DON'T POO POO THAT SIMPLE POND SYSTEM!

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ABSTRACT

Waste stabilisation (Oxidation) ponds in New Zealand continue to be a cost effective means of wastewater treatment, but thirty five years' experience working with pond systems has shown that there are many aspects of these seemingly simple systems that are still not well understood. Improved understanding of pond systems translates to better performance outcomes and greater cost efficiencies for that increasingly limited capital and operating investment.

Recent analysis of 20 pond systems throughout New Zealand presented some interesting findings regarding pond performance outcomes and upgrade strategies. This paper presents some of those findings and follows on from a paper presented by H Archer at the 2015 Water Conference "Can Performance of Waste Stabilisation Ponds be Improved", and also reviews a paper presented by CW Hickey and JM Quinn to the 1990 IPENZ annual conference "Evaluation of the Performance of Domestic Sewage Oxidation Ponds in NZ".

The paper looks more critically at pond performance in regard to the 50-year-old New Zealand national design guideline of 84 kg BOD/ha/d, at factors affecting pond performance such as loading, temperature, mixing and sludge accumulation, and at a number of approaches to improve the performance of pond systems with which the author is familiar.

KEYWORDS

Waste stabilisation ponds, oxidation ponds, pond performance, pond design, nutrient removal in ponds, aerators on ponds.

1 INTRODUCTION

The author's thirty five years' experience working with oxidation ponds has shown that these simple pond systems are as relevant today as they were when first introduced to New Zealand in 1957. However, increasingly stringent effluent and receiving environment quality standards are challenging how such existing assets can continue to deliver acceptable treatment and cost efficiencies. The effluent discharge regime and receiving environment drive the effluent quality targets and they need to be considered as an integral part of pond design, consenting, and operation. While increasing environmental standards for discharges to water place pressure on pond systems to perform better, the increasing trend to land treatment and dispersal of pond effluent means that often the effluent quality from such simple systems is well suited to this receiving environment.

An extensive list of publications on ponds that assist in the understanding of the complex processes that take place in ponds is given in Archer (2015). This paper is an opportunity to present the author's experience with pond systems in a broader sense, creating a greater awareness of issues that designers of future pond systems or upgrades may not have otherwise thought about.

The national pond design loading guideline of 84kg BOD/ha/d set down in the Ministry of Works 1974 *"Guideline for the design, construction and operation of oxidation ponds"* continues to serve NZ well. However, 40 years on it is evident that the design of pond systems is more complex than just the adoption of such a single parameter. A wide range of factors affecting facultative cell pond performance and how they can impact on pond performance and effluent quality are discussed.

Multi pond systems achieve more stable effluent quality, but in this regard understanding the design factors governing the initial facultative cell (keep well mixed-on an areal basis) and subsequent 'maturation' cells (design for plug flow) are important but are sometimes confused.

Wetlands (both floating and conventional) can be successful at improving effluent quality (whilst also addressing Maori cultural sensitivities) but there are many pitfalls. Likewise, membrane filtration is proving a successful, although more mechanically and energy intensive, technique, but again there are pitfalls - related to excessive flux rates and inadequate maintenance regimes.

2 TREATMENT PERFORMANCE TARGETS

2.1 INTRODUCTION

The target treatment performance standards need to primarily reflect a combination of the expected capability range of the treatment technology used and the receiving environment into which the treated wastewater is discharged. The potential discharge environments are freshwater bodies (streams, rivers, lakes), ocean outfall (for most of our main cities and some coastal communities), and land. Storage of treated wastewater is often a crucial component of actively managed discharge systems to ensure that discharges can cease when environmental conditions require this.

Historically in New Zealand the favoured receiving environments have been oceans, streams, and rivers, but discharges directly into waterways are now heavily discouraged by the provisions of Regional Plans, the National Policy Statement for Freshwater Management, the New Zealand Coastal Policy Statement, Maori cultural values, and community aspirations for improved water quality in rivers and coastal areas. Economic factors, including community affordability, can be outweighed by these other considerations when selecting the receiving environment and discharge regime.

The quality and discharge rate of the treated wastewater are key factors, but the receiving environment will also have limitations on its ability to sustainably assimilate some or all of the discharge with seasonal variation. It is vital that the target quality and discharge rates of the treated wastewater suit the ability of the receiving environment to sustainably receive the wastewater discharge, including its seasonal variations.

The way in which oxidation ponds can fit into different receiving environments is first considered, before moving on to looking at what ponds and pond upgrades can achieve.

2.2 SUITABILITY OF POND TREATMENT FOR MARINE DISCHARGES

For most of our main cities and communities located close to the coast, the marine environment can be attractive due to its vast volume compared with any discharge that potentially allows for almost unlimited assimilation of a treated wastewater discharge. The discharge structure's distance offshore is important for minimising the potential pathogen effects on recreational areas and fisheries, but longer pipelines are a tradeoff against increased costs of materials and construction.

Overall, pond systems are likely to provide adequate levels of wastewater treatment for ocean discharges, as the only wastewater contaminant of concern in the ocean environment is usually pathogens. Where pathogens are a sensitive concern for the discharge location, then maturation cells and/or further tertiary treatment such as UV lamps can ensure that pathogen concentrations are acceptable.

2.3 SUITABILITY OF POND TREATMENT FOR FRESHWATER DISCHARGES

The freshwater environment is not static - flow rates and contaminant loads from upstream sources vary with rainfall events, droughts, and seasons. Water temperatures and nuisance growths of algae increase during summer months. As a result, some periods of time will be better able to assimilate any wastewater discharges than others. Generally, higher flow rates generated by storm events will be less sensitive to treated wastewater discharges than summer low flow conditions. Obviously, large rivers will generally be better able to assimilate treated wastewater discharges than small streams or sensitive lakes.

For larger waterways the quality of treated wastewater from facultative or maturation ponds will be suitable for discharging into rivers because of the high dilution factors, but cultural values are likely to require some form of land passage such as rock filters or wetlands prior to entering the freshwater system. Nutrient loads can also be an issue. Recreational and public health considerations can require additional treatment such as membrane filtration or UV disinfection to reduce the pathogen discharge loads and effects in freshwater bodies.

Small streams are less likely to be able to assimilate oxidation pond discharges. Adverse effects during summer low flows can be considerable. An additional consideration for small streams is the seasonal variation in the treated wastewater parameters. During winter months the ammoniacal-nitrogen concentrations tend to be much higher than during summer. This can further restrict the amount of time each year that the receiving stream's flow rates are high enough to assimilate the wastewater discharges without risk of affecting the downstream ecology.

Nitrate is preferable over ammonia within fresh water systems because of better ecological and stock consumption tolerances of nitrate, but oxidation ponds are generally not capable of converting much of the ammonia into nitrate, particularly during winter months. In this regard oxidation ponds are disadvantaged for discharges to water.

Phosphorus discharges to waterways can be a limiting factor, particularly where wastewater concentrations require high dilution by receiving streams in order to meet environmental limits. Oxidation pond systems achieve only a moderate reduction in phosphorus concentrations, so it can be necessary to implement additional tertiary treatment that targets reductions of phosphorus in effluent so that discharges to water can occur.

2.4 SUITABILITY OF POND TREATMENT FOR LAND DISCHARGES

The land environment is generally the most ideal receiving environment, as it recycles nutrients and can be operated in such a manner that it is beneficial with minimal if any adverse effects. However, potentially very large land areas are required, and this is particularly difficult to resolve near large urban areas or in sensitive locations such as lowlands or coastal settlements. The terrain, soil types, soil drainage rates, seasonal depths to groundwater, and distances from surface water bodies will determine how much land is required for the total volume of wastewater that needs to be discharged. Buffer setbacks from residential neighbours and sensitive environments will further increase the amount of land required and often determine its preferred location. Crop types, harvesting, and land management requirements also need to be factored into land discharge systems.

Land discharges are commonly highly seasonal, as soils are often too wet during winter months for accepting wastewater discharges. The exception to this is where moderate to well drained soils are available and/or where the underlying groundwater body is able to receive increased drainage of water and nutrients without affecting any downstream groundwater users. Storage of wastewater also becomes much more important during winter because the inflows to the WWTP from the community's reticulation will also increase during storms and must be stored until the next time that it is appropriate to discharge to land. The alternative discharge to a river or stream during storm flows can be a feasible discharge option for at least some of these times when discharges to land are not appropriate (this is discussed further below).

The range of effluent quality produced by oxidation pond systems with or without maturation and other tertiary treatment processes is well suited to land discharges. The key is to ensure that the application rates are within the range of acceptable nutrient loadings for the soils and crops, and generate acceptable rates of nutrient losses into underlying groundwater. Using adequate areas of land with suitable soils and matching discharge timing to the controlling environmental factors will enable the development of a sustainable land discharge system for wastewater treated by oxidation ponds.

Plants can more readily absorb and use ammoniacal nitrogen than the nitrate or nitrite forms of nitrogen. This matches the tendency of oxidation ponds to produce ammoniacal nitrogen as the dominant form of nitrogen in the effluent. Nitrate leaching to groundwater and/or surface water bodies, and phosphorus run-off to surface water are the usual concerns with wastewater discharges to land. Often the volume of wastewater discharged to land causes soil moisture and drainage concerns before it is capable of causing nutrient loadings or losses to reach levels of concern. Soils can accumulate phosphorus when phosphorus loadings from wastewater exceed the ability of plants and soils to process it, but this generally applies to high rate application loads onto smaller areas of land or to wastewater sources that contain higher phosphorus concentrations than typical municipal sources of wastewater.

