UPGRADING WASTE STABILISATION PONDS: REVIEWING THE OPTIONS

Hugh Ratsey, The Wastewater Specialists

ABSTRACT

Waste Stabilisation Ponds (WSPôs) are still the most common form of wastewater treatment in New Zealand. However, the level of treatment acceptable a generation ago when many WSPôs were constructed is less accepted today. As resource consents become more stringent, Councils are faced with the choice of replacing existing WSPôs with more intensive treatment processes, or upgrading the WSPôs. In many cases, Councils do not have the capital and/or inclination to install more intensive treatment technologies. Instead, many Councils consider relatively low cost WSP upgrades.

This paper reviews the performance of New Zealand WSPôs which have been upgraded using a variety of technologies over the past decade or so. Many treatment technologies are reviewed, including AquaMats, floating wetlands, partitioned ponds, baffles, Actiflo, BioFiltro, wetlands, filtration, and ultra-violet disinfection. The key findings of this review are that upgrades of WSPôs which rely on natural treatment processes invariably retain one major disadvantage of WSPôs ï inconsistent and unpredictable performance. In particular, if reliable year-round nitrification is required, upgrading WSPôs is considered to be a high risk option. Where WSPôs are upgraded using physical or chemical treatment processes, the level of treatment attainable is more predictable but still with limitations.

KEYWORDS

Waste Stabilisation Ponds, Oxidation Ponds, Upgrade, Risk, Natural Systems

1 INTRODUCTION

Waste stabilisation ponds (WSPôs), or oxidation ponds, are still the most common form of wastewater treatment in New Zealand. Archer (2015) estimated there are approximately 200 WSPôs in use in New Zealand. Councils, who have invested in WSPôs to treat their ratepayers wastewater over the past 30 or 40 years, often do not have the capital and/or inclination to replace their WSPôs with more intensive treatment technologies, such as activated sludge plants. Instead, as the required effluent quality gets higher, many Councils look to relatively low cost WSP upgrades to meet these requirements. As with anything in life, low cost options invariably come with increased risk of failure.

The Kiwi No. 8 wire philosophy, combined with Councils who are looking for low-cost solutions, has resulted in a wide range of modifications to WSPôs occurring over the past decade or so. The results of many of these modifications have been presented at previous WaterNZ and NZWWA conferences, such as Craggs *et al*. (2000), Jamieson *et al*. (2001), Archer & OôBrien (2003), Keller *et al.* (2004), Holyoake *et al.* (2006), Altner (2007), Sole *et al.* (2007), Glasgow *et al.* (2007), Towndrow *et al.* (2010), Finnemore *et al.* (2010), Ross & Mace (2011), Walmsley *et al.* (2011), van Niekerken (2012), Craggs *et al*. (2014), and Archer (2015). Often upgraded ponds perform relatively well in the early months or years following an upgrade, only for performance to deteriorate over time. The long term performance of upgraded WSPôs is rarely reported.

This paper, summarising the New Zealand experience of upgrading WSPôs, has been collated to assist Councils in negotiating the potential quagmire of a WSP upgrade. Our aim is to ensure the industry understands that, while WSPôs have some very significant benefits, they also have limitations. They are, after all, a natural treatment process.

2 THE HUMBLE OXIDATION POND

2.1 TREATMENT PROCESS

WSPôs combine many different treatment processes, as shown in Figure 1. Heavy suspended solids settle out to form a sludge layer on the bottom of the pond, with the organic component of this sludge slowly being broken down through anaerobic digestion. Above the anaerobic sludge layer, WSPôs are primarily aerobic due to the photosynthetic action of algae, although an anoxic (facultative) layer is generally present between the anaerobic sludge and the upper aerobic layers. The algae produce oxygen during daylight hours, and a range of other aerobic microorganisms utilise this oxygen to break down contaminants in the wastewater. Wind and wave action help with mixing, and reduce the accumulation of solids on the surface of the pond which would otherwise impede light penetration.

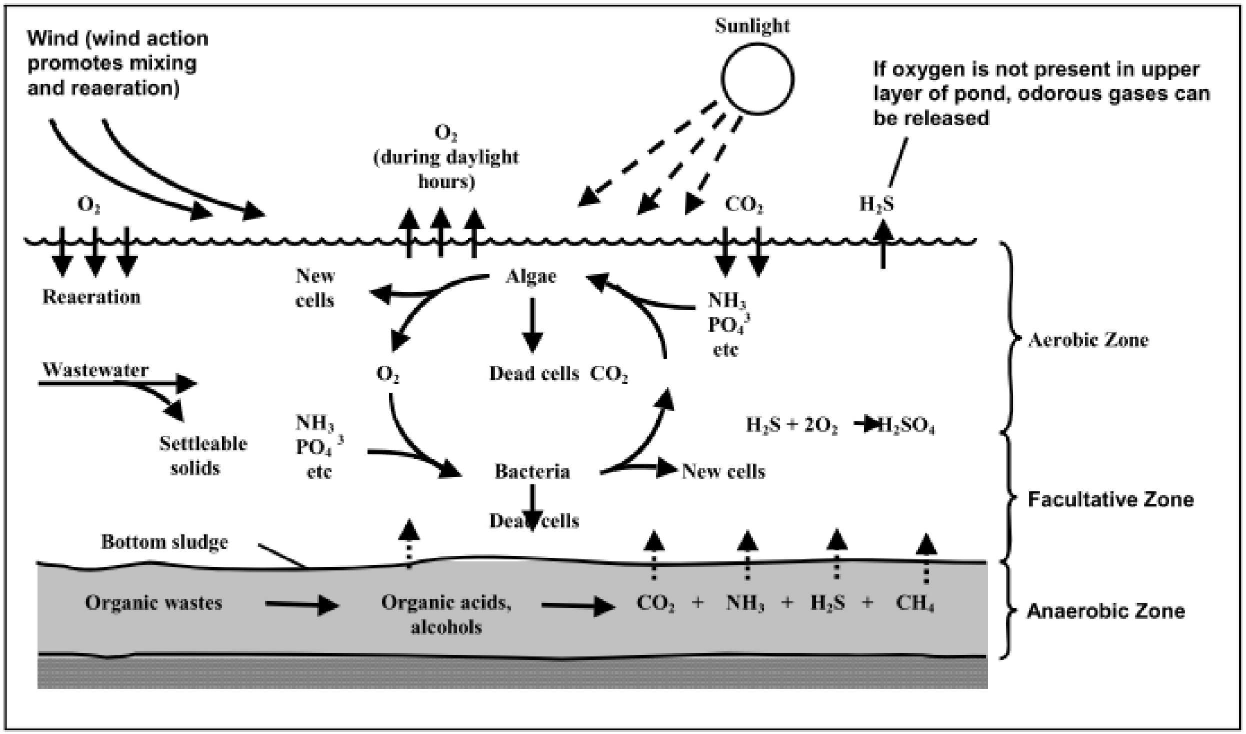

Figure 1: Treatment Processes in WSP's (Altner, 2005)

