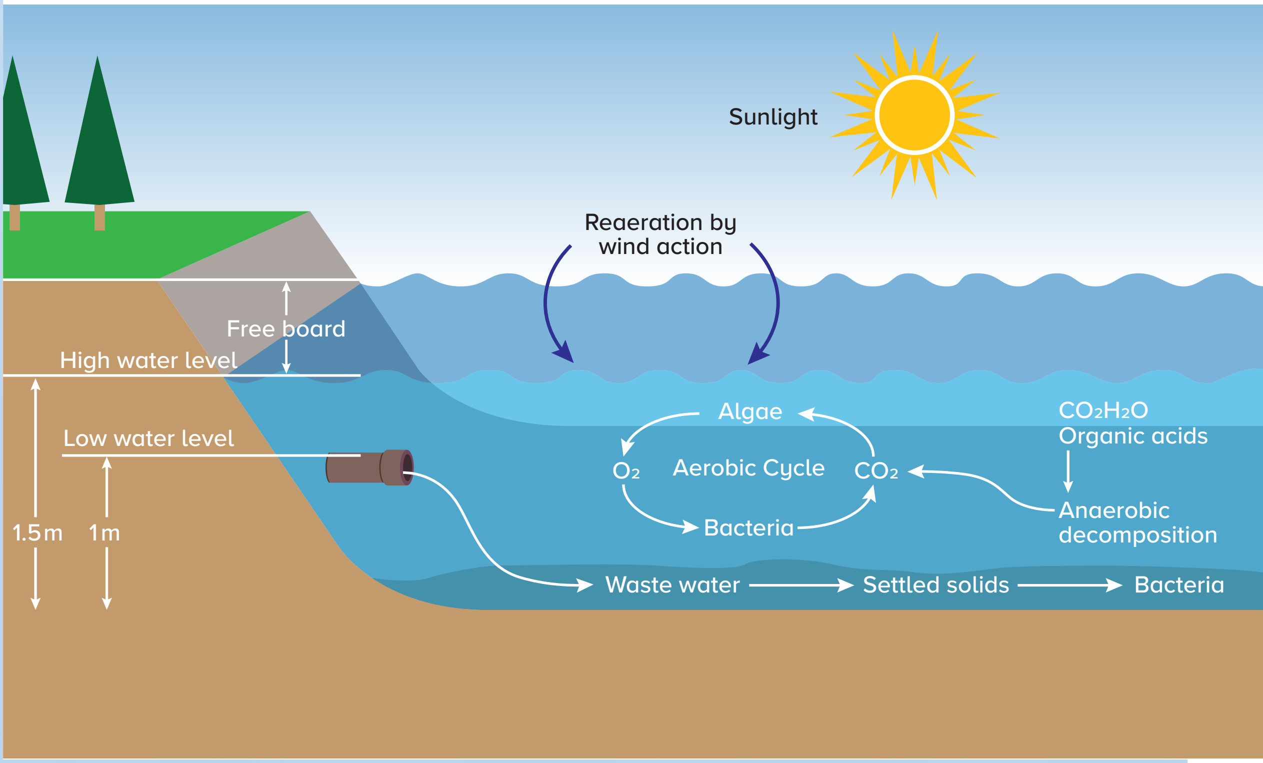
water
NEW ZEALAND
The New Zealand Water & Wastes Association Waiora Aotearoa

WATER NEW ZEALAND
Good Practice Guide for

WASTE STABILISATION PONDS: DESIGN AND OPERATION



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AUTHORS

The NZWWA 2007 draft Guidelines content was authored by:

- Steve Cameron, *NZET Ltd*
- Stu Clark, *NZET Ltd*

The content of this manual has been provided and improved by the text, review and comments of internal and external technical advisors:

- Humphrey Archer, *CH2M Beca Ltd*
- Gilles Altner, *Global Environmental Engineering Ltd*
- Rupert Craggs, *NIWA*
- John Wong, *Parklink*
- Regan Senior, *Parklink*
- Hugh Ratsey, *The Wastewater Specialists*
- Nick Walmsley, *Water New Zealand*

REVIEWERS

Assistance was greatly appreciated from the following representatives of the Water Service Managers Group, who provided valuable review comments.

- Paul Gaydon, *Horowhenua D.C.*
- Terry Dodd, *Dunedin C.C.*
- Peter Cowdell, *Water Northland*
- Mike Bourke, *Christchurch C.C.*
- Barry Somers, *Northland D.C.*

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Water New Zealand | PO Box 1316, Wellington 6140 | P: +64 4 472 8925 | E: enquiries@waternz.org.nz | W: www.waternz.org.nz

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1 GENERAL

1.1 OVERVIEW

This document is an update of the Ministry of Works Guidelines for Oxidation Ponds 1974. It follows the NZ Water and Wastes Association (NZWWA) 2007 draft Waste Stabilisation Pond Guidelines which were published as a 2nd draft but never finalised and it draws on recent research and practices. It is primarily written for those involved in wastewater treatment pond management and operations: local authorities, regional councils, and wastewater systems operations personnel. As well as management and operations, these guidelines include basic aspects of pond design, planning, cultural acceptance, and regulations. It is assumed that the reader has an understanding of basic wastewater terminology.

These guidelines cover:

- How Waste Stabilisation Ponds (WSP) work
- How they differ from other types of ponds
- How to operate WSP
- What to do when things go wrong

By their nature, these guidelines cannot cover every aspect of pond design and operation, nor should they be used like a ‘cooking recipe book’. It is recommended that the advice of experienced design and operation practitioners should be obtained when pond performance is abnormal or when significant upgrading work is planned.

Section 1 provides general introductions to the types of ponds and the terminology. Later sections describe the design and operational aspects of ponds in more detail.

Appended to this Guide are a table giving performance improvement levels possible with pond upgrades and an example pond operation log sheet. The log sheet is also separately provided as an Excel spreadsheet.

WSP are amongst the most commonly used methods for treating domestic sewage in New Zealand, as they are elsewhere in the world, both in developed and developing countries. The New Zealand Ministry of Health’s Cosinz data base reported that as of the year 2000, there were some 176 community wastewater treatment systems incorporating WSP; this hasn’t changed much since. This is over half the total number of community treatment plants in New Zealand. These community WSP systems range in number of ponds (from 1 to 8 ponds) and in population serviced (from under 100 to over 400,000 people). For small to medium sized communities, (50 to 30,000 population equivalents (PE’s)), ponds are often the sole form of wastewater treatment. For larger communities, (30,000 PE +), there is often a multiple pond system, increasingly with enhancements, to produce a tertiary standard of final effluent quality.

WSP are also used extensively in New Zealand for treatment of dairy farms and piggery effluents as well as agricultural processing (e.g. meatworks) wastewater. However, this Guide is limited to information for ponds treating municipal wastewater.

The direct discharge of pond effluents to waterways is now becoming less acceptable, for both cultural and water quality impact reasons. But ponds are experiencing resurgence in both New Zealand and overseas. This is due to the development of advanced pond systems and retrofit technologies. These improvements are able to achieve treatment qualities comparable to mechanised treatment plants such as activated sludge. Where land is available, ponds also offer significant capital and operating cost advantages when compared with alternative wastewater treatment technologies.

Modern ponds, with enhancements, have an important role to play in wastewater treatment in New Zealand. Ponds are robust, require low energy, are able to cope with hydraulic and organic loading peaks, and can provide buffer storage for downstream processes such as land treatment systems.

Greenhouse gas emissions, especially methane, are an important aspect of the “environmental footprint” of a wastewater treatment process. The 2014 National Greenhouse Gas Inventory using the IPCC 2006 methodology notes that there is considerable uncertainty in the amount of greenhouse gas emitted from wastewater treatment. However, the conversion factors proposed by

IPCC indicate that WSP which are primarily aerobic or facultative are likely to emit less greenhouse gases from the whole treatment plant than mechanical systems e.g. activated sludge, unless there is substantial energy recovery by sludge digestion.

In spite of their apparent simplicity, WSP require skilled operation and regular attention. A good understanding of how they work and attention to maintenance requirements will make sure that ponds operate reliably.

1.2 WHAT'S IN A NAME?

WSP typically include anaerobic, facultative, and maturation ponds – usually they don't include highly mixed aerated ponds/lagoons (this doesn't mean we ignore aerated lagoons, but need to make the distinction between them and facultative ponds with supplementary surface aeration).

Oxidation ponds are shallow earthen basins in which wastewater is treated biologically. Ponds are able to reduce the concentration of many contaminants in sewage including Biochemical Oxygen Demand (BOD), suspended solids (SS), nitrogen, phosphorus and microbial faecal pathogens and indicators.

Wastewater solids settle to the pond bottom where they partially digest anaerobically and accumulate as digested sludge.

Oxidation ponds use algae and wind action to introduce oxygen to the pond surface waters. The wind and inlet flow momentum will also create currents within the pond which help to mix the wastewater around the pond. The quality of outflow (effluent) from WSP is very dependent on the action of these currents and avoidance of short circuiting.

Grazing by microscopic animals, settlement and sunlight exposure all work to help reduce the levels of faecal indicator and pathogenic microbes in WSP. These processes are illustrated in Figure 1-1.

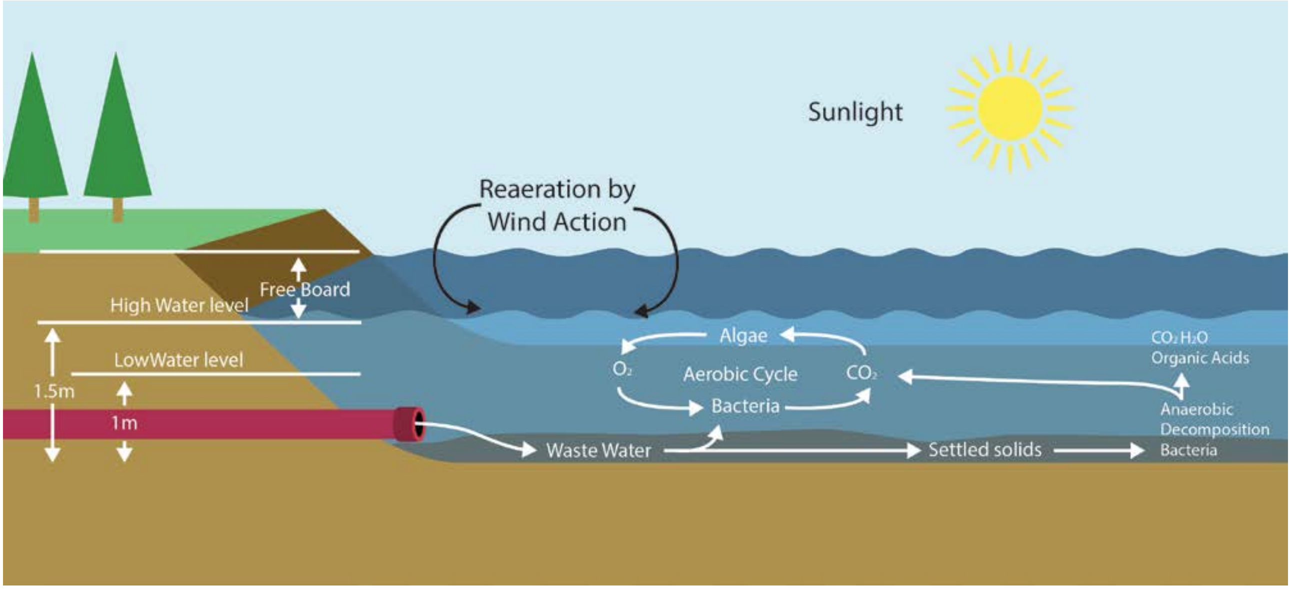


Figure 1-1 The Processes at work in WSP

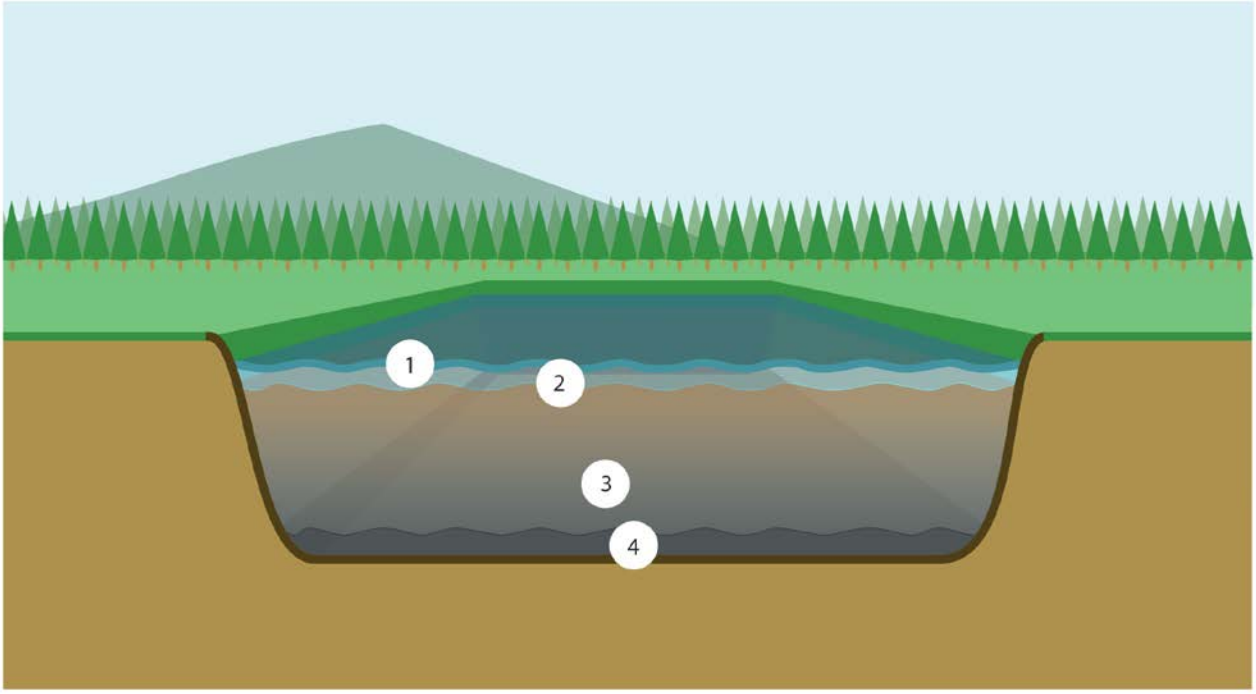
Dissolved nutrients in the sewage, such as nitrogen and phosphorus, are converted by bacteria and assimilated along with carbon dioxide (CO_2) by algae which are microscopic plants that live suspended in the water.

Like land plants, algae produce oxygen by photosynthesis during the day. Pond oxygen concentrations and some other characteristics, like pH, will therefore change throughout the day and from day to night. The oxygen sustains the aerobic bacteria which feed on and break down the incoming organic waste. At night the algae generate CO_2 which raises the ponds alkalinity.

1.3 POND CLASSIFICATION – BASED ON ORGANIC LOADING

Previous guidelines used terminology of primary, secondary and tertiary ponds. However as further knowledge has been gained it has become clear that this terminology can be confusing and does not illustrate what characteristics or functions the ponds perform. New terminology that is more accurate and descriptive, as it is based on organic loading, is now used in preference. There are three different types of passive WSP that are classified based on organic loading: Anaerobic, Facultative and Maturation.

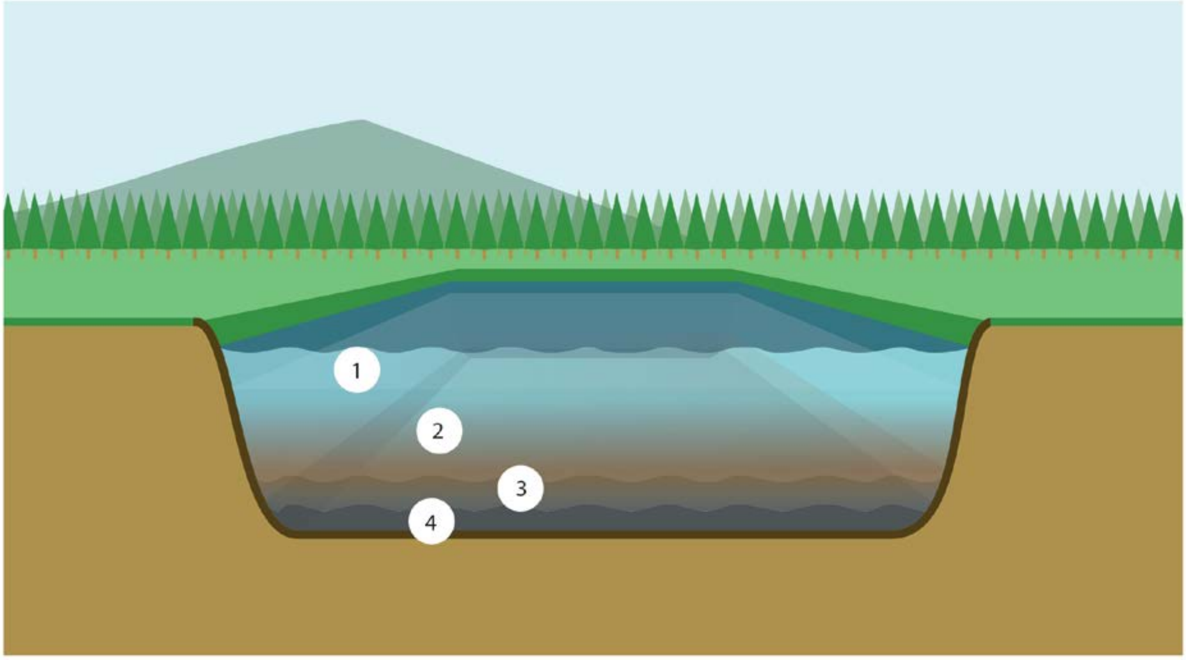
Anaerobic ponds (Figure 1-2) have such a high organic loading that all the oxygen is used by bacteria, leaving conditions that only anaerobic bacteria can survive in and break down the wastewater. They are usually deep (greater than 3m) and in New Zealand are often used to treat high strength wastewaters (i.e. high BOD) such as those from dairy farms, piggeries, meatworks, stock trucks and landfills. Anaerobic ponds are suitable to treat raw municipal sewage with high organic concentrations. There has been a perception in New Zealand that anaerobic ponds treating municipal sewage will smell, but this needn't occur if operated properly and particularly if a surface crust is allowed to develop.



Layers: ① is aerobic liquid; ② is anoxic liquid; ③ is anaerobic liquid; ④ is anaerobic sludge

Figure 1-2 Anaerobic Pond

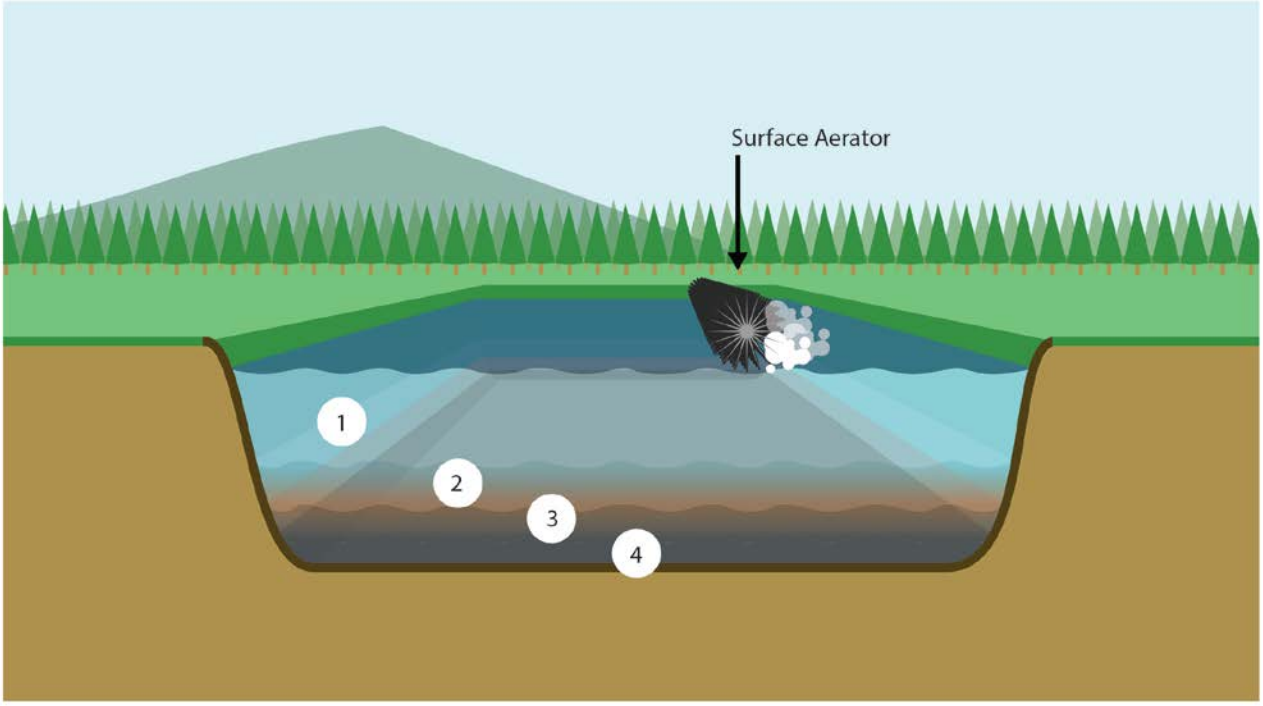
Facultative ponds (Figure 1-3) have an organic load which allows an aerobic surface with algae and aerobic bacteria, an anoxic middle zone without dissolved oxygen, but where oxidized compounds (e.g. NO_3 and SO_4) are still present, and an anaerobic bottom layer, where sludge settles and digests.



Layers: ① is aerobic liquid; ② is anoxic liquid; ③ is anaerobic liquid; ④ is anaerobic sludge

Figure 1-3 Facultative Pond

Some facultative ponds have been augmented with addition of mechanical aerators to help treat high organic load by providing both mixing and aeration. However adding more than about 1w/m^3 of mechanical aeration is disruptive to the algal cycles and creates a completely different type of aerated pond which is not covered in this guide.



Layers: ① is aerobic liquid; ② is anoxic liquid; ③ is anaerobic liquid; ④ is anaerobic sludge

Figure 1-4 Facultative Pond Augmented with Aeration

Partially and fully aerated lagoons (refer 3.8) are designed for aerobic treatment to be completely provided by mechanical aeration, in the same way as an activated sludge plant, but usually without the return of settled sludge. They can be designed with either in-pond sludge settling or be followed by a sludge settling pond or clarifier.

Maturation ponds typically follow facultative ponds, aerated lagoons or mechanical treatment plants and have the lowest organic load and are completely aerobic.

1.4 FACULTATIVE PONDS

In facultative ponds the water column can be divided into several zones: aerobic, anoxic, anaerobic liquid and anaerobic sludge. Different wastewater treatment processes take place in these four zones as shown in Figure 1-5 below. The features of each zone are described in the following discussion.

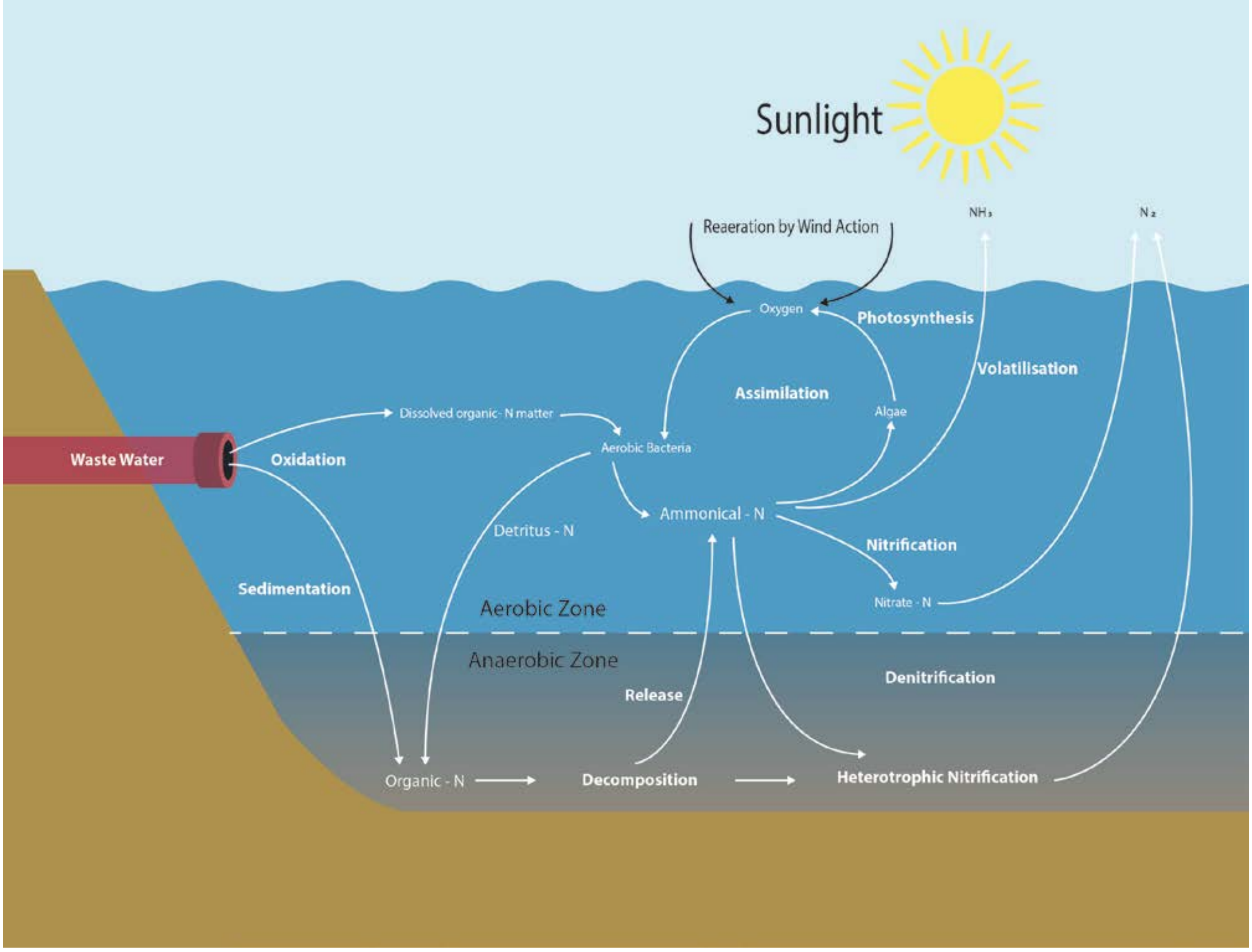


Figure 1-5 The processes at work in a Primary oxidation pond or Facultative WSP

The depth of the aerobic zone (the top zone) in a WSP depends on organic loading, hydraulic retention time, climate and season (both temperature and sunlight), mixing/stratification and the concentration of algae (dependent on all of the above, as well as algal grazers and pathogens). Aeration is predominantly from algal photosynthesis with minor (but helpful) contributions from agitation of the water surface due to wind and rain. The depth of the aerobic zone also varies diurnally as, although algal photosynthesis only occurs during the day, both algal and bacterial respirations occur throughout the day and night.

