/time)
- Risk of piling – corrosion of piles and difficulty in siting these (cost/quality)
- Unknown or undefined construction and project timeframes and therefore uncertainty over when the additional clarifier capacity would come “on line” (time/cost)

In addition to the above risks the building of a third clarifier could potentially commit RDC to a certain path with the development of the site. Building a new clarifier could commit Council to the Bardenpho and associated tankage and clarifiers and would likely lead to the above risks being revisited in the future.

4 PROJECT DRIVERS

4.1 CAPACITY ASSESSMENT

An assessment of the capacity of the treatment plant (primary, secondary and solids streams) was undertaken to determine which unit processes would need to be upgraded given the connection of the newly sewered areas and population growth. The study looked at the projected flows and loads of the treatment plant catchment to the year 2051, with the assumption that the current mass loading to the Puaeranga Stream of nitrogen and phosphorus would be maintained (if possible).

A summary of the capacity investigation is shown in Table 1.

Table 1 – Summary of Capacity Study

Process Area	**Current Units/capacity**	**Additional Capacity Required to 2051**
Primary Sedimentation	Three primary settling tanks	One additional primary settling tank required
Bardenpho Reactor(s)	7,700m^3	An additional 2,300m^3 of Bardenpho reactor needed
Final Settling	Two final settling tanks (30m dia)	Two additional final settling tanks (30m dia)
Tertiary Treatment	Not installed	Possibly required to lower TN and effluent solids concentrations
Solids Processing	Belt press and DAF	N/A – likely change to sludge dewatering technology

Table 1 shows that in addition to the immediate requirement that was identified as a project driver (i.e. an additional clarifier) the plant would also require a fourth primary settling tank, fourth clarifier and additional Bardenpho volume in the future. The decision of whether to build a new clarifier (estimated $4,000,000) therefore needed to be considered along with future upgrades that may be required and the associated risks of constructing these with variable and difficult ground conditions.

4.2 ALTERNATIVE OPTIONS

As discussed above, construction of a new final clarifier on the treatment plant site has some significant associated risks and potentially commits Council to be exposed to these in the future (through a series of large structures being required). An alternative process configuration that could limit the number of structures that would need to be built with their associated risks would therefore be of advantage to RDC.

The treatment plant site has a number of existing process tanks that have been decommissioned over time. The most significant of these are the three “donut” reactor clarifiers that were used for secondary treatment before the Bardenpho was built.

If one or more of the existing structures could be used instead of constructing a new structure this would have the advantage of saving capital costs of building new structures and provides for the mitigation of the risks associated with the poor ground conditions and constructability. The disadvantage of using these structures is their capacity, which is not necessarily optimum and the condition of the structures that were built over 30 years ago.

The structural integrity of the three donut tanks was investigated to ensure that these would be suitable for an asset life of at least 40 years (2051). The tanks were found to be in good condition although two of the three tanks (being older) had signs of some flaking and chipping of the concrete surface. These issues were not considered to be significant and it was decided to investigate the use of one or more of these structures.

Given that nitrogen, and potentially phosphorus removal was essential to meet the current and future consent standards, it was considered that an activated sludge variant was the best generic type of process suitable for meeting these standards. Conventional activated sludge (with gravity settlement) and membrane based activated sludge (MBR) were investigated. For the conventional activated sludge process the limiting factor on the capacity of the donut tanks is the surface area and depth of the clarifier and the balance between the solids inventory required in the process and effluent quality. Table 2 shows a summary of the capacity of a donut reactor in a conventional activated sludge configuration and Table 3 shows the same reactor in an MBR configuration.

Table 2 – Capacity of Donut Reactor in Conventional Activated Sludge Configuration

Parameter	**Value**
Surface area (m^2)	230
Design Sludge Settleability (SSVI, mL/g)	120
MLSS (g/L)	3
Max clarifier overflow rate (m/hr)	1.1
Peak flowrate (ML/d)	6.1
Design F/M ratio (kgBOD/kgMLSS.d)	0.1
Inlet BOD concentration (mg/L)	130
Average flow that could be treated (ML/d)	2.8

Table 3 shows that the MBR mode of operation using one tank could (subject to membrane surface area) treat up to an average daily flow of 9.2ML/d compared to approximately 2.8ML/d in conventional AS mode. The membrane configuration therefore enables over three times the flow to be treated in the same volume, with an additional advantage of essentially zero suspended solids in the discharge.