2.2 THE GOOD AND THE NOT-SO-GOOD

WSPôs have some very real advantages over more intensive treatment technologies. Itôs due to these advantages that WSPôs are so widespread throughout New Zealand and other parts of the world. These advantages include:

- Natural treatment process (so people like the idea of them)
- Low operating cost
- Low complexity
- Low operator input

However, for all of these very real and attractive advantages, WSPôs do come with some very distinct disadvantages, including:

- Natural treatment process (and are therefore largely uncontrollable)
- Seasonal performance
- Poor nitrogen removal, particularly in winter

2.3 DRIVERS FOR UPGRADE

Drivers for upgrading any wastewater treatment plant (WwTP), including WSPôs, fall into two broad categories:

1. To improve effluent quality; as resource consents become more stringent, the required quality of treated effluent continually increases.
2. To treat more wastewater load; increasing load could be due to permanent population growth, seasonal population growth, or industrial discharges.

This paper focuses on ways to improve the quality of effluent produced by WSPôs, rather than ways to treat more wastewater load.

3 UPGRADING WSP'S

3.1 WHAT NEEDS TO BE REMOVED?

For any WwTP, the resource consent conditions dictate the required treated effluent quality for discharge of effluent back into the environment. Therefore, depending on the resource consent conditions, there may be a driver for the removal of many different contaminants from the WSP effluent. The contaminants that most frequently require removal from WSP effluent are summarised in Table 1, along with a brief explanation of the nature of the contaminants and their typical concentration in WSP effluent.

Table 1: Contaminants in Typical WSP Effluent

Contaminant	Description	Typical Concentration in Primary WSP Effluent (NZWWA, 2005)		
		Average, g/m^3	Maximum, g/m^3	Minimum, g/m^3
Total suspended solids (TSS)	Predominantly algae. Particle size variable, but sometimes small (e.g. *Chlorella* 2 to 10 µm)	50	150	10
Biochemical oxygen demand (BOD)	Predominantly associated with TSS, rather than being soluble	40	110	15
Indicator organisms	e.g. *E. coli*. Individual bacterial cells are typically ~1 to 2 µm in diameter. While some bacteria are bound up in the TSS, many are free in solution	10,000	50,000	2,000
Total phosphorous (TP)	The majority of the phosphorous is present as DRP and therefore dissolved in the effluent	8	16	4
Dissolved reactive phosphorous (DRP)	Dissolved in the effluent	6	12	2
Ammoniacal nitrogen (ammonia)	Dissolved in the effluent			
	Winter concentrations	15	30	0.5
	Summer concentrations	5	10	0.1
Total nitrogen (TN)	Predominantly made up of nitrogen bound up in the TSS, plus ammonia	30	50	10

3.2 HOW CAN CONTAMINANTS BE REMOVED?

At a very simplistic level, wastewater process science dictates which mechanisms can be used to remove contaminants from wastewater, irrespective of the exact nature of a wastewater treatment process. The main mechanisms for the potential removal of contaminants from WSP effluent are summarised in Table 2.

Table 2: Main Mechanisms for Contaminant Removal

Contaminant	Mechanisms	Comments
TSS	Settlement	Algal solids generally do not settle well without chemical conditioning
	Flotation	Algal solids generally remain suspended in the effluent, and will only float en-masse with chemical coagulation and the introduction of air
	Filtration	The small size of some algae mean a small filtration pore size is required to effectively filter algae out
	Reduction of growth	Algae require sunlight for photosynthesis, so if sunlight can be blocked, algal growth can be reduced
BOD	As for TSS	As for TSS
Indicator organisms	Natural die-off or inactivation	Outside their normal host, indicator organisms (and pathogens) will die off due to a range of processes, including predation, natural decay, and sunlight
	Enhanced die-off or inactivation	The rate of die off of indicator organisms (and pathogens) can be enhanced through processes such as ultra-violet (UV) disinfection
	Filtration	The small size of bacteria mean a small filtration pore size is required to effectively filter bacteria out
Ammonia	Nitrification	The conversion of ammonia to nitrate under aerobic conditions by certain nitrifying bacteria. These bacteria grow slowly at the best of times, and their growth rate slows significantly at lower temperatures
TN	Denitrification	The conversion of nitrate to nitrogen gas under anoxic conditions. Providing nitrification occurs, WSPôs are usually effective at denitrification due to the anoxic zone that is generally present above the sludge layer
	Assimilation	Some nitrogen is required for cell growth, so is assimilated into the cells of algae and other microorganisms
	Settlement, flotation or filtration	As for TSS, providing the nitrogen is present in a particulate form
DRP and TP[1]	Assimilation	Some phosphorous is required for cell growth, so is assimilated into the cells of algae, reeds, weeds and other microorganisms. Note: removal of phosphorous from effluent by assimilation is only effective if the resulting plant matter is physically removed from the system
	Coagulation	The use of positively charged metal salts (alum, ferric) to bind the phosphate anion into suspended solids (flocs)
	Adsorption	The use of material with positively charged receptors to bind the phosphate anion to the surface of the material
	Settlement, flotation or filtration	As for TSS, providing the phosphorous is present in a particulate form

[1] It is important to note that phosphorous in raw wastewater will end up in one of two places; in the treated effluent, or it will accumulate in sludge or biomass. If the sludge or biomass is not physically removed, anaerobic breakdown of the sludge or biomass will result in re-release of DRP. This can result in increasing effluent DRP concentrations over time.

3.3 DATA ANALYSIS

The performance data obtained for the purpose of this review was often inconsistent with regard to the frequency of analysis, determinands, period of analysis, and whether sampling had been undertaken to directly assess the improvement in effluent quality which resulted from modifications to the WSPôs. To allow comparison of such inconsistent data sets, the following approach was taken to evaluate the performance of WSP modifications:

- Where pre- and post-WSP modification data was available, this pre- and post- data was used to calculate the actual removal rates achieved by the modified WSP. Where such data was available, removal rates are tagged as ñActualò removal rates in the following sections.

- Where no pre-WSP modification data was available, post-WSP effluent quality has been compared with the average effluent quality from a óTypicalô single primary oxidation pond to calculate removal rates. The baseline for óTypicalô WSP effluent was taken from NZWWAôs Draft Oxidation Pond Guidelines (NZWWA, 2005). Where no pre-WSP modification data was available, removal rates are tagged as ñIndicativeò removal rates in the following sections.

- Where sufficient data was available, performance was assessed over a period of at least 12 months.

- When comparing nitrification during summer and winter, the summer period was taken as December to April inclusive, and winter being May to November inclusive.