Given sufficient light and temperature, algal concentration is generally dependent on the concentration of nitrogen in the wastewater. However, high organic loading and/or ammonia concentrations can limit algal growth, and some cyanobacteria can grow even at low pond water nitrogen concentrations by fixing nitrogen from the air.

The depth of the algae layer typically depends on the average water clarity (depth of light penetration) and level of mixing, although some motile algae swim up and down within the pond during the day to adjust their light environment. Other algae (usually cyanobacteria) tend to accumulate in a layer at the pond surface, unless dispersed by mechanical mixing or continually removed by a surface outflow weir. Surface accumulations of algae can cause problems with elevated BOD levels, particularly if they die-off within the pond.

The dissolved oxygen concentration in the water gradually rises after sunrise, in response to photosynthetic activity, to a maximum level in the mid-afternoon, after which it falls to a minimum during the night, when photosynthesis ceases and algal and bacterial respiration continues to consume oxygen. At high daytime photosynthetic rates, the algae consume all the available carbon dioxide and carbonate and bicarbonate ions react to provide more carbon dioxide for the algae, leaving an excess of hydroxyl ions. As a result, the pH of the water rises to levels as high as 9 - 10.

In the pond's aerobic zone, bacteria use oxygen to break down dissolved organic matter releasing nutrients and carbon dioxide, which are used by algae and sometimes nitrifying bacteria for growth.

Good mixing within the upper water layer maintains a uniform distribution of algae, dissolved oxygen, pH, bacteria, BOD and nutrients, thereby leading to more efficient wastewater treatment.

The long hydraulic retention time and low velocities of wastewater in the pond means that some of the bacterial and algal biomass settles within the pond, together with any heavier solids in the influent.

The aerobic zone also scrubs the odours from gases produced in the lower layers.

Below the aerobic zone, the anoxic zone provides habitat for bacteria that survive by reducing oxidized compounds (e.g. denitrification: NO_3 to N_2 gas).

The interface between the sludge and the liquid anaerobic zone is where most anaerobic activity occurs. Settled solids are washed around the pond floor but tend to accumulate to greater thicknesses near the inlet where the heavier influent solids have settled. Over the rest of the pond there is a more uniform depth of liquid between the pond surface and the top of the sludge layer, regardless of pond floor contours (i.e. sludge tends to fill up any deep areas).

Anaerobic bacteria decompose the organic matter, converting it to carbon dioxide (CO_2), methane (CH_4), and residual matter. The bacteria derive their energy from the organic matter they consume. The carbon dioxide and methane released can be observed as bubbles and sludge eruptions on the pond surface.

1.5 MATURATION PONDS

Maturation ponds are traditionally designed based on a temperature dependent decay rate for faecal coliforms. The liquid temperature is an approximation of the sunlight radiation being received by a pond which is the major mechanism for disinfection. However, designs that minimise further algal growth and increase the level of exposure to sunlight radiation are becoming more common. Other natural processes including sedimentation and grazing by protozoans and invertebrates also contribute to disinfection.

Multiple maturation ponds-in-series can substantially reduce concentrations of faecal indicator bacteria and achieve concentrations less than 1,000 cfu/100ml. Partitioning of larger ponds can reduce short circuiting and greatly improve the consistency of disinfection (refer 3.2.9).

Maturation ponds can also reduce TSS concentrations, by promoting the growth of algal grazers (rotifers and cladocerans) which are often inhibited by high day-time ammonia levels and low night-time dissolved oxygen levels in facultative ponds.

It is now common to construct maturation ponds with perimeter planting, to form 'wetland ponds' normally in series, which enhances the habitat and landscape values of ponds. However, this can also increase the attractiveness of the ponds to birdlife whose activities increase the pathogen concentrations in the treated effluent.

1.6 POND CLASSIFICATION – RELATIONSHIP TO OTHER TREATMENT

Some typical combinations of ponds or ponds with mechanical treatment are shown in Figures 1-7 and 1-8. The terms primary, secondary, and tertiary oxidation ponds used in the MOW 1974

Guidelines are now superseded by the standard international nomenclature of calling primary ponds facultative, with secondary and tertiary ponds called maturation ponds.

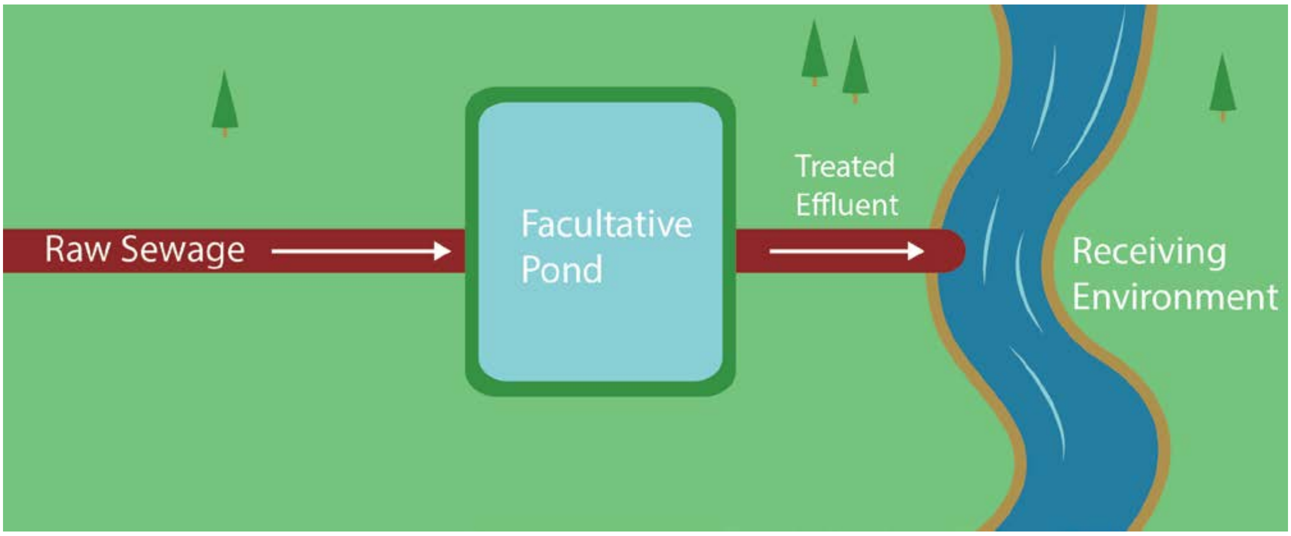


Figure 1-6 **Facultative Pond Provides Solids Settlement, Biological Treatment and Sludge Digestion**

A facultative pond can either receive raw wastewater, or primary effluent, such as that from a clarifier or Imhoff tank (this latter arrangement is now less common).

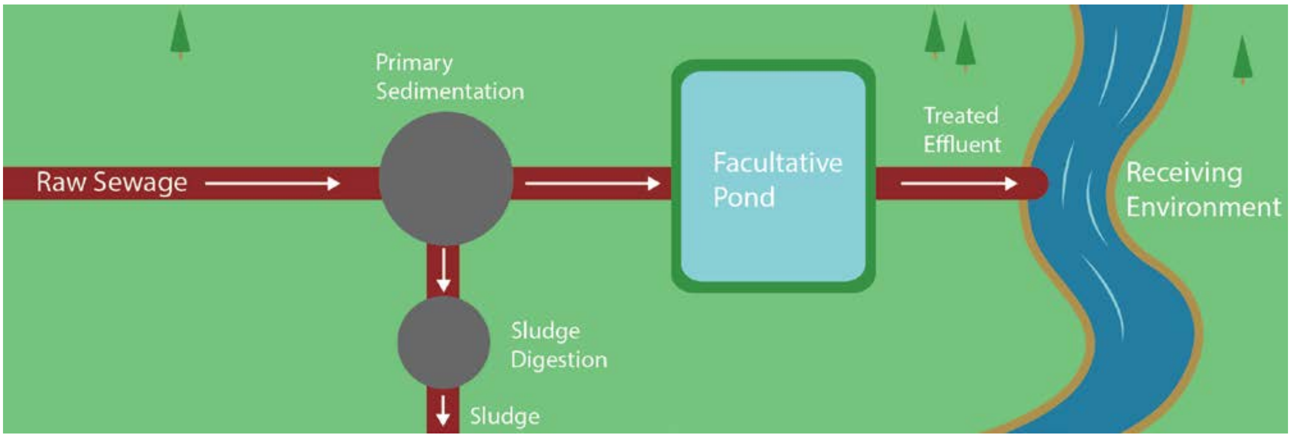
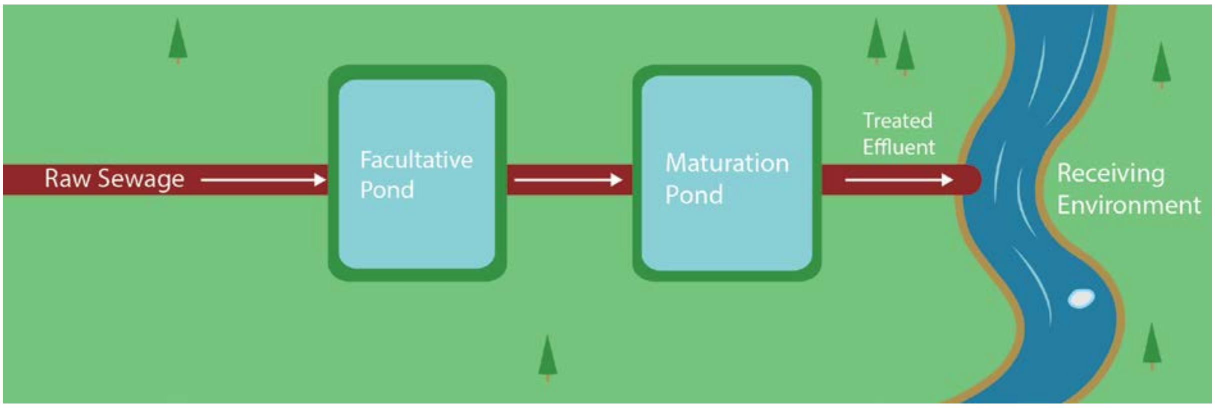


Figure 1-7 **Facultative Pond follows "Conventional" Primary Treatment, providing Biological Treatment and Sludge Digestion**

Maturation ponds can follow one or more facultative ponds, or follow a secondary treatment plant.



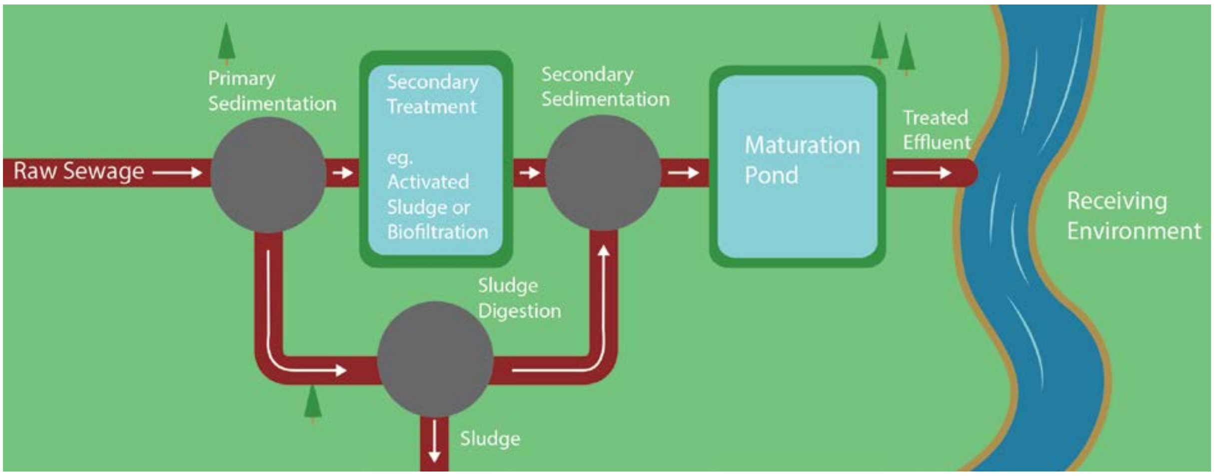


Figure 1-8 **Maturation Pond; follows either a Facultative pond or "Conventional" Primary and Secondary Treatment**

1.6.1. WSP EFFLUENT QUALITY

Currently many New Zealand wastewater systems experience high levels of inflow and/or infiltration of stormwater or groundwater. Adding to this the direct precipitation onto ponds during rain events can cause effluent concentrations of contaminants to be reduced due to dilution, rather than from treatment. Typical results for a traditional one and two cell pond systems loaded up to the traditional recommended rate of 84kg BOD/ha/day (1,200 people/ha), are shown below.

Typical effluent quality for other pond systems and pond modifications are given in Appendix A.

Table 1-1 **Typical effluent results for one and two cell facultative WSP systems: (Hickey et al 1989)**

Contaminant	Minimum	Median	95%ile
BOD_5 (mg/l)	7	27	70
Suspended solids (mg/l)	10	56	150
Faecal coliform bacteria (#/100 ml)	9×10^1	4.3×10^3	2.3×10^5
Total Phosphorus (mg/l)	1.3	8.2	11.3
Dissolved Reactive Phosphorus (mg/l)	9.5	5	0.8
Ammoniacal Nitrogen (mg/l–N)	0.001	7	29

2 DESIGN AND CONSTRUCTION

2.1 HISTORICAL OXIDATION POND SIZING

In New Zealand, facultative pond area sizing historically has been based on a population equivalent organic loading rate. This historical design value for facultative (primary) ponds has been 84 kg BOD_5/ha/day or 1,200 people/ha (assuming 70g of BOD_5 produced per person per day), (refer to Ministry of Works Guidelines for Oxidation Ponds 1974 -- MoW). It should be noted that the population loading guide applied to only the first pond in a series of ponds and the area of downstream ponds required further calculation. This loading level has proven to be conservative for many circumstances as long as the influent is from a mainly domestic source and the ponds are not located in inland locations with cold temperatures and little wind mixing during winter.

Secondary facultative ponds (i.e. ponds which follow a primary sedimentation process e.g. a primary sedimentation tank, or Imhoff Tank) were also sized on the basis of 84 kg BOD_5/ha day. However, allowing for a 33% reduction of BOD_5 in the primary treatment unit, this equates to 1,800 persons/ha.

The design of a secondary or maturation pond following a facultative (primary) pond was based on a detention period of 20 days at average flow, and was typically only one pond. The relatively large maturation pond did not need to be sized on BOD loading because the facultative (primary) pond reduced BOD by about 70%.

A suggested limitation of primary pond area was 8 to 12 hectares. The MoW considered that, in larger ponds, wind action generated waves large enough to resuspend bottom sediments which were then discharged in the pond effluent. Also, as pond size increased it was more difficult to distribute the inlet BOD loading over the whole area, which led to overloading in the inlet part of the pond. This was the case if mechanical aerator/mixers were not installed, which was typical prior to 1974 and continued until about 1995.

2.2 CURRENT DESIGN CRITERIA

Significant advances have taken place since the MOW 1974 Guidelines. Modern design trends are towards specific design for key performance parameters, factoring in as necessary controllable or predictable design aspects such as organic loading, temperature, hydraulic mixing, and the use of performance enhancing technologies, as discussed in section 3.

Useful additional information can be gained from recent texts, for example, “Pond Treatment Technology” (Shilton, 2006), available from International Water Association Publishing.

This Guide provides a comprehensive overview on WSP types, their design, trouble shooting and O&M requirements. It discusses limitations and improvement solutions and modern upgrade technologies. It is not intended that this Guide provide ‘recipe book’ type instructions for the design of all types of ponds by inexperienced designers. Appropriately qualified practitioners, with significant design experience, should supervise the design and commissioning of new ponds and the upgrading of ponds.

2.3 ANAEROBIC PONDS

Anaerobic Ponds are both solids settlers and ambient temperature pond-based digesters. They settle and digest wastewater organic solids thereby reducing sludge volume, organic content and odour potential, while solubilising organic nutrients, and producing methane-rich biogas which can be odorous.

Anaerobic ponds can be operated to minimise odour nuisance, and a crust can be allowed to develop to prevent odour release. This may be augmented by the addition of straw to the pond surface.

Covered Anaerobic Ponds (CAP) with an impermeable geomembrane cover are currently considered best practice as they not only prevent both odour issues and GHG emissions, but capture biogas for energy recovery (Craggs et al. 2015). Standard CAP designs are not suitable for all industrial effluents.

There are some specific designs e.g. high rate anaerobic lagoons (HRAL) which can be used to treat sludge or specific high strength industrial wastes. These ponds require more complicated internal mixing and gas recovery to work properly (Walmsley & van Oorschot, 2004) and are not considered in this Guide.

2.3.1. SIZING

Covered (and uncovered) anaerobic ponds are designed based on a volumetric organic loading rate (typically between 0.1-0.3 kg BOD_5 m^{-3} d^{-1} (Mara, 2005) for ponds operating in climates with average air temperatures for the coldest month between 10-30°C respectively. An organic loading rate (0.1-0.2 kg BOD_5 m^{-3} d^{-1}) is appropriate for most parts of New Zealand although climatic conditions must be taken into account. This is particularly important to minimize the risk of odour nuisance.

Anaerobic ponds with no cover (i.e. relying on a layer of alkaline water to prevent the release of odours) can only be lightly loaded compared with anaerobic ponds with a stable crust that reduces the water surface area for odour release and acts as a filter of the biogas. Covered anaerobic ponds with a geomembrane cover are able to receive a higher organic loading as the odorous gases are captured.

Anaerobic ponds typically have hydraulic retention times (HRT) of 1.5-3 days, however, the solids retention time (SRT) is much longer, usually 1-3 years, depending on when the settled digested sludge is removed.

2.3.2. SHAPE

Anaerobic ponds should have a uniform rectangular shape with a surface width that enables sludge to be removed right across the pond bottom (this will depend on pond depth, embankment slope and method of sludge removal).

2.3.3. DEPTH

To reduce the pond surface and cover area, it is best that a CAP is constructed as deep as practical (often 4-6 m) depending on groundwater depth at the site.

2.3.4. INLET STRUCTURE

Anaerobic pond inlet pipes should be placed across the width at one end of the pond. They should enter the pond at approximately mid depth and extend out from the pond embankment and point downwards towards the pond bottom. This position will avoid contact between the inflow pipe and a pond cover and also reduces the accumulation of solids from the inflow on the pond embankment.

2.3.5. OUTLET STRUCTURE

Anaerobic pond outlet pipes should be placed at the opposite end of the pond from the inlet. The outlet should be a submerged pipe located 0.5m below the typical pond surface level with horizontal holes (e.g. a horizontal T-piece) to remove pond water from the 0.5 m pond depth rather than drawing water from above or below. This position will avoid contact between the outflow pipe and a pond cover and minimize entrainment of both surface scum and anaerobic solids that periodically erupt off the pond bottom. The outflow pipe feeds into a weir box in the pond embankment to enable control of the pond level. The weir box should not be covered to avoid possible accumulation of gases e.g. H_2S.

2.3.6. PERFORMANCE

Wastewater solids settle to the pond bottom of anaerobic ponds where they digest and concentrate, leaving a liquid digestate above. The digestate typically contains ~30% of the total solids (TS) and ~20% of the volatile solids (VS) of the influent wastewater (Craggs et al. 2015).

Annual average biogas methane production from CAPs in New Zealand is 0.40 $m^3 CH_4$ kg^{-1} $BOD_{5Removed}$ (or 0.22 m^3 CH_4 kg^{-1} VS_{Added}) which is quite similar to that reported for more costly and complex mesophilic (~35°C) digesters. CAP biogas production varies seasonally with higher production occurring at warmer temperatures. The much longer solids retention time of CAP than mesophilic digesters, appears to compensate for the lower operating temperature and lack of mechanical mixing.

It is important not to construct CAP with their base below the ground water table to avoid either floatation during commissioning or maintenance, and to avoid continuous cooling of the contents by the surrounding groundwater which will reduce the rates of biological activity.

The sludge accumulation over time is similar for conventional anaerobic ponds and CAPs. However CAPs will be more difficult to desludge unless they are permanently fitted with desludging facilities.

2.3.7. BIOGAS USE

Biogas (typically ≤70% methane) can be flared, to avoid GHG emissions, or used directly as an energy source for heating or electricity generation. The wastewater treatment plant can be operated with the biogas derived electricity and any surplus can be exported to the grid. Biogas can also be cleaned (desulphurised and stripped of CO_2), dried and compressed (>20 MPa) for export into natural gas pipelines, or used as transport fuel. Much of the cleaning (removal of dust, CO_2 and H_2S) may be achieved by scrubbing the biogas using aerobic pond water. The cover of a CAP also allows biogas to accumulate and be stored for up to a week to enable it to be used most beneficially.

Cost-effective beneficial use of biogas does depend on the size of the CAP (organic loading and biogas production) as well as the local value for use of heat and power which must be evaluated before installation.

Figure 2-1 **Covered Anaerobic Pond with Biogas Flare**

2.4 FACULTATIVE PONDS

2.4.1. SIZING, MIXING AND ODOUR CONTROL

The 1974 MoW guideline, as noted in section 2.1, still provides the ‘base case’ for sizing of primary facultative ponds located in a temperate climate in coastal areas of New Zealand. However, by adding significant mechanical aeration/mixing, the loading rate can be increased to about 250 kg BOD_5/ha/day (e.g Gore pond, Archer 2015). Higher BOD loading rates are not recommended in New

Zealand because the increased growth of bacterial biomass, that is needed to reduce the soluble and suspended BOD fractions, restricts the penetration of sunlight for photosynthesis by algae. It is noted that higher BOD_5 loading rates can be used in warmer tropical areas with higher and more constant light conditions and temperatures (Mara 1992, and Shilton 2006).

Facultative ponds used in inland or sheltered locations where there are cooler temperatures in winter and/or lack of wind for pond mixing , should have a loading rate of about 60 kg BOD_5/ha/day (USEPA 2011).

It is noted that facultative ponds located in New Zealand coastal areas have generally performed well without causing odours, because of the normally frequent on-shore winds which mix them. The exception is the Nelson coastal area which typically has calmer conditions about 50% of the time – similar to inland areas of New Zealand. In other coastal areas of New Zealand calm conditions are experienced less than 30% of the time.

Pond odour nuisance results when there is a breakdown of the temperature and organic stratification in the pond. It typically occurs during spring and autumn, when odorous anaerobic pond water can reach the pond surface. In spring this is often due to sporadic pond mixing bringing anaerobic bottom water to the pond surface during stormy weather. In autumn warm anaerobic bottom water can be displaced ("turnover") with cold aerobic surface waters during cold nights. Changes in pond bacteria and algal populations and the resulting oxygen concentration also exacerbate the potential for odour release. The following comments by recognised pond experts provide useful guidance.

Gloyna (1971) noted that "*during periods of high water temperatures in shallow ponds, sludge mats may rise from the bottom. Usually the bacterial activity is intense and the odours are overpowering.*" Gloyna recommended using a jet of water to break up the mats and resettle them.

Marais (1970) reported on South African pond experience and noted: *"Of the physical factors influencing the behaviour of a pond, mixing is probably the most important. Mixing is induced principally by wind action. Lack of wind, coupled with solar radiation normally leads to a state of stratification or non-mixing in the pond"*. He strongly recommended: *"The favourable influence of mixing is so pronounced that the writer is convinced that there is a place in oxidation pond design for inducing artificial mixing."* This observation was based on ponds in sunny, warm, inland locations which did not receive adequate wind mixing.

Brockett (1975) studied the Mangere, Auckland oxidation ponds in the early 1970's and recommended as follows: "*In autumn, as the liquid temperature reduces, the methane formers cease activity before the volatile acid formers, which can result in accumulation of odorous volatile acids. The autumn instability is compounded by a change in the algal populations*"

"The importance of the presence of dissolved oxygen in lagoon liquor cannot be overstated, for these aerobic conditions oxidise any odours produced by the anaerobic decomposition of organic matter in the bottom regions of the lagoons.

Because of this, mixing is very important. Non-motile algae tend to sink to the pond floor and it is important that they are brought to the surface to be in the effective zone of light penetration. In most cases, wind action is sufficient to do this, although on occasions it may be necessary to supplement with 'aerators' whose function is as much to mix, as to aerate".

Mara (2004) made these observations: *"Gently mixing (stirring, circulating) the contents of an overloaded facultative pond can greatly aid its performance – often to the point where it no longer acts as if it were overloaded. The use of wind-powered mixers can be a cost-effective means to mix these ponds; alternatively, electric-powered mixers can be used with a power input of* $<1W/m^3$*, rather than the 3 to 6* W/m^3 *used in aerated lagoons."*

It is clear from the recommendations made by eminent researchers of ponds from overseas and New Zealand, that some mechanical mixer/aerators should be installed on facultative ponds, to extend the depth of the aerobic zone and provide a larger buffer for potential odour release from anaerobic bottom water reaching the pond surface. It may not be necessary to operate the mixer/aerators at night as long as the pond surface remains aerobic.

2.4.2. SHAPE

Primary facultative ponds should be uniform in shape, from square to rectangular with length not more than twice the width and rounded corners for efficient mixing. Ponds should not have irregularly shaped or enclosed bays in which scum can lodge and weed growth can develop.

2.4.3. DEPTH

Some facultative pond depths in 1960/70 designs were about 1.0m but current designs should be within the range 1.3m to 1.5m and can be deeper. This can be influenced by an allowance for sludge accumulation and storage before desludging. There should be at least 0.9m of aerobic water depth above any sludge layer for algae to thrive and control odours as described in section 2.4.1. The design of larger ponds should check that the sludge storage depth will not be disturbed by bottom currents induced by wind and wave action.

Some designs have depths between 1.5 and 2.0m to allow for greater sludge storage and flow buffering capacity. Little advantage is gained by making the pond any deeper. Greater depths can exacerbate temperature and organic stratification in ponds without mechanical mixing, and the potential for the pond to “turn over” and odour nuisance.