Table 3 – Capacity of Donut Reactor in MBR Configuration

Parameter	**Value**
Process volume – excluding Membrane zone (m^3)	2000
Maximum MLSS concentration at entry to membranes (g/L) – (for hollow fibre membranes)	6
Design F/M ratio (kgBOD/kgMLSS.d)	0.1
Inlet BOD concentration (mg/L)	130
Average flow that could be treated (ML/d)	9.2

Based on the assessment undertaken between conventional and MBR based activated sludge the MBR was preferred due to its ability to increase capacity over a small footprint area.

4.3 OPTIONS EVALUATION

Table 4 presents the evaluation matrix that was used to compare the advantages and disadvantages of using an MBR in the disused donut reactors versus upgrading the Bardenpho clarifiers. A scoring system was used to rate each risk/criteria using a scale of 1 to 5 with 5 being very good and 1 being poor. Option 1 is the Bardenpho and option 2 is the side stream MBR.

Table 4 – Evaluation Matrix

Criteria/Risk	**Discussion/Comment**		**Weighting**	**Score (1-5)**		**Weighted**	
	Option 1: Bardenpho	**Option 2: Side Stream MBR**		**Option 1**	**Option 2**	**Option 1**	**Option 2**
Ability to meet revised effluent quality targets	Would require tertiary solids filtration for 100% of flow to reduce TN to <4mgN/L. After 2021 forest required to remove approximately 3,000-4,000kgN/year	Tertiary filtration incorporated within process. Reduced filtration required for Bardenpho effluent. Forrest would still be required to remove same amount of nitrogen as Bardenpho with tertiary filtration	1.0	2	4	2	4
Operability	Extension of current process and no retraining or additional maintenance (over and above that required now)	New process, mechanically complex. Likely to be more maintenance required as new types mechanical equipment and instrumentation required	0.7	4	3	2.8	2.1
Process Complexity	Relatively complex with filtration, however very similar to existing plant	Highly complex mechanically and a different process to that existing at site. Additional membrane cleaning, inspection and maintenance required	0.5	4	3	2	1.5
Ability to stage upgrades	Some ability to stage however steps in capacity would be relatively large increasing risk of over sizing or under sizing for future growth.	Very good ability to stage. Highly modular with new membrane units able to be added to match growth.	1.0	3	5	3	5
Reuse of Existing infrastructure	Full use of all assets currently used with new structures required for extensions to Bardenpho reactor, final tanks and primary sedimentation system	No new structures required (with exception of chemical storage and membrane tanks). Reuse of at least one "donut" reactor clarifier	0.5	2	5	1	2.5

Criteria/Risk	Discussion/Comment		Weighting	Score (1-5)		Weighted	
	Option 1: Bardenpho	**Option 2: Side Stream MBR**		**Option 1**	**Option 2**	**Option 1**	**Option 2**
Ground conditions/Geotechnical	High exposure to geotechnical risks as new structures are required. Dependence on availably of suitable preload material. Extensive ground preparation (preloading or similar) and detailed geotechnical and structural designs required for each new structure.	Minimal as main water retaining structure already exists. Likely that some geotechnical investigations would be required for membrane and chemical storage tanks although these structures are likely to be relatively small.	1.0	1	4	1	4
Risks associated with using existing structures	Minimal. New structures built as required	High level of uncertainty as to modifications that may be required for existing donut tank(s). Structural assessment required to ascertain suitability and asset life of donut tank(s)	0.5	5	2	2.5	1
Dependence on chemicals (other than for nitrogen and phosphorus removal)	Minimal unless membranes were selected for tertiary filtration step	Chemicals required for cleaning of membranes; additional chemical storage likely to be required for these compounds. Additional health and safety considerations for site	0.5	4	2	2	1
Nature of wastewater – sulphide or other geothermal compounds	Moderate risk but this will not be increased over and above that already experienced	May be an issue with performance of membrane, in particular metal salts. Can be rectified by cleaning with citric acid	0.4	4	3	1.6	1.2
Exposure of mechanical and electrical equipment to corrosive atmosphere	Risk of corrosion not increased over current, however this would depend on the tertiary filtration system that is selected	Complex mechanical equipment and instrumentation, increased numbers of valves, pipes and cables potentially exposed to sulphide corrosion. May increase CAPEX and OPEX costs and lifetime of some assets.	0.7	4	2	2.8	1.4