3.4 IN-POND OPTIONS TO UPGRADE WSP'S

3.4.1 AQUAMATS

Key contaminant removal mechanisms; enhancement of nitrification.

Key target contaminants; Ammonia, TN

Case Studies: Raglan (Waikato District Council)

AquaMats are a high-surface area media which hang down through the depth of WSPôs. Biomass, including bacteria, protozoa and a range of higher life forms, grows on the surface of the media. Diffused air aeration is provided to increase the amount of oxygen available for aerobic organisms to break down contaminants, and to aid with water movement through the pond depth. By increasing both oxygen availability and the amount of biomass present in the WSP, the treatment capacity is increased. In particular, if a population of nitrifying bacteria can grow on the media, it may be possible to achieve year-round nitrification. For a more detailed description of AquaMats, refer to Altner (2005).

The performance of AquaMats installations in NZ to date has been varied. The performance of the Raglan WwTP provides a good example of both the potential of AquaMats technology, and the limitations. The data in Table 3 suggests that the AquaMats at the Raglan WwTP provide a good level of nitrification in summer, and some enhancement of nitrification in winter. None of the AquaMats-based WSPôs included in this review (Raglan, Te Kauwhata, Matamata) has consistently achieved high levels of year-round nitrification.

Table 3: Raglan WwTP Final Effluent Quality

	NH_4-N g/m^3 (winter)	NH_4-N g/m^3 (summer)	TN g/m^3
Typical WSP Average (NZWWA, 2005)	15	5	30
Raglan Average, Jul-13 to Jun-15	11	0.3	14.3
Indicative removal rate	**27%**	**94%**	**52%**

Key consideration with AquaMats:

- The performance of AquaMats installed in WSPôs in NZ has been variable.

3.4.2 NITRIFYING FILTERS

Key contaminant removal mechanisms; enhancement of nitrification.

Key target contaminants; Ammonia, TN

Case Study: Rangiora WwTP (Waimakiriri District Council)

As reported by Archer & OôBrien (2004), in 2003 the Rangiora WwTP was upgraded from two aerator assisted ponds in series, to two primary facultative ponds in parallel followed by five maturation ponds in series. Horizontal flow rock filters were constructed after Ponds 3, 4 and 5, with aeration provided at the base of the first two rock filters. Effluent from Pond 5 was recirculated and sprayed on the non-submerged part of the rock filters to mimic the trickling filter process. These modifications were made to enhance ammonia removal through nitrification, and were successful in Rangiora where only more reliable summer nitrification was required. As shown in Table 4, the modifications did not provide significant additional ammonia removal during winter.

Table 4: Indicative Removal of Ammonia by Nitrification Filters at Rangiora WwTP

	NH_4-N g/m^3 (winter)	NH_4-N g/m^3 (summer)
Typical WSP Average (NZWWA, 2005)	15	5
Rangiora Median, Jan-03 to Jun-04 (Archer & OôBrien, 2004)	15	2
Indicative removal rate	**Nil**	**60%**

Key consideration with Nitrifying Filters:

- While nitrifying filters may provide additional ammonia removal during warmer temperatures through nitrification, significant additional nitrification in winter is unlikely to be achieved unless the nitrifying filters are prohibitively large.

3.4.3 FLOATING WETLANDS

Key contaminant removal mechanisms; enhancement of nitrification and denitrification, reduction in TSS through disruption of algae growth.

Key target contaminants; Ammonia, TN, TSS, BOD

Case Studies: Kimbolton (Manawatu District Council)

Floating wetlands have been installed in many WSPôs throughout New Zealand over the past decade. The performance of these floating wetlands has been variable, with some providing significant improvements to effluent quality but others not resulting in the desired improvements. A case study which shows both the potential positive effects on WSP performance and the limitations of floating wetlands is Kimbolton in the Manawatu District. Floating wetlands were installed in an existing WSP at Kimbolton in May 2013. Data in Figure 2 suggests that the floating wetlands have generally improved nitrification in the WSP, but the modified WSP is not achieving reliable nitrification or denitrification, with significant peaks (>15 g/m^3) in both ammonia and oxidised nitrogen (nitrate plus nitrite) observed in the treated effluent.

Data from the WSPôs modified using floating wetlands included in this review (Kimbolton, Hunterville, Himatangi Beach, Kerepehi, Coromandel) shows widely variable levels of nitrification enhancement.

For a more detailed description of floating wetlands, refer to van Niekerken (2012) and Finnemore *et al*. (2010).

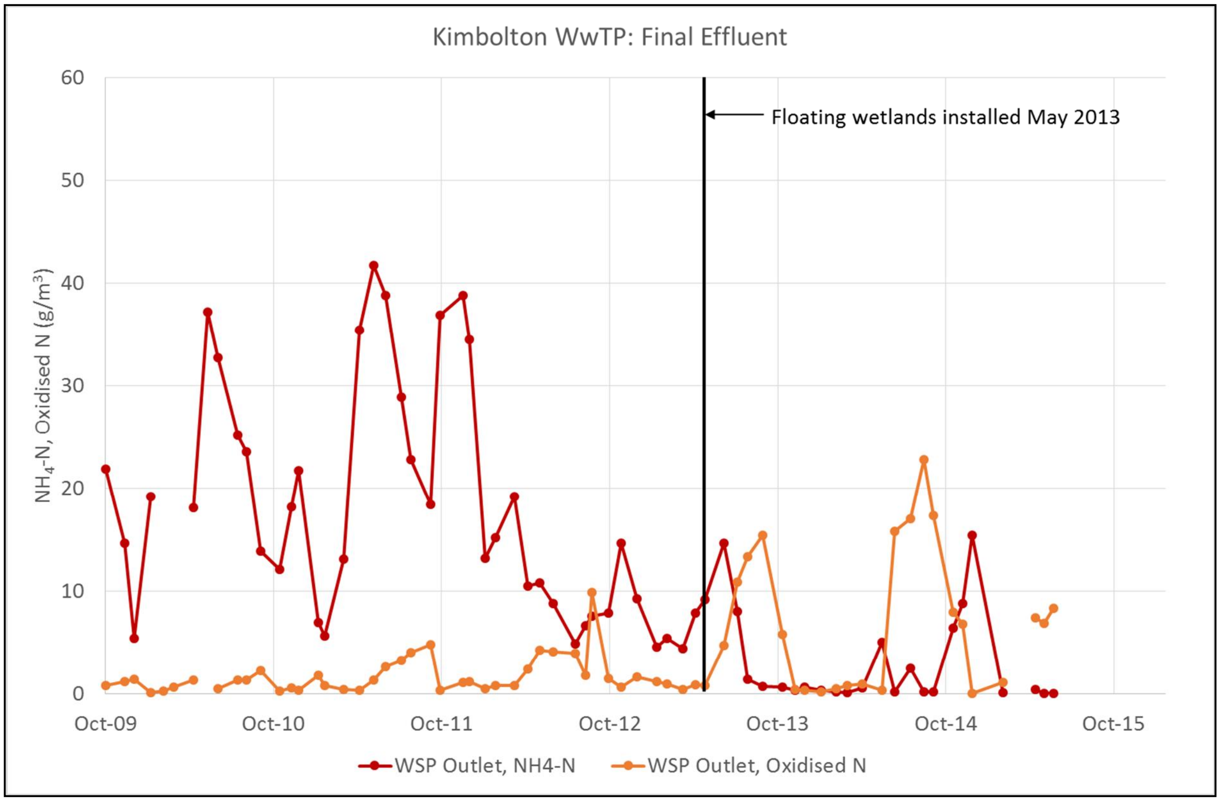

Figure 2: Effluent Nitrogen at Kimbolton WwTP

The performance of the Kimbolton floating wetlands with regard to the key target contaminants (where available) is shown in Table 5.