Ponds with adequate mechanical aeration (often used for mixing as much as for aeration), generally avoid thermal stratification and turnover events as described in section 2.4.1.

Slight variations in pond depth due to natural land contours prior to construction do not affect pond operation. The natural movement of solids tends to fill deeper areas to give a uniform depth of liquid layers.

2.4.4. INLET STRUCTURES

The placement of the facultative pond inlet pipe, especially in relation to the outlet, predominant wind direction and pond baffling, will have a big impact on the hydraulic retention time, hence treatment efficiency of ponds.

Historically the recommended design for pond inlets was to take the inlet pipe discharge away from the embankment on piers. This was often also in the direction of prevailing wind and caused short circuiting and loss of treatment efficiency. Shilton (2003) discusses this and recommends, for facultative ponds, using a horizontal flow inlet with the inlet flow directed along an embankment and using stub baffles to further direct the flow. Shilton argues that the horizontal inlet provides momentum to move the solids deposits when the flow enters the pond, and the “attachment” of the flow to an embankment wall and subsequent deflection with stub baffles dissipates this energy in a controlled manner (which should be used to minimise short circuiting). For secondary facultative ponds and maturation ponds with no settleable solids in the incoming flow, Shilton recommends more rapid dissipation of the inlet flow using a manifold or vertical jet in a corner with stub baffles each side.

Inlet structures which introduce the influent at least 200mm below the water surface will avoid splashing and the risk of odours.

Figure 2-2 shows how a primary pond inlet which previously discharged into the centre of the pond has been modified to flow along the pond embankment. In this case, the flow then passes to a surface aerator rather than a baffle.

Figure 2-2 **Modifications to Pond inlet – to provide jet attachment to the embankment wall**

Inlet flows should be screened to remove floatable material. Where mechanical screening is not used the inlet should have a baffle chamber which traps floatable material for manual removal and disposal.

2.4.5. OUTLET STRUCTURES

Facultative pond outlets should be placed out of the main flow path of the incoming wastewater. Final outlet positioning can be selected after the inlet position/type and pond baffling has been designed.

Typically, outlets have either been from the water surface or from a submerged pipe. Water surface outflows need to be surrounded by a scum baffle to prevent floating debris from passing out of the pond and to retain the algae that are needed for aeration from the pond. A submerged pipe located at approximately 0.5m below the normal water surface level is an alternative that also avoids both these issues. Ideally this pipe feeds into a weir box that can be used to control the pond level. Outlet weir boxes for larger pond systems should have facilities to allow the ponds to be completely drained.

The use of screw-down penstocks should be avoided where possible. Ingress of grit to penstock seating has caused leakages. Where penstocks are used the screw threads should be covered with thick grease or protective tape to minimize corrosion.

With the growing use of pond buffer storage as part of a treatment and disposal system, outlet structures may also be restricted to allow a fixed discharge rate. Figure 2-3 shows such a system.

Figure 2-3 Outlet structure - allowing fixed outlet flows until pond is full

Here, the small slot in the outlet chamber allows a nearly constant flow to pass with any excess creating an increase in pond depth. If storm flows occur, then the flow passes through the top of the chamber as it did prior to modification. Pond levels at this plant have been dropped to 0.8m depth leading into summer (no discharge) period, to allow for extra buffer storage. This depth reduction has not created any problems.

Outlet and transfer structures should generally be sited on the upwind side of the ponds, under prevailing wind conditions, to keep them clear of floating debris and to reduce the likelihood of short-circuiting.

Figure 2-4 shows a baffled outlet structure to prevent short circuiting currents passing along the embankments from flowing straight into the outlet. In this case, gabion baskets and a pipe boom with a suspended geotextile curtain were used to create the baffles.

Figure 2-4 **Outlet baffling using gabion baskets - outlet is between two stub baffles**

2.5 MATURATION PONDS

Maturation pond depths can be less than facultative ponds at 0.6-1.5m. The minimum acceptable depth stops aquatic plants becoming established and is based on freshwater ponds data. These plants restrict natural flow patterns within ponds. Ponds used for buffer storage have successfully been operated at temporary depths of 0.8m without any problems occurring.

The minimum depth of maturation pond is based on its function and organic loading plus whether it recycles algae. In theory a maturation pond has a low organic loading and sludge accumulation and comprises several hydraulically independent cells where algae is flushed through and not recycled. Under this situation clear warm water and good solar radiation penetration give efficient disinfection. However, if the preceding ponds are overloaded or the maturation ponds not efficiently designed and/or operated, their organic loading can increase and their function becomes a hybrid between facultative and maturation ponds. Under this situation they perform better as slightly deeper ponds above 1.0m in depth.

Maturation ponds can be rectangular and narrow in shape (without enclosed bays) to create plug-flow conditions, thus reducing short circuiting.

In the 1974 MOW Guidelines, maturation ponds were designed for 20 days retention for indicator bacteria removal. It is now more cost and area effective to design them using smaller multiple ponds in series (Mara and Pearson 1998). For example, two 5 day retention ponds in series, can achieve performance similar to one 20 day pond, with half the footprint area. However, to ensure that algal growth is limited in maturation ponds, it is important that individual maturation pond hydraulic retention times are less than 2 days (based on summer average dry weather flows). In addition, an unbaffled surface discharge is particularly important to minimize the accumulation of blue-green algae in maturation ponds with the resulting potential problems of high effluent TSS, odour and toxins.

2.6 HYDRAULIC DESIGN

Shilton (2001) presented an extensive study on the hydraulics of stabilization ponds. Twenty experimental configurations were tested in the laboratory. Ten of these experimental cases were mathematically modelled and were consistent with the experimental work. Shilton and Harrison (2003) then introduced guidelines for hydraulic design of WSP to "*help fill the knowledge gap in the pond hydraulics area*". They recommended:

- Short-circuiting should be avoided as it decreases the discharge quality.
- Influent flows can be mixed into the main body of the pond to avoid localised overloading near the inlet, while not creating short-circuiting.
- A pond should maintain a similar and reasonably well-defined flow pattern through the range of possible flow rates.
- Baffles to shield both the inlet and the outlet, should be considered.

Examples of these recommendations are given in sections 2.8 and 3.4 of thls Guide.

An important aspect of hydraulic design in ponds is the hydraulic retention time (HRT). This is the average time that the incoming wastewater stays in the pond. The HRT will affect the level of treatment the pond performs. Ideally if there are no short circuits, the pond can be considered a completely mixed system. The flow comes in at one end, travels round the pond and having been everywhere passes through the outlet. The HRT can then be calculated by dividing the water volume (excluding sludge zone) of the pond by the flow.

If a primary pond serves 5000 people and is loaded at 1200 people per hectare, then using the 1974 MoW sizing guideline, as noted in section 2.1, the pond will be 5000/1200 = 4.16 ha in area. If the pond is 1.5m deep, of which an average of 0.3m of the depth is for sludge accumulation, then the pond wastewater volume is 4.16 x 10,000 (m^2/ha) x (1.5-0.3) = 49,920m^3. If the average incoming flow is 300 litres per person per day, or 0.3 x 5000 = 1,500m^3/d, then the nominal HRT will be 49,920/1,500 = 33.3 days.

At best the average pond HRT will be 33.3 days, so it will often be longer or shorter than this. This is because of dead zones where flow does not go, and temporary wind mixed currents, which can cause short circuiting. Estimating the HRT profile is important so that pond performance can be improved using baffles and other methods. There are several methods of estimating the HRT profile as outlined below.

2.6.1. ESTIMATING POND HRT PROFILE

Pond HRT profile can be estimated by various means - computer modelling, physical modelling, use of drogues and floats, visual observation of currents, tracer studies, and even the consent compliance test results.

A tracer test involves releasing a known mass of substance which can be measured in small concentrations into the incoming sewage flow and measuring how long it takes for all of it to reach the outlet. Since it will spread around in the pond, the outlet measurements will need to be taken over many days. The testing is therefore best implemented at times of stable weather and flow conditions. The most commonly used tracer is Rhodamine WT, a fluorescent dye. Measuring the amount of dye present in a sample requires analysis using a special spectrophotometer called a fluorometer. An alternative tracer is lithium, usually dosed as lithium chloride. Reasonable measurements can also be made with sodium chloride (salt) and monitoring using conductivity, if the usual conductivity of the pond water is well known.

Although a tracer test involves a lot of time and expense it still may be worthwhile, in that it will show accurately how long the influent spends in the pond under the particular inflow, pond level, and wind and weather conditions which occurred at the time the test was run. Other wind conditions can be simulated by modelling or more simply by considering reverse flow circulation patterns.

2.7 POND CONSTRUCTION

2.7.1. LOCATION AND GROUND CONDITIONS

Ponds can be constructed in virtually any location, however it helps to reduce the cost if the site has suitable conditions and is located at a lower elevation from the area serviced, so the wastewater can flow to the pond by gravity. Ideally an area should be selected where the water table is deep and the soil is heavy and impermeable. Silt or clay soils are ideal for pond foundations and construction. Building ponds over coarse sands, gravels, fractured rock or other materials that will allow effluent to seep out of the pond or allow groundwater to enter, will require care and specialist geotechnical engineering.

WSP will ideally be located at some distance from residential areas (due to potential odours and aerosols).

The emission of undesirable odours from WSP has occurred from pond systems, especially those relying on natural aeration. In many cases these were due to overloading, poor design or poor operation. Reference should be made to the NZWWA ‘Manual for Wastewater Odour Management, 2000’. The manual covers the regulatory and legislative issues, methods of quantifying odour, dispersion modelling and guidelines, and techniques for assessing the potential for odour problems to occur. Also see section 2.4.1 and 3.2.10 for more discussion of reduced odours from ponds.

For proximity of ponds to residential dwellings and areas, the 1974 MWD Guidelines recommended: “*300m from built-up areas or 150m from isolated dwellings. For populations of less than 1,000 persons these restrictions may be reduced provided that there is adequate natural screening (by trees or landscaping) and that the prevailing wind blows away from any housing area*”.

Odour dispersion modelling studies since 1994, have confirmed the general validity of these buffer distances but each site should be evaluated on its own merits. Having mechanised aeration, for example, will reduce the risk of odour problems.

Some designers prefer sheltered sites to reduce undesirable wind-driven flow patterns. However, on balance, it is preferable to have open area to take advantage of the sun and wind which will assist the efficient operation of the WSP and improve the quality of the discharge.

It is also recommended to avoid sites that are likely to flood, have steep slopes that run towards a waterway, springs or water supply bores. The pond should be orientated with the longest diagonal dimension of the pond parallel to the direction of the prevailing wind, the inlet should be at the downwind end, and outlet at the upwind end. Ponds should not be located too close to airports, or landing/take off flight paths, as any birds attracted to the ponds may constitute a bird strike risk to aircraft. If near an airport, both the Civil Aviation Authority and the airport operating authority should be consulted.

The site should preferably be flat. Surface drainage should be away from the site or should be diverted away from the pond formation. Some WSP have previously been located in pre-existing shallow gullies, with little modification to the original floor levels. Whilst this can make for economical pond construction, the variable and excessive water depths which usually occur with such sites, often cause pond performance problems.

Where a pond is built on top of a site where considerable plant material, wood or branches are buried in the ground, such material should be fully cleaned out and NOT pushed into the pond base prior to construction to avoid the risk of such material coming to the surface over time.

Ground conditions will normally dictate what type of pond sealing material can be used, e.g. clay or an artificial liner. Both types have their advantages and disadvantages, which should be carefully considered for both life expectancy and desludging impacts prior to selection.

Ponds built without the use of a liner can initially leak slightly. This leakage will often reduce as sludge layers build up. However predicting the leakage rate is often not certain and resource consent conditions may enforce either a liner or monitoring wells to ensure the groundwater is not adversely affected. Ponds which leak due to incomplete sealing, may also have the impacts of seepage controlled by pumping the seepage back into the pond.

2.8 EMBANKMENTS, WAVEBANDS AND FREEBOARD

2.8.1. EMBANKMENTS

Embankments form the sides of the pond. They must be well constructed to prevent seepage, settlement or erosion over time. Embankment slopes are commonly 1 (vertical) to 3 (horizontal) internally and 1 to 2.5 to 4.0 externally (the flatter grade if they are to be mowed). External embankments should be protected from storm water erosion by providing adequate drainage. Internal embankments should be protected from wave action erosion by using concrete wavebands or rock rip-rap. Where a synthetic liner is used, rough textured liner must be provided in places to allow safe entry and exit for maintenance.

Embankment tops should be wide enough to permit vehicle access for maintenance purposes; a minimum width of 4m is recommended. Tracks should be metalled to provide a good base for vehicle traction. Fill embankments should be constructed on good foundations and be compacted according to earthworks construction standards for the soils involved. A well-constructed embankment, as shown in Figure 2-5, will not be at risk from moving due to the weight of the pond water. However, good compaction will also minimise settlement, form a good base for wavebands, and reduce the risk of erosion damage from floodwaters, or seepage flows from within the pond.

Special care must be taken to locate any soft spots or filled areas on the pond site. These should be excavated and refilled with well compacted, good quality fill material.

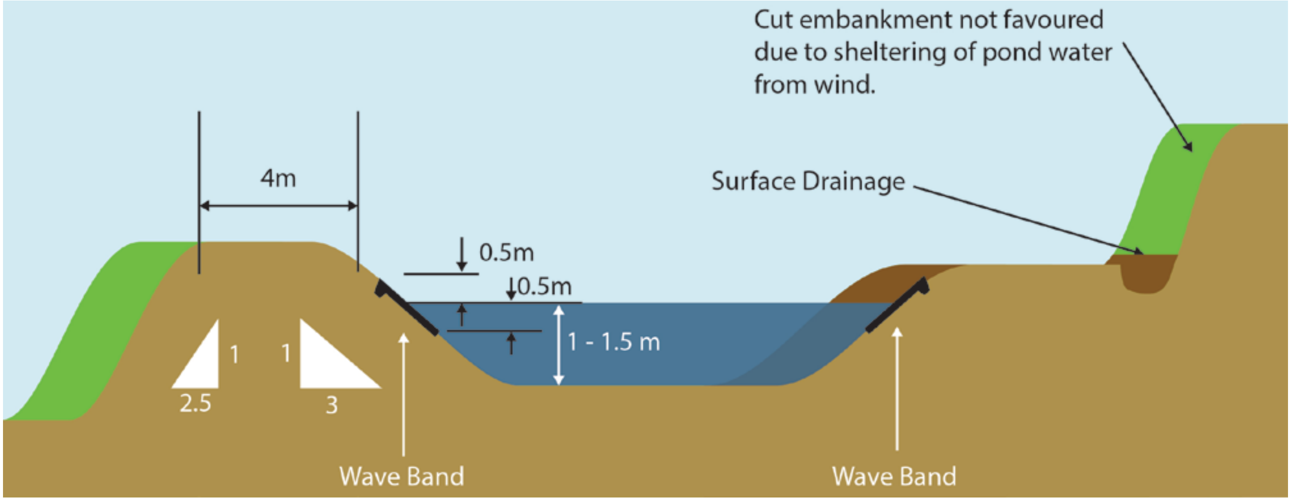


Figure 2-5 **Typical pond construction for cut and fill earthworks construction**

2.8.2. PIPES

Where pipes are laid through embankments care must be taken with back-filling around the pipe. If pipelines are laid through the base of the pond embankment it may be preferable to use Polyethylene (PE) or Glass-Reinforced Plastic (GRP) flexible pipes without joints. The pipes should be laid at the same time that the embankment is built up. This will reduce the problems associated with differential settlement and avoid the need to dig up the embankment to repair damaged pipework. Special precautions such as puddle flanges or bentonite supplements should be used to prevent water tracking along the pipe wall. Similarly special detailing is required for penetrations through artificial liners.

2.8.3. WAVEBANDS

A wave band forms a clean edge to a pond, preventing erosion and making the pond easier to maintain. Various materials have been used for wave band construction but to date, only concrete and rock have been found completely satisfactory. Geomembrane liner, while a good option for small ponds, does not allow access onto the waveband for cleaning, as it is slippery when wet, but sections of textured non-slip liner can be used where access is needed.

Concrete wave slabs must be keyed into the embankment. The use of small precast slabs is not recommended because of the difficulty of providing an adequate key; unkeyed slabs have been known to slip. Joints between pre-cast slabs are also prone to weed growth.

Rock can provide bank protection at lower cost than concrete. Suitable rock sizes need to be readily available (based on wave size) and the pond inlet must be screened to prevent debris collecting in the rock. The rock rip rap should be placed over the full slope length, on medium to heavy grade geotextile or graded rock rip rap protection. Rock and geotextile has the advantage of not being affected by bank settlement, and wave run-up is reduced.

2.8.4. FREEBOARD

Freeboard (the amount of waveband above the water surface) and waveband width must be related to the size of waves which may form and the roughness of the waveband material; the rougher the material the shorter the run-up of the wave. Freeboard sizing in texts which do not specify waveband roughness is often based on a concrete surface and should be adjusted for other materials. Wave size depends on the size and wind exposure (fetch) of the pond. Typical wave band sizing for smaller ponds (up to 2 ha), is shown in Figure 2-5. For larger ponds specific design should be undertaken.

2.9 CONSTRUCTION

Certain site-related factors, such as the location of the water table and the composition of the soil, should always be considered when designing pond systems. Ideally, ponds should be constructed in areas with clay or other soils that won't allow the wastewater to quickly percolate down through the pond bottom to the groundwater. Ponds in sensitive areas must be artificially lined with clay, bentonite, plastic, rubber, concrete, or other impervious materials to prevent groundwater pollution. Imported linings will increase construction costs significantly.

When preparing a site for WSP, all organic material should first be stripped from the pond area. The subgrade is then compacted and any soft spots filled, embankments are formed along with inlet and outlet pipework and the base and sides sealed if the soil used for construction is not fine enough to keep the rate of seepage suitably low. Finally, the wavebands and tracks are constructed.

In cases where the ground water table can rise above pond floor level, the pond must be filled as quickly as is practicable and must be kept full to prevent the sealing layer from being lifted. In such cases, site dewatering may be required if the pond is ultimately emptied for desludging. This should be clearly noted in written operational procedures. Subsoil drains or permanent site groundwater bores, which can be used for groundwater monitoring and dewatering, can be beneficial.

2.10 MAINTENANCE ACCESS

Access for maintenance and removal of equipment and structures should be planned, including jetties, mooring lines, boat launch and cranage access as appropriate.

2.11 FENCING

Fences are essential to keep livestock out of pond areas and to deter public access. The large areas of land usually involved tend to make climb-proof fencing expensive, although from a health and safety perspective its use is desirable. In many cases the “front entrance” to ponds is security fenced in this manner, with the “back door” being left at stock proof fencing. Normal 7 or 8 wire stock-proof fences are usually all that is provided. Deer fencing can provide additional security with limited additional expense.

Fencing can be erected on top of the pond embankment immediately above the wave slab. This approach lessens the amount of land to be kept tidy but makes maintenance work such as the removal of floating debris and repairing erosion more difficult. Maintenance access must be considered before erecting a fence.

A second approach is to erect the fence and leave an access-way around the top of the pond embankment. Pasture growth between the edge of the pond and the fence must be controlled by mowing or by periodic grazing. If grazing is used, drinking water must be supplied for the stock and temporary fencing used to prevent stock access to the pond. Allowance for surface damage through impact of the animals' feet should also be considered.

2.12 ROAD ACCESS

The main access-way to the ponds should be an all-weather vehicle track. The access-way around the pond embankment need not be an all-weather track since maintenance work can be planned in relation to weather conditions, but it should ideally have a firm base. However access to any mechanical/electrical equipment should be all weather access.

2.13 WARNING NOTICES

Notices warning the public that access to the pond area is prohibited should be placed so that any person approaching from any direction can see at least one notice.

Signs should make it clear that no public access is allowed to pond areas and that there are water and disease hazards associated with ponds. Where pond discharges flow to a receiving water, it is also common for signs to warn the public of disease risks from contact with affected zones of the receiving water. An example of the wording used in an outfall to river sign is shown in Figure 2-6 below.

Figure 2-6 **Typical outfall signage**

2.14 OPERATION BUILDING

It is usually desirable to provide a building in which the operator can store equipment, carry out routine tests, keep plant records and wash after attending the ponds. The size of the building should be related to the size of the ponds and to the monitoring requirements. Provision of a suitable water supply is often a problem but this can be overcome by collection, tank storage and treatment of rain water from the roof of the building. Provision of a toilet should also be considered.

2.15 FILLING

Ponds should be completely filled and maintained at operating level as soon after construction as is possible. Rapid filling prevents the establishment of weeds. This filling can use a natural water supply and, after testing for water tightness, raw sewage can be introduced to start process commissioning.

Ponds that are allowed to fill slowly, generally suffer bank erosion until the liquid level rises to the wave band. Some slow-filling ponds have become anaerobic, accumulating large areas of floating or settled sludge with limited volumes of liquid due to loss by seepage and evaporation.

2.16 MONITORING FACILITIES

2.16.1. FLOWS

In most cases the ability to accurately measure pond inflow is important. It provides information on the condition of the sewerage system as well as information for future design purposes and consents. Flow measurement of raw sewage usually involves a control device, such as a flume, which causes the flow to act in such a way that measurement of upstream depth can be used to calculate the flow rate. The increased upstream depth created by the flume can also be used to advantage when screens are installed on the inlet flow channel. This flow rate gives an instantaneous profile of flows received.

Measurement of the pond effluent flow rate is easier and has more bearing on the effect of the discharge on receiving waters. Effluent measurements do not usually agree with influent measurements as seepage and evaporation losses, and/or precipitation gains occur. A simple V notch weir is often used for pond effluent flow rate measurement. As with a flume, the application of a formula to the upstream depth measurement allows calculation of the flow rate.

WSP inflows and outflows are therefore preferable measured and recorded as continuous data to provide flow profiles, accumulative volumes and averages over specific periods.

Any flow measuring device, however, should be regularly checked and calibrated. In far too many cases such checking has found that highly inaccurate measurements have been made over long periods. This is often due to incorrect formulae being used, older control devices (weirs or flumes) being too small for current flows, worn or corroded plates, or poor or non-calibration of the upstream depth measurement devices. Accurate flow measurement and reporting is often a resource consent requirement.

Figure 2-7 V-notch weir with ultrasonic depth measurement on pond effluent

Terminal pumping stations should be fitted with a flow measuring device and an "hours run" meter. For pumped flows a "full bore" magnetic type flow meter usually provides accurate measurements.

2.16.2. RECORDING

Most pond monitoring equipment comes with outputs for recording and data logging of critical information (like pond inflow rates and dissolved oxygen measurements). One option is for the data to be manually entered during a site visit or, alternatively, it can be automatically logged onto a data logger or sent electronically through a telemetry system to be logged at a base station.

Many discharge consents for pond systems now require automatic measurement and logging of key parameters such as flow, temperature, and dissolved oxygen. Telemetry systems are also becoming more common for ponds. Both automatic measurement and telemetry are desirable if there is the possibility of the ponds requiring rapid intervention, for example in response to low oxygen levels.

2.17 SEASONAL VARIATION

WSP will experience seasonal loading variations due to local weather conditions, rainfall intensity and stormwater infiltration. Some ponds also have to cope with variable loading from holiday populations or seasonal industry. Most ponds need more frequent checking in the spring and summer when grass and weeds grow quickly and when seasonal properties are occupied causing a higher influent loading.

In colder climates the rate of biological activity during winter will be slower and could cause a reduction in pond performance. The pond operating level (and therefore hydraulic retention time) may need to be increased to offset the reduced operating temperature for the pond organisms.

Pond life varies seasonally, with cyanobacteria (commonly known as blue-green algae) occurring and often accumulating on the surface of many ponds during late summer and autumn due to lower inflows and higher evaporation leading to extended HRTs. With the increased recognition of the possible impacts of blue-green algae and algal toxins on people, stock, and the environment, this is an important aspect of pond discharges to surface waters. Enabling direct discharge of effluent from the pond surface and agitation of the pond surface e.g. using brush aerators, can greatly reduce the accumulation of blue-green algae scum on ponds.

2.18 ALLOWANCE FOR POPULATION GROWTH

Ponds should not be designed for more than a 25% increase of the population at the time of construction, except where there is good evidence that a high rate of growth or loading will occur in the near future.

In the past ponds have been oversized and, because of evaporation and seepage, have never filled. In some cases this problem has been accentuated by the use of temporary fences for dividing a facultative section from a maturation section. This practice simply increases the pond areas to be filled simultaneously. Facultative and maturation ponds should be completely separate hydraulic units.

Measurements taken at several pond systems have shown that seepage and evaporation losses can be of the order of 100-150 m^3/ha day during the summer months. To illustrate the effect of this order of pond water loss, consider the following calculations:

Raw sewage pond area required for a design population of 5000 people.

Area = 5,000 people / 1,200 people/ha = 4.2 ha

Daily inflow from present population of 4,000 (at 300 litres/person day) = 1,200 m^3/day.

Losses due to seepage and evaporation = 4.2ha x 150m^3/ha/day = 630 m^3/day.

Therefore during the summer more than half the inflow to the facultative pond can be lost by seepage and evaporation.

If a large (20 day detention) maturation pond was included in the system a further 2 ha of pond surface area would be required to provide an additional 20 days retention.

Total loss due to evaporation and seepage would then be: 6.2ha x 150m^3/ha/day = 930 m^3/day.

Now the major portion of the pond daily inflow would be lost. Virtually a “nil discharge” condition could result.

It has been shown that the average open-water evaporation rate is between 650 and 800 mm per year in most areas where WSP are constructed in New Zealand. January monthly average open-water evaporation is generally between 100 and 225 mm in these areas (Finkelstein, 1973). The effect of such losses must not be ignored when a pond system is designed. Specific data for individual sites below 500m altitude can be obtained from the NIWA climate database using the local weather station.

2.19 CONSULTATION AND CONSENTING

Any wastewater treatment and disposal system in New Zealand is required to operate under resource consents. Land use consents are required from the Territorial Authority, (TA), and discharge consents are required from the Regional Council. The overarching legislation governing these consents is the Resource Management Act, (RMA).

Under Part 2 of the RMA the relationship of Maori and their culture and traditions with ancestral lands, water, sites, wahi tapu and other taonga must be recognised and provided for. The tangata whenua of a particular area (the iwi or hapu holding mana whenua or customary authority over that area), will be an affected party if any discharge is to occur there. Even if the iwi or hapu is not directly affected, it is necessary to consult with them.

