POND UPGRADE OR PLANT REBUILD – A GUIDE TO NAVIGATING THE PROS AND CONS

John Crawford, Reuben Bouman, Claire Scrimgeour – Beca Ltd

ABSTRACT

Due to higher environmental performance expectations from the public, and the added rigour applied to consenting processes through a matured RMA (including guidance such as the National Policy Statement for Freshwater Management, MfE 2020), plus additional capacity required due to municipal and industrial growth, many pond systems have been unable to comply with treatment requirements, and in particular nitrogen limits.

To provide for likely future Capacity and Levels of Service requirements and to upgrade 'tired', end of life assets, the owners, typically local authorities, are faced with the dilemma of whether to persevere with the ponds as core treatment process at a particular site or to largely start again with new technology. This paper considers the pros and cons of each approach from a number of different perspectives related to future management of the asset or site. While these may seem obvious to some, the answers are not necessarily clear cut and we note that there are still a lot of asset owners in the wastewater sector for whom the best way forward is still unclear and confusing.

There are many different possibilities for upgrading of oxidation pond systems to improve capacity and performance. Hugh Ratsey dealt with many of these in his excellent 2016 paper This paper will not revisit the 'options' part of the equation, except to briefly mention the newer- options that have subsequently arrived on the scene. These include the 'Return Stream MBBR' (Moving Bed Biofilm Reactor) as employed at Hāwea, and the newer side stream MABR (Membrane Aerated Bioreactor) technology being employed at Helensville and Te Kauwhata.

KEYWORDS

Wastewater Treatment Plant Upgrade, WWTP Upgrade, Waste Stabilisation Ponds, WSP Upgrade

BACKGROUND

From the 1970s through to the 1990s, the majority of New Zealand towns were provided with wastewater treatment plants in the form of waste stabilisation pond systems. When considering the pre-existing conditions and systems in New Zealand up until that era, pond systems represented a very large step forward in terms of public health benefits and environmental performance improvements, in a repeatable, cost effective and relatively simple package. Further, given the comparatively small urban areas and small populations, space for the establishment of these pond facilities was relatively easy to fund.

In the 21st century (roughly speaking) there are higher environmental performance expectations from the public and added rigour applied to consenting processes through a matured RMA (including guidance such as the National Policy Statement for Freshwater Management, MfE 2020). Along with additional capacity required due to residential and industrial growth, many pond systems have been unable to comply with treatment requirements, and in particular nitrogen limits.

INTRODUCTION

To provide for likely future Capacity and Levels of Service requirements and to upgrade 'tired', end-of-life assets, the owners, typically local authorities, are faced with the dilemma of whether to persevere with the ponds as core treatment process at a particular site or to largely start again with new technology. This paper considers the pros and cons of each approach from a number of different perspectives related to the future management of the asset or site. While these may seem obvious to some, the answers are not necessarily clear cut and we note that there are still a lot of asset owners in the wastewater sector for whom the best way forward is still unclear and confusing.

There are many different possibilities for upgrading pond systems to improve capacity and performance. This paper does not attempt to revisit the 'options' part of the equation, except to briefly mention the newer- options that have subsequently arrived on the scene. These include the 'Return Stream MBBR' (Moving Bed Biofilm Reactor) as employed at Hāwea, and the newer side stream MABR (Membrane Aerated Bioreactor) technology being employed at Helensville and Te Kauwhata. Likewise, there are many options available for the more intensified, bio-mechanical plants and we do no more here than to mention some of the more common approaches.

The above examples of pond upgrades and the Queenstown Shotover wastewater treatment plant, as an example of converting ponds to a fully bio-mechanical plant, are presented as case studies.

When the vast majority of the pond systems were conceived, designed and installed the key consideration was, how big is the population and how large will it grow? What BOD load will result from that population (plus foreseeable trade wastes), at 84 kgBOD$_5$/ha/day, how much land will be required and where can that land be found near to the town and near to a stream to receive the discharge. There was not normally even influent screening or any form of disinfection, apart from that naturally occurring in the ponds due to solar irradiation, micro-faunal predation or just simply the lack of a warm bodied host. This was essentially a lowest-cost approach that provided a high degree of public health risk reduction and reasonable (for the time) environmental outcomes.

An unintended consequence of this rather narrow focus has been that the treatment plants have, by and large, not been future proofed. They have not been set up well to deal with what is now a much larger list of considerations that must be made. Some of these are as follows:

- Land Area & Capacity and the ability to future proof a site
- Levels of Service (focusing on nitrogen performance and disinfection)
- Potential Cultural Implications

- Unit process compatibility
- Surrounding land use and aesthetics
- Odour
- Greenhouse Gas Emissions
- Operators
- Energy
- Resilience
- Transitional operation
- Sludge quantity, quality, and management
- Capital cost
- Whole of life cost
- Wet weather flows
- Seasonal peak loads

RECENT TECHNOLOGIES FOR POND UPGRADES

PRIOR TECHNOLOGIES

There are many different possibilities for upgrading of oxidation pond systems to improve capacity and performance. Hugh Ratsey dealt with many of these in his excellent 2016 paper U*pgrading Waste Stabilisation Ponds Reviewing The Options*, and is also covered in Water NZ's *Good Practice Guide for Waste Stabilisation Ponds: Design and Operation*.

The following section is a general discussion of a couple of new technologies without going into the process kinetics in any detail. Boths these systems have been developed to be suitable for side stream or main stream systems on with package plants.

MABR

Membrane aerated bioreactors (MABR) supply air through hollow tube membranes which also form the media for the biomass to grow on. This allows for high-efficiency diffusion of molecular oxygen out into the biomass rather than conventional, low efficiency transfer of oxygen from air bubbles through the outside of the biomass. The energy cost for nitrification is therefore substantially less than for conventional nitrification is, say, a suspended growth system.

Thus in MABR, the oxygen and the substrate for treatment move counter current, whereas, for conventional suspended growth and fixed film systems the oxygen and substrate approach the biomass ‘co-current'.