Criteria/Risk	**Discussion/Comment**		**Weighting**	**Score (1-5)**		**Weighted**	
	Option 1: Bardenpho	**Option 2: Side Stream MBR**		**Option 1**	**Option 2**	**Option 1**	**Option 2**
Nature of solids produced	No chance in relative mix of primary and secondary sludge provided primary tank capacity is increased. Additional solids generated from chemical dosing for phosphorus removal and with tertiary filtration	Increase in percentage of WAS to primary sludge. Will decrease dry solids content of dewatered sludge thereby increasing the volume of sludge to be disposed off. Increase in solids production from chemical P removal and potential increase in WAS generation due to 100% solids capture in membrane system. No increase in primary sludge generation.	0.8	4	3	3.2	2.4
Totals			7.6	37	36	23.9	26.1

Each criterion was allocated a risk weighting, between 0.1 (least important) to 1.0 (most important), to indicate how significant each risk was respective of the other items within the table. For instance, the ability of the plant to meet the targeted effluent quality standards was been given a weighting of 1.0, as is considered very important. This compares to reusing the existing structures which was given a weighting of 0.5. Overall based on this evaluation the side stream MBR rated higher than the Bardenpho/clarifier option primarily due to:

- Reuse of the existing reactor/clarifier structure
- Improved solids capture and improved effluent quality
- No requirement to build any additional process structures
- The ability to stage the plant capacity with population without needed to invest in large structures that could be under or oversized given the actual population growth rate within the catchment

While the MBR was identified as having significant risks, relating primarily to the structures and their remaining asset life and the costs associated with installing mechanical and electrical equipment within these existing structures, it is the lower risk compared to expanding the Bardenpho and clarifiers.

4.4 MEMBRANE SELECTION

The membranes are an integral part of the functioning and design of the MBR and their selection is essential to the outcome of the project. Council wished to tender the membrane supply as part of a 4911 (supply without install) contract and therefore the membrane supplier could not be selected until after this tendering process was completed. However to limit the variation in types of membranes offered by suppliers an evaluation was undertaken on the generic type of membrane that could be used for the MBR. The membrane types included:

- Submerged flat sheet membranes (Kubota or similar) and
- Submerged hollow fibre

The first issue to be addressed with the type of membrane was the room that they would occupy in the process, their effect on the process configuration and how they would fit within the depth of the reactor. Table 5 shows a summary of the advantages and disadvantages of the membrane types. The evaluation was based upon GE, Siemens (both hollow fibre) and Kubota membranes (flat sheet).

Table 5: – Membrane Comparison

Parameter	**Flat Sheet**	**Hollow Fibre**
Operating depth (m)	4.5	3.085
Permeate system	Gravity	Pressurized
Volume occupied by membrane modules (based on peak flow of 11.3ML/d) m^3	1000	250
Maximum MLSS	>12g/L	8g/L
Minimum recycle ratio	N/A	4
Average Air Scour rate (Nm^3/hr)	8,500	1,800
Peak Air Scour rate (Nm^3/hr)	11,300	3,600

The selection of the generic type of membrane was made based on the above comparison. In particular the volume occupied by the membrane modules ($1000m^3$ versus $250m^3$) and the aeration rates ($11{,}300Nm^3$/hr and $3{,}600m^3$/hr) were the critical factors in the selection of hollow fibre for this application. At this time a whole of life cost evaluation was not undertaken, however the aeration rate and membrane volume were sufficient go/no go decisions to allow the selection to be made without a whole of life evaluation being undertaken.