Table 5: Kimbolton WwTP Final Effluent Quality

	TSS g/m^3	BOD g/m^3	NH_4-N g/m^3 (winter)	NH_4-N g/m^3 (summer)
Typical WSP Average (NZWWA, 2005)	50	40	15	5
Kimbolton Average, May-13 to Jun-15	13.5	N/R	1.8	3.8
Indicative removal rate by floating wetlands	**73%**		**88%**	**25%**

Key consideration with floating wetlands:

- The performance of floating wetlands installed in WSPôs in NZ has been extremely variable.

3.4.4 OUTLET SHADING

Key contaminant removal mechanisms; reduction in TSS through disruption of algae growth.

Key target contaminants; TSS, BOD

Case Study: Kerepehi WwTP (Hauraki District)

By covering the final portion of the WSP҆s with shade, the growth of photosynthetic algae can be reduced. At Kerepehi WwTP, the shade is provided by floating wetlands spaced close together, and natural growth of duckweed in between the floating wetlands. Performance data in Table 6 suggests that significantly lower effluent TSS and BOD concentrations can be achieved by providing shade in the latter part of WSP҆s. However, we have only reviewed data from a single WwTP with such a modification, so do not know how repeatable such technology would be.

Table 6: Kerepehi WwTP Final Effluent Quality

	TSS g/m^3	BOD g/m^3
Typical WSP Average (NZWWA, 2005)	50	40
Kerepehi Average, Jul-14 to Jun-16	18.9	6.5
Indicative removal rate by outlet shading	**62%**	**84%**

Key consideration with outlet shading:

- Data from only a single modified WSP with outlet shading has been included in this review, so repeatability of this technology is unknown.

3.4.5 ADVANCED POND SYSTEM

Key contaminant removal mechanisms; enhanced WSP processes.

Key target contaminants; TSS, BOD, ammonia

Case Study: Cambridge WwTP (Waipa District Council)

An advanced pond system (APS) consists of at least four ponds in series, with each pond designed to optimise the various functions that occur simultaneously in a conventional WSP system (Craggs *et al*. (2000)). The first pond is deep, providing settlement of heavy solids and anaerobic digestion of the resulting sludge layer. The second pond is a shallow high rate algal pond designed to maximise algae growth and aerobic activity, and is followed by algal settling ponds. The final pond is a maturation pond, to enhance disinfection processes.

NIWA recently installed a demonstration APS system at the Cambridge WwTP, with this installation reported by Craggs *et al.* (2014). This demonstration system treats approximately 25% of the wastewater from Cambridge. The performance of this APS system is shown in Table 7.

Table 7: Cambridge WwTP APS Final Effluent Quality

	TSS g/m^3	BOD g/m^3	NH_4-N g/m^3 (winter)	NH_4-N g/m^3 (summer)
Typical WSP Average (NZWWA, 2005)	50	40	15	5
Cambridge APS Average, Aug-15 to May-16	57	25	10.9	5.1
Indicative removal rate	**Nil**	**39%**	**27%**	**Nil**

3.4.6 PARTITIONED PONDS

Key contaminant removal mechanisms; natural die-off of indicator organisms through reduced short-circuiting.

Key target contaminants; Indicator organisms

Case study: Greytown, South Wairarapa District Council

WSPôs are prone to short circuiting, with influent tracking through the pond much more quickly than the theoretical hydraulic retention time (HRT) would suggest. This results in a significant deterioration in the performance of a WSP, in particular with regard to the removal of indicator organisms. Partitioning ponds to create several smaller ponds in series can significantly reduce the effects of short-circuiting. By reducing the effects of short-circuiting, more effective removal of indicator organisms can be achieved through WSPôs. For further information on the use of multiple ponds to improve indicator organism removal, refer to Archer & OôBrien (2003) or Keller *et al*. (2004).

The Greytown WwTP comprises a primary pond and a tertiary pond, with the outlet to the tertiary pond being divided into two small additional cells by rock groynes. The average quality of the effluent discharged from the Greytown WwTP over a five-year period is summarised in Table 8 (South Wairarapa District Council, 2014).

Table 8: Greytown WwTP Final Effluent Quality

	FC cfu/100ml	TSS g/m^3	BOD g/m^3
Typical WSP Average (NZWWA, 2005)	20,000	50	40
Greytown Average, Jan-09 to Jun-14	2,317	63	42
Indicative removal rate	**0.9 $\log_{10}$**	**Nil**	**Nil**

Key consideration with partitioned ponds:

- While partitioned ponds can achieve significant reduction in indicator organisms, performance is variable.

3.4.7 BAFFLES

Key contaminant removal mechanisms; natural die-off of indicator organisms through reduced short-circuiting.

Key target contaminants; Indicator organisms

Case Study: Matamata WwTP (Matamata Piako District Council)

As discussed in the preceding section, WSPôs are prone to short circuiting. This results in a significant deterioration in the performance of a WSP, in particular with regard to the removal of indicator organisms. Massey University undertook research into understanding and improving the hydraulics of WSPôs, and, through modelling, determined that baffles can significantly reduce the effects of short-circuiting (Shilton & Harrison, 2003). The key findings from Shilton & Harrisonôs work are shown in Figure 3, where the numbers refer to inlet and outlet indicator organism concentrations.