Because they are significantly smaller than the heterotrophic bacteria with which they compete, the nitrifying bacteria are able to dominate the microscopic spaces immediately adjacent the membrane surface, and so nitrification occurs first. The heterotrophs (responsible for BOD consumption and denitrification) colonise the outer layers of the biofilm. The MABR membrane modules are typically installed in an anoxic reactor. And so simultaneous nitrification and denitrification is able to occur.

Full nitrification in the MABR relies on all ammonium ions permeating through to the nitrifiers. Because there are comparatively large spaces where there are no membranes and a lack of pressure gradient to 'drive the ammonium 'in' to the biomass, nitrification by MABR alone will normally not be quite as complete as in a properly configured, suspended biomass nitrification reactor, which can consistently reduce ammonia-N to less than 1 mg/l (but at a massively higher energy cost).

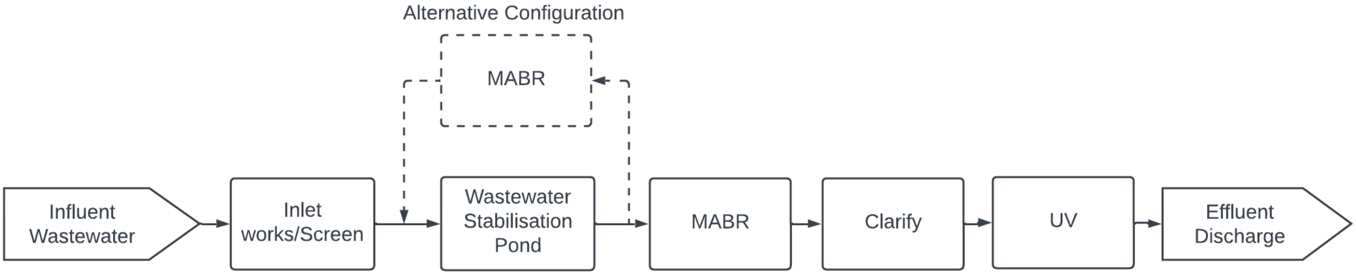

Figure 1: MABR Process Flow Options.

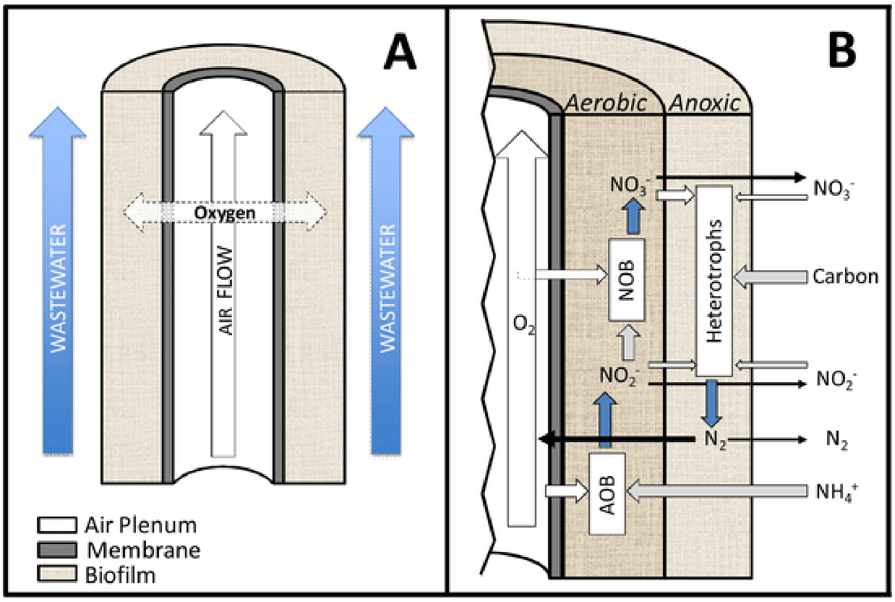

Figure 2: (A) Locations of air and wastewater flow in a membrane-aerated biofilm reactor (MABR), and (B) Processes occurring that enable simultaneous nitrification/denitrification inside of a redox-stratified, MABR. Source: (Landes et al, 2021)

MBBR

Moving bed bioreactors (MBBR) are a hybrid form of high rate biological process in which the majority of the active biomass is attached to small, high surface area, plastic media discs. There will be some suspended active biomass, including active material and sloughed material.

The media allow a higher inventory of active biomass to be held and used in a given volume than in a conventional suspended growth (e.g Activated Sludge) reactor. Traditionally MBBR, originally developed by Purac as the Kaldness process, has typically been used for main-stream treatment where available space has been limited. For example, the Moa Point and Karori WWTPs in the mid-1990s. However, in recent years it is being more and more deployed as a compact, return stream or tertiary stream nitrification process, with short HRT, after the soluble BOD has been dealt with by other, more conventional processes.

Oxygen requirements are supplied through traditional medium or course bubble air diffusers. This also mixes the tank and suspends (‘Moving’) the small plastic media on which the biomass grows. To drive the necessary DO gradient through the fixed biomass, the dissolved oxygen level in the reactor will need to be higher than for an equivalent suspended growth process.