Where recreational activities or human food cropping (including dairy grazing) occur within or near the land discharge area, public health considerations can require additional treatment such as UV to reduce the pathogen concentrations in the effluent. Odour and spray drift controls are also likely to be imposed.

2.5 COMBINED DISCHARGE ENVIRONMENTS

It is possible to implement two different discharge systems that operate under different but complementary conditions. The most common of these is combined land and water discharge (CLAWD). Generally, discharges to land will occur during dry periods, while discharges to water will occur when soils are too wet for wastewater discharges. Discharges to water may be restricted to high river flow brackets in order to protect the aquatic ecology from elevated contaminant concentrations. The storage volume requirement can be very large for times when discharges are not possible to either receiving environment.

Overall, the same target treated wastewater quality can suit both receiving environments, because the permitted circumstances for discharging and the permitted rates of discharge can be controlled to match the assimilative capacity of the relevant receiving environment.

3 THE HISTORICAL CONTEXT OF POND DESIGN

The national NZ design guideline for oxidation ponds of 84kg BOD/ha/d, or 1200 persons/ha, is familiar to most, but where did these criteria originate from and how relevant still are they today?

While early pond systems pre-1960 were designed on overseas information at 56kg BOD/ha/d (Hickey and Quinn 1990), experiments performed at Templeton in 1961, where pond loadings were varied from 56-224kg BOD/ha/d, resulted in the derivation of an “optimal” loading rate of 84kg BOD/ha/d. The apparent basis for this criterion was the maintenance of aerobic conditions within the primary (facultative) pond throughout the 12 month study period.

In 1967 a Department of Health and Ministry of Works and Development (MWD) survey of pond performance reported the conclusion (Cameron 1983) *“that the majority of ponds operate free of odour and fly problems”*, and in 1974 the 84kg BOD/ha/d criteria became a national guideline when the MWD produced their “*Guideline for the Design, Operation and Construction of Oxidation Ponds*”. This figure was then developed into a per capita guideline of 1200 persons/ha based on an assumed per capita BOD of 70g/person/d.

These guidelines have seemingly served NZ well for the past 50 years, but interestingly in 1990 Hickey and Quinn (H&Q) reported that after studying the performance of 18 ponds having varying loadings and detention times over a 12 month period, they found in respect of dissolved oxygen (DO), 5-day biochemical oxygen demand (BOD), suspended solids (SS), ammonia (NH_4-N) and faecal coliforms, that: *“For these effluent constituents there was not apparent relations with % of design loading. Retention time showed no relationship with either median BOD or SS. However median NH_4-N decreased and DO increased with increasing detention time. Faecal coliform concentrations showed minimal differences between all ponds.”*

So given such depressing findings why do we continue to still use that standard originally developed in 1961 and what more do we now understand about pond performance and its relation to BOD loading and retention time? What are key considerations when it comes to upgrading pond systems? These questions are considered in the following sections.

4 POND PERFORMANCE - AN OVERVIEW

Figure 1 summarises the findings of H&Q’s study of 18 ponds in the late 1980s. This on the face of it appears to show an almost random array of results and it is not surprising that they concluded as quoted earlier. It is suggested, however, that these were mostly two pond systems and they didn’t look too closely at inter-pond performance and aspects of pond configuration.

Critically, the facultative (primary) pond must be evaluated separately to that of subsequent ponds and the total area or volume of the pond system must not be used to evaluate loading rate or compare detention periods.

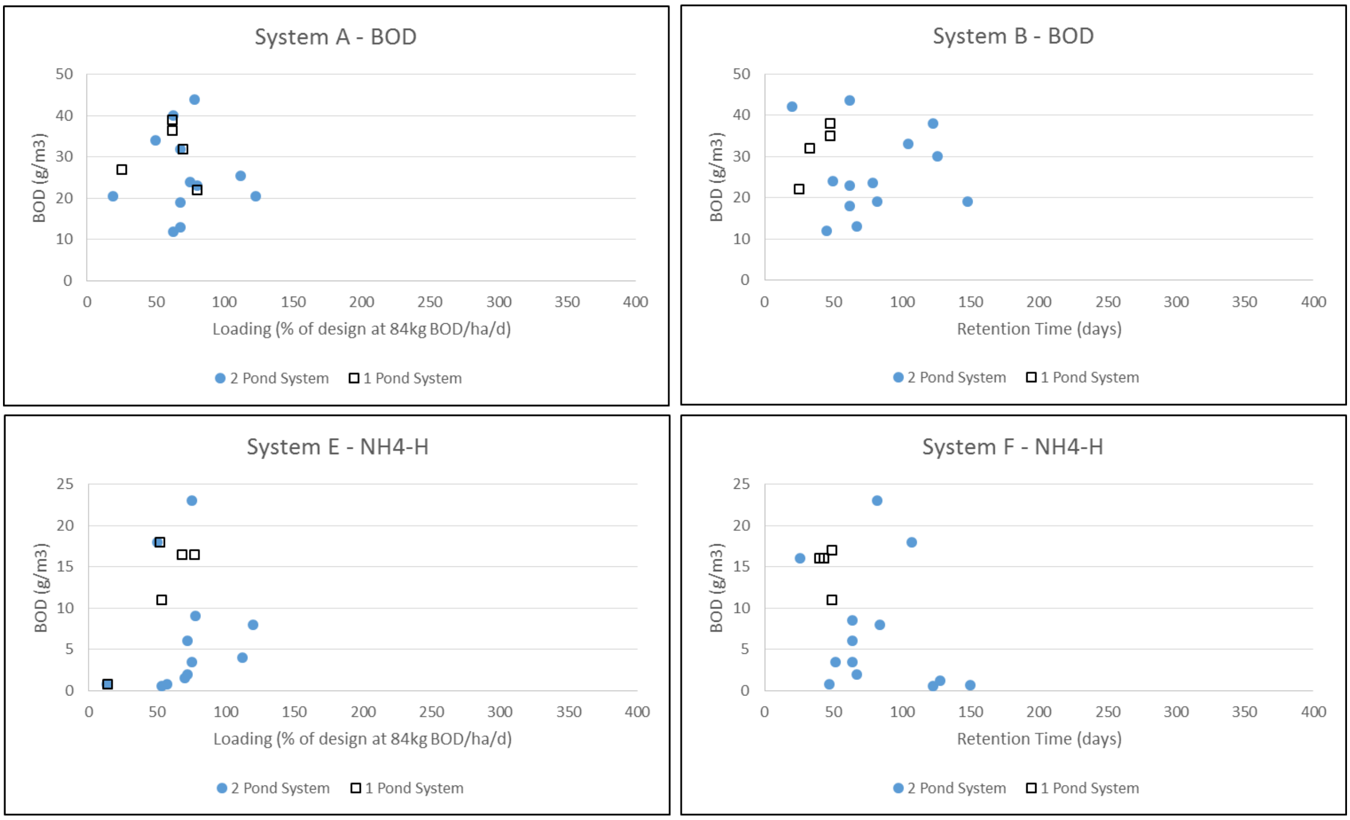
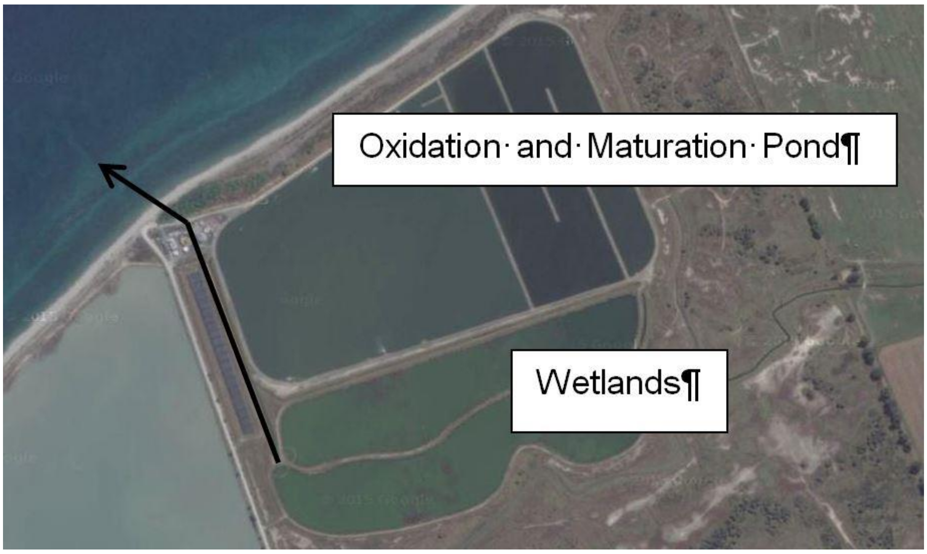


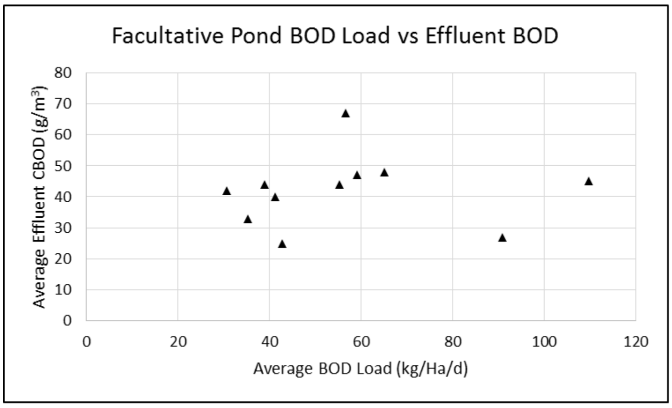
Figure 1: Summary of the analysis for 18 pond systems studied by Hickey and Quinn (1990) in respect of loading rate and detention time

For the two-pond systems, early design saw a more simplistic 2/3-1/3 (approximately) split of the primary and secondary cells, whereas more current design practice is to arrange the secondary cell more in plug flow configuration as seen at the Nelson North pond system upgraded around 6-7 years ago - see Photo 1.