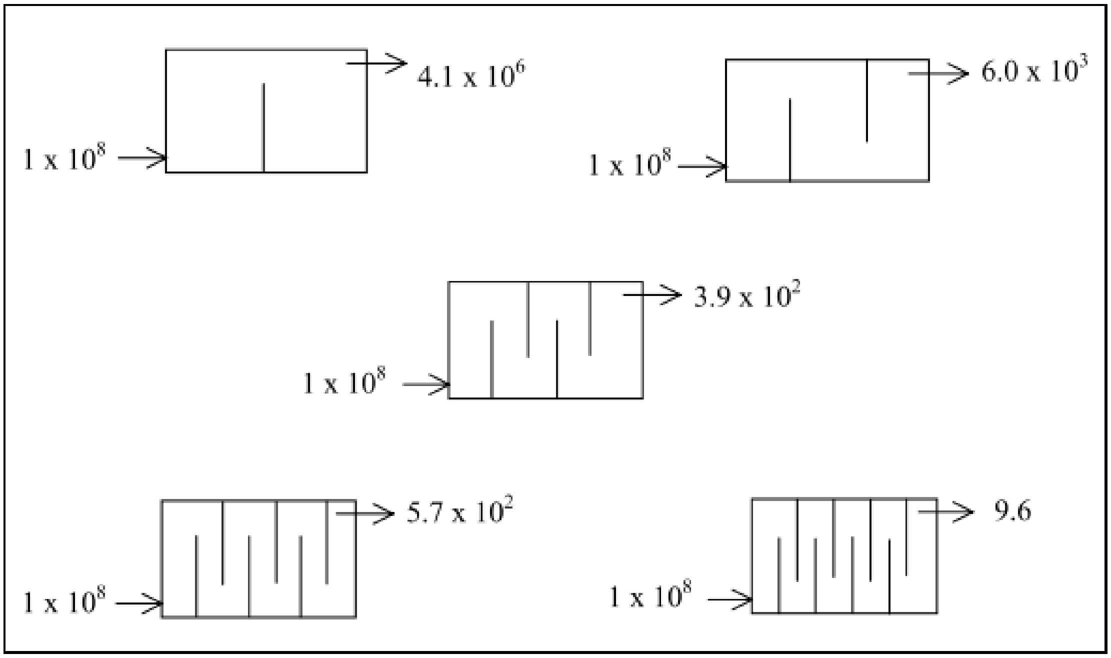

Figure 3: Use of Baffles to Improve Indicator Organism Removal (Shilton & Harrison, 2003)

Baffles have been used to effectively improve the performance of WSPôs in this way, an example being Matamata WwTP. Matamata WwTP comprised two WSPôs in series. As part of an upgrade in 2010, three baffle curtains were installed in Pond 1, and a single baffle curtain was installed in Pond 2. While the baffle curtains were only the first part of an upgrade that ultimately saw both AquaMats and membrane filtration also installed, installation of the baffle curtains alone resulted in a 2-log (99%) removal of indicator organisms to <100 cfu/100ml, as shown in Table 9. This was consistent with the results of the modelling undertaken by Shilton & Harrison (2003). We do, however, acknowledge this data is from an extremely short timeframe, and would welcome the opportunity to review data from other WwTPôs where the performance of WSPôs modified with pond baffles could be assessed over a longer duration.

Table 9: Indicative Removal of E. coli at Matamata WwTP by Pond Baffles

	E. coli cfu/100ml
Typical WSP Average (NZWWA, 2005)	10,000
Matamata Average, Sep-10 to Oct-10	58
Indicative removal rate	**2.2 $\log_{10}$**

Key consideration with baffled ponds:

- Short-term data from only a single modified WSP with baffles has been included in this review, so long-term performance and repeatability of this technology has not been verified.

3.5 POST-POND OPTIONS TO UPGRADE WSP'S

3.5.1 MEMBRANE FILTRATION

Key contaminant removal mechanisms; filtration.

Key target contaminants; TSS, BOD, Indicator organisms

Case Study: Hikurangi (Whangarei District Council)

With membrane filtration, effluent is taken from the end of a WSP and passed through membranes with small pore sizes, typically <1 micron in diameter. Any contaminants which are larger than the effective pore size will be retained, while dissolved contaminants will pass through. Given the pore size, membrane filtration can effectively remove TSS and associated BOD, and any microorganisms that are larger than the pore size. A reject flow carries the removed contaminants away for further treatment, usually back to the WSP.

For further information on membrane filtration on the end of WSPôs, refer to Sole *et al* (2007), or Towndrow *et al.* (2010).

The performance of the Hikurangi membrane filtration plant with regard to the key target contaminants is shown in Table 10. The performance of both membrane filtration plants treating WSP effluent included in this review (Hikurangi, Matamata) showed similar performance levels.

Table 10: Hikurangi WwTP Final Effluent Quality

	BOD g/m^3	TSS g/m^3	*E. coli* cfu/100ml
Typical WSP Average (NZWWA, 2005)	40	50	10,000
Hikurangi Average, Mar-14 to Dec-15	3.9	2.1	54
Indicative removal rate	**90%**	**96%**	**2.3 $\log_{10}$**

Key considerations with membrane filtration:

- Membranes are hydraulically limited to how much liquid can pass through (flux rate). It is not possible to increase the flux rate beyond the capacity of the membranes, so if wastewater flows are greater than designed for, it will not be possible to treat all WSP effluent through the membranes.

- The reject flow from the membrane plant contains TSS, BOD and associated contaminants, and this reject flow rate may be relatively high (15 to 30% of feed flow). If returned to the WSP this could reduce the hydraulic retention time (HRT) in the WSP and increase the rate of sludge accumulation.

3.5.2 ACTIFLO

Key contaminant removal mechanisms; chemical coagulation, settlement.

Key target contaminants; TSS, BOD, TP, DRP

Case Study: Ngaruawahia (Waikato District Council)

Actiflo is a proprietary accelerated settlement process supplied by Veolia. It uses both coagulant and polymer to coagulate and flocculate suspended and dissolved contaminants, along with a fine sand (microsand) which provides a ballast to aid settlement. pH adjustment may be required to optimise coagulation. Settlement occurs in a lamella clarifier, and the microsand is recovered through a hydrocyclone. Removed contaminants require further treatment.

Waikato District Council installed an Actiflo plant on the end of the WSP at Ngaruawahia to remove phosphorous and TSS. TSS reduction was required to enable the effluent to be disinfected by UV prior to discharge. Prior to installation of the Actiflo, the Ngaruawahia WwTP was not able to consistently meet the required median *E. coli* concentration of 126/cfu100ml. Since the Actiflo has been optimised, the UV has been able to effectively disinfect the effluent to the required standard. A high level of phosphorous removal has been achieved, however this is really a by-product of operating the Actiflo for effective TSS removal.

The performance of the Ngaruawahia Actiflo plant with regard to the key target contaminants is shown in Table 11.

Table 11: Ngaruawahia WwTP Final Effluent Quality

	BOD g/m^3	TSS g/m^3	TP g/m^3
Typical WSP Average (NZWWA, 2005)	40	50	8
Ngaruawahia Average, Mar-14 to Dec-15	11.5	25.7	0.9
Indicative removal rate by Actiflo	**71%**	**49%**	**89%**

Key considerations with Actiflo:

- A small portion of the microsand is lost in the treated effluent and must be replaced on an ongoing basis. This microsand is imported from overseas and is costly.
- The reject flow from the Actiflo contains TSS, BOD and associated contaminants. If returned to the WSP this could reduce the hydraulic retention time (HRT) in the WSP and increase the rate of sludge accumulation.
- Chemical conditioning is required to coagulate dissolved and suspended contaminants for effective enhancement of settlement.