Where low temperatures (e.g southern latitude pond systems) are rate limiting for nitrification and denitrification, the reactor DO can be increased to improve nitrification. However, denitrification may still be problematic for the stream returned to the pond and this may require addition of an MBBR post anoxic stage (with some carbon dosing) or configuration of a dedicated anoxic zone at the head of the pond system that receives pre-mixed influent & MBBR effluent (and possibly a small return stream from the body of the pond)

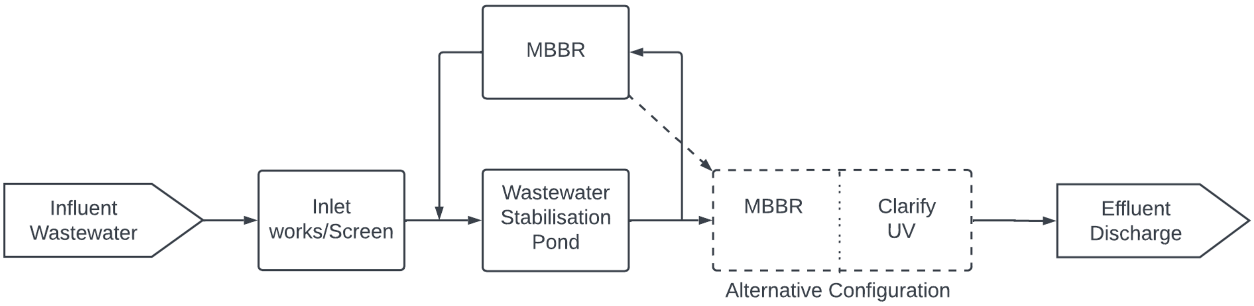

Figure 3: MBBR Process Flow Diagram

COMPARISON OF ASSESSMENT CRITERIA

This section reviews a generalized upgrade and considers the advantages and disadvantages of the two different approaches against a number assessment criteria.

LEVEL OF SERVICE

NITROGEN

In most regards, a well performing pond system can be added to and/or modified to produce similar quality nitrogen effluent to 'average to good' biomechanical systems, approximately 10 mg/L. If discharge limits are tighter, then it is likely that a full plant upgrade will be required. In low temperature zones, low pond temperature may however prevent either significant nitrification or denitrification proceeding. And where the starting point for the nitrogen upgrade is poor performance with little or nitrogen removal, then the ‘add-on’ requirements and recycle rates may be such that it will ultimately cost more than a comparative new treatment plant.

Typically, supplementary aeration and one or more additional unit processes will be required. However, the plant area will have to continue getting larger to remove sufficient soluble BOD (or significant supplementary aeration will be required).

New, high-rate, plants are readily configured to very reliably achieve 6 to 7 mg/l TN and 1 mg/l or less as ammonia N. Regularly now these plants, in 4 stage biological configuration, with membrane solids separation, are being configured to reliably achieve 4 mg/l TN as a median, or even mean.

In general, when nitrogen is the targeted analyte, the high-rate plant will be smaller and more reliable. When, from an acute aquatic toxicity perspective, the effluent ammonia-N needs to be driven very low, 1mg/l and below, the pond-based treatment upgrades are unlikely to be sufficient unless they can be located directly in the main process stream as a tertiary process rather than a return stream process. But either configuration would require the ability to handle very large flows. The Helensville case described below however, indicates that this may change as our technology and process understanding continue to evolve.

PATHOGENS

Pond based treatment systems, naturally provide some disinfection, (in the order of 1×10^3 cfu/100mL coliform inactivation) which can be sufficient depending on the discharge environment. To achieve lower than this additional disinfection will be required. Algal production is a hinderance to final effluent disinfection, and additional clarification or filtration is likely required to do this. Without this, typically 1 to 2 log less inactivation is achievable than on secondary clarified effluent.

The modern, high rate plant with membrane based solids separation or clarification, filtration and UV disinfection can be configured for almost complete bacterial removal or inactivation. The amount of viral inactivation will depend upon the amount of disinfection subsequently applied.

It is also worth noting that ponds will likely have better helminth control (if indeed there is a helminth issue in the community), due to the longer retention time.

PHOSPHORUS

Phosphorus is removed relatively easily, to very low levels, by chemical precipitation from either form of treatment plant upgrade, typically in the sedimentation or other solids separation process. Normally aluminium or iron-based chemicals are used. The chemical addition will add considerably to the plant operating cost due to management of at least one additional process, chemical cost and disposal of the additional solids produced. Typically the further along the treatment train that the metal salt is dosed, the lower the cost as there will be less other ‘stuff’ for the metal to complex with.

If enhanced biological phosphorus removal (EBPR) is required, as opposed to chemical precipitation, then a fully bio-mechanical plant will be required. The key additional cost with this approach is the additional CAPEX for larger reactors.

LAND AREA AND THE ABILITY TO FUTURE PROOF A SITE

Clearly, pond-based treatment systems will take a significant quantity of land. Assuming that any upgrade is focused on removing nitrogen, the area of a pond based treatment plant is in the order of 2 m²/person compared to 0.3 m²/person for a reactor clarifier based treatment plant site. Therefore, if the existing pond area has a high value this may add pressure to upgrade to a high rate plant based treatment (however, see commentary on PWWF in Table 1).

- The ability to future proof a given treatment plant site will depend on a number of interrelated factors, such as:
- Likely growth in the area of benefit of the treatment plant. Pond may have to grow to accommodate more flow, BOD and TSS load. But there may not be room. Supplementary aeration can be added but there is a limit to this too, before the algal based pond becomes an aerated lagoon with a different operating basis.
- Possible Level of Service (LoS) increases for the discharge. E.g moving from no effluent TN limit to a 15 mg/l mean effluent TN then potentially later to 4mg/l mean effluent TN. The processes adopted now for 15 mg/l may not be suitable for incorporation into a 4 mg/l plant.
- Deferred maintenance / renewal of assets retained in the upgrade process. Renewal of a key piece of equipment in 15 years' time may have changed the process selection if it had been considered early.
- Development growth pressure immediately surrounding the plant (reverse sensitivity)
- Extent to which land has been acquired and designated for current and future wastewater treatment needs.
- Industrial private plan changes are an unknown quantity, especially when very highly resourced.

If there is likely to be growth in the catchment, and there is not space to expand the ponds then there will likely be a requirement to go to at least hybrid plant and pond-based system (see the Queenstown case study in Section 6.2).

RELIABILITY

Many 'Add on to Pond' processes have been tried for the delivery of capacity and performance gains on pond based systems. Ratsey (2016) describes a number of these. The performance and reliability of these has been highly variable. Reliability issues have resulted from one or more of the following:

- Temperature issues
- Historical sludge inventory not dealt with AND recycling sludge from new processes back to ponds
- High TSS & very small size of algal particles
- Soluble BOD not first dealt with (before ammonia-N)
- The industry does not fully understand the biokinetics of nitrogen removal in algal based ponds
- Poor process and mechanical engineering
- Poor optimization of chemical/mechanical systems at commissioning
- High operator intervention requirements
- High maintenance requirements

RESILIENCE

The resilience to various hazards of the two upgrade pathways is discussed in Table 1.