Under tikanga Maori, human waste should be passed through Papatuanuku (mother earth) or biotransformation to be cleansed. Of particular concern is any discharge of sewage effluent, treated or otherwise into areas used for food gathering. Maori therefore often favour discharge of effluent to land including wetland areas. Maori have a strong cultural view that good waste management is imperative. However, views on the detail of how wastes should be managed vary across regions and open dialogue on wastewater management and appropriate local solutions is important.

Other affected and interested parties for a new or upgraded WSP include Ministry of Health, Department of Conservation, Fish and Game, other water users, downstream consent holders, environmental groups, local landowners and occupiers and the public.

It is important, therefore, to start consulting early on the options for treatment and discharge. Consultation must be undertaken in good faith and solutions considered that genuinely address people's concerns. Local people will understand the physical and technical conditions of their area that can constrain the feasible options if they are clearly presented.

Careful planning for consultation and consent application will generally save time and expense and avoid a project becoming contentious.

3 POND MODIFICATIONS AND UPGRADES

3.1 MAINTAINING OR UPGRADING

3.1.1. DRIVERS

Reasons for implementing modifications or upgrades of a pond system are generally due to one or more of three reasons:

- **Significant operational problems** such as odour, non-compliance with Resource Consent conditions, complaints from neighbours or equipment failure. These are generally the consequence of a prolonged and systematic lack of maintenance and operational care of the pond. Often this is due to a lack of knowledge of the fundamental O&M requirements of a pond-based treatment system. Signs of such a situation include overgrown or crumbling embankments, unacceptable sludge accumulation, frequent or prolonged odour or non-compliant discharge events. In such a case it is important to initially review and update the O&M protocols applied at the plant and to consider upgrade options only as a second step.

- **An increase in loading or more stringent Resource Consent conditions**. Such changes can, but do not need to automatically result in upgrade works. Maintenance and/or operational changes can provide capacity increases or improvements in discharge quality. A good knowledge of the plant, its O&M requirements and the applied sampling process and procedures is fundamental in deciding on the need for operational changes or upgrade requirements.

- **Political reasons**, e.g. "*ponds are old technology, which cannot achieve the required treatment standards*", and therefore "*it is better to treat wastewater using a mechanical treatment plant*". This reason will always be the most difficult to satisfy. It is often based on a lack of in-depth knowledge of the pond-based treatment process itself. Often it is not founded on either process or technical reasons. It can therefore be difficult to change the stakeholders' views without a good process and operational knowledge of the existing plant together with a list of successfully operating pond-based reference plants.

Experience shows that all reasons put forward for the need for a pond upgrade have generally an O&M issue at their root. Recognition of the importance of effective O&M practices is therefore paramount. It is therefore here that the needs and requirements of the pond should first be considered and changes be implemented. A pond's O&M requirements as well as recommendations for sampling process and procedures are provided in section 4.

3.1.2. OPERATION AND MAINTENANCE

Before starting on significant pond system upgrades it is recommended to first verify the extent that the O&M recommendations presented in section 4 are currently being implemented at the treatment plant. Indeed, O&M practices can have a significant impact on a pond system's short- as well as long-term treatment quality. For example, it is of little use upgrading a facultative pond by adding expensive aerators to try to improve its discharge quality if the plant is full of sludge. Pond maintenance such as mechanical desludging or an operational change such as implementing a longer-term biological desludging program would, in such an instance, be much more effective.

A good understanding of the requirements and correct sampling process and protocol is equally recommended before considering upgrading a treatment pond. The sampling and monitoring recommendations outlined in section 4 will help the operator to gain a good understanding of the biological process and hydraulic conditions within the pond and why problems might arise. They will also allow collecting adequate pond data, which is fundamental for an accurate plant analysis and for an upgrade strategy to be developed.

Prior to considering a plant upgrade the treatment plant's Resource Consent conditions should also be reviewed. They may not include the correct time, location and frequency of sampling or adequate plant and environmental parameter collection. In the past this has been the case when

Resource Consent conditions developed for mechanical treatment plants were directly applied to pond systems.

It is recommended that the operator be proactive in sampling and analysis of parameters that are not required by the Resource Consent conditions if, after reading this Guide, she/he considers that there is insufficient data to fully understand the operation of the pond system or the plant's condition.

Section 5 discusses issues related to Resource Consent conditions for ponds. It encourages operators and Councils to work with the Regional Authorities in developing pond-specific Resource Consent conditions, which do provide adequate and comprehensive information on the plant's condition and give a correct picture of the quality of effluent being discharged.

The reader is therefore encouraged to read sections 4 and 5 before starting with an investigation into possible plant upgrade options.

3.1.3. POND UPGRADES

Pond upgrade options discussed in this section cover minor to comprehensive plant modifications. They also include solutions to cater for particular waste streams. Most upgrade options can be mixed and matched to achieve a specific treatment outcome or to cater for specific loads.

Whatever upgrade is adopted it is always recommended to improve a pond system by addressing the fundamentals of the treatment and to only increase in sophistication once the basic design criteria have been satisfied. Optimising inlet and outlet structures, reducing short-circuiting, preventing shock loads and peak flows should all be addressed before more advanced upgrade work is considered.

When developing an upgrade strategy it is recommended to take into account the characteristics of a pond-based treatment system and to use them to advantage:

- Ponds have a large reactor volume, a long hydraulic residence time (HRT) and treat the wastewater load slowly.
- Ponds can be used effectively to buffer peak flows and peak loads.
- Ponds have a low sludge production rate and provide integrated sludge storage and digestion.
- Ponds have minimal O&M needs and costs and are simple to operate. They are ideally suited to rural locations.
- Ponds can be upgraded gradually as load increases or as discharge requirements change

Gradual upgrades can be related to the application of more stringent Resource Consent conditions over time which can significantly reduce overall upgrade costs.

Traditional ponds are heavily impacted by environmental and seasonal changes on which the operator has minimal influence. In contrast, modern ponds and the upgrade options discussed in this Guide, provide more treatment consistency and the operator with more control over the plant's treatment process and quality.

3.2 TREATMENT IMPROVEMENTS

This section is intended as a tool to help the reader find adequate upgrade options based on a specific problem or problems experienced at the treatment plant. The sections are arranged according to the contaminant, which represents the main issue at the plant. First the issue related to the contaminant and its possible reasons for occurring are discussed. Then possible improvement and prevention mechanisms are listed according to an increasing level of complexity. For more information the reader is directed to the relevant sections of the Guide in which the process, technology or recommended operational changes are discussed in more detail.

3.2.1. ALGAL SOLIDS

Pond algae can vary significantly in size, type and behavior. They nevertheless all require certain conditions to develop and thrive. These include sunlight, nutrients, the possibility of free movement within the water column, little disturbance (avoidance of intense mixing), correct pH, and the absence of predators (e.g. invertebrates), algaecides or high concentrations of chemicals preventing their development.

Because of the wide range of algae developing in WSP depending on the type of pond, climate and weather conditions the removal of algae can be difficult and inconsistent. Simple, low-cost options can often be as effective as high-cost systems. This is to be kept in mind when considering more advanced, technical treatment or removal options e.g. the storage and final disposal of algae or algae and chemical sludge generated by some advanced removal processes can be difficult, expensive and can create their own environmental issues, which should be investigated thoroughly prior to implementation.

Table 3-1 Upgrade Options for Algal Solids

Mechanism	Upgrade Options	Use		Refer Sections
		Pond	Term	
Prevention	Artificial pond cover	F/M	L	3.4.10
	Aeration & mixing	F/M	S/L	3.4.4, 3.4.5
Retention	Improved outlet structure	F/M	S/L	3.4.2
	Pond subdividing	F/M	L	3.4.6
	Wetlands / Floating wetlands	F/M	L	3.4.8, 3.5.8
Electrical inhibition	Ultrasound	(F)/M	S/(L)	3.4.11
Filtration	Pond internal biological filter	F/M	L	3.4.8, 3.4.9
	Pond external micro screening	F/M	L	3.5.1
	Pond external membrane treatment	F/M	L	3.5.2
	Pond external biological filter (trickling filter)	F/M	L	3.5.6
	Slow sand filtration	(F)/M	L	3.5.1
	Rapid sand filtration	F/(M)	L	3.5.1
Chemical dosing	Pond internal	F/M	S	3.4.10
Flotation	DAF / IAF	F/M	L	3.5.3
Code: A/F/M: Anaerobic, Facultative, Maturation pond; S/L: short, long-term; (...): limited application				

3.2.2. BIOMASS SOLIDS

Biomass is present in every WSP in attached, settled and suspended forms, that vary depending on the type of WSP and the loading or location within the WSP. WSP biomass does not settle as quickly as activated sludge biomass due to wind action and smaller floc size and as algae are often nearly neutrally buoyant. Some similar removal methods can nevertheless still be used. Biomass return can increase pond efficiency, but is rarely applied to traditional WSP arrangements; more commonly to partially or fully aerated lagoons or the PETRO® Process.

Table 3-2 Upgrade Options for Biomass Solids

Mechanism	Upgrade Options	Use		Refer Sections
		Pond	Term	
Retention	Improve flow conditions	F/M	L	3.4.1, 3.4.3
	Pond subdividing	F/M	L	3.4.6
	Outlet structure upgrade	F/M	S/L	3.4.2
	Wetlands / Floating wetlands	F/M	L	3.4.8, 3.5.8
Filtration	Pond internal biological filter	F/(M)	L	3.4.8, 3.4.9
	Pond external micro screening	F/(M)	L	3.5.1
	Pond external membrane treatment	F/M	L	3.5.2
	Pond external biological filter (trickling filter)	F/M	L	3.5.6
	Slow sand filtration	(F)/M	L	3.5.1
	Rapid sand filtration	F/(M)	L	3.5.1
Assisted Clarification	Coagulation & co-precipitation	F/M	L	3.5.4
Floatation	DAF / IAF	F/M	L	3.5.3
Code:	A/F/M: Anaerobic, Facultative, Maturation pond; S/L: short, long-term; (…): limited application			

3.2.3. INERT SOLIDS

Large inert solids such as rags and plastics will enter and accumulate in WSP if no or insufficient pre-screening is provided. Such solids, will accumulate over time and affect the O&M of the pond and equipment. Accumulation of these solids will have a significant impact on the type of equipment which can be used as part of an upgrade and of the advanced plant upgrade options for nutrient removal because they can float up from the bottom and interfere with the new installations. The removal of large solids should therefore represent an early upgrade priority to any long-term pond upgrade strategy.

Heavy, small inert solids are rarely an issue in WSP as they generally settle out within the pond naturally. Such solids e.g sand, grit and introduced biomass (often in septic tank effluent) can settle out at the plant inlet where they can create a localised reduction of HRT (overloading) in this area and possible generation of odour. Too much sludge accumulation can prevent the installation of aerators because of a lack of water depth.

Light small inert solids e.g. silts, passing through a pond are rarely an issue but if need addressing can be treated using the same options as listed in section 3.2.2 for Biomass Solids.

Table 3-3 Upgrade Options for Large Inert Solids

Mechanism	Upgrade Options	Use		Refer Sections
		Pond	Term	
Screening	Adequately sized inlet screen of the correct type	A/F	L	3.3.1
	Septage screening system	F	L	3.3.2
Removal	Regular removal by operator	F	S	4, 5
	Regular removal as part of desludging	A/F	L	4, 5
Retention	Outlet structure upgrade	A/F	L	3.4.2
	Grit removal system	F	L	3.3.3
	Pond subdividing	F	L	3.4.6
	Wetland / Settlement pond	F	L	3.4.8, 3.5.8
Filtration	Pond internal biological filter	F/(M)	L	3.4.8, 3.4.9
	Pond external micro screening	F/(M)	L	3.5.1
	Pond external membrane treatment	F/M	L	3.5.2
	Pond external biological filter (trickling filter)	F/M	L	3.5.6
	Slow sand filtration	(F)/M	L	3.5.1
	Rapid sand filtration	F/(M)	L	3.5.1
Assisted Clarification	Coagulation & co-precipitation	F/M	L	3.5.4
Flotation	DAF / IAF	F/M	L	3.5.3
Code: A/F/M: Anaerobic, Facultative, Maturation pond; (...): limited application			S/L: short, long-term;	

3.2.4. SURFACE SLUDGE

The occurrence of surface sludge in a facultative pond is generally due to severe pond overloading or lack of maintenance that leads to excess sludge accumulation on the base of the pond which rises to the pond surface, or as a result of seasonal changes such as severe pond mixing or pond turn-over which cause bottom sludge to move to the pond surface. The actions to be taken are therefore primarily to be found in the O&M section rather than in this upgrade section.

Surface sludge in a maturation pond indicates issues of a similar nature as outlined above. It therefore also indicates that the “maturation” pond is in fact operated as a facultative pond, i.e. it receives too high an organic loading.

The occurrence of surface sludge in an anaerobic pond is generally related to the beginning of the formation of a surface crust and can be a positive development. In certain circumstances it can be encouraged by adding straw onto the pond surface. A thick (0.1-0.4 m) and stabilised (with surface plant growth) crust will prevent odours from escaping and help insulate the pond.

Table 3-4 Upgrade Options against Surface Sludge on Facultative Ponds

Mechanism	Upgrade Options	Use		Refer Sections
		Pond	Term	
Prevention	Desludging	F/(M)	L	3.4.12, 4.4.7
	Aeration & mixing	F/(M)	S/L	3.4.4, 3.4.5
Intervention	Chemical dosing	F/(M)	S	3.4.10
	Other (aeration & mixing)	F/(M)	S	3.4.14
Code: A/F/M: Anaerobic, Facultative, Maturation pond; S/L: short, long-term; (...): limited application				

3.2.5. BOD

Excessive BOD within a pond or at its discharge can relate to algae biomass, biological floc (biomass solids) or dissolved BOD. This section addresses specifically the removal of dissolved BOD. Algae and biomass related BOD can be addressed as described in the relevant sections 3.2.1 and 3.2.2.

Dissolved BOD issues can either be related to an excessive loading of the pond or inadequate treatment capacity because of incorrect pond sizing, a gradual filling up of the pond with sludge or severe short-circuiting. Generally the occurrence of excess dissolved BOD will be preceded or happen at the same time as a range of other issues at the plant (e.g. odour, floating sludge). It should initially be addressed through good O&M prior to investigating upgrade options.

Table 3-5 Upgrade Options for Dissolved BOD

Mechanism	Upgrade Options	Use		Refer Sections
		Pond	Term	
Prevention	Desludging	A/F	L	3.4.12, 4.4.7
Treatment	Aeration & mixing	F/(M)	S/L	3.4.4, 3.4.5
	Improve pond hydraulics	A/F/(M)	L	3.4.3
	Subdivide	F/(M)	L	3.4.6
	Pond internal biological filter	F/(M)	L	3.4.8, 3.4.9
	Pond external biological filter	F/(M)	L	3.5.6
	Chemical aeration	F	S	3.4.10
	Other (aeration & mixing)	F/(M)	S	3.4.14
Code: A/F/M: Anaerobic, Facultative, Maturation pond; S/L: short, long-term; (...): limited application				

3.2.6. AMMONIACAL-N

Excessive NH_4-N concentrations at the inlet or within a pond can often be traced back to high inflow NH_4-N concentrations and therefore unusual discharges into the plant (e.g. industrial, portaloo, or septic tank discharges). Such loads can have a severe impact on the pond's health as high NH_4-N concentrations are toxic to algae, nitrifying bacteria and pond invertebrates, particularly at warmer temperatures and high pond pH.

High NH_4-N concentrations at the pond outlet can either be the result of insufficient treatment or the release of NH_4-N during degradation of organic compounds within the pond. NH_4-N is also released within a few days of the pond algae population being grazed by invertebrates or treatment against excessive algae growth causes the algae to settle and degrade on the pond bottom.

Traditional WSP have limited NH_4-N treatment capacity with NH_4-N reduction rates mainly depending on assimilation into algae biomass which depends on sunlight, temperature and pond HRT. These algae then settle to the pond bottom. NH_4-N can sometimes be partly removed by volatilization of NH_3 (at high pond water pH and temperature with pond surface agitation) or by nitrification to NO_3. However, nitrifying bacteria are slow growing and prefer to be attached to aerobic surfaces. Nitrification in facultative and maturation ponds can be augmented by the addition of growth media and purpose-designed aeration which can reduce NH_4-N levels down to 1mg/l. Such systems do nevertheless represent a significant upgrade and have to be properly designed and operated.

Table 3-6 Upgrade Options for Ammoniacal-N at the Inlet

Mechanism	Upgrade Options	Use		Refer Sections
		Pond	Term	
Prevention	Prohibition of highly concentrated NH_4-N loads	F	S/L	3.2.6
	Storage & slow release of highly concentrated NH_4-N loads	F	S/L	3.2.6
Treatment	Aeration & mixing at plant inlet	F	S/L	3.4.4, 3.4.5
Code: A/F/M: Anaerobic, Facultative, Maturation pond; S/L: short, long-term;				

Table 3-7 Upgrade Options for Ammoniacal-N within the Pond / at Outlet

Mechanism	Upgrade Options	Use		Refer Sections
		Pond	Term	
Prevention	Desludging	F/(M)	S/L	3.4.12, 4.4.7
Treatment	Aeration & mixing	F/(M)	S/L	3.4.4, 3.4.5
	Improve pond hydraulics	F/(M)	L	3.4.3
	Subdivide	F/(M)	L	3.4.6
	Pond internal biological filter	F/(M)	L	3.4.8, 3.4.9
	Pond external biological filter	F/(M)	L	3.5.6
	Other (aeration & mixing)	F/(M)	S	3.4.14
Code: A/F/M: Anaerobic, Facultative, Maturation pond; S/L: short, long-term; (...): limited application				

3.2.7. TOTAL NITROGEN

Total Nitrogen reduction in ponds relies mainly on a combination of sedimentation of wastewater solids, algal assimilation of NH_4-N followed by settling within the pond. Both the sedimentation and ultimate digestion of wastewater and algal solids result in some release of NH_4-N back to the pond water. Both ammonia volatilization (at high pond water pH and temperature with pond surface agitation) and nitrification may periodically contribute to NH_4-N removal. For total N removal nitrification has to be followed by denitrification of nitrate to nitrogen gas, which requires anoxic conditions and available organic carbon.

Consistent total N removal down to low levels can only be achieved using traditional WSP at water temperatures > 5 °C and HRT of > 20 days when they are augmented to promote both nitrification and denitrification. This requires the addition of biofilm attachment surfaces to support a population of nitrifying bacteria in aerobic surface water and denitrifying bacteria in anoxic deeper water. Mechanical aeration is also required to maintain adequate dissolved oxygen levels for nitrification. While denitrification can occur to some degree within facultative ponds it is most efficiently achieved using a subsurface flow wetland or denitrification filter following the pond. These provide more stable anoxic conditions compared with ponds, and provide both attachment surfaces for the denitrifying bacteria as well as an organic carbon source.

Table 3-8 Upgrade Options for Total N

Mechanism	Upgrade Options	Use		Refer Sections
		Pond	Term	
Treatment	Advanced NH_4-N reduction as per 3.2.6 plus:			
	Pond internal biological filter ie growth media	F	L	3.4.8, 3.4.9
	Floating wetlands	F	L	3.4.8
	Pond internal rock filters	F	L	3.4.7
	Pond external rock filters	F/M	L	3.5.6
	Wetlands	F/M	L	3.5.8
Code: A/F/M: Anaerobic, Facultative, Maturation pond; S/L: short, long-term;				

3.2.8. TOTAL PHOSPHORUS

Total phosphorus (TP) can be divided into particulate phosphorus and dissolved reactive phosphorus (DRP).

Particulate phosphorus is generally bound to biomass or other solids and can therefore be quite effectively removed with most processes addressing solids removal as outlined in sections 3.2.1, 3.2.2 and 3.2.3.

Dissolved reactive phosphorus (DRP) is in solution and first must be converted to particulate form before being removed from the wastewater. It is assimilated by algae and bacteria as they grow, but since the ratio of N:P in wastewater is lower than that of biomass it is impossible to remove all the DRP by assimilation alone. Both algae and bacteria are known to remove DRP by luxury uptake, but the conditions in traditional WSP do not promote this process. Even though DRP may be taken up by pond biomass, unless the biomass is removed from the pond water there may be little overall TP removal as DRP can be released back into the liquid as the solids anaerobically decompose. Traditional WSP are typically only able to remove about 20% of the TP load of wastewater. Supplementary treatment by chemical coagulation is one of the most effective means for the removal of DRP. It is best applied to WSP effluent to take full advantage of the in-pond treatment processes.

Table 3-9 Upgrade Options for Particulate P reduction

Mechanism	Upgrade Options	Use		Refer Sections
		Pond	Term	
Treatment	Refer to sections 3.2.1, 3.2.2 and 3.2.3 for treatment options			

Mechanism	Upgrade Options	Use		Refer Sections
		Pond	Term	
Code: A/F/M: Anaerobic, Facultative, Maturation pond; S/L: short, long-term;				

Table 3-10 Upgrade Options for DRP reduction

Mechanism	Upgrade Options	Use		Refer Sections
		Pond	Term	
Treatment	Increase biological uptake	F/(M)	S/L	3.4.8, 3.4.9, 3.4.10
Chemical	Pond internal Ferric treatment	F/M	S/L	3.4.10
	Pond external Alum treatment	F/M	L	3.5
	Pond external Ferric treatment	F/M	L	3.5
	Pond external Polyacrylamide (PAM)	F/M	L	3.5
Adsorption	Wetlands	F/M	S	3.5.8
	Slag Filters	F/M	S	3.5.6
	Soil uptake	F/M	S	3.5.8
Code: A/F/M: Anaerobic, Facultative, Maturation pond; S/L: short, long-term; (...): limited application				

3.2.9. FAECAL BACTERIA AND VIRUSES

Faecal bacteria and viruses are inactivated or removed by various processes within WSP. The main process is inactivation by natural sunlight, particularly the solar-UV component. This occurs mainly in the maturation pond where the light can penetrate deeper into the water column. Other processes include sedimentation, adsorption to pond biomass and inorganic solids, and grazing by pond protozoa and invertebrates. Removal rates are typically higher in summer than winter especially in ponds with less suspended solids where the sunlight can penetrate further into the pond depth. Since faecal bacteria and virus removal are measured in terms of log removal, issues of hydraulic short circuiting or over loading are often first noticeable by increased effluent concentrations. The reader should therefore initially refer to sections 4 and 5.

Best disinfection is achieved by a series of maturation ponds and when the organic and nutrient concentrations (BOD, TN, TP) as well as suspended algal and bacterial biomass have all been well reduced by prior treatment stages. Advanced disinfection can be achieved in shallow maturation ponds, which have a higher surface area exposed to sunlight than traditional deeper maturation ponds. Artificial UV disinfection can also be added although there is often a high variability in transmissivity, through seasonal algae, colour and solids concentrations, which limits its efficiency. However, if pond effluent TSS is low (UV transmissivity is high) artificial UV disinfection can be added to almost completely remove all faecal bacteria and viruses.

Faecal bacteria and viruses are generally in suspension so solids filtering (refer sections 3.2.1, 3.2.2 and 3.2.4) may only give 1-2 log removal at best, unless advanced technologies such as membrane filtration are employed.

Table 3-11 Upgrade Options for Bacteria and Viruses

Mechanism	Upgrade Options	Use		Refer Sections
		Pond	Term	
Solar-UV inactivation	Reduction of solids	F/M	S/L	3.2.2, 3.2.4
	Reduction of algae	M	S/L	3.2.1
Reduced short-circuiting	Multi-stage ponds	F/M	L	3.4.6
Advanced treatment	Membrane filtration	F/M	L	3.5.2
	UV disinfection	F/M	L	3.5.5
Code: A/F/M: Anaerobic, Facultative, Maturation pond; S/L: short, long-term;				

3.2.10. ODOUR

Odour can be a serious nuisance issue for WSP and is one of the main reasons why ponds have been discredited. Odour is nevertheless only the result of a malfunction of the plant. A correctly designed and operated WSP rarely generates nuisance odour.

Odour generation tends to be limited to anaerobic and facultative ponds and is either related to over- loading or to an upset within the treatment pond. The former includes excessive or uncharacteristic influent loads (e.g. too hot, too low/high pH, too high conductivity). It also includes an excessive loading of the inlet area, which may have filled up with solids (reducing HRT) or has insufficient aeration. It can also be related to the under loading of an anaerobic pond, which is unable to build up a stable crust.

Pond related issues include incorrect pond designs as well as seasonal issues such as pond turn-over, seasonal DO deficiency or excessive sludge accumulation. Many of these issues can be linked to poor operation and maintenance.

It is therefore important to first establish the exact location and true reason(s) for the odour production and use this to initiate the best counter measures.

Odour nuisance can also be generated within maturation ponds when a cyanobacteria bloom accumulates and dies.

Table 3-12 Upgrade Options for Odour Issues

Mechanism	Upgrade Options	Use		Refer Sections
		Pond	Term	
Prevention	Reduce loading	A/F	S/L	4, 5
	Introduce load dosing	A/F	S/L	4. 5
	Desludging	A/F	S/L	3.4.12, 4.4.7
	Improve pond hydraulics	F	L	3.4.3
	Install aeration	F	S/L	3.4.4, 3.4.5
	24/7 DO measurement & automated aerator control	F	S/L	4.3.2
	Promote surface crust	A	L	3.4.9
	Add impermeable cover	A	L	3.4.9

Mechanism	Upgrade Options	Use		Refer Sections
		Pond	Term	
Treatment	Increase aeration & mixing at inlet	F	L	3.4.4, 3.4.5
	Increase overall mixing	F/M	L	3.4.4, 3.4.5
	Implement Sodium Nitrate dosing	F	S	3.4.10
External	Anti-odour sprays	A/F	S/(L)	4
Code:	A/F/M: Anaerobic, Facultative, Maturation pond; (…): limited application	S/L: short, long-term;		

3.2.11. OTHER

Other parameters related to the raw influent as well as to the condition of the pond and its operation and maintenance can also have an effect on the treatment quality.