3.5.3 INDUCED AIR FLOTATION

Key contaminant removal mechanisms; chemical coagulation, flotation.

Key target contaminants; TSS, BOD, TP, DRP

Case Study: Waihi (Hauraki District Council)

The principles of induced air flotation (IAF) are similar to dissolved air flotation (DAF). Air is dissolved into water under pressure. As the pressurised water is released in the IAF tank, air bubbles come out of solution due to the resulting pressure drop. Air bubbles attach themselves to flocs, and float the flocs to the surface of the tank. The resulting ñfloatò (sludge) is scraped from the surface and requires further treatment. Coagulants and polymer are used to encourage coagulation and flocculation of suspended and dissolved contaminants. pH adjustment may be required to optimise coagulation.

Armatec installed an IAF plant at Waihi in 2003. The key aims were to remove TSS and phosphorous; TSS to enable effective UV disinfection after the IAF plant, and phosphorous to reduce the phosphorous load to the Ohinemuri River.

For a more detailed description of the IAF process, refer to Holyoake *et al*. (2006).

The performance of the Waihi IAF plant with regard to the key target contaminants is shown in Table 12.

Table 12: Waihi WwTP Final Effluent Quality

	BOD g/m^3	TSS g/m^3	TP g/m^3
Typical WSP Average (NZWWA, 2005)	40	50	8
Waihi Average, Jul-14 to Jun-15	3.0	8.2	0.1
Indicative removal rate by IAF	**93%**	**84%**	**98%**

Key consideration with IAF:

- Chemical conditioning is required to coagulate dissolved and suspended contaminants for effective removal by flotation.

- The reject flow from the IAF contains TSS, BOD and associated contaminants. If returned to the WSP this could reduce the hydraulic retention time (HRT) in the WSP and increase the rate of sludge accumulation. At Waihi, the sludge has been returned to the WSP for the past 12 years, and plant data suggests this may be having an impact on the performance of the WSP, with effluent ammonia concentrations having increased in recent years. This deterioration in effluent ammonia at Waihi is shown in Figure 4.

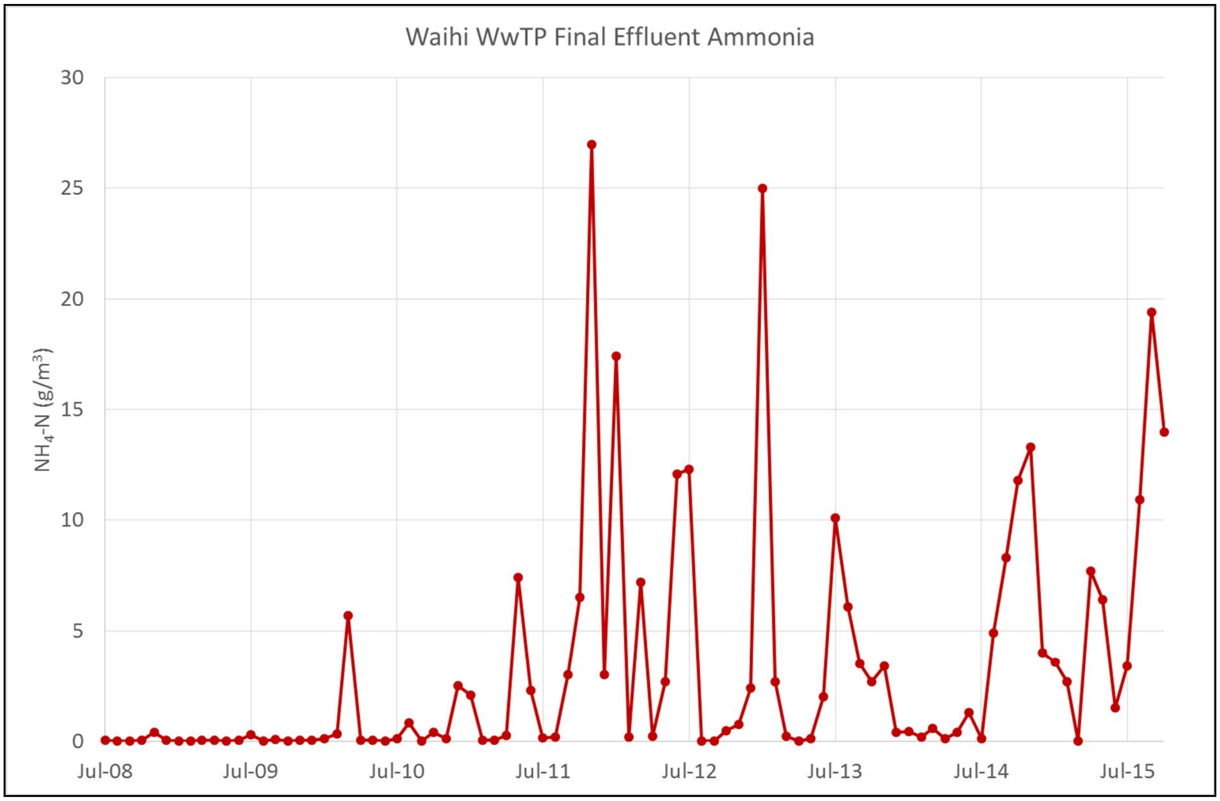

Figure 4: Effluent Ammoniacal Nitrogen at Waihi WwTP

3.5.4 BIOFILTRO

Key contaminant removal mechanisms; vermibiofiltration, enhancement of nitrification.

Key target contaminants; Ammonia, TSS, BOD, Indicator organisms

Case studies: Kaka Point and Owaka (Clutha District Council)

In a BioFiltro Plant, WSP effluent is sprayed over the surface of a bed of wood shavings which is naturally colonised with microorganisms, forming a biofilm. The top layer of the bed is populated with earthworms which both aerate the bed and break down contaminants. The biofilm oxidises dissolved organics and other nutrients, while the worms break down solid organic material. The removal of ammonia is due to nitrification. Clutha District Council have found that maintenance requirements with BioFiltro systems are higher than expected, but manageable (Ross, 2015).

For a more detailed description of the BioFiltro process, refer to Ross & Mace (2011).