Table 1: Resilience Comparisons

Hazard	Pond Upgrade	Plant Build
General	Resilient to most hazards and reasonably quick to reinstate but variable depending upon the event. High volume environmental incidents plus full loss of treatment for a short period in the event of an embankment breach.	Asset failure in critical systems. Design for damage rather than failure. Normally IL3. But repair still takes time.
Flooding	Advisable to raise mechanical and electrical gear above design flood level. (e.g Waipawa mechanical system largely untouched during cyclone Gabrielle whereas the pond section of the plant was completely inundated.	Vulnerable to flooding – particularly electrical systems (e.g Napier following cyclone Gabrielle)
Power failure	Significant treatment still available with power failure	Standby power must be provided. Standby communications (SCADA & Telemetry) advisable
Peak load	Pond systems have limited ability to treat peak seasonal loads. Summer peaks can coincide with improved pond capacity due to warmer temperatures. Industrial peaks may cause treatment performance issues. Can be mitigated to a certain extent by having supplementary aeration available and sometimes dosing with sodium nitrate or similar	Some of the mechanical systems can be very adaptable to peak loads e.g. SBR. Additional treatment trains can be added as needed. As loading grows, 'standby' plant can be re-assigned as 'assist' and eventually additional standby capacity added.
Peak Flows	Pond systems have the ability to treat a wide variety of flows with similar treatment performance. Some buffering of outflows can be provided. Washout of widely dispersed nitrifying bacteria may occur during winter with poorer nitrification performance in the spring.	Buffer storage is often required, particularly for older wastewater networks with high levels of infiltration and inflow. Low-strength wastewater can impact performance by reducing plant hydraulic retention time without providing a suitable substrate for processes such as denitrification.

Hazard	Pond Upgrade	Plant Build
Toxicity	Also reasonably resilient to toxic spills due to very large relative volume Can be to site of botulism epidemic to ducks Eel die off due to low DO.	Susceptible to toxic spills because of the high density of biomass and the comparatively short hydraulic retention time.

OPERATIONS

Key differences in plant operations are discussed in Table 2

Table 2: Operational Comparisons

Pond Upgrade	Plant Build
Lower level of training required Fewer operators required for a given plant. Number and skill level will increase with number of added mechanical systems	More operators likely to be required. Higher levels of skills will be required. Specialist maintenance contracts likely to be required

There is no common theme around which type of WWTP upgrade creates the most issues for transitional operation. This largely depends upon whether the upgrade works are undertaken largely ‘greenfield’, on new ground or if existing processes have to make way for the new. For example, the transitional works associated with reclaiming part of a pond in order to build a new process reactor may cause many months of disruption. Having to change the nature or location of a disinfection system, or adding ion tertiary filtration or clarification, could lead to several weeks of disruption. Adding in a new, major pipe to or from an inlet works may lead to disruption of only a day, but this could be a very major disruption, involving an entire plant shut down, depending upon how the plant was configured beforehand.

ENERGY

A pond-based system has a lower energy requirement than a high rate plant-based system. The majority of the energy requirement is contributed by the sun (heating and photosynthesis) and wind (oxygen transfer at the gas / liquid interface). However, adding on a nitrogen reduction system as described in the previous section will increase this. Even with this addition, the pond will still have a significantly , artificially added (Scope 2), energy requirement. Roughly 0.1 to 0.2 kWh/m³ compared to >0.35 kWh/m³ for a conventional activated sludge reactor clarifier system.

CARBON

Greenhouse Gas emissions from wastewater represent a significant proportion of emissions from the water sector. As per the *Carbon accounting guidelines for wastewater treatment:*CH_4 *and* N_2O (WaterNZ, 2021) pond-based systems are estimated to release 20% of the total methane (CH_4) potential in the wastewater, but have negligible nitrous oxide (N_2O) emissions. The addition of side stream treatment to a pond-based system will have the additional negative of having both methane and nitrous oxide emissions. For this assessment the N_2O emissions have been assumed to be 90% of a conventional activated sludge with biological nutrient removal in line with the typical pond removal factor from the guideline. The main benefit of the pond-based system is the low yield of a stabilized sludge.