Table 3-13 Upgrade Options for Other Issues

Parameter	Upgrade Options	Use		Refer Sections
		Pond	Term	
pH too high / low	Raw influent: slow dosing	A/F	S/L	4
	During advanced treatment: Adjust level of Nitrification	F	S/L	3.4.4, 3.4.5, 4
	Treatment: Adjust alkalinity	F	S/L	3.4.10, 4
Alkalinity (lack of)	Maintain a healthy algae population, keep aeration 24/7	F	L	3.4.4, 3.4.5
	Add lime, Sodium Bicarbonate or other chemicals	F/M	S/L	3.4.10
Temperature stratification	Increase aeration & mixing	F/M	S/L	3.4.4, 3.4.5
Low DO	Increase aeration & mixing	F/M	S/L	3.4.4, 3.4.5
	Sodium Nitrate addition	F/M	S/L	3.4.10
Waves (height)	Subdivide ponds	F/M	L	3.4.6
	Flow directing devices	F/M	L	3.4.3
	Adjust pond operating level	F/M	S/L	3.4.2
Code:	A/F/M: Anaerobic, Facultative, Maturation pond;	S/L: short, long-term;		

3.3 PRE-POND UPGRADES

3.3.1. SCREENING

Raw influent screening has always been standard equipment at mechanical treatment plants, but unfortunately, not for pond systems. This view persists even though screening has multiple benefits:

- It reduces maintenance through the removal of larger solids, which would otherwise float on the pond surface, settle on the embankments or obstruct overflow weirs.
- It protects equipment installed within the pond such as aerators and mixers from jamming and growth media and rock filters from clogging.
- It improves the pond's sludge quality so that it can be put to beneficial re-use in the future.
- It can reduce the raw influent BOD_5 loading by up to 5%.
- Such improvements to the plant operation will come at some costs:
- Screening incurs relatively high capital costs for the civil work, the screen and power and wash water connections.
- It increases operating costs; power, maintenance, screening collection and disposal.

The type, aperture and sizing of a screen depend on the level of protection and load removal to be achieved. A screen for a pond system can range from the most basic manual 20mm bar screen to an automated, fine 6mm diameter hole or 3mm wedgewire drum screen. A good screenings washing and compaction system is always recommended to avoid odours and flies and to reduce the volume of screenings to be disposed of. The screenings quantity (washed) can be estimated using the general guideline of about 2–5 l/PE/yr for rough screens and 5–15 l/PE/yr for fine screens.

The quality of workmanship and material selection for a screen are both important for the longevity of the screen; for larger, heavy, manual bar screens HDG steel or aluminum bars are acceptable. Finer manual and all automatic screens should be made from at least SS304. Plastic screens should only be used as secondary screens after a rough pre-screening. SS316 material is essential for all installations near the sea or in case of a high industrial input (e.g. brine or similar) or after long rising main discharges. Automated screens should always be fitted with an overflow and by-pass channel integrating a correctly sized manual bar screen. These should be made from the same quality material as the main screen.

Whatever screen type is being selected, it should not be undersized. In today's competitive environment some suppliers tend to size their screens for only the current flow to secure the project. It is in fact recommended to oversize the screen, the by-pass screen and channel to be able to cater for future flow increases. Screen selection shuld also consider the type and length of the sewer network: small bore pressure systems with grinder pumps will generate different screenings from long or very short gavity systems.

Screen types, costs and capacities should therefore always be compared using the screen's clean water throughput as well as the screen's throughput using the same blinding factor and the resulting amount of capacity reduction. The final selection should also take into account ease of maintenance and the availability and costs of spare parts.

If the plant's peak flow and infiltration are not fully known, or if high industrial loads or a short sewer network can be expected, significant oversizing or provision for two parallel screens should be envisaged to handle unexpected flows and potential blinding.

Table 3-14 Screen Types for Pond System Upgrades

Type	Suggested Aperture and Application	Advantage	Disadvantage
Manual bar screen	15mm to 25 mm; small plant or by-pass channel	Low cost, low head loss	Manual cleaning
Auto bar screen	3mm to 20mm; small plant	Low cost, auto cleaning if small aperture and correctly installed but relatively low head loss	Possible odour generation if no cleaning system and screenings collection
Step screen	6mm generally sufficient, 3mm	For medium to deep channels. Accepts larger	The screen's hydraulic design allows certain

Type	Suggested Aperture and Application	Advantage	Disadvantage
	possible; medium to larger plants	screenings and flows. Relatively immune against grit and sand.	solids to pass (e.g. cotton wool buds, some sanitary pads). Can pass 50% of screenings.
Rotary inclined basket screen	6mm wedgewire screen generally sufficient; 3mm wedgewire and 5mm holes possible; Small, medium and larger plants	For medium to deep channels. Good capture rate due to flow diversion. Increased screening (and BOD reduction). Smaller aperture screens only recommended for special applications due to significant increase in the volume of screenings. Can remove 90% of screenings.	Careful selection of screen brushing mechanism recommended due to possible blinding and/or need for frequent replacement. Limited capacity to deal with peak loads if not correctly sized.
Horizontal, “Contrashear-type” drum screen	2mm, 3mm, 6mm, 10mm wedgewire screen; medium to larger plants	For shallow to medium depth channels. Reliable concept with high screenings capture rate at already larger apertures.	Possible abrasion due to grit and sand. High oil and fat concentration in raw influent can require hot water cleaning.
Vertical band screen	6mm, center-fed medium to large plants with high peak flows	For medium to deep channels. Excellent screening performance and for high flow variability	Sensitive to screenings type as only water cleaned.

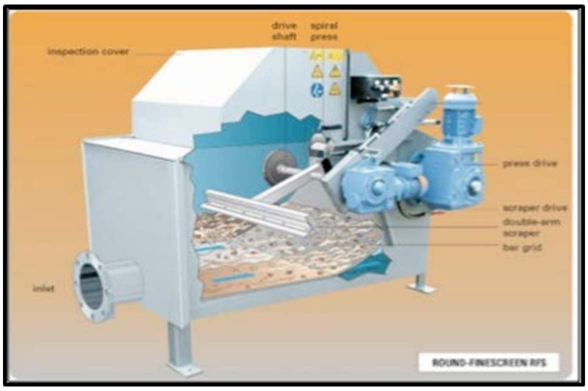


Figure 3-1 **Auto Bar Screen**

Figure 3-2 **Step Screen**

Figure 3-3 Basket screen

Figure 3-4 Drum Screen

3.3.2. SEPTAGE RECEIVING STATIONS

Septage discharges can have a significant impact on the health, the treatment capacity and the long-term operation and maintenance needs of a pond system. A septage discharge not only represents a high instantaneous load (e.g. 6 $m^3 \approx$ 600PE) for a pond, but it adds a high percentage of digested, heavy sludge as well as inert solids, such as sand and grit and often also lighter material which can float to the pond surface. Its impact is often under-rated but can represent an equivalent load of a small village. It can therefore make the difference between deciding to upgrade a pond system to a mechanical plant versus being able to operate existing WSP for many more years.

The different characteristics of a septage load will affect a pond in different ways:

- The high instantaneous load can generate localised overloading in the pond's inlet area resulting in odour release and a potential pond crash.
- In case of high NH_4-N concentrations in the septage, the high instantaneous load can kill the algae population around the inlet and a wider area of the pond and reduce the available oxygen resulting in lower pond capacity and potential odour production.
- The heavy portion of the septage (old sludge, sand, grit) will tend to settle out and accumulate around the inlet area of the pond. This will require more frequent pond desludging, and reduce the pond's treatment capacity in that area, which always receives the highest load concentration. As a result, it will increase the potential for odour generation and possible destabilisation of the pond.
- The light, inorganic waste content of septage will float to the pond surface and increase maintenance requirements.

The addition of a septage receiving system can significantly improve the treatment capacity, operation and maintenance of WSP. It is nevertheless important to select the correct design, system type and sizing to ensure that the plant is adequately protected. A septage system should screen, dilute and store the septage for a slow feed into the pond to avoid any shock or short-term overloading.

A septage screening system should not only be robust, well-built and fitted with high quality components to ensure an extended life expectancy, it should also be designed to cope with New Zealand's specific, often thick and compact, septage. In contrast, many European systems are designed for more dilute septage due to the more frequent septic tank pump-out requirements in Europe. Such systems will need adapting to allow quick and trouble-free discharges or tankers with thick septage.

Septage systems can incur high capital costs and cheaper or lighter built systems are often preferred. But incorrectly designed or undersized systems can result in significant down time and O&M costs.

Septage receiving stations in general should help:

- Prevent rogue, uncontrolled discharges of high loads from septic tankers.
- Allow to keep records for improved plant management and trade waste billing.
- Screening and dilution of septage.

- Septage storage and slow injection within the pond's treatment capacity.

Septage receiving stations should preferably provide:

- An enclosed, odour-proof acceptance container, which allows a direct connection of the septic tanker for gravity or in some cases, pressure discharges.
- Sufficient treatment capacity to allow for the emptying of a tanker within minutes.
- A rock trap for rocks and large stones.
- A flow meter.
- Anti-blockage, anti-overloading and auto-cleaning mechanisms.
- A heavy-duty screen with a cutter-type cleaning mechanism and a screenings washing and collection system.
- A septage storage, dilution and dosing system for an extended, slow injection of the septage into the pond over several hours or days.
- An electronic recording system for the septic tanker identification, time of discharge and volume discharged, which is linked to Council's trade waste records and charging system.

An extensive number of septage systems are currently on the New Zealand market, and their specific design, purpose and limitations should be understood so that the system is selected in line with the plant's requirements:

- European and US "compact" septage systems provide good screening and a certain amount of septage load dilution. They do not provide septage storage. Such systems can rapidly be limited in their throughput capacity when confronted with old, thick sludge such as typically found in New Zealand (ie septic tanks emptied every 20 years instead of every 5 years). The result can be lengthy discharge times (>20min per load) which lead to illegal discharges elsewhere in the sewerage system to shorten truck journey times.

  These systems were designed for mechanical treatment plants and do not reduce the instantaneous high loading of the pond. So, for high loads or small plants they should be fitted with a septage storage and dosing system after the initial screening.

- Step screens, rotary drum screens and inclined basket screens with large apertures are used in New Zealand as part of locally designed septage receiving stations in order to avoid expensive compact units.

  Experience has shown that such screens are acceptable, but that they have to be oversized to deal with the compact and heavy New Zealand loads. They will be more expensive to run because of their higher O&M requirements and they tend to have a reduced life expectancy when compared with their application in raw effluent screening. Septage storage and dosing is recommended for high loads and/or smaller ponds.

- Alternative, site-specific low-cost septage receiving systems using manual or semi-manual bar screens and a storage and dosing system can be developed locally as long as the septic loads are well known and understood. Simple systems are prone to odour production, clogging and cleaning issues if not correctly designed or maintained. Tanker drivers should therefore be involved in the system's design from the start and should accept responsibility for its operation and maintenance.

Apart from screening and storage or direct discharge into a stabilisation pond there are also a number of alternative options available, which are mainly used overseas and are slowly coming into New Zealand. They include the use of Geobags or septage specific (anaerobic) ponds. These are discussed in more detail in the section 3.3.4.

3.3.3. GRIT REMOVAL SYSTEMS

Grit removal systems are rarely installed before pond systems. This is because ponds with their low flow velocity generate an immediate settling out of any sand or grit. Mechanical equipment installed within ponds is therefore less at risk of abrasion and early wear than it would be in mechanical plants.

Grit and sand quantities in wastewater can vary widely between 20 and 200l per 1,000 m^3 of wastewater with an average of about 60l per 1000 m^3. High quantities of such solids settling out in the pond's inlet area can lead to a reduction in treatment capacity in this crucial treatment area and therefore an increased risk of odour. In such instances, a grit removal system can be justified to avoid the need for a costly desludging of the pond.

A grit system for a treatment pond should as a minimum include:

- Two parallel channels operating as duty/stand-by or a single channel / circular grit chamber fitted with an automatic cleaning system, isolating gates and by-pass channel.
- A grit classifier, a grit washing system and a storage bin for the clean grit.

Discussions about the positioning of a grit removal system in relation to the inlet screening system are ongoing:

- Its installation upstream of an inlet screen will protect the latter from abrasion and wear. Its installation downstream of an inlet screen will prevent rags and heavy inorganics to settle out in the grit chamber and contaminate the grit. Both issues can be avoided through correct design. System positioning should preferentially be decided based on the operator's past experience with the quality and characteristics of the raw influent.
- A grit system should not be used instead of or as a replacement for a septage receiving system as it is not designed for such an application. Grit systems are also not recommended if the plant receives regular septage discharges. In this case the construction of a dedicated septage pond would be the preferred option because of the systems' overall lower O&M costs and added treatment benefits.

3.3.4. SEPTAGE PONDS, IMHOFF TANKS AND GEOBAGS

The purpose of a dedicated septage pond, Imhoff Tank or Geobag is to retain organic and inorganic solids for the protection of the primary facultative pond from overloading and/or for extending its treatment capacity. They all constitute effective treatment options for WSP, which are severely impacted by frequent or high volumes of septage loads.

In contrast with anaerobic ponds, septage ponds and Imhoff Tanks have generally a much smaller sludge storage volume and require regular emptying out. The sludge is taken to a drying area and later disposed of or reused depending on its quality. This two-stage treatment is combined into one single stage within a Geobag where solids are retained, dewatered and decomposed within the same bag over time.

All three processes can produce high quality digested and disinfected sludge. The final quality of sludge and its use as a fertiliser or soil conditioner does nevertheless depend on the level of pre-screening the septage has received prior to passing through a Imhoff Tank, septage pond or Geobag. Post-screening is also a viable option. This decision should be considered as part of a wider septage sludge management strategy.

Advantages of Imhoff Tank, Septage Pond and Geobag treatment:

- Such pre-treatment systems significantly reduce the BOD_5, TSS and F&G loading to the WSP and therefore increase the system's overall treatment capacity.
- They are simple long-term options, which do not require highly skilled operators.
- They reduce the amount of solids entering the main treatment pond and therefore extend its treatment capacity and period between desludging.

Disadvantages of Imhoff Tanks, Septage Ponds and Geobag treatment:

- They are all long-term treatment options.
- Some of them are prone to odour production if not correctly designed or operated (e.g. Imhoff Tank, New Zealand type septage ponds).
- They require reasonable capital investment and septic tanker driver buy-in and community acceptance.
- They provide temporary storage which needs a future end use or permanent storage discharge facility.

- They are most cost-effective if the final product can be re-used. Many re-use options require pre- or post-screening, which increases the overall costs.
- Design requirements for Imhoff Tank, Septage Pond and Geobag treatment:
- Determine the final disposal path of the treated sludge (ie reuse or disposal).
- Find a long-term partner for disposal or reuse.
- Depending on the final usage, decide on the required pre-treatment (e.g. septage screening) and if the origin of the septage may have to be restricted (e.g. heavy metals, industrial loads).
- Design the system for long-term operation and get the buy-in from the septic tanker drivers and preferably also from the local community.

Set the septage charges in accordance with the long-term operation and maintenance of the system.

3.3.4.1 SEPTAGE PONDS

Septage ponds in New Zealand have generally been small deep holes in the ground to primarily provide sludge storage. They resemble anaerobic ponds in that they have a liquid top layer, with or without a crust. They can have a capacity for up to 5 years' sludge storage and are combined with a shallow pond for solids disposal and drying (ie for secondary sludge treatment) when the main pond is emptied out. Such "standard" NZ septage ponds are prone to odour generation if they cannot maintain a stable surface crust. Septage ponds should be fitted with a well-designed inlet structure to avoid odour generation during tanker discharge.

Septage ponds internationally are, in contrast, quite shallow ponds with a maximum 1.5m sludge depth. They are fitted with surface discharge and under-drainage to achieve rapid sludge drying within the pond itself. They are generally built in pairs with one to two years of sludge storage in each. This arrangement achieves a high level of sludge digestion, drying and disinfection without generating odour. Currently there are only a few examples of septage ponds in New Zealand e.g. Oamaru.

3.3.4.2 IMHOFF TANKS

Imhoff Tanks have been used for decades as pond pre-treatment and standard design parameters are readily available in the specialized literature for adaptation as septage storage and treatment. Imhoff Tanks can be quite labour intensive as they generally have a smaller sludge storage capacity than septage ponds. They also need sludge drying beds or some other post-processing of the sludge if disinfection is a requirement prior to final disposal or re-use. Imhoff Tanks have, on the other hand, an advantage compared with septage ponds in their defined structure, which can be designed to minimize odour production and facilitate sludge withdrawal.

3.3.4.3 GEOBAGS

Geobags can be used for direct septage sludge storage and treatment. They are more commonly known for their use in pond desludging, but internationally they are also used for direct septage treatment. In such applications Geobags are used in pairs with a one to two year rotation. Chemical dosing (Alum) can be applied, but is generally avoided as it does not have the same benefits as for pond desludging and can generate issues for the beneficial re-use of the sludge. During the resting time the Geobag achieves good sludge decomposition and high disinfection rates resulting in a readily reusable sludge.

3.3.5. ANAEROBIC PONDS

Addition of an anaerobic pond to an existing pond system can significantly improve the overall plant treatment capacity through their capacity to receive and treat high BOD loads (particularly agricultural processing organic loads) as well as retain wastewater solids, fat and oil so that they don't enter subsequent ponds. Their solids retaining capacity means that an inlet screen and grit system or septage receiving station are not as necessary as pre-treatment for a facultative pond, although they are still recommended to reduce the accumulation of inorganic sludge within the pond and as a lack of screening will limit the final sludge disposal options.

Addition of an Anaerobic pond as part of a WSP upgrade needs to take into account other aspects of the upgrade, particularly with respect to the availability of organic carbon in the wastewater for denitrification if nitrification is going to be promoted.

More details about their sizing, pond design as well as the design of inlet and outlet structures are provided in Section 2.3

3.3.6. OTHER

WSP can be used for a wide range of effluent treatment as long as components of the raw influent do not negatively affect the biological treatment process within the ponds. WSP will even adapt to difficult raw influent characteristics (e.g. high salt content) if they are kept small and have minimum variation. It is therefore possible to adapt WSP to a large variety of wastewaters by selecting specific pre-treatment systems.

Pre-treatment options, which are considered too wastewater specific to be included in the previous chapters include:

- Pre-aeration
- DAF treatment
- Physical or chemical precipitation
- pH adjustment and neutralization
- Alkalinity adjustment
- Heavy metals and/or chemicals adsorption
- Hydrocarbon pre-treatment
- Other, industrial influent-specific pre-treatments

Such pre-treatment options need to be selected and integrated into the overall WSP design on a case-by-case basis to operate either on the main- or a side stream. Some of these are better considered as pre-treatment at source prior to an individual discharge into the sewerage system.

3.4 IN-POND UPGRADES

3.4.1. INLET MODIFICATIONS

Traditional pond inlets discharge the raw influent through a straight pipe and dropper into the center or at least a significant distance into the pond. The assumption was that this would ensure rapid and equal distribution over the whole pond. Such an arrangement does in fact result in ever changing flow and treatment conditions within the pond adding a level of uncertainty to the treatment process. At times of high inflows this arrangement tends to create directional short-circuiting. At times of low inflow the raw wastewater accumulates around the inlet and can lead to odour generation due to localized overloading.

Modern pond designs recognize the need to use the whole pond volume more efficiently and to create consistent, well-defined flow conditions. The pond inlet design has consequently changed radically and upgrading the plant inlet can contribute to significantly improved treatment at the pond's front end. It is therefore always recommended as one of the first in-pond improvement on a waste stabilisation pond.

Two approaches can be taken:

- The Jetting Inlet

With this design the inflow is directed along the embankment through the installation of a 90-degree elbow directly at the edge of the pond. The "jetting effect" created by this single pipe will propel the raw influent over a significant distance along a defined flow path, which will remain "attached" to the embankment over a considerable distance.

In combination with other flow directing devices (e.g. floating curtains, rock groynes, aerators etc.) this inlet design can be used to distribute the influent rapidly over a wider, but defined area of the pond.

The jetting inlet is more efficient if the flow into the plant does not vary widely and comes at a known flow rate (i.e. on/off pump operation). This allows for a more accurate sizing of the inlet pipe resulting in a more effective and consistent jetting effect.

- The Distribution Inlet

If the inflow to the plant is of a highly variable nature (e.g. gravity flow, VSD pump operation) the opposite approach to the jetting inlet is often preferred. The distributing inlet first breaks the inflow velocity by directing it towards a T section before the flow is divided into two streams, which are then distributed over multiple outlets (generally two to four) over a wider area at the front of the pond. This design tries to inhibit any sort of jetting effect and instead distributes the load over a large surface area from the moment it enters the pond.

Care has to be taken with the design of a distribution inlet if the raw influent contains a high level of heavy solid material, which could settle out within the distribution pipe due to the reduced flow velocity. In this case the designer will either select a lesser number of discharge ports or will select a jetting inlet design instead.

The choice of inlet design depends on the pond design, type of inflow (gravity, pumped), size of pond, loading as well as the type and number of other flow directing devices to be installed. “Jetting Inlets” are often combined with surface mixers and aerators (e.g. brush aerators) to further direct the flow through the pond. “Distribution Inlets” are more frequently combined with sub-surface aeration, which provides a high level of pre-aeration and mixing in the area over which the raw influent is distributed.

Transfer works between ponds are preferably upgraded using the “distribution inlet”. This is because the flow between ponds can vary widely and a “jetting inlet” would therefore not be able to maintain a consistent flow pattern.

Whatever inlet design is adopted the raw influent should always be injected into the pond sufficiently below the water surface to avoid any splashing. The inlet pipe should always remain submerged even if the pond is operating with variable water level.

Figure 3-5 Jetting Inlet Upgrade

Figure 3-6 Distribution Inlet

3.4.2. OUTLET MODIFICATIONS

Traditional outlets have consisted of simple open pipes, circular manholes with a flat overflow weir or fitted with a square hole cut into the side incorporating wooden planks as a weir for water level control. Such traditional discharge designs result in significant solids entrainment, uncontrollable discharge flows and high variability in treatment quality. They do not allow any control over the pond’s flow or load buffering capacity. They create preferential flow conditions within the pond, which reduce the ponds ideal HRT and some (i.e. straight pipes) limit the pond’s maximum discharge capacity and therefore present a significant risk for a potential pond overtopping.

An upgrade of a pond’s traditional outlet structure comes therefore as a close second behind its inlet structure upgrade for improving flow and discharge conditions of a pond system.

Modern outlet structures have become significantly more sophisticated and are now a crucial element of the hydraulic and process control of a pond system. The weir design should ensure:

- Solids and floatables are retained within Anaerobic and Facultative ponds.
- The approach velocity around the outlet is limited to minimize entrainment of settled solids in the discharge.
- It provides maximum flow discharge capacity in case of an emergency (peak flows).

- It defines and controls the amount of designer-specified water level variations within the pond.
- It controls the discharge velocity from the pond and therefore it's buffering capacity.
- It provides a hydraulic separation between the pond and downstream process units.
- An outlet structure should therefore present at least four control elements:
- An outside baffle to retain floatables and to ensure that the effluent is only withdrawn at a specific depth below the water surface (except Maturation Ponds).
- An overflow weir, which can be flat, V-crested or be fitted with a purpose-designed narrow gap control section for level and flow control.
- Weirs should include a replaceable discharge section to allow adjustment for possible flow changes in the future
- Weirs should be fitted with a device which allows the outflow to be completely stopped.
- A collection chamber, which hydraulically separates the pond from the discharge pipe (see below).
- An adequately sized discharge pipe.

Outlet structures can further be fitted with a manual fine screen if downstream treatment units need to be protected from potential discharges of debris or wildlife such as eels or ducks. Such screens can either be integrated into the discharge structure itself or they can be installed into a dedicated discharge manhole located outside of the pond.

Generally a pond is fitted with a single outlet structure, representing a single point of discharge. For shallow, wide ponds where a single point of discharge could have a significant and negative impact on the flow pattern and treatment capacity of the pond, an outlet manifold structure fitted with multiple baffles and overflow weirs is preferred as it will provide a significantly improved flow within the pond and reduce the potential for short-circuiting.

The weir itself should always remain the sole element of level and flow control and should not be obstructed or influenced through the installation of any upstream pipe, screen or similar elements. To enable the weir to remain the controlling element it is important that it hydraulically separates the pond from the discharge pipe itself. The discharge pipe should therefore be located at the bottom of an effluent collection chamber which has sufficient volume and internal height to cater for any water level variations due to head loss in the discharge pipe.

The weir and its baffle design must take into account the location within and size of the pond in which it will be installed as well as prevailing wind/wave action, uplift forces, and extreme flow conditions. They are generally made from stainless steel (SS304 or SS316 depending on the location of the plant) and some elements may be made from concrete, aluminum, GRP or plastic materials. The choice of material and design for any removable section (i.e. control weir element or gate) must ensure that they can be easily removed or adjusted in all temperature conditions, even if solids clog the guide rails. Outlet structures also have to be easily and safely accessible by the operator for verification and maintenance purposes.

Figure 3-7 Flow Control Weir

Figure 3-8 Level Control Weir

Outlet structures must be designed in accordance with the specific requirements of the type of WSP they are installed in:

- **Anaerobic pond** weir designs depend on whether they have a crust or impermeable cover. Anaerobic ponds with a crust require a weir which will only allow a limited amount of water level variation in order to prevent breaking-up the pond's crust. The outlet structure should have a baffle, which reaches sufficiently above the water surface to retain the crust. It should also reach sufficiently below the water surface to ensure that the bottom of the crust is not entrained: The baffle should therefore extend between 200 to 400 mm above and about 400mm or more below the water level.
- **Covered anaerobic ponds** should not have an outlet structure at the pond surface as it will interfere with the pond cover. An outlet manifold with several horizontal openings should be place at ~500 mm below the pond surface to avoid entrainment of floating solids.
- **Facultative pond** weir designs require a baffle so that the algae in the surface layer of the pond are not removed with the treated effluent. The baffle is also required to protect the weir from wave action, and therefore should extend about 600+mm below the minimum operating water level and 200mm or more above the maximum water level. Larger ponds with potential for higher waves require higher baffles.

  The space between the baffle and the weir is used for flow velocity control to ensure minimum discharge of any settleable and minimum preferential flow of suspended solids and is therefore an important design factor of the outlet design.

  The weir design will pre-determine the operating conditions of the facultative pond during low, normal and peak flow conditions. It can be designed to control the discharge flow velocity and can create buffer storage or maintain a constant water level. It will also determine the maximum allowed water level in the pond in case of an emergency.

  As a result, a weir for a facultative pond can combine a flat crested weir, a narrow gap weir, a certain type of V-notch weir or more sophisticated weir slots depending on the specific pond operating conditions the designer wants to achieve.
- **Maturation pond** weir designs should not have a baffle to ensure that the most highly disinfected surface water is discharged from the pond and floating blue/green algae do not accumulate in the pond and cause blooms. Any large floatables can be prevented from being discharged by using a screen. Maturation pond weirs are therefore generally flat crested or shallow V-notch weirs

  The weir design for a maturation pond will not generally be used to control the discharge flow such as on facultative ponds. That is, unless the system's Resource Consent limits the maximum daily discharge. In this case the need for a maximum flow buffer capacity may require the use of a narrow gap weir or similar.