The performance of the Kaka Point and Owaka BioFiltro plants with regard to the key target contaminants are shown in Table 13. This data suggests the performance of BioFiltro plants can be quite variable. We understand that the suppliers of BioFiltro have lowered their design loadings on the basis of the Kaka Point experience to achieve more reliable contaminant removal (Ross, 2015). The suppliers of BioFiltro are also trialing process modifications to further enhance performance, including improved bed coverage, alkalinity control, enhanced aeration, and separate beds to enhance denitrification. Note: BioFiltro offer a proprietary UV disinfection system after the vermibiofiltration bed. Indicator organism removal is not included in Table 13 because it is currently unclear what percentage removal of indicator organisms is achieved through the vermibiofiltration bed, and what is achieved through the UV system.

Table 13: Kaka Point & Owaka WwTP Final Effluent Quality

	BOD g/m^3	TSS g/m^3	NH_4-N g/m^3 (winter)	NH_4-N g/m^3 (summer)	TN g/m^3
Typical WSP Average (NZWWA, 2005)	40	50	15	5	30
Kaka Point Average, Sep-13 to Jun-16	13.9	34.2	12.1	8.6	29.2
Actual removal rate by BioFiltro	**65%**	**47%**	**38%**	**63%**	**11%**
Owaka Average, Sep-13 to Jun-16	8.1	17.3	1.2	1.6	12.0
Actual removal rate by BioFiltro	**74%**	**65%**	**88%**	**88%**	**38%**

Key consideration with BioFiltro:

- The performance of BioFiltro systems installed after WSPŝ in NZ has been variable.

3.5.5 SURFACE FLOW WETLANDS

Key contaminant removal mechanisms; enhancement of nitrification and denitrification, settlement, filtration.

Key target contaminants; TSS, BOD, ammonia, nitrate, TN, Indicator organisms

Case Study: Otorohanga (Otorohanga District Council)

With surface flow wetlands, the wetland reeds are rooted in a substrate such as gravel, and the effluent flows over the surface of the substrate. The wetlands potentially provide contaminant removal through a variety of different mechanisms, including filtration as the effluent passes through the reeds, nutrient removal through assimilation into plant matter, denitrification by bacteria growing on the reeds, and indicator organism through both natural die-off and ultra-violet (UV) light from the sun.

The Otorohanga WwTP comprises a single oxidation pond containing a baffle curtain, followed by two surface flow wetlands. Performance of the Otorohanga WwTP, shown in Table 14, suggests that the surface flow wetlands promote moderate removal of TSS, BOD, TN and *E. coli*, but poor removal of ammonia. Given the mechanisms of contaminant removal through surface flow wetlands, the Otorohanga performance is considered likely to be representative of the performance of surface flow wetlands, providing they are appropriately sized.

Table 14: Otorohanga WwTP Final Effluent Quality

	BOD g/m^3	TSS g/m^3	NH_4-N g/m^3 (winter)	NH_4-N g/m^3 (summer)	TN g/m^3	*E. coli cfu/100ml*
Typical WSP Average (NZWWA, 2005)	40	50	15	5	30	10,000
Otorohanga Average, Jul-15 to Jun-16	12.9	28.9	15.3	7.2	15.6	647
Indicative removal rate by SFW	**68%**	**42%**	**Nil**	**Nil**	**48%**	**1.2 log_{10}**

Key consideration with surface flow wetlands:

- Historically in New Zealand, wetlands as a tertiary treatment method have been installed with the expectation that minimal maintenance would be required. The reality is that wetlands require a significant amount of maintenance, including reed replacement, weed removal, and desludging.

3.5.6 SUB-SURFACE FLOW WETLANDS

Key contaminant removal mechanisms; enhancement of nitrification and denitrification, settlement, filtration.

Key target contaminants; TSS, BOD, ammonia, nitrate, TN, Indicator organisms

Case Study: Ngunguru (Whangarei District Council)

With sub-surface flow wetlands, the wetland reeds are rooted in a substrate such as gravel, and the effluent flows through the substrate. The wetlands potentially provide contaminant removal through the same mechanisms as surface flow wetlands, including filtration as the effluent passes through the gravel and reed roots, nutrient removal through assimilation into plant matter, denitrification by bacteria growing on the reed roots, and indicator organism removal through natural die-off.

The Ngunguru WwTP has sub-surface flow wetlands installed after two WSP൴s in series. Performance of the Ngunguru WwTP, shown in Table 15, suggests that moderate to good removal rates of BOD and TSS can be achieved through sub-surface flow wetlands, but with minimal nutrient removal achieved. Note: It has not been possible to determine the effectiveness of the Ngunguru sub-surface wetlands with regard to indicator organism removal because a UV disinfection system is installed after the wetlands, and samples for consent compliance monitoring are taken post-UV.

Table 15: Ngunguru WwTP Final Effluent Quality

	BOD g/m^3	TSS g/m^3	NH_4-N g/m^3 (winter)	NH_4-N g/m^3 (summer)	TN g/m^3
Typical WSP Average (NZWWA, 2005)	40	50	15	5	30
Ngunguru Average, Jan-14 to Jan-16	13.1	14.3	19.0	14.5	21
Indicative removal rate by SSFW	**67%**	**71%**	**Nil**	**Nil**	**31%**

Key consideration with sub-surface flow wetlands:

- Historically in New Zealand, wetlands as a tertiary treatment method have been installed with the expectation that minimal maintenance would be required. The reality is that wetlands require a significant amount of maintenance, including reed replacement, weed removal, and desludging.

3.5.7 ULTRA-VIOLET DISINFECTION

Key contaminant removal mechanisms; enhanced microorganism inactivation.

Key target contaminants; Indicator organisms

Case Study: Huntly (Waikato District Council)

Effective ultra-violet (UV) disinfection relies on light being able to pass through water to reach and deactivate the microorganisms. There are two main obstacles to the passage of light through wastewater; light being absorbed by dissolved contaminants, and light being obstructed by suspended solids. Due to normal algal growth in WSPôs, WSP effluents are typically high in suspended solids. These algal solids can provide some shielding of microorganisms from UV light, potentially reducing the effectiveness of a UV disinfection process.

The performance of the Huntly WSP followed by UV disinfection with regard to *E. coli* removal is shown in Table 16.

Table 16: Huntly WwTP Final Effluent Quality

	E. coli cfu/100ml
Typical WSP Average (NZWWA, 2005)	10,000
Huntly Average, Jul-14 to Jun-15	50
Indicative removal rate	**2.3 $\log_{10}$**

Key consideration with UV disinfection:

- The effectiveness of UV disinfection is dictated by the ability of light to shine through water. High TSS in WSP effluent (due to alge) may impede disinfection.

3.5.8 SAND FILTRATION

Key contaminant removal mechanisms; filtration.

Key target contaminants; TSS, BOD

Case Study: Coromandel (Thames Coromandel District Council)

The Works Filter System (WFS) at the Coromandel WwTP was previously utilised at the Pauanui WwTP. Coagulant is dosed into the WSP effluent to coagulate suspended and dissolved solids, with the resulting flocs removed through sand filtration. Periodic backwashing is required to remove the accumulated flocs from the filtration media, and this backwash water is returned to the WSPôs. The indicative removal of key contaminants by sand filtration at the Coromandel WwTP is shown in Table 17.