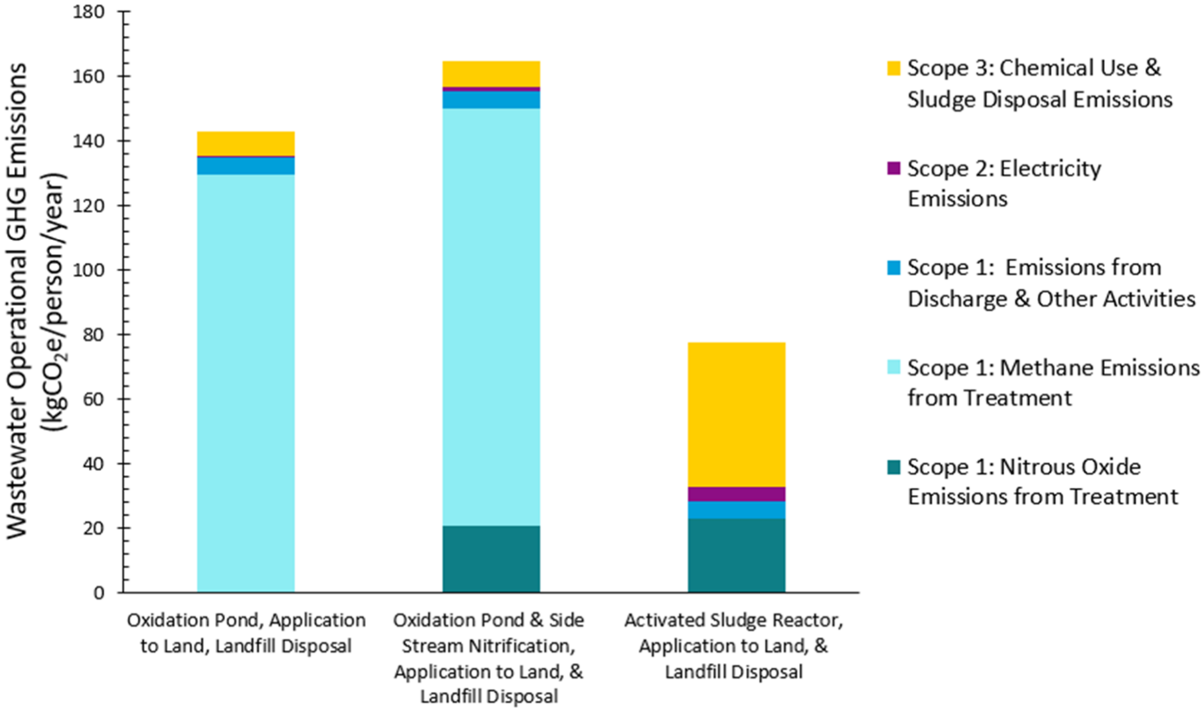

Figure 4: Comparative GHG Emissions

Figure 4 gives a comparative emissions profile assuming discharge to land and sludge disposal to landfill with gas capture. This shows that pond-based systems have the highest operational emissions. The high embodied emissions associated with the plant build with only like off set around one year's worth of emissions.

The other advantage of the plant build is that Scope 3 emissions which are predominately sludge disposal, have the potential to be reduced through the introduction of anaerobic digestion or other sludge treatment methods. The main benefit of the pond based system is the low yield of a stabilized sludge resulting in low Scope 3 emissions. Note these emissions have been annualised.

ODOUR

Pond based systems typically present a higher odour risk, and hence typically require more separation distance. Primary factors in this are:

- Large surface area
- Seasonal risk at Spring/Summer turnover
- Increased loading > higher odour risk
- Algal blooms and scum at the downwind corners.

The extent of odour generation is typically related to the surface area of the process in which the odour compounds are being generated. Odour mitigation is therefore more difficult on pond systems because of the difficulty or impracticality of covering the pond and extracting gases from it for destruction.

Plant based treatment is more contained so high-risk processes (e.g. sludge processing) are easier to configure for odour capture & destruction. There are also more process control options available to address process disruption and quickly reduce any odour generation.

A 150m buffer is generally recommended from residential properties for plants. For ponds systems a 300m or greater buffer is recommended to sensitive receptors and areas typically downwind during light wind conditions.

SLUDGE

Sludge quantity, quality and management requirements are quite different for pond-based and plant based system systems. These are discussed in Table 3. Upgrading a pond based system is unlikely to impact on these fundamental differences.

Table 3: Sludge Issues Comparison

Parameter	Pond Based	Plant based
Yield	Significantly lower	Higher (although can be reduced by using fixed growth system)
Removal	A major, disruptive, sludge removal and dewatering exercise will be required once every 10 to 15 years.	Small amounts of waste sludge will need to be dealt with daily, or at best, several times a week. With appropriate dewatering or thickening technology on site and a disposal strategy, the logistics are reasonably simple.
Treatment	Digested in pond sludge layer	Sludge digestion can be added. But typically a sizeable population of over, say 40,000PE is required to make this cost effective. At that point supplementation of the site energy requirements with biogas may be considered.
Contamination	Historical screenings and metals contamination Very highly digested so %age by weight of heavy metals and TPH is very high just by virtue of not much short chain carbon molecule material remaining.	Without digestion, some form of additional post treatment stabilization is preferable. Particularly if some form of primary sludge is produced.
Disposal	Can be difficult to home the extracted sludge due to apparent contaminants (see above). Where space is available, often mono-filled on site permanently	Commonly accepted at landfills. Other opportunities available including drying and pelletizing as a fertilizer (e.g New Plymouth) or Biochar (Logan City), again as a fertilizer

CULTURAL ISSUES

The predominant cultural issue, in New Zealand, for wastewater treatment is whether or not the treated wastewater has contact with land, either in disposal, such as irrigation or rapid infiltration of as part of treatment e.g. a wetland. Due to the higher solids (TSS) in the discharge from a pond-based system it could be argued that this is slightly more problematic due to the accumulation of solids within the wetland or disposal system. This is generally not so problematic where surface irrigation to land is used. High effluent TSS can be overcome with high-capture tertiary filtration from higher rate plants. However, for high algal content effluent from pond systems, something like a DAF is likely to be required to reduce TSS below nuisance levels.

Another consideration is that for some WWTPs, land was taken, compulsorily (e.g under the Public Works Act), that was wahi tapu or where the land owners were not willing sellers. For example, Rawene and Porangahau Beach. These remain culturally sensitive issues. Upgrading to a smaller, more intensive plant (possibly in a new location) presents an opportunity to address these issues

COST

We would normally expect the CAPEX for a new-build to be higher than for a pond upgrade as almost all the infrastructure, not just the process units needs to be built. It will typically also require significantly more concrete, steel and technology input. The new plant infrastructure will often include a new inlet works, some form of sludge processing facility an MCC room, basic laboratory and operator facilities. Arguably, these facilities should also be provided for pond upgrades, but frequently they are not, and this leads to some of the downstream problems.

In the pond system the bulk of the solids and BOD treatment/removal is done by the expansive, largely natural pond (and possibly wetland) system. And an intensive, anaerobic or aerated, fully mixed stage can be included via a plastic lined hole in the ground rather than a deep, expensive concrete tank.

However, for a given amount of money, the pond upgrade is unlikely to produce an equivalent level of service or effective asset life. Newer options such as ammonia oxidation process add-ons to ponds are causing the gap to be closed. And, depending upon the amount of nitrogen to be removed, persisting with 'add-ons' may end up being more expensive than a new plant.