A separate category is represented by **floating weir structures**. These can be used on facultative as well as maturation ponds. Their baffles are designed for effluent withdrawal at optimal depth at or below the water surface and the weir is generally a flat crested or shallow V-Notch weir. Flow discharge will be constant or can be controlled by varying the buoyancy control or using a control valve located in a manhole outside the pond.

Floating weir structures have the advantage of optimal effluent withdrawal with high accuracy of flow and level control over a wide range of flow conditions. Their disadvantages are their high costs, relative high level of sophistication and the reliance on power and control equipment for more sophisticated options.

For any of these outlet structures it is important that the weir length is sufficiently long that the approach velocity within the pond (i.e. around the outer baffle) and close to the weir (i.e. between baffle and weir) remains sufficiently low to avoid solids capture. Simple, straight outlet pipes, even if followed by a weir arrangement outside the pond, should therefore be avoided.

3.4.3. FLOW DIRECTION DEVICES

Traditional ponds present an uninterrupted water surface with an inlet at one end and the outlet at the other. Flow conditions and treatment quality in such ponds are highly variable due to multiple factors listed previously.

In modern ponds the flow is directed through a defined flow path in order to reduce this variation. Flow directing devices are one way of ensuring that the flow of the wastewater through the pond is optimised.

Flow directing devices can be divided into two main categories:

- **Active flow directing devices** include aerators and mixers. They use electricity to create directional flow or mixing, which impacts on the flow direction and velocity of the wastewater through the pond. These devices are discussed in more detail in section 3.4.4.
- **Passive flow directing devices** include baffles, rock groynes and floating curtains. They are used to divide ponds, redirect the flow or to create a defined flow path through a pond. Such devices are generally permanent installations and their design, strength and material selection has to take into account their long-term maintenance and resistance to seasonal weather conditions. These devices are discussed in this section.

A number of passive flow directing devices are available for the use in pond upgrades. The selection of the type of device, its placement and its design depend on the type of pond in which it is to be used, the site ground conditions, what is to be achieved and the available budget.

The use of passive flow directing devices is normally limited to their use in facultative or maturation ponds. Their use in anaerobic ponds is rare and not recommended unless they are used to subdivide an over-sized anaerobic pond into two parallel ponds. Because of the different goals behind subdividing ponds this upgrade technology is discussed in its own section 3.4.6.

Flow directing devices can achieve a number of benefits for pond treatment:

- Stub-baffles (Figure 2-4) can be used to detach jetted flows (refer 3.4.1) from the embankment and direct them into the pond.
- Stub- baffles can be used to protect a pond outlet from short-circuiting around the outside of the pond.
- Longer walls or floating baffle curtains can be used to create a defined flow path through a pond along which different treatment stages can be achieved.
- Longer baffles help reduce wave height by breaking up long ponds into smaller narrow sections.
- Baffles can reduce short-circuiting as well as dead zones and increase actual HRT.
- Baffles reduce the impact of changing wind direction on treatment.

However, passive flow directing devices can also have some negative impacts on pond performance:

- They can retain or accumulate floating matter.
- They can reduce the pond's capacity (i.e. wide rock walls).
- They can make desludging more difficult.
- They could potentially lead to localised overloading due to smaller more defined treatment areas, especially around the inlet.
- There is an optimal amount of baffling within a pond, beyond which there is no additional benefit, because of the increase in dead zones.

A number of parameters should be taken into account when selecting and designing passive flow directing devices:

- The design, type of device and material to be used need to be selected based on pond size, depth, site conditions and treatment goal to be achieved.

- Site conditions (weather, wind, earthquake prone), site access for installation and the device's required life expectancy.
- The pond depth, sludge depth, sub-base condition and strength in the proposed location(s) of installation have to be known together with the expected variation in water level.
- Desludging of the entire pond or at least along the line of installation is recommended if the sludge layer exceeds 200mm. Installation into ponds with a deeper sludge layer is possible but not recommended. It carries the risks of incorrect design, difficulties for installation and alignment and an ultimately poor overall performance.
- Materials used, including any liners, anchoring posts, gabion material, cables, shackles and weights, should be corrosion and UV resistant and able to resist the strong forces from wind and waves.

3.4.3.1 BAFFLES AND SEPARATION WALLS

Baffles and separation walls are made from wooden or concrete posts anchored into the base of the pond and connected with fibre cement sheeting, precast concrete walls or similar permanent materials. Thin fibre cement sheeting is weak and brittle and can shatter over time.

Wall construction is expensive and their installation in operating ponds relatively difficult. Their advantage is that they are long-lasting and they can securely divide a pond without taking up much treatment volume. An alternative is the installation of concrete barrier sections set close together to form walls or baffles which have the advantage of easier installation, but they do not provide a tightly sealed baffle. The pond base must also be able to support their heavy weight and they are not recommended for earthquake prone regions of New Zealand.

Figure 3-9 Old Fibre Cement Wall

Figure 3-10 Concrete Wall

Figure 3-11 Concrete segments

3.4.3.2 ROCK GROYNES

Rock groynes are mainly used as stub-baffles that extend only a few meters into the pond. They redirect the flow by detaching it from the embankment (e.g. after use of a "jetting inlet") and help protect the pond's outlet from short-circuiting. Their installation is relatively inexpensive and if well placed they can create an optimized flow pattern through a pond, especially if combined with active flow directing devices such as aerators. Rock groynes can take up a relatively large amount of pond volume, especially if they are installed in a relatively deep pond, are long or are constructed simply as a rock pile. Rock groynes are therefore preferably built using rock gabions, which are assembled and filled outside of the pond and then placed in position using a digger. This allows a more precise placement, narrower groynes and will allow modification if performance is not as expected. Overall rock groynes are efficient structures for protecting certain parts of the pond or re-directing flow. They are less efficient for creating a permanent flow path for the wastewater independent of weather or wind conditions unless the pond has significant spare capacity. Addition of rock groynes or barriers requires a good understanding of the quality of the pond's sub-base. A geotechnical assessment should be undertaken before design to ensure that the base can support the extra weight without subsiding as the risk of failure of rock barriers due to weak ground conditions is high.

3.4.3.3 FLOATING CURTAINS

Floating curtains can be used in smaller ponds (approximately 2ha) to create barriers to provide a defined flow path and reduce short-circuiting even at times of high wind and wave action. In larger ponds, especially in coastal locations, the wind and wave forces can damage curtain type and other barriers, such as rigid sheeting on posts.

Floating curtains have to be designed to a high standard with respect to the material used, their anchoring system and their connection to the embankment. Sealing at the base can be difficult if the base is uneven (see later).

Research has shown that curtains of about 70% the width of a pond are most effective for creating a flow path through a pond. The effectiveness of curtain addition on pond improved treatment performance increases with typically up to three curtains.

Floating curtains should be made from a strong impermeable material such as HDPE or FPP of about 0.75 to 1.5mm thickness. PVC is generally to be avoided as its life expectancy can be reduced in New Zealand's high UV environment. The type of material selected depends partly on the application; for a pond operating with a constant water level a more rigid HDPE curtain is possible, for a pond with a changing water level a more flexible FPP material is preferred.

Figure 3-12 Rock Groynes

Figure 3-13 Floating PE Curtain

Figure 3-14 Poor Quality Curtain

Composite materials (i.e. fibre reinforced liners or tarpaulin material) should be avoided as the thin cover membrane is prone to abrasion and the underlying reinforcing material is generally not UV resistant. A combination of materials for above and below the UV impacted area is possible (i.e. generally above water to 600mm below water), but rarely financially advantageous.

The curtain floats should be both strong and light. They can consist of marine grade polystyrene blocks enclosed and sealed into individual liner capsules. Other floats may be made from PE pipe or PVC tubing. The latter should be limited to heavy duty PVC (i.e. pressure pipe PVC, not electric ducting). The pipe ends should be permanently sealed with glue-on caps. To extend their life expectancy floats are preferably filled with marine grade polystyrene or a similar light, hydrophobic material to keep them afloat, even if their glued-on end seals fails.

The use of larger diameter floats (i.e. 200mm or even 250mm diameter versus 100mm) has advantages as they present a stronger barrier against wave action and will therefore be more effective against short circuiting over the baffle even in windy conditions. Since larger floats present a greater obstacle to wind and waves they require a stronger anchoring system for the baffle.

Floating curtains should be fitted with a heavy chain at their base to hold them in position and to form a seal with the pond base. The chain should be hot dip galvanized and preferably enclosed and sealed within the curtain material. In order to achieve a good barrier, the curtain has to reach and seal with the pond base along its whole length. It is therefore imperative that a survey of the pond depth is undertaken along the potential position of a new curtain. Depth measurements should be made at about 1.0m intervals so that any changes in depth can be incorporated during manufacture of the curtain.

Floating curtains can be used in ponds operating at a constant water level or with a variable water level. The sophistication of curtain design varies significantly between the two. Curtains operating with a constant water level can be sized according to the pond base variation and the specified water level. They can be made from more rigid material (i.e. HDPE), can have minimum slack and can sit relatively straight in the water column. During strong winds or storms such curtains remain in position as long as the anchoring chain and anchors remain in place.

Curtains operating with a variable water level have to be designed to prevent excess curtain material from floating loosely or being captured by the wind when the pond operates at low level. In storm conditions such spare material is at risk from wind damage. Variable level curtains therefore need to be made from more flexible material (e.g. FPP) and are preferably fitted with an intermediate ballast chain, which holds down and straightens the spare material at times of low water level.

If the curtain has ever to be shifted within the pond, dedicated lifting ropes should be attached to the chain and floats at regular short distances during construction. Otherwise the weight of the chain and the effect of the chain sinking into the pond base or sludge will make lifting the chain off the bottom too difficult. The position of a curtain is therefore permanent, unless the curtain is inadequately designed and shifts during strong wind conditions (e.g. too much material, inadequate anchoring).

In the past, long curtains had to be joined at regular distances with mechanical joining pieces, which created sealing issues. Today pre-fabricated sections of a long curtain can be welded together on site, which allows for strong continuous barriers. The whole curtain can then be floated into position, anchored and then deployed.

Curtains have been installed in ponds with sludge levels up to 600mm. This is done by “jetting” the curtain into the sludge layer. This practice is not recommended and considered shortsighted. Installing curtains into a pond with significant sludge accumulation carries the risk of the curtain moving due to the weight of sludge and makes desludging after installation much more difficult. As a general rule, regular pond desludging remains best O&M practice and should be considered as a first step towards improving pond performance.

One of the more difficult aspects of a curtain design is effective sealing with the pond embankment and most incidences of short-circuiting with curtains occur here. If the embankment consists of rock riprap a reinforced section of the curtain can be permanently embedded into the riprap. If the embankment has a concrete or liner waveband the sealing between the embankment and the curtain needs careful consideration and design. The curtain should continue as far as possible up to the top of the embankment or at least 300mm above the maximum water level. The attachment of the curtain should be sufficiently low above the top of the embankment to avoid lifting the curtain out of the water and creating a ‘sail’ area for the wind to catch on. It should also be sufficiently high so that the stainless cable or rope does not damage the embankment material or wear out over time.

3.4.4. AERATION AND MIXING; TYPE AND PLACEMENT

The addition of aeration and/or mixing devices to a pond can improve pond operation and treatment performance. However, the level of improvement largely depends on the correct selection, positioning and application of these devices, so that the investment and extra O&M costs can be justified.

Aerators and mixers can provide oxygen, prevent stratification and set up beneficial flow pathways within ponds to improve treatment performance.

The types of aerators, which can make a real impact in the operation and possibly treatment quality of a pond system are limited because of the shallow nature and large surface area of facultative and maturation ponds. A list of the types of aerators, their advantages and disadvantages and recommended uses are given in Table 3-15 below.

Table 3-15 Mixing and Aeration Devices for Facultative and Maturation Ponds

Type	Application	Comments
Vertical Shaft aerator	Only for small, deep ponds, not designed for normal facultative and maturation ponds	Designed for deep ponds > 2.0m. Localized mixing & aeration. Tend to lift bottom sludge to surface. Can erode the pond base. Can block with rubbish lifted off the base.

Type	Application	Comments
		Not recommended for facultative & maturation ponds
Inclined shaft aerator	Limited application in facultative ponds, with depths > 1.5m. Anti-erosion plates recommended in clay-lined ponds.	Good aeration and mixing efficiency and flow directing properties. But originally designed for deep ponds (> 2m). Can be adjusted for shallow ponds but with a significant drop in efficiency. Prone to high O&M needs in ponds with no current or past screening due to frequent clogging of impeller. Relatively high power requirement vs. aeration efficiency in shallow ponds. Recommended for deeper areas of facultative ponds
Brush aerator	Traditional aerator for facultative and maturation ponds	Good mixing and aeration in shallow ponds (<1.2m). For deeper ponds (< 2m) limited aeration capacity, but still good flow-directing properties and mixing of pond strata in area of influence. Relatively high capital costs compared with aeration efficiency and O&M requirements vary significantly depending on manufacturer. Recommended for shallow ponds and where flow-directing properties are the main focus.
Air induced mixer Type A (NZ made)	Facultative ponds, for high mixing and aeration applications	Device with good aeration & mixing properties and good long-distance flow directing properties. Needs to be installed close to the embankment because blowers are installed outside of the pond. Aerator design and blower capacity need to be specifically adapted by manufacturer to each particular application. Relatively low capital costs and O&M requirements, but with higher running (power) costs. Recommended for facultative ponds (< 2m) in areas where high mixing and turbulent aeration is of benefit.
Air induced mixer Type B (US made)	Facultative and maturation ponds, for slow mixing and gentle aeration	Excellent aeration, slow mixing and good flow-directing properties with low power consumption. Can be installed in all locations within a pond due to its on-board blowers. Exists in two versions, aluminum and SS. Latter is to be used for any application anywhere close to the sea. Medium level capital costs, low O&M and low running (power) costs. Recommended for facultative and maturation ponds for all applications, which do not specifically require turbulent mixing.

Figure 3-15 **Brush Aerator**

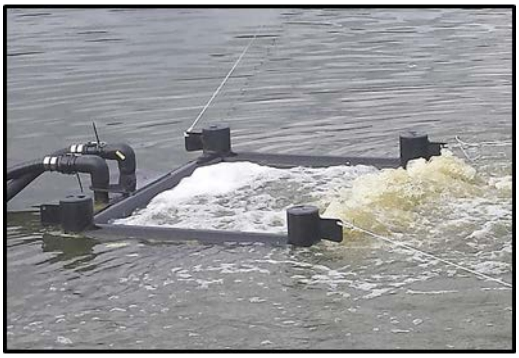


Figure 3-16 **Air induced Mixer Type A**

Figure 3-17 **Inclined Shaft Aerator**

Figure 3-18 **Air Induced Mixer Type B**

Typical situations in which aerators can be successfully used to achieve improvements in pond performance include:

- In the pond inlet area for odour control, in case of an increase in loading and/or to disperse the load (and sludge) rapidly over a wider pond area.
- For oxygen supplementation during day, or during night-time to prevent a possible pond crash due to low oxygen concentration.
- During a change of seasons to prevent pond stratification and pond turnover.
- In specific locations within the pond to prevent dead zones or to create back mixing and circular mixing zones.
- A few aerator types can positively contribute to the aerobic digestion of organic bottom sludge through a combination of aeration and mixing. This arrangement must recognise the increased oxygen demand from the re-suspended solids and the influence they may have on algal health.
- Aeration can help improve the pond's discharge quality. But a lack of artificial aeration may not be the reason for a non-compliance of a pond system. The operator should understand the underlying causes for non-compliance first.

The positioning of an aerator and the amount of turbulence it generates should be carefully considered at the time of selection. If an aerator/mixer with high turbulence is suited for installation towards the inlet of a pond and in areas with high sludge accumulation, an aerator with predominantly flow-directing properties will be better suited to prevent dead zones and for flow-directing. Less turbulence should be preferred towards a pond outlet or where surface mixing or flow direction is the dominant requirement.

Aerators are mostly installed in facultative ponds to address overloading, odours or sludge accumulation, but aerators can equally achieve effluent improvements when installed in maturation ponds. The disinfection properties of higher oxygen concentrations in ponds, as well as the difficulties for algae to develop significantly in continuously mixed environments, are both factors for which certain aerators can be used successfully. Aerators for maturation ponds would therefore be those with slow mixing rates, but good oxygen input.

Both the capital and operational costs of an aerator should be considered prior to purchase. While there may be a capital budget constraint, the total cost may be less for a more expensive aerator with greater efficiency running long hours. The combined capital, maintenance and power costs of one type of aerator can often render an initially more expensive aerator more attractive within a few years of operation than a cheaper one.

The addition of any aerator to a pond will have an impact on the O&M requirements of the plant, through the need for motor, bearing and general maintenance, but especially for its need for regular cleaning. The latter will be required more often if the pond is not or was never fitted with a raw influent screening device, or has never been desludged even though a screen has been installed. The aspects of accessibility for servicing and ease of cleaning and/or ease of removal should all be considered carefully at the time of aerator selection.

Damage to a pond as a consequence of the installation of an aerator can be easily avoided if adequate steps have been taken at the time of selection. Ponds with artificial liners require forward thinking and great care during aerator installation, placement and anchorage. Anchoring posts should be strong, correctly placed and anchor cables adequately sized and correctly fitted. Continuous movement by the aerator as well as wind and wave action can, over time, dislodge and pull simple steel stakes from the ground resulting in significant liner damage and/or a sinking aerator.

3.4.5. PASSIVE AERATION EQUIPMENT

In addition, or as an alternative to active, floating aerator equipment a pond can be retrofitted with passive, bottom deployed aerators or aerators suspended in the water column. In both cases the aeration consists of membrane diffusers or purpose-designed PDP (pressure differential piping), systems which are connected to a blower located outside of the pond. Similar systems have been developed using injectors with draught tubes set at regular distances on a pond base.

Similar to the active aerators, the passive aeration devices should be carefully selected depending on goals to be achieved and type of installation. Table 3-16 lists some of the currently available types of passive aeration systems and their recommended applications.

Table 3-16 Passive Aeration Devices for Facultative and Maturation Ponds

Type	Application	Comments
Membrane Diffusers	Most effective in small, deep ponds. Can be used in facultative ponds in areas of high loading to assist treatment and to prevent odour.	Can be effective for localized air injection & mixing, especially in linear arrangements either on the pond base or suspended from the surface. More effective in deeper areas >1.8m Relatively high air consumption, i.e. high power use Used for deeper inlet zones of facultative ponds
PDP Aeration	Most effective in facultative ponds to augment treatment capacity and in maturation ponds for algae control.	Can be deployed over large areas of the pond and will provide fine bubble aeration throughout. Can augment treatment capacity in case of load increase or for combatting algae in maturation ponds Various models are on the market with highly variable air outputs per meter, i.e. variable power use/m ratings. Requires care at installation, needs regular maintenance and special attention during pond desludging. Used for pond capacity augmentation, odour and algae control and for combatting dead zones
Draught Tube Aeration	Used overseas for mixing and aeration in facultative ponds	Can be implemented in small and wider areas. Increases in efficiency with increase in depth. High air output and high power use. Only use for spot aeration/mixing in ponds with well-screened effluent to avoid clogging.

3.4.6. SUBDIVIDING PONDS

Mara et al have found that the use of multiple ponds of the same combined surface area of a single large pond can improve the overall treatment quality of a pond system. Subdividing an oversized single pond to achieve higher quality treatment is therefore a realistic upgrade strategy.

A real improvement in effluent quality relies on the rigorous division of one large reactor basin into multiple, fully separated smaller basins in which the inflow and outflow as well as the overall pond hydraulics can be much better controlled. Significant improvements will therefore only be possible through full separation with embankments, new inlet and outlet structures and possibly mixers/aerators to create defined flow patterns in each new pond.

Such an upgrade has significant investment costs, as well as the loss of some reactor volume through the construction of new embankments within the existing pond. Successful examples are in larger ponds at Blenheim, Nelson North, Queenstown, Greytown, Geraldine and Temuka. The installation of permanent dividing walls (e.g. sheet piling, concrete posts with pre-cast concrete panels) is an alternative for smaller ponds, but may not be less expensive.

A more economical option for smaller ponds is the division by floating curtains. The separation by curtains will never be as effective as a division by solid earth banks or walls, as curtains will always allow a certain amount of bypass and return flows. Also, curtains may not be suitable for larger ponds because of the excessive forces generated by wind and waves (refer also section 3.4.3.3). A well-designed curtain may not achieve the full treatment quality improvements of a solid wall division. Floating curtains in smaller ponds can nevertheless be applied successfully to achieve improvement:

- A continuous curtain wall can retain floating solids and protect downstream treatment equipment (e.g. aerators, growth media etc.).
- Multiple curtain walls can be used to create individual treatment zones with different process characteristics (e.g. high aeration zone, algae settling zone, facultative/maturation zones).
- By increasing the number of curtains their overall effectiveness can be increased.

To achieve maximum effectiveness, floating curtain walls have to be carefully designed and have to be of a high quality in respect to material used, their fitting within the pond and their sealing on the embankments. Material selection (fully impermeable or partially impermeable) should be adapted to the goal to be achieved. Transfer openings should be adapted in size and position to the characteristics of the effluent to be transferred to the next zone (e.g. opening located below the algae level for facultative ponds).

With floating separation walls the designer should keep in mind that pond division will only be partially achieve, even by using multiple curtains. The inlet and outlet of a pond should remain as far from each other as possible and be separated with as many curtains as possible to achieve best overall results.

3.4.7. ATTACHED GROWTH MEDIA

The addition of growth media to a facultative pond can achieve significant capacity and final effluent quality improvements in line with those of mechanical treatment plants. Growth media in ponds uses similar plastic or other type of support media as an activated sludge plant: The biomass, which attaches to the media, provides extra treatment capacity to the suspended biomass. Similar to the addition of growth media to a mechanical plant, the addition of growth media to a pond system does rely on a high biomass concentration within the reactor.

In contrast to media used in a conventional mechanical treatment plant, growth media in a pond will not be exposed to permanent high turbulence. It is therefore designed differently. It will also hold up to 95% of all active biomass in a pond with about 5% remaining as free-floating biomass. Therefore, the traditional oxygen generation through algae, wind action and mechanical aerators will not be sufficient to provide the extra oxygen required by this additional biomass. The addition of growth media always needs to be combined with an adequately designed growth-media dedicated aeration system. Such a system not only provides sufficient oxygen, but also a mixing of the water column and adequate contact between the nutrient-rich effluent and the attached biomass.

Systems specifically targeting Nitrification therefore need to accurately determine the surface area required for their amount of nitrification, the need for this to be replenished by turbulent mixing and to provide the necessary aeration requirements.

By shifting the WSP from an algae and suspended biomass based process to an artificially aerated and attached biomass process the dependence on sunlight and wind mixing is significantly reduced. The amount of growth media and aeration is determined according to loading, temperature range, HRT and the treatment standard to be achieved. The operator is then able to take control of the process by adjusting and optimizing the amount and location of aeration and mixing according to treatment requirements and seasonal changes.

Figure 3-19 Curtain Growth Media

Figure 3-20 Cellular Growth Media

Growth media exists for installations into shallow (1.2m) as well as into deeper ponds (i.e. 3.0m). Although it can – theoretically – increase a pond capacity up to 10 times, a growth media system design requires the involvement of a specialist. Its sizing has to take into account the pond hydraulics, pond depth, pond base horizontality, HRT as well as multiple wastewater and environmental parameters. Also, the resulting system will only be able to achieve its design discharge quality if it is based on a comprehensive set of data. It is therefore important that the operator knows his plant well and has collected representative data over a sufficiently long time.

Growth media upgrades can allow a pond system to achieve treatment standards equal to those achieved by an activated sludge or SBR plant. The sludge production of a pond system retrofitted with growth media will not noticeably increase compared to its pre-upgrade due to the slow growth of attached biomass as well as the sludge digestion effect of the permanent aeration.

A growth media plant upgrade as an advanced stage pond upgrade should only be implemented once inlet, outlet, screening and hydraulic optimization has taken place. Overall costs for an upgrade of a pond using growth media can vary between 30% and 100% of those of an activated sludge plant depending on the available infrastructure. The significant cost savings will therefore often only show during operation with about 20% to 50% of those of a mechanical plant. Growth media upgrades also have the added advantage of maintaining simplicity of operation and operators need not be trained to the same level of process knowledge as for an activated sludge or similar mechanical plant.

3.4.7.1 WARNING 1 – MEDIA PERFORMANCE

There are various types of growth media for ponds available on the international market which are overseas products designed and developed specifically for their application in treatment ponds. A few locally made alternatives using trickling filter media, geotextiles or similar have been installed in New Zealand, with dire consequences. Operators and designers should therefore take great care to ensure growth media suppliers can provide successfully operating reference plants as proof for the quality and reliability of their product and their capability to design plant upgrades. Reference plants should have been operating for several years and should have their performance verified. The consequences of inadequate growth media selection can not only result in the loss of significant capital investment, but also in severe effluent quality degradation and high removal and disposal costs for the media.

Figure 3-21 Inadequate Media Type A

Figure 3-22 Inadequate Media Type B

3.4.7.2 WARNING 2 – MEDIA AERATION

Growth media always comes with its own dedicated aeration system, which has been adapted to the requirements of the specific growth media (or sometimes vice versa). This typically includes provision for satisfying the biochemical reactions e.g. BOD removal or nitrification, mixing and scouring excess growth off the media surface. Some aeration systems operate with little output and turbulence, other systems operate in various conditions depending on the growth media within in its processing or cleaning cycles. Combining a non-adapted aeration system with a growth media can lead to anaerobic conditions in a pond, effluent degradation, and even potential damage to the growth media or the aeration system itself.

3.4.7.3 WARNING 3 – HRT VS TEMPERATURE

The quantity of media and aeration required is directly dependent on the type and level of nutrients to be reduced, the effective HRT of the pond and the temperature range within which the treatment level has to be achieved. For advanced Nitrification and Denitrification a minimum effective HRT of 20 days in the treatment pond should be available, although this can vary depending on the type of proprietary equipment. If Nitrification at water temperatures below 10 °C has to be achieved the quantity of media and aeration required increases significantly. For Nitrification and Denitrification below 8 °C it may be prudent to add a low-temperature post-pond treatment to maintain consistently high nutrient reduction.