Photo 1: Aerial photo of the 27ha Nelson North WWTP pond system, with the secondary pond configured for plug flow



A more recent study of the 8 single cell systems listed in Table 1 - see Figure 2 - seemingly leads to a similar conclusion to that of H&Q. On closer inspection, however, it is perhaps not as simple as that, as studied next in Section 5.



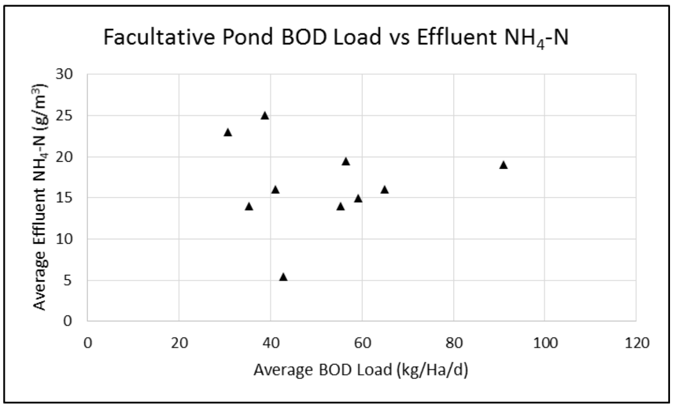


Figure 2: An analysis of the performance of 8 single cell ponds against loading rate and detention time showing seemingly little correlation with either

5 A CLOSER LOOK AT POND PERFORMANCE

5.1 INTRODUCTION

Table 1 introduces the more than 20 pond systems that have been evaluated to varying extents in this study and sets out the key parameters related to their sizing and loading.

The estimated loading and detention times in Table 1 are given in broad terms only as certain assumptions have often been made relating to influent concentration and flow. Loadings calculated on this basis have been tested against estimated BOD loading based on 70g BOD/p/d, and where appropriate the two values averaged. A notable observation is the wide ranging difference in daily flows related to population, which introduces some complexity into the evaluation of pond performance results.

Table 1: Summary of ponds studied

Location	Population (approx)	Pond Size Ha		Ann. Average Flow m3/d	FAC Cell Detention Time Days	Est. FAC Cell Loading (kg/Ha/d)	No. of Aerators
		Facultative	Secondary				
FACULTATIVE PONDS - EFFLUENT ONLY							
Kaka Point	200	0.43	-	92	56	31	0
Lawrence	430	0.6	-	263	27	65	1
Stirling	310	0.36	-	102	42	55	0
Tapanui	750	1.2	-	231	62	35	0
Heriot	120	0.25	-	58	52	41	0
Kaitangata	760	0.97	-	446	26	59	0
Taihape	1788	3.2	-	710	56	43	2
Waihola	335	0.38	0.16 Wetl.	93	51	57	0
Otane *(pre-upgrade)*	558	0.44		195	27	91	0
Foxton	2650	4.8	1.6	1300	44	110	0
Bannockburn	130	0.36	-	-	-	39	0
FACULTATIVE PONDS WITH MATURATION CELLS - EFFLUENT							
Shotover	14,000	9.35	6.45	12,000	10 - 14	220 400 Summer	18
Owaka	330	0.43	0.32	263	20	69	0
Foxton	2650	4.8	1.6	1300	44	110	0
Foxton Beach	1640	0.5	0.46	518	12	140 Summer	1
Bulls	1515	1.87	1.55	453	78	62	1
Sanson	540	0.4	0.19	167	38	95	0
Halcombe	220	0.23	0.11	60	48	67	1
Nelson North	28,000	17	10	7700	26	Varies	5
FACULTATIVE PONDS + FLOATING WETLANDS EFFLUENT							
Hunterville	520	0.5	0.32	229	26	78	2
Otane	558	0.13		195	8	315	1
Waipukarau	4320	1.1		2200	6	440	5
Waipawa	1901	1.6		850	23	97	4
Shannon	1500	2.6	0.26 Wetl.	550	47	48	2

The following sections delve a little deeper into factors affecting pond performance with a particular focus on the primary (facultative) cell and assessing how loading (as BOD) affects performance.

5.2 AERATORS ON PONDS AND SIZE OF PONDS

Archer (2015) offers the opinion that multiple mixer/aerators are crucial to maintaining a healthy pond which is generally free from nuisance odour and this is very much the Author's experience. Going further, however, it is suggested that small ponds (say less than 0.4ha) are particularly sensitive to more direct short circuiting effects that create greater variability in pond performance than in larger ponds (say 1ha or more). Figure 3 presents a comparison of effluent ammonia with facultative cell size, which gives some credence to this, though clearly other factors are at stake. The installation of an aerator to promote mixing on small ponds is therefore considered good practice.

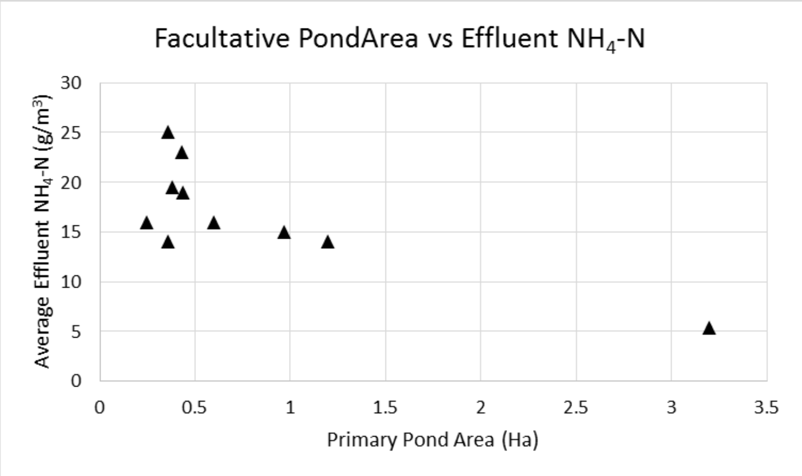


Figure 3: Effluent ammonia vs pond cell size

The selection of ponds presented in Figure 4 (all without aerators) tends to support this observation. The larger (around 1ha) Kaitangata and Tapanui ponds exhibit a generally more consistent performance than the smaller (around 0.4ha) Stirling and Waihola ponds, notwithstanding some outliers in all cases. Kaka Point is also a small pond, but the variation in performance here is likely more associated with an influx of summer visitors.

Larger ponds while perhaps not so sensitive to short circuiting effects also benefit from the addition of aerators(s), particularly in regard to reducing thermal stratification effects during the critical autumn and spring transition periods, and in promoting the more uniform spread of incoming load over the whole facultative cell area.

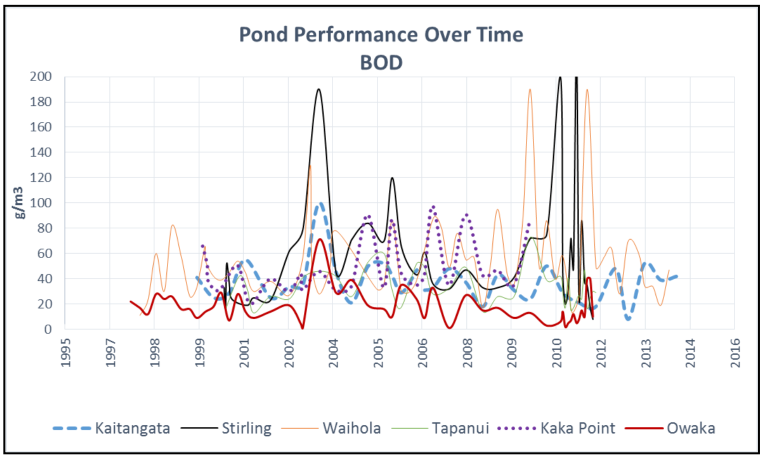


Figure 4: Typical BOD performance with time and seasonality

5.3 BOD PERFORMANCE

Figure 4 presents a selection of six ponds that would all be regarded as low to moderately loaded. The purpose of this figure is first to show the broad range of effluent BOD that can be expected from a single cell facultative pond and the level of variability that can occur. Other ponds studied showed similar behavior.

Tapanui is a "large" pond and one of the most lightly loaded (around 35kg BOD/ha/d) yet its effluent BOD typically ranges between 20 and 50g/m^3. Kaitangata is also a "large" pond, loaded more highly (around 60kg BOD/ha/d), and its performance is pretty well the same as Tapanui.

Perhaps aerators on these larger ponds would achieve some improvement in performance, but the conclusion starts to be drawn that pond loading below the national guideline of 84kg BOD/ha/d do not achieve significant benefits in pond performance in respect of effluent BOD and that this guideline remains an appropriate value to target in respect of the oxidation of organic matter (reduction of BOD), particularly with regard to maintaining adequate levels of dissolved oxygen in the pond.