The extent of work required will depend not only on the load of a contaminant that has to be removed but also the effluent concentration that is required for that contaminant. i.e the work required to remove 30 kg of ammonia-N from a pond effluent, to get down to an effluent ammonia-N concentration of 15 mg/l will be substantially less than the work required to remove 30 kg of ammonia-N to get down to an effluent concentration of 1 mg/l. Load reduction as well as concentration reduction requirements will play a part.

For example, a 4 MLD pond plant performing reasonably well and needing to remove 22 kg/d (down to effluent 16 mg/l) of ammonia-N through a return stream process might require 150 m³ of MBBR reactor (50% fill ratio) and 1.5 MLD recycle rate while a 3MLD plant, performing poorly and needing to remove 34 kg/d (down to effluent 8 mg/l) of ammonia-N might require 450 m³ of reactor volume and a

6 MLD recycle rate. The scale (and hence cost) becomes out of proportion to the plant size.

At face value the whole of life cost would seem lower for a pond based system. However, there is, in our experience, no fixed rule in this regard. The next consent renewal process, for example, could dictate a full technology change. Whereupon the previous, potentially very significant upgrade could end up being a 'sunk' cost. Due to a necessary change in technology or plant format.

SUMMARY

Table 4 summerises, using a 'traffic lights approach' the above discussion on Pros and Cons.

Table 4: Pond Upgrade vs New Build WWTP Comparison Summary

	Pond Upgrade	New Build Plant
Nitrogen Removal	🟧 🟥 If TN<10 mg/l	🟩
Pathogen Removal	🟩 Filtration & UV 🟧	🟩
Real Estate	🟥	🟩
Reliability	🟩 Depends on 🟧 technology 🟥 chosen	🟩
Resilience	🟩	🟧
Operation	🟩	🟧
Energy	🟩	🟥
Emissions	🟥	🟧
Odour	🟧	🟩
Sludge	🟩	🟧
Cultural	🟩	🟩
Cost	🟧	🟥
Future Proof	🟥	🟩

As can be seen the is no 'default' answers to the question on whether to upgrade a pond-based WWTP or built a new plant. Issues that may preclude a pond upgrade are low discharge nitrogen requirements or limited land availability.

COMMON UPGRADE ISSUES

When planning for wastewater treatment plant upgrades, there are a number of common, recurring issues that design teams regularly face when commencing the process and before even being able to determine the appropriate form of upgrade. These include:

- Process monitoring issues. Poor data on inflow and effluent flow, influent and pond temperatures and pH. The data can be absent, wrong (e.g TN by analysis is different to TN by addition) or inconsistent (outflow is higher than inflow)

- Wastewater characterization. Often limited if any exists. It must be planned for and executed to a high standard well ahead of the design process (Crawford & Leizour 2016). While influent characterization is paramount, it is also extremely helpful to the process modelling to have effluent and inter-process characterization. It is very helpful to add, to common compliance monitoring, analytes such as effluent UVT, undegradable COD
- Unusual inputs. Landfill leachate, abattoir blood, toxic substances, other highly coloured organics should be characterized and quantified. As should all trade waste inputs.
- Planning approvals have been given for developments encroaching on the treatment plant odour buffers. This allows for reverse sensitivity issues to be raised by the new comers, restricting what can be done at the existing WWTP site
- The wastewater treatment plant site has no designation in place.
- Design population changing part way through the planning process. Private plan changes in particular, can lead to significant additions to the design population and cause scheme re-assessments to be required.
- Future Consenting. Having to second guess what future, medium to long term consents are likely to require in that regional context.

CASE STUDIES

HĀWEA WWTP

Community and size: Lake Hāwea. Approx 1MLD.

Operator: Veolia Water

- Problems statement:
- Nitrogen consent conditions contravention
- Level of total nitrogen in final effluent discharged to Hāwea River.
- Population growth pressure at both Hāwea and Hāwea Flat
- Operationally, does QLDC wish town and operate a multitude of smaller treatment plants, with regular, consequent consent renewal requirements
- Interim only upgrade. Medium term decommissioning of plant

From around 2019 the treated wastewater discharged from the Hāwea waste stabilization pond consistently exceeded the consented requirements for nitrogen (total and ammoniacal) on both a rolling mean basis and a 95- percentile basis. Prior to that period, rolling mean concentrations were in compliance while the 95-percentile concentrations of total nitrogen and ammoniacal nitrogen consistently exceeded consented requirements. The deterioration coincided with increased dry weather flows to the plant, shorter hydraulic retention time and consequent summer break through of ammonia.

Over the same period, there appeared to have been no significant increase in the effluent BOD_5 or TSS, indicating that the basic organic treatment capability of the pond was adequate. These and many similar ponds around New Zealand were typically designed with a BOD_5 loading rate of 84 kg/ha/day, with little if any consideration or capacity given specifically to nitrogen removal.

Requirements subsequently imposed for nitrogen removal were probably based upon the historical performance of the plant at the time of a prior consent renewal. At that time, the raw sewage flows to treatment would have been below the original design intent and the hydraulic retention times in the pond were longer than the original design intent. Increases in flow, due to population growth, had reduced the HRT significantly and, coincident with that, nitrogen removal performance had deteriorated.

The contravention of consent conditions meant that action was required in the short term. QLDC planned for this by undertaking an options study for short term improvements and preparation of a Business Case exploring options for the long-term fate of the treatment plant.

The short term options included 'return stream' upgrades using: Moving Bed BioReactor (MBBR) or the new Membrane Aerated Biofilm reactor (MABR) process as targeted nitrogen removal upgrades, or Breakpoint Chlorination, or 'High Lime' pH adjustment that encourages ammoniacal nitrogen to be given off (stripped) in gaseous molecular form as NH_3. And a sidestream, nitrifying Trickling Filter. Ultimately the MBBR was selected and implemented as the short to medium term upgrade technology. Being: proven technology, comparatively simple, does not significantly change the chemical composition of the effluent and can be redeployed if and when no longer required at Hāwea. See Figure 4 for the schematic. The upgrade also included adding directional lanes to the single pond and additional aeration.