The supply contract was tendered by two suppliers namely Siemens and GE, with GE being selected on a whole of life basis.

The Rotorua MBR process consists of a suspended growth biological reactor integrated with a GE ultrafiltration membrane system, based on the ZeeWeed® hollow fibre membrane.

The ZeeWeed® ultrafiltration membranes are submerged in the bioreactor (in isolated tanks), in direct contact with the mixed liquor. Through the use of a suction duty pump, a vacuum is applied to a header connecting the membranes. The vacuum draws the treated water through the hollow fibre ultrafiltration membranes and into the pump. The pump then discharges treated water. The energy associated with permeate pumping is relatively small. An airflow is introduced to the bottom of the membrane modules, producing turbulence which scours the external surface of the hollow fibres transferring rejected solids away from the membrane surface. This airflow also provides a portion of the process biological oxygen requirements.

The ultrafiltration membrane system consists of four trains of ZeeWeed® 500D membranes, with each train having two cassettes installed. Each cassette contains 48 membrane modules and a total of 384 modules are installed in the plant.

5 DESIGN OF THE MBR PROCESS

5.1 PROCESS CONFIGURATION

The process drivers for the MBR plant are based upon nitrogen and phosphorus removal. There is a fixed mass loading allowance in the discharge from the land disposal system. In order to maintain the same total mass loading in the future with both the Bardenpho and the MBR plant operating in parallel, the MBR would need to deliver nitrogen and phosphorous concentrations that are significantly lower than the current Bardenpho process. The MBR process was therefore sized and designed on the following criteria:

- Total nitrogen in MBR permeate <5mgN/L
- Total Phosphorus in MBR permeate <1mgP/L

In this design some of the "typical" MBR drivers such as low suspended solids and disinfection were not required hence the design focused on the removal of nutrients.

In an MBR as with a conventional activated sludge process, the solids liquid separation (i.e. membrane filtration or clarification) stage of the process needs to be undertaken at the end of the process train where most of the soluble nutrients have been removed. With an MBR this presents a design issue in that a highly aerobic, largely endogenous reactor at the end of the process will release some nitrogen via biomass decay and can make it difficult to obtain very low final effluent nitrate concentrations. This issue is overcome with the GE hollow fibre systems in that a recycle of at least four times the permeate rate must be used to prevent a solids gradient occurring over the membranes. A disadvantage of the high recycle rate is the carryover of dissolved oxygen to downstream anoxic or anaerobic zones of the process. This dissolved oxygen recycle must be considered in design and can be overcome by the addition of a "de-aeration" zone downstream of the membranes. Figure 3 shows a process schematic of the process and the membrane reactor.