3.4.8. FLOATING WETLANDS

Artificial floating wetlands used in waste stabilization ponds are a development from natural floating islands, which exist in some lakes. The artificial floats consist of a base matrix made from three-dimensional synthetic webbing into which selected wetland plants are grown. To give the raft its buoyancy it is combined with or injected with a floating material (e.g. expanded polyurethane foam). Over time the plants develop a root system, which penetrates the float and hangs about 600mm down into the water column below. Above the water the plants grow naturally and require regular maintenance.

The floating wetland affects the wastewater in four ways:

- The plants take up and convert nutrients through their root system.
- The roots provide oxygen and act as growth media for natural biomass.
- The roots act as a natural filter through their tightness and attached biomass.
- Multiple rows of floating wetland rafts prevent sunlight from reaching the water and therefore reduce the pond's algal growth.

Some floating wetland manufacturers have added a curtain to one side of the wetland raft to increase solids retention during plant growth and, if the water is deeper than the length of the root system, to seal or partially seal with the pond floor.

The size of the wetland rafts has increased over the years. Longer rafts need firm anchoring at regular distances to hold the heavy raft in place. The rafts' width has increased from around 2m to more than 4m with a central access way for servicing and cutting the plants.

Floating wetlands have a lot in common with artificial growth media (refer 3.4.7); they significantly increase the amount of biomass and general bioactivity, which directly impacts on the pond area beneath and close to them. Floating wetlands can therefore, in certain circumstances, achieve significant nutrient and solids removal rates. Their efficiency depends on a good hydraulic flow pattern, an adequate loading rate per square meter and sufficient oxygen in the pond water.

As with artificial growth media, the installation of floating wetlands should only be considered once all basic upgrade steps, including pond desludging have been implemented. Floating wetlands can be used for a wide range of applications and it is important to establish what their true purpose will be and their compatibility with the pond in question before even considering design and sizing options e.g.:

- Are the floating wetlands installed to replace an existing, traditional, failed wetland?
- Is this new floating wetland installed to satisfy cultural requirements?
- Will the floating wetland be used as a solids retainer only (e.g. at the outlet of a facultative or a maturation pond)?
- Will they also have to achieve nutrient removal? What kind? How much?
- What loading rate can a wetland raft accept with and without dedicated aeration?
- How can the maximum loading rate per raft be maintained?
- Could existing pond conditions impact on their treatment (i.e. sludge accumulation) and have these to be addressed first?
- How easily are the rafts accessible and stable for plant cutting and general maintenance?
- Who will maintain them?
- Is there a plan for pond desludging in future?

Figure 3-23 Floating Wetland (new)

Figure 3-24 Anaerobic Pond Cover

Floating wetlands are not a treatment solution for all ponds and will not solve all pond problems. While a number of floating wetland installations in New Zealand have shown good nutrient removal results, an equal number of plants have shown that overly optimistic design or treatment quality assumptions can lead to substandard results and non-compliance. Failure to adequately prepare the plant (e.g. not desludging prior to installation) has also led to failures to perform and even to a deterioration of effluent quality.

The potential range of applications of floating wetlands is much wider than for traditional wetlands. They are more compact and allow access for maintenance and plant replacement independently of the water level. However, their capital investment costs are high and maintenance costs are relatively high.

Floating wetlands should be considered as one upgrade option out of many. A close collaboration between experienced designers, operators and suppliers will establish the number of rafts required and their positioning. When considering floating wetlands one should keep in mind the possibility of a phased upgrade approach, which allows confirmed treatment improvements in increments and to optimize the cost-benefit balance of an installation.

3.4.9. POND COVERS AND IN-POND ROCK FILTERS

This section combines two treatment technologies for addressing odour, solids or algae reduction in waste stabilization ponds. A clear distinction has to be made between technologies used for anaerobic ponds, where the main focus is odour prevention and for facultative and maturation ponds where the main focus is suspended solids and algae reduction.

Floating covers for anaerobic ponds can be divided into two categories:

- Fully impermeable floating covers which seal the whole pond and are used for odour and greenhouse gas emission prevention and for biogas collection.
- Floating, permeable, natural or artificial covers which are only used to prevent odours.

Fully impermeable covers for anaerobic ponds are not considered an upgrade option and are therefore not discussed here.

Floating, permeable, natural covers (crusts) on anaerobic ponds form by themselves if the pond is fed with sufficiently concentrated loads of floatable material. Such natural covers/crusts provide an effective means of preventing odour nuisance from anaerobic ponds. They also reduce wave action and therefore also protect the pond embankments and provide some thermal insulation to the pond. While all anaerobic ponds should be fenced off for health and safety purposes, this is particularly important for those with natural covers as they can easily be mistaken for a meadow.

Floating, permeable artificial covers are not recommended for anaerobic ponds unless the water surface under the cover remains clear at all times, i.e. without floating sludge, solids or oil and grease. This is generally only achieved on some selective industrial plants and even in such special conditions the risks remain that the cover clogs over time or does not resist New Zealand's high UV exposure. The use of permeable artificial covers on anaerobic ponds on municipal plants is also not recommended because of the extremely high failure rate of such installations in the past and the resulting high costs, environmental and health and safety issues related to their removal. If a new type of cover were to be developed an in-depth due diligence should be undertaken before selection.

Floating wetlands on anaerobic ponds could potentially present an alternative to purely natural covers for those applications where the load and oil and grease content of the wastewater is insufficient or wind or climate conditions are such that a natural cover does not develop. To date there are very limited examples for such installations and some have failed, and therefore insufficient data is available on their long-term operation and maintenance. There is also no information available on the long-term effect of the anaerobic pond water on the root growth of wetland plants and the impact of the plant roots on treatment. Considering the lack of information available on the benefits and drawbacks of floating wetland covers for anaerobic ponds, particularly long-term operation experience, and the high installation costs (higher than impermeable covers), their use is considered high risk.

Pond covers for facultative and maturation ponds provide an option to reduce algal biomass, the associated BOD_5 and TSS in a pond discharge through algal settling by eliminating light and reducing wind mixing. Use is consequently focused on the discharge end of a pond. For maximum algae elimination the covered volume has to have a hydraulic residence time of at least 4 days.

Care has to be taken in respect to the selection of material used as a pond cover. Materials used range from individual small floats (e.g. hand-size hexagon shaped floats, black, hollow PE balls) to specially designed and manufactured continuous floating covers. This equipment is mostly manufactured overseas and has to be imported at significant capital cost.

In-pond rock filters for facultative and maturation ponds present an alternative to artificial pond covers as they also eliminate light within the filter. Rock filters have the added advantage in that they will grow biomass on the rocks, which will bind algae and floating biomass. They act as artificial growth media and can assist with nitrification and especially denitrification.

The type of material used has an influence on the effluent treatment (e.g. Lime rock will provide extra alkalinity). It is important that rock filters are constructed using sufficiently large rocks (100 to 250mm diameter) with minimum undersized material. Otherwise the openings can clog up over time and/or the rock filter will rapidly develop anaerobic conditions.

Neither floating covers nor rock filters should be installed in areas of a pond that are treating high organic loads or that are not desludged. The result can have multiple detrimental consequences such as cover or filter clogging as well as the establishment of anaerobic conditions, effluent deterioration and the generation of odour.

3.4.10. CHEMICAL DOSING

Chemical dosing can be used in waste stabilization ponds for a number of short-term emergency situations and for longer term treatment. Short-term applications include:

- Short-term chemical oxygen supplementation.
- Short-term action after a pond crash.
- Short-term treatment to tackle excessive algae growth.

These situations are considered to fall under O&M rather than representing a treatment upgrade. They are therefore discussed in Section 4 of the guidelines.

The chemical dosing implemented to achieve longer-term treatment improvements and which fall therefore under WSP upgrades include:

- Chemical dosing for alkalinity adjustment
- Chemical dosing for total phosphorus reduction.

3.4.10.1 CHEMICAL DOSING FOR ALKALINITY ADJUSTMENT

Alkalinity adjustment can become important after upgrade of a pond with the installation of growth media. Alkalinity adjustment is necessary if the raw effluent has insufficient initial alkalinity to support a high level of nitrification. In this case the pond can experience a rapid and sharp drop in pH, which will require rapid intervention to avoid the pond crashing.

Adjustment of alkalinity can be implemented at the front end of the plant (e.g. at a lift station, after the inlet screen etc.) or directly into the affected pond. The former will be applied in a precautionary manner or as a long-term alkalinity adjustment. It will render the raw influent more treatable in case of a specific nitrification / denitrification process within the ponds.

The addition of alkalinity within a pond has to be implemented immediately if a sharp drop in the pond's pH has already been noted. In such a case the sole addition of alkalinity at the plant's inlet will take too long to reach the whole pond volume and a pond crash would be likely. Alkalinity dosing has therefore to be implemented over the whole of the affected pond, either by motorboat addition of the chemical powder directly into the pond or by producing a highly concentrated solution and spraying it onto the pond from the embankment using a fire hose.

A number of chemicals are available for alkalinity adjustment (refer Table 3-17). Each chemical also creates a different pH/alkalinity relationship but control is typically based on the pond pH measurement. For example some chemicals can over-correct pH with small excess dosages while others will only adjust to pH7 independently of how much is being added.

Some chemicals are significantly cheaper than others (e.g. hydrated lime (Calcium hydroxide)) but will contain significantly more insoluble matter, which can settle out in pumping stations, pipework or dead zones.

Some of the chemicals used for alkalinity adjustment are also hazardous and others highly irritant. If deciding to use such chemicals the operator should understand the health and safety requirements and have had adequate training to handle such chemicals.

For emergency and short-term applications it is therefore recommended to utilize Sodium Bicarbonate. It may be more costly than some of the alternatives but it is a safe product to handle and has both the advantage of containing minimum waste (i.e. inert matter) as well as increasing the level of alkalinity without changing the pH past pH7.

Table 3-17 Selective Chemicals Used for Alkalinity Adjustment

Chemical	**Comments**	
	Advantage	**Disadvantage**
Hydrated Lime / Calcium Hydroxide [$Ca(OH)_2$]/ Slaked Lime	Relatively cheap, available.	Not easy to handle (Read product H&S sheet). Limited solubility. Used as a slurry, which needs to be

Chemical	Comments	
	Advantage	Disadvantage
🟧		kept constantly in motion otherwise it will settle and will clog pipework rapidly. Can raise the pH above pH7 if overdosed.
🟥 Caustic Soda / Sodium Hydroxide [NaOH]	Fast-acting. Easier dosing than with solid agents.	Easy to overdose and end up with pH 9+. More hazardous than other agents.
🟥 Quicklime/Calcium Oxide [CaO]	Cheaper than hydrated lime.	Not easy to handle (Read product H&S sheet). Highly irritating dust. More impurity than hydrated lime. Can raise pH above pH7 if overdosed.
🟩 Limestone [$CaCO_3$]	Cheapest. Will not raise pH above pH7 when overdosing. Can be used for long-term, slow release.	Highly insoluble so slow to react. Will sink to the bottom, where it will not contact the main body of water.
🟧 Soda Ash / Sodium Carbonate [Na_2CO_3]	Cheap and fast-acting.	Can raise pH over pH7 if seriously overdosed.
🟩 Sodium Bicarbonate [$NaHCO_3$]	Relatively easy to handle. Will not raise pH above pH7 when overdosing. Readily available. Fast acting.	More expensive: needs 60% by mass more than soda ash for equivalent chemical effect.

🟥 Hazardous	🟧 Irritant	🟩 Benign

Table provided by Julian Glen of Prolyze Ltd, Auckland

For longer-term alkalinity adjustment the raw influent composition as well as the reason for a pH drop should be investigated in detail. The selection of the chemical to be used should be based on process considerations and health and safety issues as well as chemical and implementation costs and any extra O&M procedures and costs, which could be generated by the product and/or its implementation.

3.4.10.2 CHEMICAL DOSING FOR TP REDUCTION

The requirements for WSP to achieve more stringent TP reduction targets often result in the addition of external chemical dosing and filtering systems. This is discussed in more detail in section 3.2.8.

Another option consists of direct dosing chemicals into the pond itself. For in-pond chemical dosing ferric-based reagents are preferred over alum-based products. The reaction products from ferric-based TP reduction are chemically stable and can be stored long-term in the base sludge. Ferric is more expensive and is more hazardous for handling, but is more efficient than Alum over a wide pH range and does not present a potential environmental hazard for fish such as excess Alum if discharged into the environment.

Overseas, ferric salts are used for TP reduction in large ponds with long HRT in a batch-type application. Upon TP reaching its maximum concentration at the discharge the operator distributes ferric over the whole pond, often mixing it into the water column with the means of the impeller of an outboard motor. As a result the TP concentration drops rapidly in the whole pond and will only increase back up slowly over time. A treatment plant with 80 days HRT will only need one such treatment every 3 to 5 months.

In New Zealand, ferric dosing is generally implemented on an on-going basis, i.e. a small contact tank is installed upstream or between two ponds and the resulting ferric phosphate settles out in the pond with the sludge. Ferric phosphate is a stable compound and will not dissolve unless the pH of the pond drops below pH5, which is unlikely in a normally operating pond system. Long-term the ferric phosphate can be removed when the pond is desludged.

TP reduction for Resource Consent purposes can be optimized by ferric injection at the end of the treatment process. In this instance chemical dosing can be implemented post-pond discharge in a separate small reactor if the operator feels uncomfortable with dosing directly into the pond. Dosing at the end of the process will allow a more accurate dosing to target the exact amount of residual TP required. It will allow a reduction in dosing rate, as some TP will already have been taken up by the biological process upstream. The amount of ferric phosphate generated will therefore be less. Post-pond treatment is also useful if only seasonal TP reduction is required.

3.4.11. ULTRASONIC ALGAE CONTROL

Ultrasonic devices can be used for controlling algae in large reservoirs and ponds to improve the clarity of the water. There are many brands and systems available and their efficiency depends on equipment quality as well as on the type of algae to be targeted. Ultrasonic Algae Control should only be installed in well-maintained ponds as a final treatment stage, i.e. in maturation ponds to improve UV disinfection rates and to reduce algal biomass associated TSS and BOD_5 in the discharge. Ultrasonic treatment is not appropriate to minimize algal biomass in the discharge from facultative ponds or when nutrient levels are still high enough to promote algae growth.

The ultrasonic unit's efficiency depends mainly on the type of algae present, the device's power output and its location. Efficiency can be significantly improved if the ultrasonic unit is placed in a well-defined treatment zone, i.e. if the area within the pond in which the device is installed is separated from the rest of the pond with floating curtain walls or similar. The treatment zone should also be located directly prior to the pond outlet so that the treated effluent is discharged before algae regeneration can take place.

Ultrasonic devices can be deployed rapidly and can be used as a short-term solution or as seasonal treatment. The efficiency of ultrasonic algae control is highly site-specific and is best determined by long-term testing at the site. System sizing and installation should be implemented by the supplier in accordance with the manufacturer's requirements and a performance specification. The success of this treatment process is therefore not guaranteed from the start. However, the low costs for acquiring and running such a unit compared with its potential benefits make it worthwhile investing in a trial.

3.4.12. ENHANCED MICROBIAL DIGESTION

Enhanced Microbial Digestion can be used to halt or reduce sludge accumulation in WSP. It is a method that relies on the natural processes by which bacteria digest wastewater colloidal and particulate material. Microbial digestion occurs in all WSP, however, as evidenced by sludge accumulation in WSP, the rate of digestion that typically occurs is insufficient to prevent sludge build up. Enhanced Microbial Digestion aims to increase the rate of bacterial digestion in WSP, so that sludge accumulation can be halted or reversed.

3.4.12.1 THEORY

Many naturally occurring bacteria have the capability to excrete enzymes outside of the cell into the wastewater (exoenzymes). These enzymes hydrolyse colloidal and particulate organic material into simple, soluble material that can be taken up by the bacteria and broken down to inorganic compounds. In this process, a fraction of the organic material (10% to 40%) is converted into new biomass, and the remainder is converted to CO_2 NH_4-N, DRP and water, thus causing a net reduction in total sludge.

The rate of hydrolysis of colloidal and particulate organic substrate significantly influences the rate of sludge accumulation or digestion. The rate of hydrolysis can be increased through physical/chemical methods or by Enhanced Microbial Digestion.

3.4.12.2 ENHANCED SLUDGE DIGESTION THROUGH PHYSICAL – CHEMICAL MEANS

Sludge digestion is increased by reducing the average size of sludge particles by methods including:

- Maceration. Maceration physically chops, grinds, or blends sludge into smaller particles.
- Chemical addition. Chemical addition uses acids or bases such as sodium hydroxide (NaOH), ammonia hydroxide (NH_4OH), and sulphuric acid (H_2SO_4) to promote hydrolysis of the wastewater
- Thermal Hydrolysis. Thermal hydrolysis is achieved by heating the wastewater to 100-200 °C for 30-120 minutes.
- Sonication. Sonication is the application of ultrasound waves to sludge for a period of time.

Research has shown that each of these methods converts colloids and particulate substrate into soluble substrate at varying efficiencies, and that this conversion improves overall sludge digestion. However, while these methods are helpful in operations such as anaerobic digesters, their use is not generally practical in WSP.

3.4.12.3 ENHANCED MICROBIAL DIGESTION

Enhanced Microbial Digestion is the process of adding specific cultures of microorganisms to WSP in quantities sufficient to increase the average rate of hydrolysis, resulting in reduction of accumulated organic sludge.

Many species of bacteria are capable of producing exoenzymes that hydrolyse wastewater sludge, but they grow at a slow rate so don’t often occur in high numbers in WSP. Moreover, different exoenzymes hydrolyse specific organic function groups, so different exoenzymes are needed to digest the different (e.g. starch, cellulose, protein and fat) components of WSP sludge.

Therefore, Enhanced Microbial Digestion adds sufficient quantities of a diverse range of exoenzyme producing bacteria, which together can significantly increase the rate of hydrolysis compared to the natural rate of hydrolysis in the WSP.

3.4.12.4 ENHANCED MICROBIAL DIGESTION OPTIONS

One version of Enhanced Microbial Digestion is the addition to WSP of mixed culture bacteria that are capable of high rate and broad spectrum enzyme activity. This method requires that the added bacteria are capable of surviving in the WSP environment and capable of producing the quantity and quality of needed exoenzymes to significantly increase the existing rate of hydrolysis in the WSP. Over time, the added bacteria that are producing the exoenzymes will die-out due to their slow reproduction rate. Therefore, repeat additions of bacterial cultures will be needed to maintain the increased hydrolysis rate.

A second version of Enhanced Microbial Digestion is the addition of commercially prepared enzymes to the sludge in WSP. With this option, the enzyme product must contain all the digestive functions needed to hydrolyse the WSP sludge. As enzymes are proteins, and protein digestion must occur for Enhanced Microbial Digestion to be effective, enzyme products will have a limited time of usefulness in the WSP. Frequent repeat doses will be required to continue treatment.

Both versions of Enhanced Microbial Digestion are available in New Zealand.

3.4.12.5 UPTAKE OF THE HYDROLYSED SOLUBLE ORGANIC MATERIAL

Hydrolysis is considered the slowest ‘rate-determining’ step in Enhanced Microbial Digestion. The product of hydrolysis is low molecular weight soluble organic material which is readily consumed by any bacteria that are present in the wastewater system. Thus, in theory, the use of Enhanced Microbial Digestion should not cause an increased discharge of soluble organic material in the final effluent. However, especially in systems with extremely short retention times, care must be used to ensure that effluent BOD / COD concentrations do not increase while using Enhanced Microbial Digestion.

3.4.12.6 PRACTICAL CONSIDERATIONS FOR ENHANCED MICROBIAL DIGESTION

All of the following are important when evaluating the possible use of Enhanced Microbial Digestion to reduce accumulated sludge in the WSP

- **Sludge solids concentration and volume**. Any use of Enhanced Microbial Digestion will require knowing the wet sludge volume and dry solids concentrations in the WSP prior to application. Accurately measuring the sludge volume and solids concentration during the course of application is essential to ensuring measurable treatment success (see section 4.2.10). As Enhanced Microbial Digestion progresses and organic solids are consumed in the upper more biologically active sludges, the lower compacted solids will begin to hydrate and increase in volume until equilibrium in solids concentration is reached throughout the sludge column. This can be monitored as a progress indicator during the first phases of treatment. The initial reduction in solids concentrations can equate to the removal of significant quantities of material while the overall sludge volume may not have reduced by much.
- **Safety**. Whether using an enzyme product or mixed bacterial cultures or a combination of both, the safety of applicators and compliance with New Zealand and local laws with respect to biosecurity are essential. All users of Enhanced Microbial Digestion should ensure that the supplier provides the proper Safety Data Sheets, and where applicable, proof of legal importation of the products into New Zealand.
- **Effluent Quality**. In WSP with heavy sludge accumulation or where effluent compliance is borderline, caution must be exercised to ensure good effluent quality. In such situations, a gradual stepwise initiation of the treatment program with ongoing monitoring is essential.
- **Cost Effectiveness**. The cost / benefit of standard sludge removal vs Enhanced Microbial Digestion should be compared. Enhanced Microbial Digestion, when properly implemented and measured, has the potential to significantly reduce the cost of sludge removal in WSP.

The rate of reduction of accumulated sludge will depend on many factors including the age of the sludge, history of chemical addition to the sludge, presence or absence of aeration and mixing, climate, and influent loading. For example, Enhanced Microbial Digestion will theoretically digest organic sludge, but will not digest inorganic sludge (grit). Therefore, the amount of sludge reduction that can be achieved with an old, digested pond sludge which has a high inert solids fraction is less than a younger sludge with a lower inert fraction.

The most important considerations for the WSP manager are to know the general rate of sludge build up over time, the starting sludge volume and solids concentrations, intermediate and final sludge inventory, maintaining or improving the quality of the final effluent discharge, and a cost comparison (e.g. Enhanced Microbial Digestion compared with sludge removal, dewatering and disposal).

3.4.13. POND CONVERSIONS

Apart from the use of WSP as treatment process units, the structures themselves represent a valuable asset as a potential reactor for alternative treatment processes. However, seismic factors need to be considered. During the Canterbury earthquakes in 2010/11, none of the ponds in the region failed to the extent where the pond contents were discharged. However, the Christchurch Wastewater Treatment Plant Ponds were damaged and subsequently required significant repairs and strengthening to current seismic design standards. It is noted that ponds designed prior to about 1980, may not have been designed to resist significant earthquake forces.

If none of the above upgrade options are considered sufficient or adequate for the long-term operation of a treatment plant, the conversion of a facultative to an aerated lagoon or even to a SBR or activated sludge plant can be considered. Numerous examples of such conversions on industrial as well as municipal sites are available in New Zealand. The downsides of such conversions are the significantly higher sludge production and operating costs, as well as the advanced level of training required for the operators.

Conversions of anaerobic ponds to aerated lagoons or activated sludge plants are generally more successful because of the smaller surface area and greater depth of the original pond. Great care has to be taken when converting such ponds to adequately protect embankments and the pond base against erosion as well as for the selection of the aeration system. A detailed hydraulic analysis is also required to ensure that the anoxic – aerobic zone separation will be achieved in an aerated lagoon and that the sludge will be maintained in suspension in an activated sludge plant.

The conversion of facultative ponds (e.g. 1.5m water depth) can be challenging and might require raising the embankments. The investment in design, engineering and earthworks can nevertheless be worthwhile with potential savings compared with the construction of a new concrete structure.

Figure 3-25 Anaerobic Pond Conversion

Figure 3-26 ... to an Activated Sludge Process

A number of companies overseas have developed technologies targeted specifically at converting WSP to high rate plants such as SBR or growth media based aerated lagoons. Not many plants in New Zealand have yet been converted using these technologies, but this may change over time.

3.4.14. OTHER

A number of further in-pond upgrade options are currently being developed or have recently been installed into plants overseas and are therefore not yet ready for inclusion into this Guide. The general trend is towards increasing the overall pond depth from the traditional 1.2 -1.5m water depth to 2.0 and even 2.5m water depth. This gives better advantage of the pond's flow buffering capacity as well as effectively merging the new technologies into existing ponds.

Increasing pond and operating water depth is therefore becoming an option consistent with a general upgrade of WSP. This can be done by deepening an existing pond; although it will affect the existing liner and can potentially interfere with the ground water. Another option is to instead lift the pond's embankments. This has the advantage to not only gain operating depth, but also surface area. Existing pumping stations can often accommodate one extra metre of lift and therefore only require minimum adjustments. Modifications to inlet and outlet structures in accordance with sections 3.4.1 and 3.4.2 are also easier after the lifting of a pond's embankments.

Increasing a pond's treatment volume through raising its existing embankments has the added advantage that it allows pond operation at varying water levels, e.g. loads can be stored and treated at extended HRT and storm flows can be more effectively stored and released at a slow rate. Looking into the future such deeper ponds will be ready to accept growth media or other, newer, technologies to achieve higher treatment standards without the need for new extensive civil works.

3.5 POST-POND UPGRADES

3.5.1. POST FILTRATION

A filtration stage after a facultative pond or even after a maturation pond can add significant benefits to the overall treatment. It can be used for remaining solids and algae TSS and BOD removal especially if combined with chemical precipitation with the added benefit of TP reduction. Filtration with chemical precipitation will also achieve a 1 to 2-log reduction of *E. coli* and *Faecal Coliforms*.

The downside of post-pond filtration is that it has to be sized to treat the maximum possible discharge flow, i.e. plant inflow plus the rainfall onto the ponds, which for large area ponds can significantly increase pond outflows, and hence the size of the required filtration system. Another potential downside resides in the disposal of the concentrated solids. Disposing of this waste in an upstream pond is not recommended as it will contribute to sludge accumulation and over time release nutrients (e.g. NH_4-N) leading to overall effluent deterioration. Instead it should be disposed into a dedicated solids storage pond for concentration and ultimately off-site permanent disposal or re-use. Table 3-18 lists some of the filtration systems and their recommended applications.