For further information on sand filtration after WSPôs, refer to Jamieson *et al*. (2001).

Table 17: Coromandel WwTP Final Effluent Quality

	BOD g/m^3	TSS g/m^3
Typical WSP Average (NZWWA, 2005)	40	50
Coromandel Average, Feb-14 to Jun-16	2.1	3.7
Indicative removal rate by Filtration	**95%**	**93%**

Key considerations with sand filtration:

- The reject flow from the sand filters contains TSS, BOD and associated contaminants. This reject flow is typically returned to the WSP, potentially reducing the HRT in the WSP and increasing the rate of sludge accumulation.

- Chemical conditioning is required to coagulate dissolved and suspended contaminants for effective removal by filtration.

3.5.9 SLAG FILTER

Key contaminant removal mechanisms; adsorption of phosphorous, filtration of TSS and associated BOD, enhancement of nitrification.

Key target contaminants; TP, DRP, TSS, BOD, ammonia

Case Study: Waiuku WwTP

ñSlagò is a byproduct from the iron and steel processing industry (McCoy *et al*. (2006)) which has been found to have the ability to adsorb phosphorous. Slag filters have been installed at Waiuku WwTP for more than a decade. As WSP effluent passes through the slag filter, suspended solids, mainly in the form of algae, are crudely filtered, and are then broken down by aerobic microorganisms.

The hydraulic loading rate onto slag filters is typically <0.3 $m^3/m^3.d$ (Crites *et al*. (2014)), meaning that slag filters are very large. For further information on the use of slag filters, refer to McCoy *et al*. (2006) and Crites *et al*. (2014).

The performance of the Waiuku slag filters with regard to the key target contaminants is shown in Table 18. The performance of all WSPôs with slag filters included in this review (Waiuku, Ngatea, Paeroa) has been similar.

Table 18: Waiuku WwTP Final Effluent Quality

	TP g/m^3	DRP g/m^3	TSS g/m^3	BOD g/m^3	NH_4-N g/m^3 (summer)	NH_4-N g/m^3 (winter)
Typical WSP Average (NZWWA, 2005)	8	6	50	40	5	15
Waiuku Slag Filter Ave, Jan-11 to Dec-15	4.3	3.8	26	7	1.7	2.3
Actual removal rate	**24%**	**5%**	**51%**	**69%**	**52%**	**41%**

Key considerations with slag filters:

- Phosphorous removal is achieved by adsorption, and slag has a finite ability to adsorp phosphorous. Therefore, adsorption capacity will diminish over time.

- Over time, organic material (sludge) will accumulate in the slag filter. This will reduce the effectiveness of the slag filter, and eventually the slag filter will require refurbishment to remove the accumulated sludge.

4 SUMMARY

From performance data from both the case studies listed in this paper and other New Zealand installations of WSP modifications, the ability of different WSP modifications to remove key target contaminants is summarised in Table 19.

Table 19: Performance Summary of Modified WSP's in New Zealand

	BOD	TSS	Ammonia	TN	DRP/TP	Indicator Organisms
AquaMats			Poor - Good	Poor - Good		
Floating wetlands	Poor - Good	Poor - Good	Poor - Good	Poor - Good		
Outlet shading	Moderate - Good	Moderate - Good				
Nitrifying filters			Poor - Moderate	Poor - Moderate		
Partitioning Ponds						Poor - Good
Pond Baffles						Poor - Good
Advanced Pond System	Poor - Moderate	Poor	Poor			
Actiflo	Good	Moderate - Good			Good	
Membrane filtration	Good - Very Good	Good - Very Good				Good - Very Good
IAF/DAF	Good	Good			Good	
Biofiltro	Moderate - Good	Poor - Moderate	Poor - Good			(No data)
Surface Flow Wetlands	Moderate - Good	Poor - Moderate	Poor	Poor - Moderate		Moderate
Sub-Surface Wetlands	Moderate - Good	Moderate - Good	Poor	Poor - Moderate		(No data)
UV disinfection						Moderate - Very Good
Sand filtration	Good - Very Good	Good - Very Good				
Slag filter	Moderate - Good	Moderate - Good	Moderate - Good		Poor - Moderate	

Notes:

- For BOD, TSS, ammonia, TN, TP and DRP, >40% removal = ñModerateò, >70% removal= ñGoodò, >95% removal = ñVery Goodò
- For indicator organisms, 1 $\log_{10}$ removal = ñModerateò, 2 $\log_{10}$ removal = ñGoodò, 3 $\log_{10}$ removal =òVery Goodò
- IAF/DAF, Actiflow and sand filtration require chemical conditioning to achieve the indicated performance

5 CONCLUSIONS

WSPôs are natural treatment systems and, as such, are variable in performance and are largely uncontrollable. Modifications to WSPôs that also rely on enhancements to natural processes (Pond Baffles, Partitioning Ponds, AquaMats, Nitrifying Filters, Floating Wetlands, BioFiltro, Wetlands, Slag Filters) retain the advantages of low operating cost and complexity of WSPôs, but generally also retain the performance variability and unpredictability. In particular, if reliable year-round nitrification is required to consistently achieve effluent ammonia concentrations <5 g/m^3, WSP modifications should be treated with caution.

Modifications to WSPôs that involve physical and/or chemical processes (IAF/DAF, Actiflo, Membrane Filtration, UV Disinfection, Sand Filtration) are more predictable in performance, but do come with higher cost and complexity. Such processes do not remove dissolved contaminants, such as ammonia, nitrate, and DRP, so are only likely to be appropriate if reductions in contaminants such as BOD, TSS or indicator organisms are required. Chemical conditioning can be used with some of these processes to achieve significant phosphorous removal.

When considering upgrades to WSPôs, the key target contaminants will dictate which WSP modification(s) may be appropriate. Furthermore, the concentration of contaminants stipulated by resource consent conditions will further dictate what WSP modification(s) may be appropriate. In some instances it may be realistic for enhancements to natural processes to achieve the required effluent quality. In other situations where the required effluent quality exceeds what could reliably be expected from an enhanced natural process, physical and/or chemical modifications to WSPôs may be appropriate. However, for more stringent resource consent conditions, it may be unrealistic to expect a modified WSP to achieve the required effluent quality. In which case, alternative treatment processes are likely to be required to achieve reliable resource consent compliance.

When modifying a WSP, it is also necessary to consider the effect such modifications may have on normal WSP treatment processes. For example, return of membrane reject flow back to the WSP will reduce the HRT and increase contaminant loading, potentially resulting in accelerated sludge accumulation and deterioration of WSP performance.

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