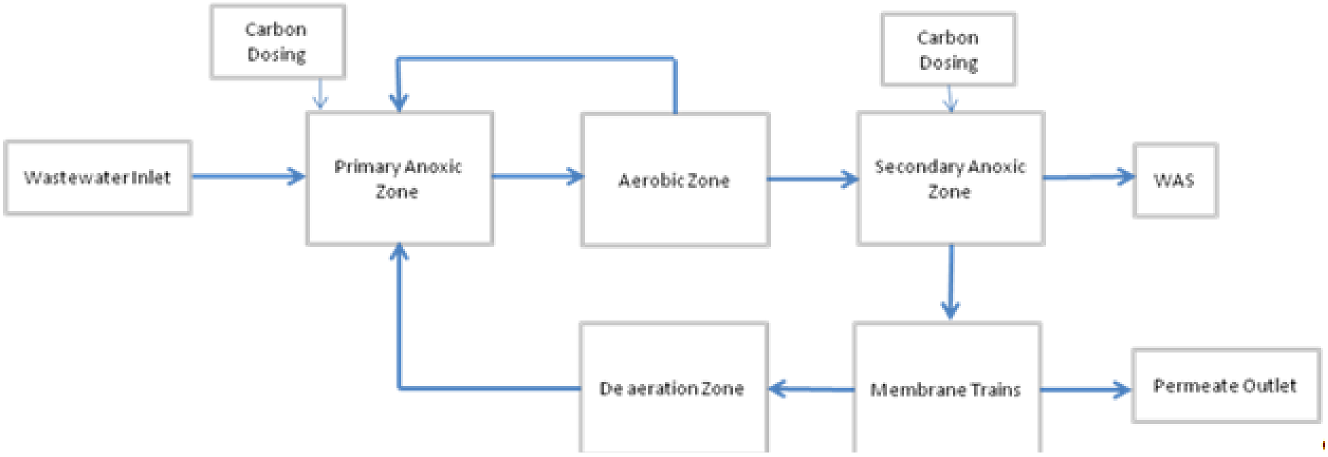

Figure 3: –MBR Process Schematic

The process reactors in the MBR are based on a sequence of anoxic, aerobic anoxic and de aeration zones as shown in Figure 3. This is essentially a 4 stage Bardenpho configuration with the membranes replacing the final clarifiers. Due to the limited carbon available in the raw wastewater carbon dosing in the form of ethanol has been allowed for in both anoxic zones and the process has been designed for phosphorus removal via the dosing of alum.

5.2 DESIGN INNOVATIONS

The design innovations of this MBR are centered on using the existing donut reactors and making the best use of the available carbon in the wastewater.

5.2.1 FORWARD FEED OF CARBON

The current Bardenpho plant configuration uses primary sedimentation to remove some of the influent solids from the wastewater with the aim of fermenting these to generate volatile fatty acids for the phosphorus removal process. A disadvantage of primary settling for a nutrient removal process is the removal of some readily degradable carbon from the wastewater thereby reducing the nitrogen removal potential of the activated sludge process. In this design the feed of wastewater can either be sourced from the primary treated effluent or screened raw wastewater. Sourcing from the raw wastewater effectively supplements some of the carbon dosing that would be required to achieve nitrogen removal.

5.2.2 PUMP TO MEMBRANE TRAINS

The GE membranes selected for this application operate on a pressurized permeate system and do not rely on a head of water to drive permeate through the membranes; hence the membrane tank can be relatively shallow (3.1m). In the Rotorua process configuration mixed liquor is pumped from the aerated zone to the second anoxic zone and then flows by gravity into the membrane tanks and on to the de aeration and primary anoxic zones. This has allowed maximum use of all the tank volume which has resulted in more efficient aeration due to greater tank depth

5.2.3 LOW ENERGY MIXED LIQUOR RECYCLE

There are essentially two mixed liquor recycles in this process. The first is via the membrane recycle (RAS) and the second is via an internal recycle from the aerobic zone to the primary anoxic zone. By placing the end of the aerobic zone and the beginning of the primary anoxic zone at the same location and at approximately the same level the energy needed for the internal recycle is greatly reduced using high flow low head pumps..

6 PLANT LAYOUT

The layout of the plant within the donut reactor is shown in Figure 4. The primary anoxic and aeration zones are located around the outside of the tank with the second anoxic, membrane and de aeration zones positioned within the old clarifier area of the reactor. Structural walls were required for the membrane trains to separate the de aeration zone from the membranes and some additional height is needed for the membrane walls such that they are at a higher level than the anoxic and aerobic zones. Other than this (and removal of the existing tank internals) no structural modifications have been made to the tank. To protect the membranes and maintain the guarantee, the tanks were refurbished and coated with an epoxy resin. Contractors were given the option to reuse an existing building for the blower room, or demolish and build a new building. The contractors selected the latter based on time and cost.