Figure 4 also presents for comparison, the performance of the Owaka pond, a reasonably conventional two-pond system. This shows quite dramatically the improvement in effluent quality that can be achieved by simply adding a secondary pond. The facultative cell in this case is "small" (0.43ha) and the loading is a touch higher (70kg BOD/ha/d) than in all the other 5 ponds. The pond experiences a similar climate to those other ponds.

To conclude this section on BOD, it is perhaps interesting to observe USEPA (USEPA 2011) guidelines that recommend as follows:

"For average winter air temperatures above 15°C, a BOD5 loading rate range of 45-90kg/ha/d is recommended. When the average winter air temperature ranges between 0-15°C the organic loading rate should range between 22-45 kg/ha/d. For average winter temperatures below 0°C the organic loading rates should range from 11-22 kg/ha/d."

Clearly the US is more conservative than NZ, but perhaps this adds a cautionary note about under sizing the facultative cell.

5.4 EFFLUENT CBOD VS BOD

The BOD measurements presented thus far are in terms of total BOD (TBOD). There is however an increasing trend and acceptance by Regional Councils to measurement of BOD effluent quality as carbonaceous biochemical oxygen demand (CBOD), wherein the contribution from nitrogenous bacteria is suppressed. Some go even further to only consider the soluble CBOD (ScBOD) fraction, which excludes all particulate and algae.

TBOD, however, which is what the original design guideline is based on, remains appropriate as this represents the total oxygen demand on the pond.

For the two Nelson treatment plants (Nelson North pond (Photo 1) and Bell Island) NELMAC operational staff report that the Nelson North ponds have gone through a couple of periods where TBOD in the discharge effluent spiked and breached consent although the CBOD levels remained around their normal average. More frequently at Bell Island, nitrification in the sample during laboratory analysis has produced TBOD results at odds with the measured low CBOD and sBOD levels. A case has therefore been made to the regulatory authorities to accept CBOD as the proper indicator of treatment of the discharge from the oxidation ponds/wetlands.

Figure 5 presents a comparison of TBOD and CBOD for effluent from the maturation pond at Nelson North.

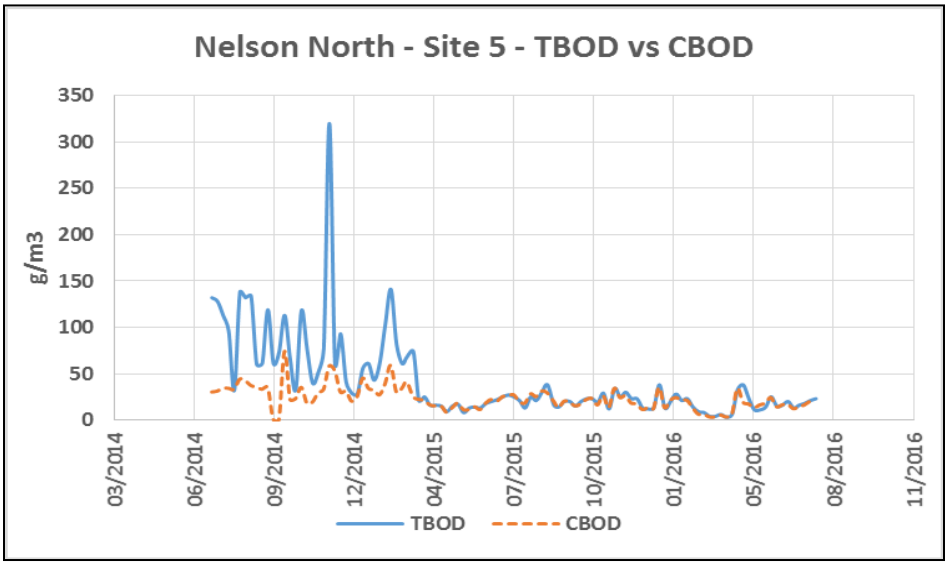


Figure 5: A comparison between TBOD and CBOD at the Nelson North Wakapuaka Ponds

5.5 SUSPENDED SOLIDS PERFORMANCE

Effluent suspended solids (SS) in a single cell facultative pond is typically erratic and the fluctuations shown in Figure 6 for the same ponds as in Figure 4 typify what might be expected. This is really no surprise as it is well known that effluent SS are largely elevated by algal growth in the pond. Larger detention times can actually be a disadvantage due to the extended opportunity for such algal growth.

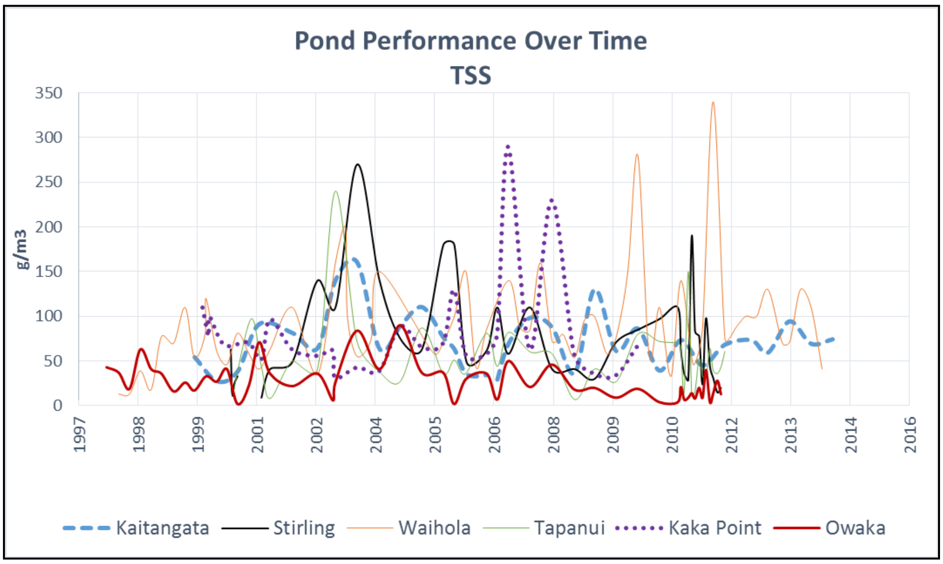


Figure 6: Typical SS performance with time and seasonality

Figure 6 also presents the opportunity to look at effluent SS trends on a seasonal basis. The reasonable expectation is higher SS levels in summer and lower in winter. Figure 6 however, appears to show little correlation in this regard.

The reduction and better control of effluent SS is often a key focus when pond upgrades are considered. Again, the benefits of a two pond system (Owaka) in achieving lower effluent SS is demonstrated in Figure 6, though levels are nonetheless still quite high.

Suspended solids levels can be successfully reduced by suppressing the opportunity for algal growth, by covering a final section of the final secondary cell. However this leads to the suppression of dissolved oxygen levels (DO) and the potential to create anaerobic conditions. Floating wetlands combined with covered zones near the end of the pond system can help inject oxygen and maintain adequate DO levels.

Duckweed, if you can get it established and then kept it in place (very hard), is a particularly successful means of achieving high clarity of effluent whilst maintaining aerobic conditions. The Author recalls experiences in the 1980s whereby duckweed established itself "by accident" on the Coronet Peak oxidation pond, and at another time on the Omakau oxidation pond, delivering pristine effluent out of each pond.

Photo 2: Establishment of duckweed on the second cell of the Hunterville Ponds

A recent visit to the Hunterville ponds, where performance is exceptional (discussed in Section 6), witnessed the establishment of duckweed (Photo 2) between strips of floating wetlands - which can be a great way to keep duckweed in place! The question posed here is: to what extent do the floating wetlands and the duckweed zones each contribute to the pond's excellent effluent quality?

5.6 NITRIFICATION AND NITROGEN REDUCTION

From the foregoing analysis of effluent BOD it is concluded that the NZ design guideline of 84kg BOD/ha/d remains an appropriate value to target in respect of the oxidation of organic matter (reduction of BOD). This is not surprising as that was the basis on which the guideline was originally established in 1961.

However, at that time the nitrification of ammonia and overall removal of nitrogen was likely not of great interest. Fifty years later it certainly is. Much attention is now given to achieving lower and more stable levels of ammonia (NH_4-N) and total nitrogen (TN) in pond effluent.

Figure 7 presents ammonia levels for the same six ponds in Figures 3 and 5. Generally a typical performance band between around 10 and 30mg/L NH_4-N is observed. The "small" Kaka Point and Stirling ponds exhibit more extreme fluctuations. With the imminent installation of aerators on each of these ponds it will be interesting to see the extent of any change in performance of facultative cell [1]

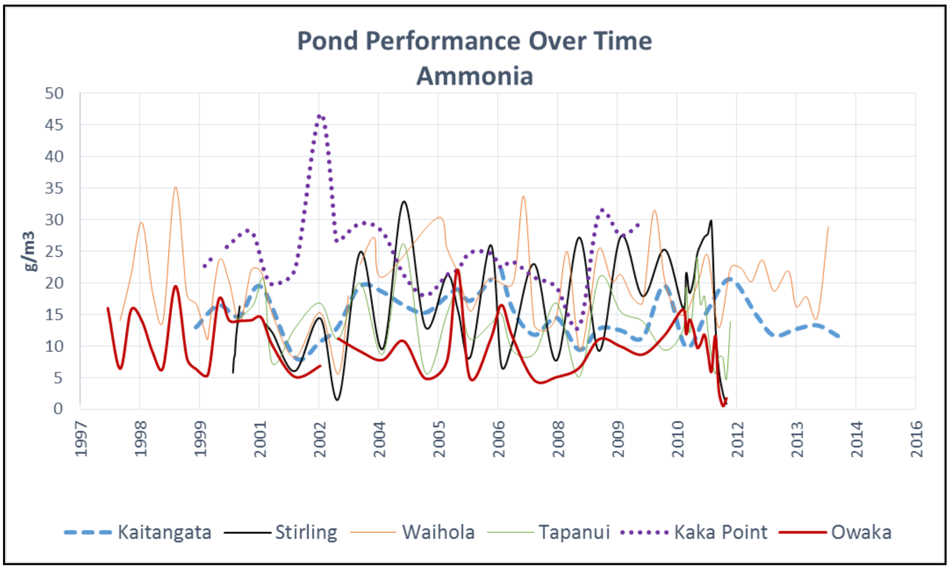


Figure 7: Typical NH_4-N performance with time and seasonality

It is the Author's observation from the analysis of the ponds in Table 1 (and others) that unlike BOD, nitrification is sensitive to the BOD loading rate on the facultative cell. It is suggested that at lower loadings (say less than 50-60kg BOD/ha/d) lower and more stable levels of nitrification are achieved, and the well-established relationship of reduced nitrification at lower (winter) temperatures becomes more distinct. The Heriot pond (at around 40kg BOD/ha/d; 0.25ha) presents a good demonstration of this in Figure 8. Note the increase in ammonia levels in 2012 - when a truckwash was established in town!