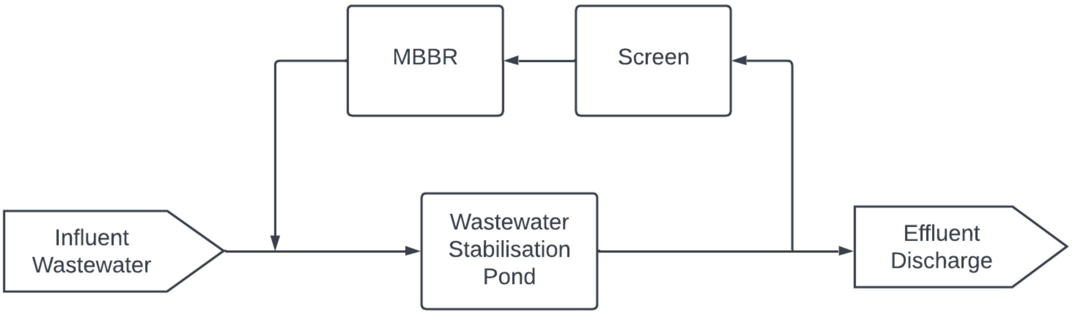

Figure 5: Hāwea Upgrade Process Flow Diagram

The long-term study (formal Business Case) considered the following with the results given in Table 5:

- 'in plant' options building upon the technology adopted by the Short Term Upgrade,
- a new BNR activated sludge style plant at Hāwea or
- transfer of the raw sewage to Project Pure (Wānaka WWTP) for treatment and discharge
- The long term options were assessed on multiple performance criteria including:
- Environmental Impact, assessed via Capital and Operational GHG emissions, nutrient discharges

- Resilience, assessed via seismicity, wet weather flow management and resistance to toxic shock
- Future proofing considered how well the option could be adapted to changes in projected demand (both increases and decreases) and in discharge quality standards for the design horizon. Consideration was also given as to how the solution could be staged or developed over time to meet community needs and how the option could adapt to new technologies.
- Cost assessed via Capital, Operational and Whole of life cost

Table 5: Hāwea Upgrade options assessment

	Pond Plant Upgrades to Infiltration	New Local WWTP to irrigation	Transfer to Pure
Whole of Life Carbon	🟧	🟧	🟧
Resilience	🟧	🟩	🟩
Environmental Impacts	🟥	🟩	🟩
Whole of Life Cost	🟥	🟥	🟧

SHOTOVER WWTP (QUEENSTOWN)

Community and size: Wakatipu Basin. Approx 12MLD.

Problems statement:

- Already severely under capacity
- Very rapid population growth
- Pathogenic pollution of Kawerau River
- Level of total nitrogen in final effluent discharged to Kawerau River.
- Long term upgrade.

Constraints

- Existing waste stabilization ponds already grossly overloaded
- Limited space at designated site
- Multiple alternative use claims on immediately surrounding land
- New communities developed on 3 sides of designated site
- High groundwater table on the non-developed side
- Operational sensitivity from nearby airport
- Aesthetic sensitivity from neighbouring land owners and developers

Upgrade:

A new inlet works was initially constructed with the ultimate treatment plant in mind (although not designed or conceptualized). It was required regardless of the future works as the old inlet works had essentially collapsed. The design philosophy of the client's advisors, for the treatment plant upgrade, was to provide treatment capacity, to a design horizon of year 2051, in two stages. Because of the combination of problems and constraints, it was envisioned that this would be partly mechanised and partly residual ponds at Stage 1.

Stage 1 subsequently was developed as a Modified Ludzack Ettinger (MLE) Activated Sludge plus UV disinfection and waste sludge dewatering In Stage 1, it was intended that the ponds would be unloaded so that a residual of only 37% of flow was retained through old pond system. However, after commissioning, it was found that the large ponds, although substantially unloaded, were still unable to lower nitrogen to a level sufficient to make the final, blended effluent compliant. As a result, the load balance has been shifted further to 80%MLE : 20% Ponds.

Following the global financial crisis in 2008 and prior to the new procurement process commencing in 2013, Council revised (downward), what had previously been very aggressive growth projections for the Wakatipu Basin, the area of benefit for the WWTP. However, the projected 2027 flows and loads were actually reached in 2017. As a result, the third upgrade stage was brought forward by four years and a tender awarded in mid-2023. This time however, the COVID 19 pandemic was not allowed to influence the medium to long term population projections, which sit somewhere between the early, aggressive numbers and the under-done post GFC numbers.

The Stage 3 works will see a duplication of the high-rate biological plant implemented at Stage 1. Except that the original UV disinfection and sludge dewatering facilities had already been futured proofed and will require little intervention. The Stage 0 Inlet Works will see a third screen and screenings compactor added. The ponds will be decommissioned and repurposed for stormwater attenuation, calamity flow storage and for other Council owned facilities.

Costs for the various upgrade stages are as follows:

Table 6: Summary of Shotover WWTP Upgrade Costs

Stage	Date	Works	CAPEX
Stage 0	2013	New Inlet Works	$3M
Stage 1	2016	MLE#1, Clarifier#1, UV, Dewatering, Operator facility, Septage Reception, Roading	$20M
Stage 2	2018	Rapid Infiltration Beds	$5M
Stage 3	2023	MLE#2, Clarifier #2, Calamity pond remodelling	$38M