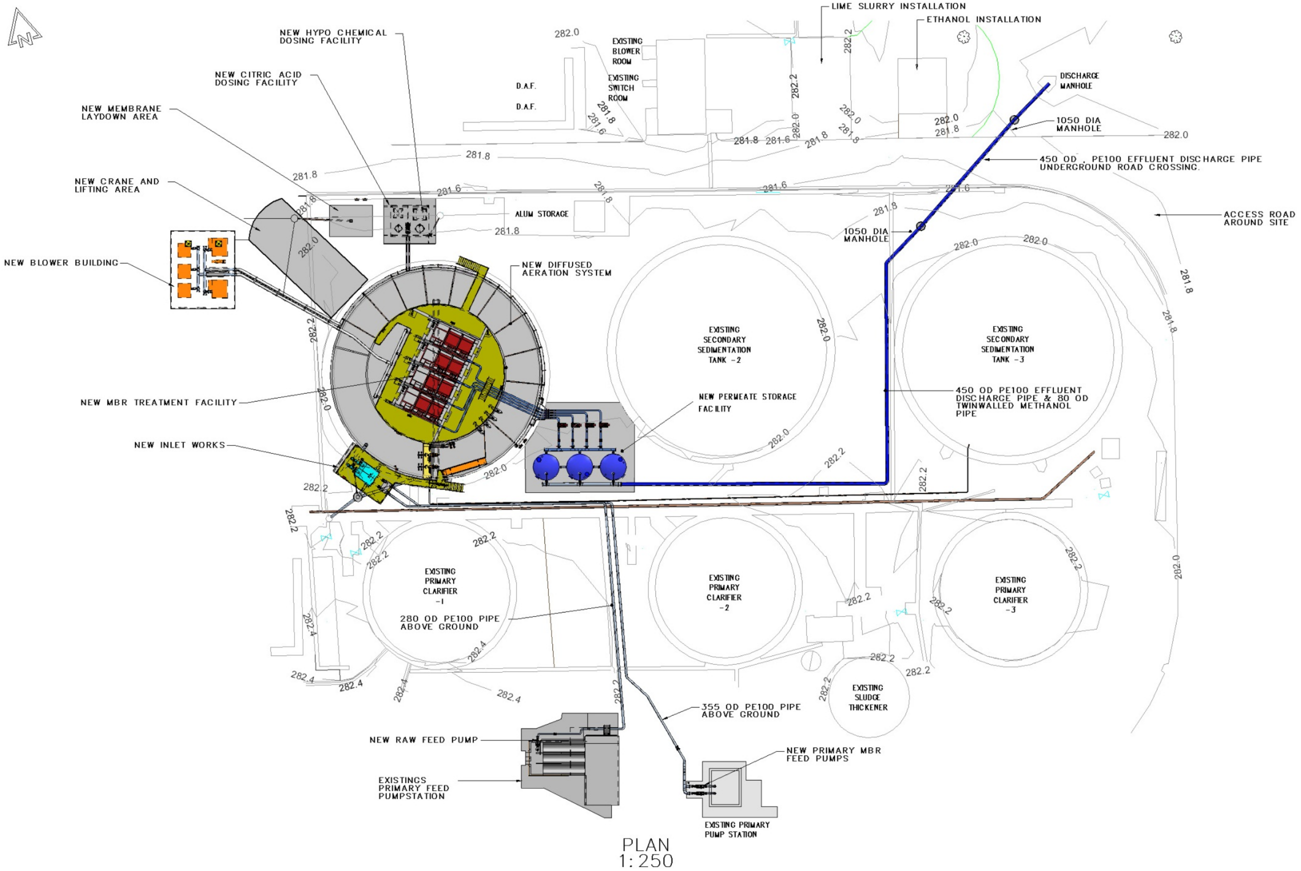

Figure 4: –MBR Layout

7 CONCLUSIONS

The side stream Membrane Bioreactor currently being commissioned will provide a high level of treatment in terms of nitrogen and phosphorus and an additional 11ML/d of treatment capacity to the Rotorua WWTP. No significant structures were constructed for this project and this eliminated the risks associated with poor ground conditions on site. The MBR will provide treatment capacity for growth in the District and for newly sewered communities for the next 30 years. This was achieved through innovative design and procurement and the reuse of existing assets.

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