By contrast, Waihola and Kaitangata, loaded at around 60kg BOD/ha/d, and experiencing a similar climate, show a more confused seasonal pattern (Figures 9 and 10). Kaitangata as the larger of the two ponds, however, exhibits a more stable performance and lower NH_4-N than the smaller Waihola pond.

Perhaps the more conservative US approach of lower BOD loadings has merit when it comes to nitrogen reduction and not just BOD reduction. A consistent theme however seems to link smaller facultative ponds (less than about 1 ha in size) to poorer performance across a range of wastewater quality parameters.

[1] Both of these ponds now have the Biofiltro process, but this process follows the facultative cell, notwithstanding some recirculation at times.

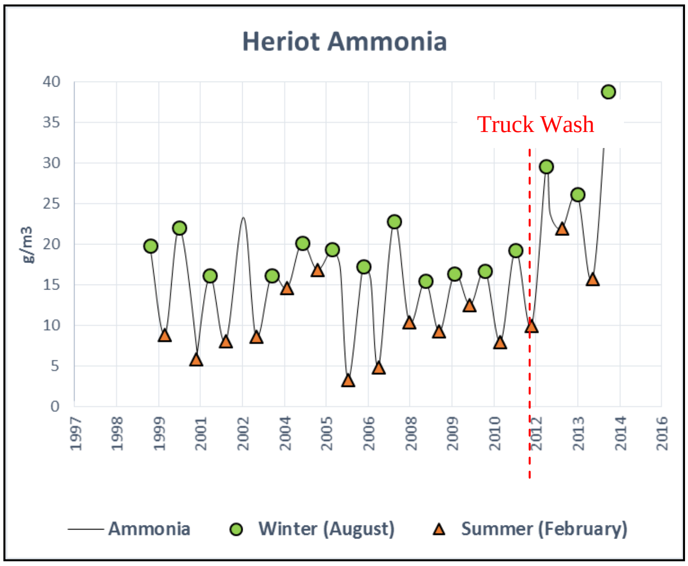


Figure 8: Heriot seasonal ammonia records

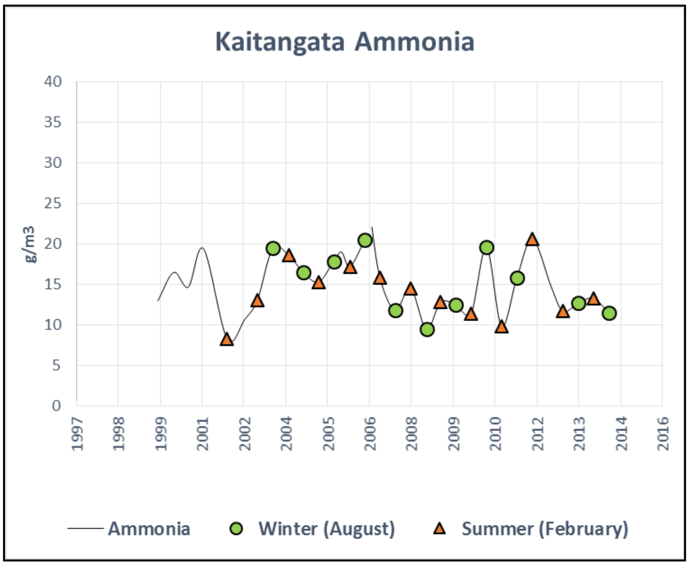


Figure 9: Kaitangata seasonal ammonia records

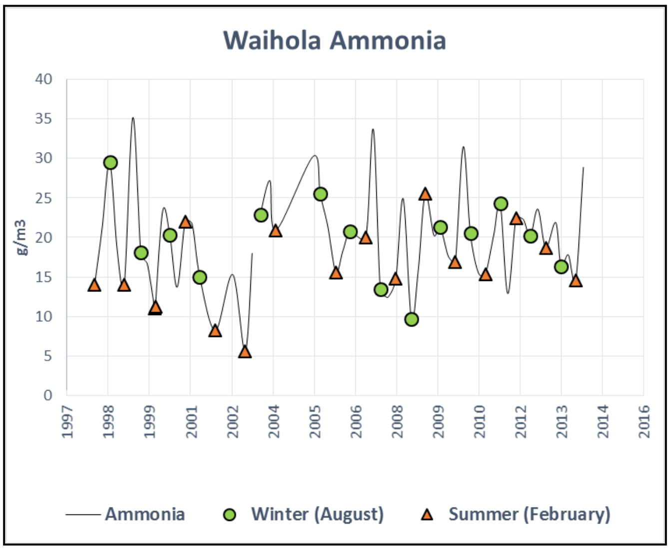


Figure 10: Waihola seasonal ammonia records

As the loading on the facultative cell increases above the NZ guideline, and often more and more aerators start to be added, there is a clear trend that nitrification in the facultative cell drops off almost completely.

Looking at the Waipukarau and Waipawa ponds, then, we see the loading on the facultative cell is estimated at around 100kg/ha/d for Waipawa and 400kg/ha/d for Waipukarau. At Waipawa, with the more reasonably loaded facultative cell a clear performance trend with temperature is seen - higher N in winter, lower in summer. However at the highly loaded Waipukarau pond, these similar secondary processes struggle to get to this level at all. At nearby Otane, where loading on the facultative cell is similar to that at Waipukarau, we see some correlation with temperature (Figure 11 - 2010 post wetland installation), though generally a confused picture is presented, possibly also as a result of the much more variable population of Otane.

5.7 TN VS AMMONIA

The foregoing Section on effluent BOD commented on the use of TBOD and CBOD. A similar point arises with effluent N measurement in regard to the use of TN and ammonia. By and large ammonia predominates in pond effluent. When nitrification of ammonia to nitrate occurs the nitrate quickly denitrifies (from contact with the carbonaceous material in the fresh sludge layer) leaving little nitrate in the effluent. Attention is therefore often focused on ammonia levels.

Figure 11 (Otane), then, presents some interesting information comparing effluent total nitrogen and ammonia over a long period, both for the original single facultative cell (pre-2010) and following installation of the floating wetlands. Clearly low effluent ammonia does not always translate to low effluent total nitrogen.

Note again that with the highly loaded facultative cell, effluent N levels remain high after the floating wetlands, similar to that of the original facultative cell.

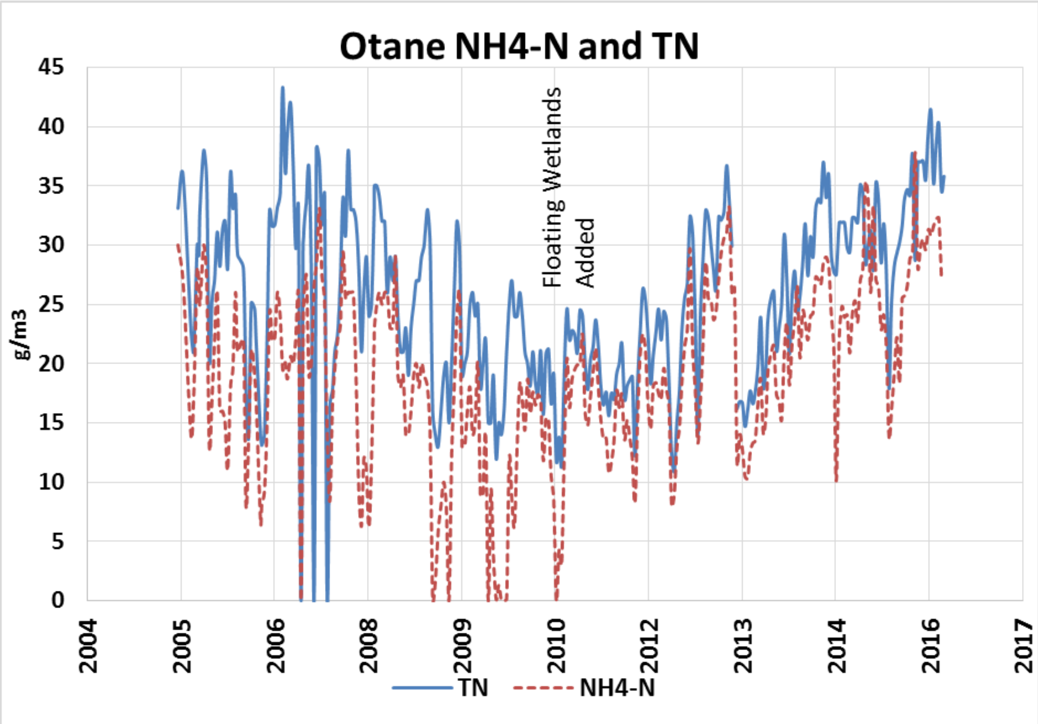


Figure 11: Otane showing both total nitrogen (TN) and seasonal ammonia records before and after floating wetland treatment. Note that the loading on the Otane facultative cell is similar to that on Waipukarau's, but Otane has a highly variable population load dominated by its boarding school and hospitality businesses.