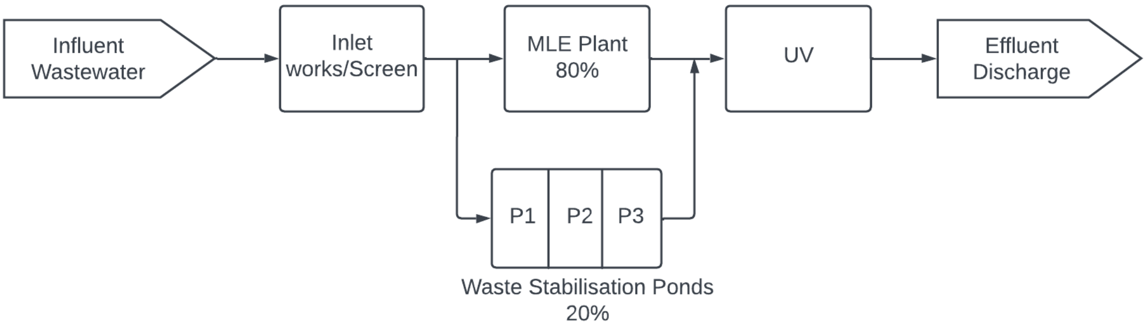

Figure 6: Shotover Upgrade Process Flow Diagram to Stage 1

HELENSVILLE WWTP

Community and size: Hellensville and Parakai, approx. 1 MLD

Problems statement:

- Non-compliant ammonia discharge
- Struggled to cope with peak wet weather flows.

Upgrade:

The Helensville WWTP featured an oxidation pond and ultra-filtration, wasn't consistently meeting consent requirements for the level of ammonia in the discharge. An abatement notice was issued by Auckland Council in late 2021.

Watercare selected a membrane aerated biofilm reactor (MABR) which they had been trialing at it's innovation centre at the Māngere Wastewater Treatment Plant, so while it hadn't been done before in New Zealand, it was tested.

The treatment plant's upgrade also included additional ultra-filtration capacity, the installation of a standby generator to keep the plant running during power outages or surges and work to strengthen and restore the capacity in the oxidation ponds by reinforcing the embankments.

The $17M upgrade went into service in April 2023 and has been closely monitored as part of the commissioning process. It's significantly outperforming the design standards. The target was a reduction of ammonia-N to 10 mg/L, which is below the consent requirements, but current performance actual performance sees ammonia levels in the treated wastewater discharge to the Kaipara River about 1.4 mg/L.

- The technology also has other benefits:
- Cheaper than the alternative membrane bioreactor
- Small footprint
- Reduces the greenhouse gas emissions from the biological treatment process by up to 50%.

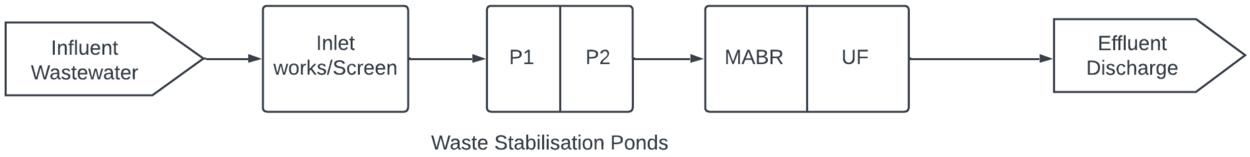

Figure 7: Helensville Upgrade Process Flow Diagram

WAIPAWA WWTP

Community and size: Waipawa plus Ōtāne. Approx 2MLD

Problems statement:

- Non-compliant ammonia discharge
- Non-compliant UV disinfection
- Ineffective floating wetlands
- Ineffective lamella clarifier
- Similar problems at adjacent WWTP sites

Constraints

- Very high wet weather flows
- Little or no spare space on two existing sites to expand
- Community desire for future discharges to be to land

Upgrade:

CHBDC was subject to an environment court prosecution following the failure, of year 2013 pond-based upgrades (floating wetlands, media curtains, lamella Clarifier, Sand filter and UV disinfection), to bring about necessary improvements to discharge effluent quality from their Waipawa WWTP. Following that, CHBDC undertook to make significant upgrades to the Waipawa WWTP that would ensure that the key failings were addressed. They then undertook an extensive engagement progress with community stakeholders that covered the Waipawa site and all the balances of their wastewater management schemes. The outcome of that engagement and the ensuing technical and financial studies was a strategy to work toward a new, medium term facility on open ground at Waipawa (midway between Ōtāne and Waipukurau plants). This would be a high rate, suspended growth facility, focusing on nutrient and pathogen removal. In the interim period, short term upgrades would be undertaken at Waipawa and Waipukurau. And effluent flows from the smaller Ōtāne plant would be transferred to Waipawa. This would avoid costly consent renewals at Ōtāne. The Takapau plant would receive its own, pond-based upgrade. The Pōrangahau and Pōrangahau Beach pond-based plants would eventually be decommissioned and fully replaced, on a new site, with a new, but low tech, mechanical plant servicing the combined communities, with discharge going to land via surface irrigation.

Interim upgrades at Waipawa would be to remove the floating wetlands and media curtains, which were doing nothing, and to remove the lamella clarifier and sand filter, both of which were performing poorly on the light weight and very tiny algal particles. A DAF would replace those and clarify the effluent sufficiently to allow the UV system to operate compliant. The very large, sludge accumulation was removed. This in itself improved (but not sufficient for compliance) the ammonia-N removal performance.

Interim upgrades at Waipukurau were to include desludging, additional aeration, replace the filters and lamellas with a DAF and install a new, larger, UV disinfection system. These works are currently on hold due to financial pressures induced by Cyclone Gabrielle devastation in the area. The desludging has been undertaken, as has removal of the floating wetlands and media curtains.

The plan is for the new suspended growth plant to be configured with two thirds of its ultimate capacity and receive the existing flows from Waipawa, Otane and Waipukurau, allowing for significant growth to be provided for, when required, by a third reactor.

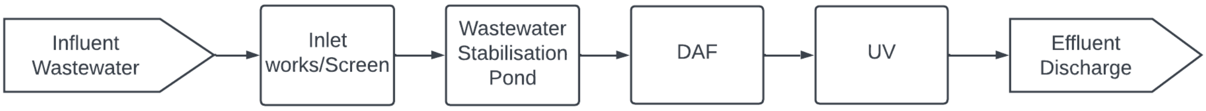

Figure 8: Waipawa Interim Upgrade Process Flow Diagram

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