The on-occasions high difference between TN and NH_4-N may be accounted for in several ways:

1. Some would be expected to be organic, largely as protein in the algae and would likely correlate with high TSS;

2. However, the concentration of organic N would likely only be 1/8 or so of the algal TSS, so if the TN was a lot higher than ammonia, then it would have to be in the nitrate or nitrite form. BOD and COD have sometimes been observed to be higher than anticipated due to nitrifying cultures, and it has been necessary to prevent nitrification in the BOD test, but this usually only happens in maturation ponds, or very lowly loaded ponds with high DO.

5.8 PATHOGEN ATTENUATION

An approximately Log 2 reduction in pathogen levels can be expected in the facultative cell of a pond loaded within the guidelines for pond design. It is well established that Pathogen removal is effective in multiple cell pond systems with suitable detention times and this is discussed further in Section 6.

5.9 PHOSPHORUS REMOVAL

Phosphorous removal by ponds is limited and can not be relied upon unless chemical dosing is employed. Clearly some removal occurs through physical (settlement) processes, but little is presented in literature about removal in oxidation ponds. Most literature refers to removal by chemical means or adsorption techniques. So it was with some interest that seasonal trends were clearly evident in some of the pond systems studied. It is possible that algal sequestration of P reduces DRP during spring/summer, then releases most of it again upon mass die-off of algal blooms in autumn. Figures 12 and 13 present effluent phosphorus results for the Heriot and Kaitangata ponds.

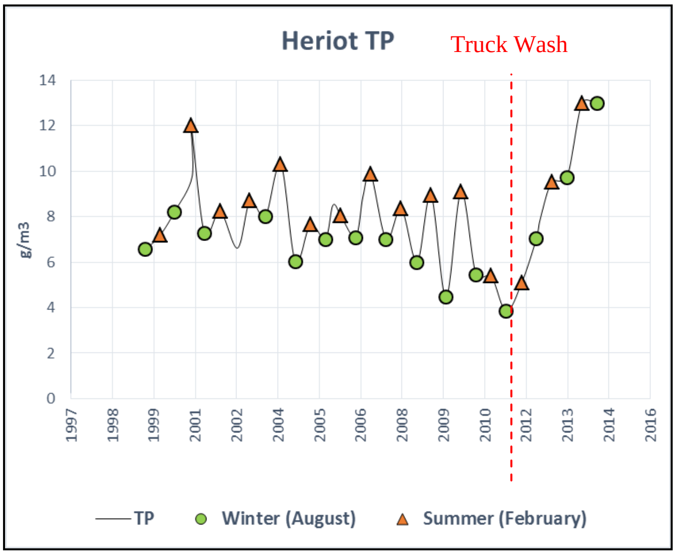


Figure 12: Seasonal TP performance at Heriot

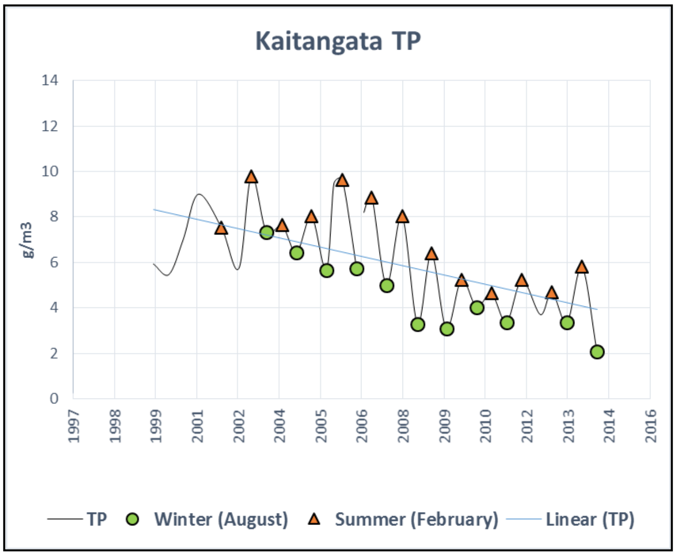
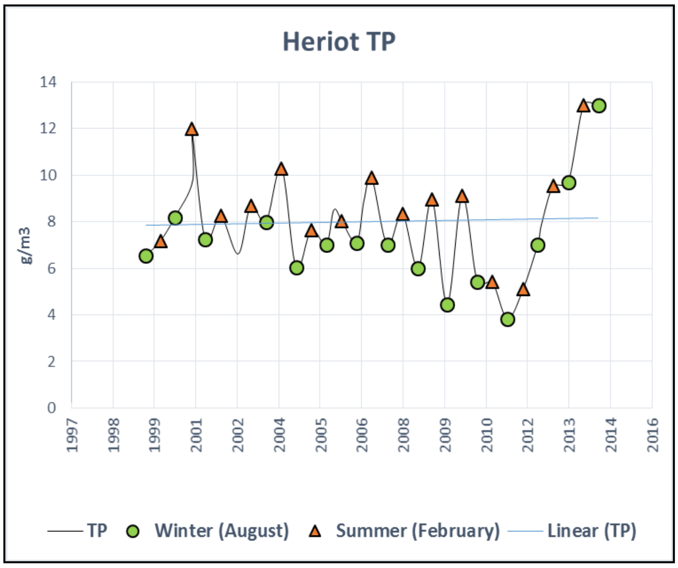


Figure 13: Seasonal TP performance at Kaitangata



Of interest also is the decreasing trend in effluent P over the past 15 years, a trend that you start to notice with almost any pond system you look at - Figure 14 presents a sample of pond systems showing typical effluent P levels and confirming the general downward trend of effluent P over time. It is assumed that this trend is likely due to the reduction in phosphate containing detergents over the past 15 years.

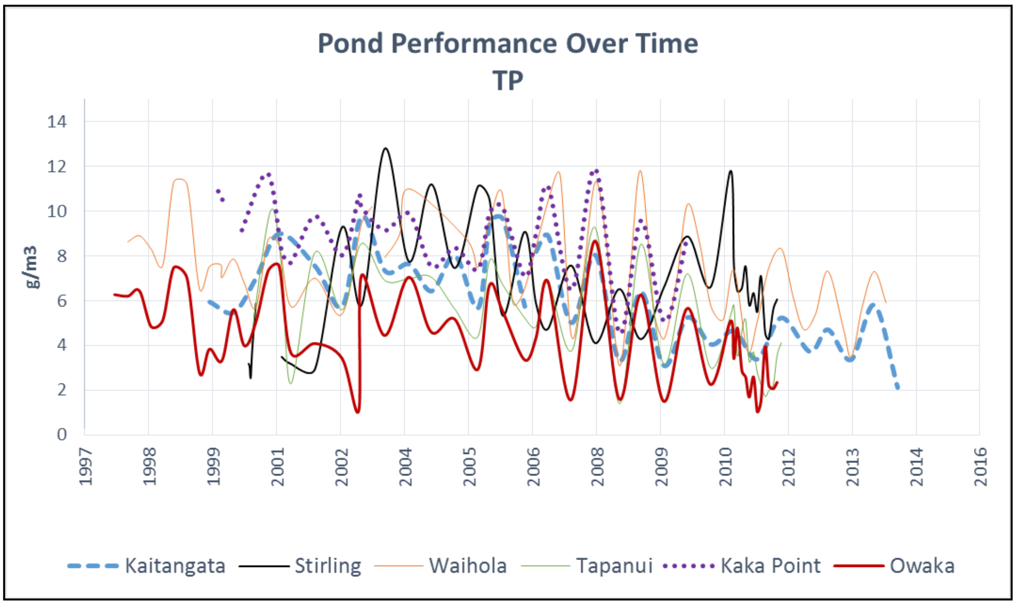


Figure 14: Typical TP performance with time and seasonality

5.10 AERATED, MORE HEAVILY LOADED PONDS

As the year round load on the facultative cell increases above 100-120kg BOD/ha/d, the addition of aerators becomes more important to support the biochemical oxidation of the incoming organic load, as opposed to just promoting mixing of the pond. There is, however, a limit to how high the load on the facultative cell can rise to and how many aerators can be added before the natural oxidation pond process is overwhelmed and fundamentally changed to that more of an aerated lagoon. Here the Shotover pond system at Queenstown is considered to be an example of a pond close to that point.

The Shotover pond comprises two in-parallel facultative cells of total area 9.35ha followed by a maturation pond of area 6.45ha, essentially configured as two cells (Photo 3). Around 18 aerators are installed on the facultative cells. Annual average loading on the pond is around 200kg BOD/ha/d rising to a peak of around 400kg BOD/ha/d during the New Year holiday season. Over the years more aerators have been added as odour issues arose. The pond was desludged about 4 years ago and has largely operated odour free since then.

The effluent quality in respect of BOD and SS, out of the maturation cells, is typical of a relatively poorly performing facultative cell at 50-70 and 100-130g/m^3 respectively. Nitrogen removal is almost non-existent with all effort seemingly going into managing the BOD loading on the pond. With an average influent TN around 45g/m^3, effluent TN and NH_4-N are around 40 and 30g/m^3 respectively.

Photo 3: Shotover oxidation ponds at Queenstown

5.11 SLUDGE ACCUMULATION EFFECTS

With many ponds in NZ reaching 30-40 years of age, and more, desludging of ponds is now a common activity throughout the country. The benefits of desludging are to some extent anecdotal. Modest sludge accumulation in a pond, leaving a 0.9-1.0m water column above the sludge layer has little effect on pond performance, but more significant accumulation, and particularly mounding, can lead to unstable conditions and associated odour release. Increasing CBOD and SS concentrations in the effluent are also apparent with increasing accumulation of sludge. Aerators have been known to stir up sludge and elevate the SS in the effluent or to assist its transfer into maturation ponds. A significant percentage of insoluble phosphorus can be retained in the sludge.

The Nelson North wastewater plant (Photo 1) is a case in point. Following completion of the upgrade around 2009 the facultative cell continued to exhibit odour events so severe that local schools were closing. While much of the pond had reasonable water depth, there were areas of significant mounding, and a general layer of sludge over the pond floor accumulated since the pond was constructed over 40 years ago. The addition of five aerators to promote mixing and the desludging of the pond together have addressed the odour issues and the Nelson plant is now performing very well. As mentioned above, desludging of the Shotover ponds was also a likely factor in resolving its odour issues.

6 POND ENHANCEMENTS

6.1 INTRODUCTION

There are many strategies to improve the performance of pond systems. A few with which the Author is familiar are presented below.

6.2 MATURATION CELLS (AND OPEN WETLANDS)

It is well established that Pathogen removal is effective in multiple cell pond systems with suitable detention times. Several models for predicting pathogen die-off were studied by the Author in the 1990's: one relating die-off to solar radiation (Sarikaya and Saatci 1987) and one to pond water temperature (Marais 1974). Interestingly these two different approaches gave similar outcomes in some situations but the Marais formula seemed to have the edge - and was simpler. In 1997/98 the opportunity arose at the 27ha Nelson North Wakapuaka pond to compare actual performance with that predicted using the USEPA formula. This followed construction of an earthen partition dividing the pond into an 18ha facultative cell and a 9ha maturation cell. Figure 15 presents actual measured performance with that predicted for an assumed band of influent pathogens between $3x10^6$ and 10^7 fc/100ml. A reasonably good correlation is observed.

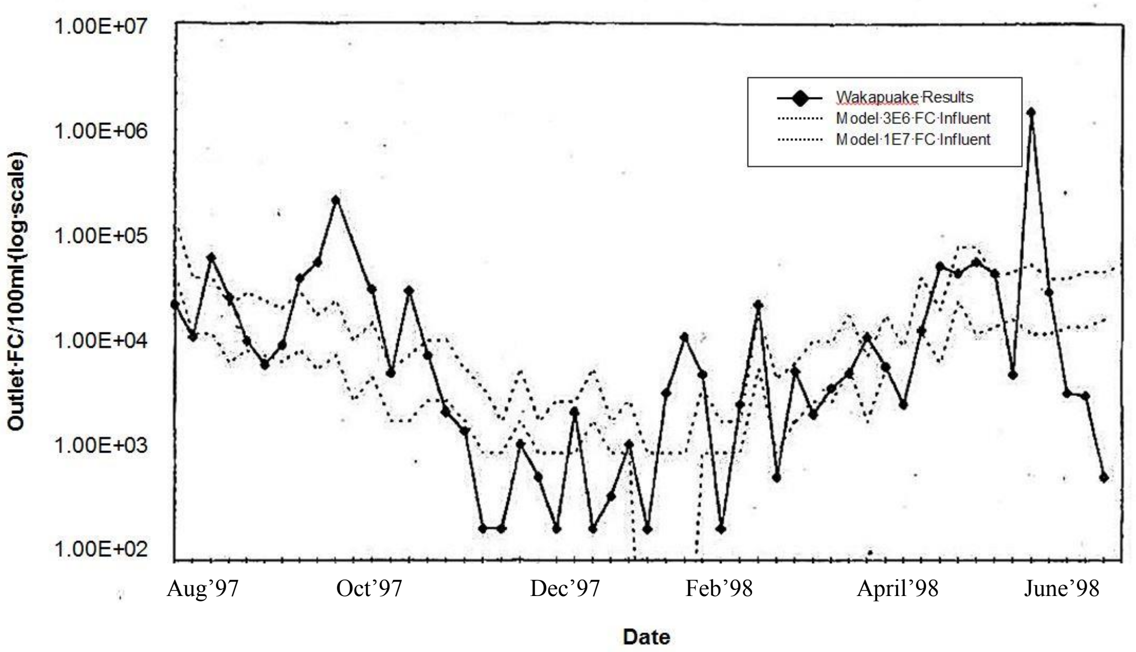


Figure 15: Comparison of Actual Pathogen attenuation vs USEPA estimation

Unfortunately, the reduction in the size of the facultative cell led to the collapse of the pond in mid-1998 and the decision was made to urgently pull the embankment out again. The little stubs seen in Photo 1 to the left hand end of the pond show where this embankment lay. At that time the flow regime was from right to left, the opposite of the current configuration. This is a cautionary tale of making the facultative cell too small for winter conditions and gives some credence to the low winter loading rates recommended by the USEPA.

With the final upgrade of the Nelson North Wakapuaka ponds completed in 2009 (see Photo 1) the smaller 17ha facultative cell was reinstated, but with a pre-treatment primary clarifier / trickling filter load removal facility upfront to take load off the now reduced size facultative cell in winter. The maturation cell was now constructed to provide plug flow configuration and an in-parallel 2-cell wetland constructed, largely to satisfy Maori cultural sensitivities.

For consenting purposes, no improvement in effluent quality was assumed to be achieved in the wetland facility, which has proven to be a wise approach as little further improvement is seen (Figure 16) apart from some further pathogen removal (Figure 17). The effluent quality is very good and a testament to a good plug flow configured maturation pond section.

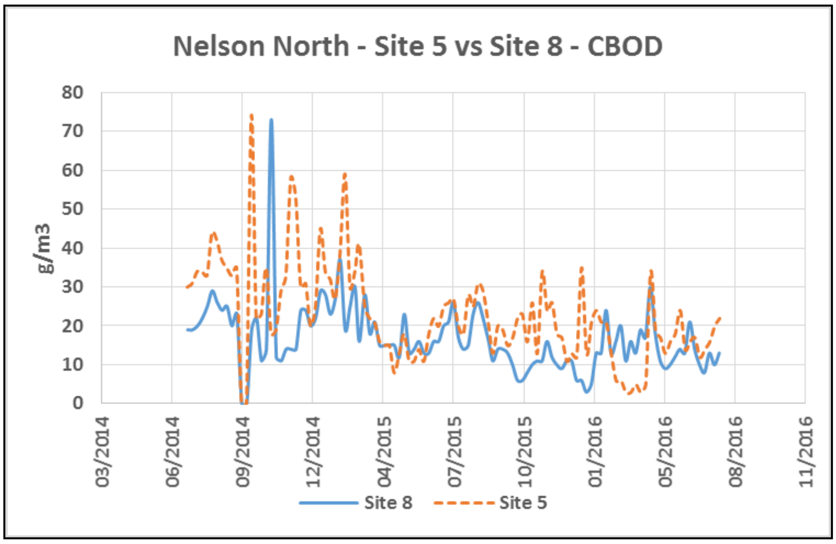


Figure 16: Comparison of BOD effluent quality from the oxidation pond (Site 5) and from the subsequent wetlands (Site 8)

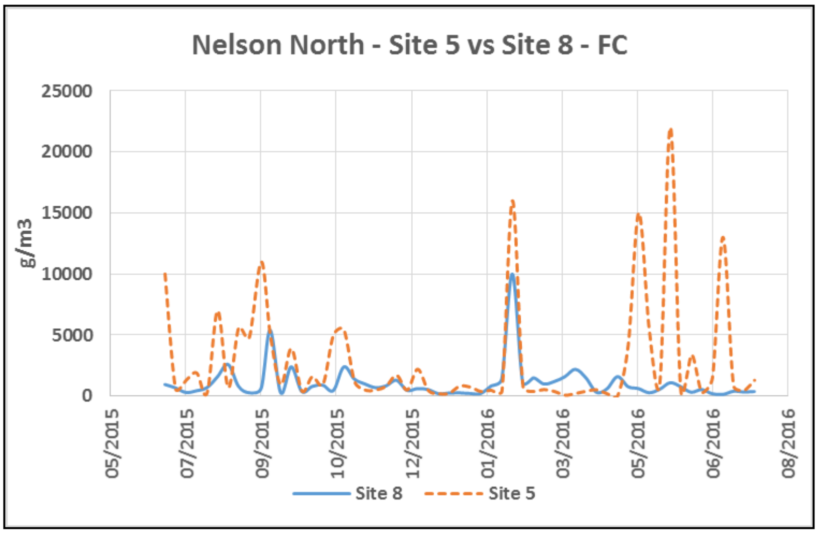


Figure 17: Comparison of FC effluent quality from the oxidation pond (Site 5) and from the subsequent wetlands (Site 8)

Regarding the wetland system, this was designed as a series of planted and open (deeper) cells which is consistent with the practice noted by Archer (2015). These open sections help redistribute flow between the planted sections and promote further pathogen removal - though at some point wildlife limit the levels this can be brought down to.

6.3 PRE-TREATMENT PRIOR TO POND

The upgrade work at the Nelson North plant is a testament to the cost effective use of existing facilities to accommodate growth and more stringent effluent requirements. The work has been generally described already, but to summarise, a pre-treatment primary clarifier and trickling filter plant was constructed at the head of the ponds, allowing a reduction in the facultative cell to around 17ha. This reduction then allowed the construction within the pond of the plug flow maturation cells (seen in Photo 1) targeting pathogen removal (more particularly) and general improvement in other effluent parameters. The subsequent wetlands were constructed for cultural reasons to permit continuation of the coastal sea discharge.

Operation of the plant now targets a pond loading of 130kg BOD/ha/d peak in summer and 60kg BOD/ha/d in winter, with transition loading in between. For most of the year the pre-treatment facility is kept "idling" and only brought on as necessary. The addition of aerators on and desludging of the facultative pond have been important factors in achieving stable operation of the overall plant.

6.4 FLOATING WETLANDS

Floating wetlands are an increasingly popular means of improving effluent quality, but their design in regard to the whole pond system must be carefully considered. The opportunity in early 2016 to study the four floating wetland installations at Hunterville, Otane, Waipukarau, and Waipawa presented an opportunity to draw some interesting conclusions. Here we find four generically similar plants exhibiting completely different levels of performance as Table 2 summarises.

Table 2: Summarising performance of the Hunterville, Otane, Waipukarau and Otane floating wetland systems

Plant	**Facultative Cell Size as % of Total Pond Area**	**Average Facultative Cell Loading Kg BOD/ha/d**	**Effluent cBOD g/m^3**	**Effluent SS g/m^3**	**Effluent TN g/m^3**	**Effluent TP g/m^3**
Hunterville	60%	60	<1	<5	3.5	0.2 (DRP)
Otane	30%	315	~14	~30	~29	~4
Waipukarau	44%	440	~8	~14	~29	~4
Waipawa	65%	112	~5	~15	5 - 15	~4

It is not possible within this Paper to describe or analyse these four plants in detail, suffice to say the following broad conclusions and observation are noted:

- The facultative cell has an important role in providing the main level of treatment, leaving the subsequent aeration/aerated curtain and floating wetland sections to perform a polishing role. For optimum performance then, the facultative cell should therefore be loaded around, or less than the national guideline of 84kg BOD/ha/d.

- TN removal is improved when loadings on the facultative cell are reasonable, and become more temperature dependent. At high facultative cell loadings the whole system just struggles to remove nitrogen.

- In the design of a floating wetland system open sections between wetland "strips" are recommended so that future access for desludging under the floating wetland sections can be facilitated.

6.5 BIOFILTRO

The Biofiltro process is a type of packed bed reactor which utilises timber shavings as a medium and worms to assist the treatment process. When applied to oxidation pond systems effluent is pumped from the facultative cell to the Biofiltro plant, essentially in a single pass, although recirculation back to the pond does occur to utilise the pond for effluent flow buffering. Five systems are installed on Clutha District ponds and three more ponds are proposed for similar upgrades.

A detailed analysis of the performance of the five existing plants showed some variability in performance, attributed largely to loading rate, uneven hydraulic application and suspended solids carry-through, and these matters are in the process of being addressed by Biofiltro.

An analysis of the current performance of the five existing Biofiltro systems is not presented here, as it would form the basis of a Paper in itself and anyway improvements currently being made to the process would mean that those findings are now less relevant. Suffice to say that the Biofiltro process has good potential to improve pond effluent quality.

6.6 ROCK FILTERS

Rock filters have the potential to improve oxidation pond effluent and a 12-month study of two in-parallel filters loaded at different rates with effluent from the Shotover Oxidation Ponds is presented in Railton DE (2007). These trials showed that the treatment effectiveness of rock filters fluctuates considerably, and that treatment effectiveness only improved to a limited extent when hydraulic loading rates (HLR's) were reduced from around $0.7m^3/day/m^3$ to $0.18m^3/day/m^3$.

SS treatment effectiveness in terms of SS percent removal fell mostly in the 35% to 65% range when HLR was around 0.60 to $0.80m^3/d/m^3$. At lower HLR's around $0.18m^3/d/m^3$, SS percent removal largely fell in the 50% to 85% range. Percentage removal of BOD_5 fell in the range 10% to 55%.

There are a large number of influences affecting the performance of rock filters and caution is recommended when designing rock filters and predicting effluent quality, particularly for compliance purposes.

6.7 MEMBRANE FILTRATION

The understanding of the application of membrane filtration (MF) to pond effluent has improved considerably over the past 10 years. Experience with the MF plants at Maungaturoto and Hikurangi showed that excellent performance, delivering near pristine effluent, could be achieved subject to (amongst other things) appropriate selection of flux rate and attention to the operational cleaning cycle of the membranes and other operational procedures.

Membrane flux rates need to be less than that practiced for water treatment plants and 7 years on, those employed at Maungaturoto, of around $7\text{-}10L/m^2/hr$ average flow and $25L/m^2/hr$ peak flow, have proven the ability of the membrane plant to cope with high influent TSS levels in the $100\text{-}200g/m^3$ range. A good understanding of the influent characteristics, particularly suspended solids, is however still important in selecting the appropriate flux rate.

7 CONCLUSIONS

The national pond design loading guideline of 84kg BOD/ha/d set down in the Ministry of Works 1974 *"Guideline for the design, construction and operation of oxidation ponds"* continues to serve NZ well. However, 40 years on it is evident that the design of pond systems is more complex than just the adoption of such a single parameter. Being largely 'natural' systems ponds are subject to significant variability in performance, according to site specific factors and circumstances, and it is hard to develop conclusive findings covering all ponds. However a number of observations are made regarding factors affecting pond performance, and of upgraded pond systems, based on the author's experience and following the analysis of the 20+ ponds in this study.

It is concluded, then, that:

- Simple waste stabilisation (oxidation) ponds continue to be a cost effective means of wastewater treatment. Improved understanding of pond systems translates to better performance outcomes and greater cost efficiencies for that increasingly limited capital and operating investment.

- While increasing environmental standards for discharges to water place pressure on pond systems to perform better, the increasing trend to land treatment and dispersal of pond effluent means that often the effluent quality from such simple systems is well suited to this receiving environment.

- Where higher levels of pond effluent quality are required, these can be achieved in a reasonably cost effective manner - but a key to achieving this is to ensure that the initial facultative cell(s) is not overloaded, allowing it to maximise that initial stage of treatment, taking pressure off subsequent tertiary processes.

- The NZ guideline of 84kg BOD/ha/d remains a good design benchmark, but was originally developed more for pond stability, and the control of odour and flies. Where reasonable and more stable levels of nitrification are desired, then the loading of the facultative cell should be lower than this, noting that USEPA guidelines go as low as 22 - 45kg BOD/d/ha for winter temperatures between 0-15 °C.

- While seasonal temperatures do not appear to have a strong influence on effluent quality in respect of BOD, they do on levels of nitrification. However, as BOD loadings increase towards and beyond the national guideline, the influence of temperature becomes less marked as the facultative cell increasingly loses its ability to nitrify.

- As the year round load on the facultative cell increases above 100-120kg BOD/ha/d and more aerators are added to focus on the degradation of the incoming organic matter, it becomes increasingly difficult to achieve meaningful reduction in the nitrogen loading on the pond.

- As the year round load on the facultative cell increases above 100-120kg BOD/ha/d, the addition of aerators becomes more important to support the biochemical oxidation of the incoming organic load. There is, however, a limit to how high the load on the facultative cell can be and how many aerators can be added before the natural oxidation pond process is overwhelmed and fundamentally changed.

- Small ponds (say less than 0.4ha) are particularly sensitive to short circuiting effects that create a greater variability in pond performance. The installation on such ponds of an aerator to promote mixing is considered good practice. Larger ponds while perhaps not so sensitive to short circuiting effects also benefit from the addition of an aerator (or two), particularly in regard to reducing thermal stratification effects during the critical autumn and spring transition periods, and promoting the more uniform spread of incoming load over the whole facultative cell area.

- Modest levels of pathogen attenuation (around Log 2 reduction) are typically achieved in the facultative cell. For greater and more stable levels of pathogen attenuation a multi cell in-series, or channel arrangement configured to facilitate plug flow conditions after the facultative cell is particularly successful.

- Levels of pathogen attenuation in a pond system show a strong correlation with temperature, with significantly higher effluent pathogen levels in winter than in summer and can be reasonably approximated using first order kinetics (Marais 1974) for pathogen reduction.

- Effluent suspended solids are always subject to the vagaries of warm summer temperatures and sunlight, but can be reduced to a more stable level by a covered section of a final secondary cell. It is important however to avoid anaerobic conditions developing - floating wetlands and duckweed (if you can get it to stay in place) can be effective in this regard.

- Modest sludge accumulation in a pond (leaving at least a 0.9-1.0m water column above the sludge layer has little effect on pond performance, but more significant accumulation and particularly mounding can lead to unstable conditions and associated odour release.

- There are now a range of proven technologies to improve pond effluent quality but all have operational constraints and require careful design. Maximising performance of the facultative cell is a key step in optimising downstream process performance.

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