Table 3-18 Post Filtration Devices for Facultative & Maturation Ponds

Type	Application	Comments
Rapid Sand Filtration	For algae and TSS removal. Can be used in conjunction with chemical dosing for TP reduction. Should not be used for TP reduction using Alum without pH and alkalinity control to avoid severe clogging.	Standard deep-bed sand filter, similar to those used in water treatment. Removes solids through depth filtration (i.e. over the first 500 to 800mm of the filtration media). Needs to be backwashed regularly, therefore requires at least two filters. Correct and precise sand grading, adequate backwash air and flow capacity and careful design of the effluent distribution are all essential elements of such a filter. Often requires pumping between pond and filter. Can be effective if correctly designed but are expensive.
Continuous Backwash Sand filters	For algae and TSS removal. Can be used in conjunction with chemical dosing for TP reduction. Should not be used for TP reduction using Alum without pH and alkalinity control!	Deep-bed filters remove solids by depth filtration. Constant removal and washing of the sand allows continuous operation. Exists in vertical and horizontal versions. Effective for solids removal. Not recommended for TP reduction using Alum as these filters are difficult to clean once clogged. Material compatibility should be checked before using Ferric salts. Typically requires pumping between pond and filter. Expensive, but generally reliable and long-lasting when operated correctly.
Slow Sand Filters / Intermittent Sand Filters	For algae and TSS removal, BOD_5 and FC and *E. coli* reduction. Not recommended for TP reduction.	Shallow-bed filters remove solids by a combination of surface and partially depth-filtration. Requires large filtration beds, which are either fed continuously at a slow rate or which are fed intermittently. Expensive but simple and reliable to operate. Requires regular operator input for cleaning. Can often be operated by gravity.
Micro-screening	For TSS reduction, excluding most algae	Micro-screening is effective for solids removal such as biological floc and inorganic matter. But it is only of limited effectiveness for algae removal even at aperture sizes down to 5 micron.

Most failures involving the use of filters after stabilization ponds observed in New Zealand are either due to an incorrect sizing of the filters or, more often, due to the use of Alum as the flocculent without adequate control systems to measure and adjust alkalinity and pH prior to dosing. This rapidly results in an infiltration of excess Alum into the depth of the sand bed with the effect of severe bed clogging, incomplete backwashing or a complete failure of some automatic backwashing filters. In such cases it is not the filters, which are to blame, but the lack of understanding by the operator of the intricacies of Alum dosing and the necessity for the required comprehensive pH control system when using the cheaper Alum instead of Ferric salts.

3.5.2. MEMBRANE FILTRATION

The use of membrane filtration (micro or ultrafiltration) as post-treatment has become more common in New Zealand e.g. at Dannevirke, Helensville, Matamata and Motueka. It provides the advantage of complete solids removal combined with a disinfection stage. It can therefore achieve high discharge standards on both accounts.

Membrane plants are normally supplied on a design-build basis and these factors need to be considered by the designers who now have experience in NZ:

Type of process: A membrane reactor, even if only used as a filtration and disinfection device is a sophisticated treatment plant, which can be fully automated. It requires well trained operators and regular servicing and maintenance. It relies on power to operate and in a pond situation it requires pumps to lift the effluent into the plant and produce the necessary pressure against the membranes. Membrane plants are compact and can have a significant foundation loading which may require ground improvements.

Type of membrane: Only a few membrane suppliers offer membranes which are specifically designed to operate on pond effluent, i.e. at a TSS concentration, including algae, of between 100 and 200mg/l in the pond, which translates to 500mg/l to 1,000mg/l in the reactor. Most membranes on the market are designed for either MBBR plants (MLSS of 10,000 to 15,000 mg/l) or potable water applications (TSS of 50 to 300 mg/l). Using inadequate membranes generally involves a reduced flow capacity, higher backwash rate and frequency and a shorter membrane life expectancy.

Flow limitations: The costs and size of a membrane plant are directly proportional to the flow it has to treat. Peak inflows combined with rainfall on ponds can result in significant and sudden flow increases. Unless the ponds have an effective in-built buffer capacity (e.g. additional freeboard for storage) the membrane plant should be sized for peak discharge flows. Membrane plants do allow for short bursts of peak flows, but their effectiveness, life and run lengths are often overrated by the suppliers. Peak flow treatment has therefore to be considered with caution in a plant combining membranes and ponds and a substantial safety factor is recommended.

Return rate: Membranes have to be backwashed frequently. In addition, they have to be chemically cleaned at regular intervals. These flows are generally returned to the front end of the stabilization ponds. Here they will add to the overall flow and will therefore reduce the HRT of the ponds. Membrane plant return rates currently range between 10% and 30% of the flow treated. The use of incorrect membranes, operating membranes in peak flow conditions as well as aging membranes will all result in higher return rates. These factors have to be taken into account in respect of the plant's overall HRT as well as to the organic and nutrient load returned to the front end of the ponds. A reduction in the overall plant's HRT will further reduce its capacity for nutrient removal (e.g. NH_4-N, TN).

An optimal post-pond membrane plant will focus on limiting peak flows to the membranes by using the freeboard flow buffering capacity of the ponds. It will incorporate a membrane plant with ample spare capacity, reliable and high-quality membranes and the possibility for modular capacity expansion over time. It will have an overall return rate of less than 20% (preferably less than 15%) as a "not-to-exceed" performance criterion and ensure that this extra flow does not affect the ponds' HRT (e.g. through increasing the operating level and volume). An increase in nutrient load at the pond system's inlet due to backwash return will also have to be taken into account in respect to current and future treatment and effluent discharge requirements.

3.5.3. DAF OR IAF TREATMENT

DAF (and IAF) plants have been successfully implemented post facultative and maturation ponds for the removal of pond solids and algae (TSS and particulate BOD, and some TP), however, they achieve little reduction in faecal indicators without flocculant addition. Depending on the chemical used, alkalinity and/or pH adjustment may also be necessary. For best results dosing rates should be adjusted over time to the changing algae population and concentration. Capital costs are similar to a continuous backwashing sand filter. Operating costs will be similar but will depend on chemicals use. Reliability of operation will be similar.

The negative aspect of a DAF plant for post pond-treatment resides in its production of a special type of sludge, which is thick, highly concentrated, foam-type algae/flocculent sludge. This is not easy to handle and it should not be returned to the front end of the plant. It is recommended to dispose of it at a dedicated pond for drying and later removal for disposal.

3.5.4. LAMELLAR CLARIFIERS AND MICRO-SAND INJECTED RAPID GRAVITY SETTLERS

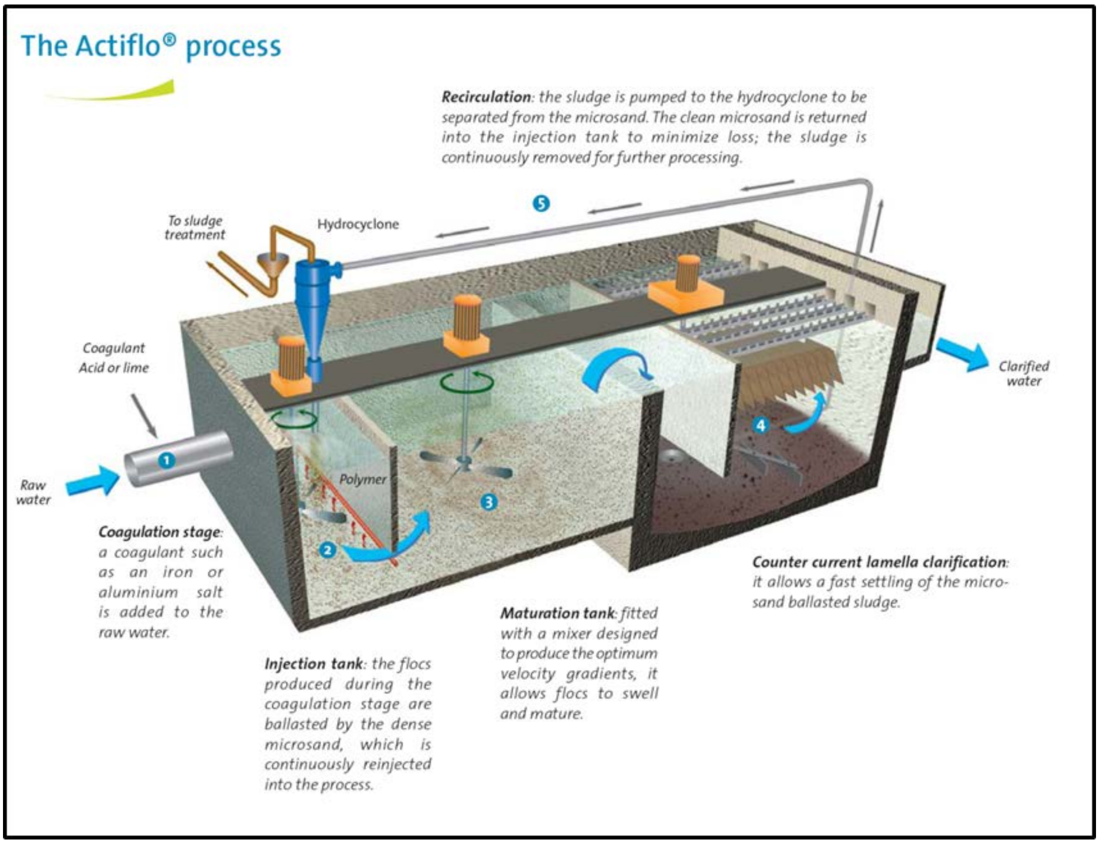
Lamellar clarifiers can be used for post-clarification. They can be effective for settling out biological floc and some larger algae but have only a limited efficiency for small algae.

Ballast assisted gravity settlers (e.g. Actiflo, Densadeg) can be effective in the post-treatment of pond effluent. They use a combination of physico-chemical processes, mixing, micro-sand and tube settlers to achieve a high rate of solids removal, TP reduction and even faecal indicator reduction. They were developed for stormwater treatment and can therefore treat variable flow conditions and peak flows.

The process works by creating a floc of the solids with a coagulant to which micro-sand is added as artificial ballast. After growing the floc the sludge settles and is pumped from the unit through a hydrocyclone, which separates and returns the micro-sand to the process. A process diagram is shown in Figure 3-27 with typical treatment performances in Table 3-20 and a picture of a unit in Figure 3-28.

Table 3-19 Actiflo Treatment Standards in Different Applications

Performance for municipal and industrial wastewater applications (% removal)				
	Stormwater	**Biofilter backwash** **Biological sludge**	**Primary settlement**	**Tertiary polishing**
TSS	80-98%	75-99%	75-90%	50-80%
COD	65-90%	55-80%	55-80%	20-50%
Total Phosphorus	50-95%	50-95%	50-95%	50-95%
Orthophosphate	50-98%	50-98%	50-98%	50-98%
Faecal Coliforms	1-1.5 log removal	1-1.5 log removal	1-1.5 log removal	1-1.5 log removal


The Actiflo® process

Recirculation: the sludge is pumped to the hydrocyclone to be separated from the microsand. The clean microsand is returned into the injection tank to minimize loss; the sludge is continuously removed for further processing.

Coagulation stage: a coagulant such as an iron or aluminium salt is added to the raw water.

Injection tank: the flocs produced during the coagulation stage are ballasted by the dense microsand, which is continuously reinjected into the process.

Maturation tank: fitted with a mixer designed to produce the optimum velocity gradients, it allows flocs to swell and mature.

Counter current lamella clarification: it allows a fast settling of the micro-sand ballasted sludge.

Figure 3-27 Actiflo Micro-sand Assisted Rapid Gravity Settler process diagram

Table 3-20 Actiflo Treatment Standards in Different Applications

Performance for municipal and industrial wastewater applications (% removal)				
	Stormwater	**Biofilter backwash** **Biological sludge**	**Primary settlement**	**Tertiary polishing**
TSS	80-98%	75-99%	75-90%	50-80%
COD	65-90%	55-80%	55-80%	20-50%
Total Phosphorus	50-95%	50-95%	50-95%	50-95%
Orthophosphate	50-98%	50-98%	50-98%	50-98%
Faecal Coliforms	1-1.5 log removal	1-1.5 log removal	1-1.5 log removal	1-1.5 log removal

Figure 3-28 Actiflo Reactors

Although such micro-sand ballasted gravity settlers can achieve good results, a number of issues have to be considered when selecting and operating such systems:

Type of process: While the process itself is relatively simple, the reactor is highly technical and maintaining optimal operating conditions through the full range of varying flows is not easy. Maintaining treatment performance during rapid flow variations is also difficult. Start-up, dosing adjustment and optimisation do take time and operators have found that such units cannot be started by the turn of a key. Operators have to be well trained and supplier support should be available for several years to get the best out of the system.

Capital and operating costs: The unit is tall and compact and therefore requires stable foundations. Capital costs can depend on the place of fabrication, and so can the quality of workmanship. Such expensive systems should be provided with adequate warranties for a few years covering materials and fabrication as well as process performance guarantees.

Operating costs depend significantly on how well the unit is optimized, automated and if it is fitted with adequate process controls. Pumping costs are one aspect. If Alum is being used as coagulant for TSS and TP reduction the installation of a pH and alkalinity control system is highly recommended although often not part of the standard supply. Dosing Alum within the wrong pH range results in the build-up of a poor floc and the resolubilisation of Alum. This has to be countered by the operator through constant overdosing, which in turn results in a continuous loss of Alum through the discharge as well as a loss of micro-sand, which is an expensive and essential process additive. As a result, operating costs of more than $1,000 per day in additives can easily be reached for a poorly controlled system.

3.5.5. UV DISINFECTION

UV disinfection is an effective way of reducing pathogen levels in the final effluent. It should only be applied in situations where adequate transmissivity can be guaranteed. Its application is therefore recommended after a well operating maturation pond or after post-pond-treatment to remove most algae and TSS.

UV systems should be fitted with flow pacing and preferably also allow intensity adjustment to compensate for a drop in transmissivity. System capacity should be sized for peak flow conditions, although storm flows at pond outlets often have a reduced pathogen count and a higher transmissivity and therefore do not necessarily require a larger UV unit than for average daytime flow.

The location of the UV disinfection within the treatment train should be discussed in detail with the consenting authority as well as Iwi, especially if wetlands are to be part of the treatment system. A wetland will increase the pathogen count through the presence of natural bird life. For best final discharge results UV disinfection should therefore take place after any wetlands, although the higher faecal indicator and possibly solids and algae TSS levels at this point can make such installation more challenging. The alternative is to agree compliance measurement after UV and before the wetland which may then have a diffuse number of discharge points to the general environment.

3.5.6. EXTERNAL ROCK FILTERS

External rock or media filters have been successfully used for the reduction of nutrients (e.g. nitrification, denitrification, BOD_5, TP reduction) and algae solids reduction. They are preferably used after maturation ponds to limit the amount of solids loading onto the filter. But they are also used after facultative ponds for solids reduction, in which case the loading rate has to be adapted. Overseas one can find treatment plants operating solely on anaerobic ponds followed by a trickling filter as well as advanced rock filters used after waste stabilization ponds to achieve high nitrification rates in post-treatment, even in cold climates. This is similar to the PETRO® concepts (refer 3.7)

The filter media of a rock filter has to be selected in accordance with the level of treatment the filter has to provide and for how it is to be used (type of material, size, layout and quantity). Experience is necessary to avoid clogging or premature failure. A range of external rock filter applications is given in Table 3-21 below.

Table 3-21 External Rock Filters

Type	Application	Comments
Rock Filter	Solids and algae (TSS and BOD) reduction, Nitrification, denitrification	Generally natural rock in large, shallow beds or in dam-like structures (external or at the edge of the pond) spray irrigated with the effluent. Can have some treatment effect, but not as effective and consistent as a well-defined structure such as a trickling filter.
Lime Stone Filter	Solids and algae (TSS and BOD) reduction, some TN reduction, but mostly used to gain alkalinity	Built within or on the edge of a pond or between ponds to regain alkalinity prior to further treatment. Expensive to build, but with practically no maintenance costs. Mainly used for nitrification and denitrification. Consider rock hardness re life and solubility effects.
Trickling Filter	Solids and algae (TSS and BOD) reduction and assistance in TN reduction	Most well-known for its application as part of the Petro® process, which uses a combination of ponds and a trickling filter for nutrient removal (refer Figure 3-32). Trickling filters are expensive to build, but are simple to operate. Operating costs involve mainly pumping costs.
Slag Filter	Mainly for TP reduction but will also reduce TSS.	Shallow-bed rock filter constructed solely from slag. Slag adsorbs DRP onto its surface and therefore reduces TP in the effluent. Slag filters have proven effective for TP reduction, but expensive in the long-term because of their limited life expectancy i.e. limited adsorption capacity.
Aerated External Rock Filters	For advanced BOD and TN reduction in cold climates	A large, gravel-type rock filter built above or below ground and fitted with a well-designed effluent distribution and aeration system. Used overseas for advanced TN reduction. Expensive to build, but requires minimum operator input.

3.5.7. OTHER EXTERNAL FILTERS

A number of developments should be taken into consideration when looking at advanced nutrient removal using simple technologies and requiring minimum operator input. Two such technologies involve the use of bark as biological carrier material as well as a carbon source for bacteria.

Bark filters have been tested in New Zealand for TN reduction in a number of places. Bark acts as a type of trickling filter media, but in addition provides a carbon source for denitrification. Bark filters have been used in bark beds, which can be fed by gravity from pond outlets. At this stage there is limited information available on sizing and the treatment standards which can be achieved consistently. Further studies and treatment installations could in the future provide design criteria for the use of such filters after WSP.

Biofiltro nitrifying filters have been introduced into New Zealand from South America. They consist of a sand filter type structure filled with wood chips and seeded with Tiger worms. The effluent is spray irrigated over the surface of the bark and trickles through the filter for treatment. Construction and operating costs for such a filter are low. The filters operated in New Zealand on pond effluent show good BOD_5 reduction and nitrification, but little denitrification. Biofiltro filters have proven successful in combination with ponds as the pond protects the filter from large solids and an overloading in BOD_5. The treatment ponds can also provide flow buffering to ensure a consistent irrigation rate over the filter. Biofiltro plants are generally equipped with a simple but effective UV disinfection system at their discharge end.

Bio-domes and bio-shells were developed by Wastewater Compliance Systems Utah, USA and are marketed in New Zealand. They are submerged, aerated, fixed film, concentrically nested domes giving a high surface area to volume media that provide substrate for bacteria. They are placed on the bottom of a pond, creating a dark environment with robust air and wastewater mixing which removes contaminants from the water. They do not rely solely on pond retention time but calculate the number of bio-domes or bio-shells required based on mass loads of N to be removed. Bio-domes also remove BOD and operate well in colder climates. Bio-Shells utilize the same underlying principles as the Bio-Domes, only they have 2.7 times the surface area.

3.5.8. WETLANDS

Wetlands not only provide effective treatment of pond effluent but in New Zealand they can also play an important part in the cultural acceptance of a wastewater treatment plant. Wetlands are used overseas for small to large treatment plants including providing full wastewater and sludge treatment for towns up to 200,000 inhabitants. Wetlands can achieve up to 80% BOD_5 reduction, 70% TN reduction as well as significant pathogen and some TP reduction. They are becoming increasingly important as a tertiary process in wastewater treatment in Europe because of their capacity to absorb and treat micro-pollutants, which are currently not effectively treated in conventional mechanical treatment plants. However, wetlands require up to 10 times the land area of WSP for similar treatment capacity, so they are best used as a post treatment for ponds. Wetlands can be broadly divided into surface and sub-surface flow wetlands, although combinations and alterations of both types exist.

Surface flow wetlands have open water visible and meandering between wetland plants set in a shallow pond. Such wetlands are often separated into multiple cells to achieve better flow conditions and to allow for easier servicing of smaller wetland portions. Surface flow wetlands are the most common wetlands in New Zealand and many of them either do not achieve the predicted treatment standard or have become overgrown and out of control through lack of regular maintenance.

The design of a surface flow wetland is complicated as it must take into account the wetland's hydraulics, treatment quality and ease of maintenance at the time of planting, as well as its natural growth and changes over time. Wetland designs fall therefore into an area between landscape and plant specialists and wastewater engineers. Both should closely work together for best long-term results. The construction of an artificial wetland is expensive and the quality of its design cannot easily be evaluated at the time of commissioning. It will only become apparent after at least 3 years of operation when plants have fully established and quality of treatment, maintaining good hydraulic conditions and ease of servicing become increasingly important.

Wetlands can experience significant flow variations, which should not substantially change their flow pattern. Over time plants will grow, others will die off and weeds will develop. Sludge will accumulate and preferential channels can develop. Regular maintenance and easy access by the operator and maintenance specialists have therefore to form an essential part of any wetland design.

Sub-surface flow wetlands consist of a large gravel bed into which the wetland plants are planted and through which the effluent travels from one end to the other. With such wetlands the effluent should only be visible at the wetland inlet and its outlet. Subsurface wetlands have to comply with strict design criteria in respect to hydraulic and biological loading as well as in respect to the gravel sizing, size distribution and bed depth.

The hydraulic flow through a sub-surface wetland and its consistency over many years is even more important than for the surface flow wetland. Clogging of sections of the wetland can rapidly lead to an overloading of other parts, resulting in further clogging and ultimately a failure of the whole system. A division of a large wetland into smaller cells presents therefore a real advantage for maintaining a healthy wetland treatment long-term.

A sub-surface wetland is much more accessible for servicing and maintenance as the operator or specialized personnel can walk on the gravel bed for weeding and plant maintenance. Plant selection and the manner of planting are important in that their root system will directly affect the hydraulic flow conditions in the gravel bed. Plants with root systems which could take over major parts of the wetland are to be avoided to prevent localized hydraulic overloading or channeling.

Sub-surface wetlands do not allow desludging. They rely on the natural deterioration of any solids and biomass accumulating in the gravel bed over time. It is because of this that subsurface wetlands are limited in respect to their hydraulic, BOD_5, TSS and nutrient loading.

Hybrid flow wetlands allow mixing of wetland types to the available terrain and treatment requirements. Some have been developed in New Zealand as a consequence of failed sub-surface wetlands. Such a wetland consists of rows of wetland plants set in a gravel bed. Shallow channels are dug into the gravel to carry the wastewater through the rows of wetland plants. The shallow nature of the channels provide for full exposure of the effluent to the sunlight and therefore for maximum UV disinfection. The gravel allows the effluent to percolate easily to the root system of the wetland plants and maximizes nutrient uptake without the risk of gravel bed overloading. Efficient influent distribution at the wetland inlet, as well as treated effluent collection at the outlet, are essential for optimum treatment.

The hybrid flow wetland offers some of the advantages of the surface flow wetland (e.g. a wider acceptable range of flow and load variation) with some of the advantages of the sub-surface wetland (e.g. ease of maintenance). In addition it can provide high natural disinfection efficiency.

Wetlands of any kind should be designed based on sound and proven design criteria. They should not be regarded solely as landscape features but as complex engineering and natural treatment systems, which have to remain operational long-term.

As a general guide design features of a modern wetland should include:

- A division of a large wetland into multiple smaller cells to ensure better defined hydraulic conditions, treatment standards and easier maintenance e.g. can take one off line.
- An inlet structure, which distributes the effluent equally between wetlands.
- An inlet distribution and spreader system that can cater for a wide range of flows.
- Distribution systems, which spread the effluent over the whole width of the cells.
- Wetland plants should be selected for the required nutrient uptake as well as for their resilience, longevity and ease of maintenance requirements.
- Wetland plants should neither have tendency to take over the wetland over time nor should they become too large to maintain or handle.
- A sequencing of wetland plants according to treatment and hydraulic requirements can at times provide better treatment and easier servicing and maintenance.
- The wetland should allow for easy access for the operator and maintenance personnel to the plants and for desludging or weeding purposes (if appropriate).
- For surface flow wetlands the introduction of a sludge settling zone, free of plants is a good option to allow for regular, easier desludging.
- Surface flow wetlands should be fitted with a water level control device, which allows operation over an extended period of time within a range of pre-set water levels. This is to ensure better access as well as for the planting of new plants, which cannot initially be submerged and require shallow water for quite some time.
- A final effluent collection system, which ensures low velocity discharge flows over the whole width of the wetland cell.

- A hydraulic separation between the wetland and the discharge pipe to ensure downstream headloss does not affect the wetland operation.
- A strict maintenance schedule. Hand weeding and removal of dead plants should take place once every 1 to 2 months. More intensive maintenance should be undertaken once per year. If the operator cannot undertake this task on a regular basis Council should engage an outside contractor
- When a wetland is installed for a future capacity, costs can be saved by planting for the short term needs and allowing natural plant growth (numbers and size) to increase in line with treatment capacity. This may require division and repositioning of plants across the wetland.

Wetland capital costs are high and regular hands-on maintenance is essential to maintain long-term performance thus seasonal operating costs can be significant. Councils should therefore consider their use carefully as the conversion or dismantling of a failed and inoperative wetland can be more expensive than its construction. Before committing to a wetland Councils should visit reference plants of the same design, which have successfully operated for a number of years and interview the operators of these plants.

Designers should therefore refer to recent wetland development and design manuals such as in New Zealand, France and the USA (e.g. NIWA NZ Constructed Wetland Planting Guidelines, 2006 and USEPA Constructed Wetlands Treatment of Municipal Wastewaters, 2000).

3.5.9. ELECTROCOAGULATION PROCESS

Electrocoagulation (EC) is a process that destabilises suspended, emulsified, and/or dissolved contaminants by passing an electrical current through the water as it flows past electrodes. The cathode, which doesn't have to be metal, hydrolyses water into hydroxyl (OH-) ions and hydrogen (H_2) gas, while the sacrificial metal anode (usually iron or aluminium) releases metal (M+) cations to the water. For example, an iron anode will release both iron (II) and iron (III) cations to the water:

Fe(s) → Fe2+ + 2e-

Electricity

Fe(s) → Fe3+ + 3e-

Electricity

The electrical current provides the electromotive force that drives strong chemical oxidation and reduction reactions to form elements or compounds that approach their most stable state. The hydroxyl ions and metal cations react together. With other anions and cations already in the water they form insoluble precipitates or neutralize the charge of suspended solids in the water. The available cations neutralize the charge on the surface of the suspended solids, so that they no longer repel one another and coagulate (clump together). They then settle once gas bubbles are dislodged.

The electricity required for treatment is affected by the conductivity of the water. Water with higher conductivity can be treated at lower voltage to achieve the same current. Therefore this process is likely to be more effective on effluents from areas where the water supply derives from groundwater rather than surface water supplies. Time versus voltage applied can also be traded against each other to optimise efficiency and cost.

The majority of the metal ions added during treatment precipitate out and are removed from the water along with the solids which typically have good settleability and dewaterability. Thus there is less sludge produced than with chemical flocculation.

The EC process would require simple equipment and be easy to operate. Costs are dominated by electricity use. It has the potential to substantially reduce pathogens, nutrients (particularly phosphorus) and TSS, but there is limited published data for use on WSP effluent. No plants yet exist in New Zealand although the process is being marketed here.

3.6 HIGH RATE ALGAL PONDS AND ALGAL HARVEST PONDS

3.6.1. HIGH RATE ALGAL PONDS (HRAPs)

3.6.1.1 TREATMENT ROLE

High Rate Algal Ponds, as their name suggests, promote the aerobic treatment process that occurs in the surface layer of facultative ponds by optimising algal photosynthesis and growth. As such HRAP do not treat raw wastewater but typically follow a covered anaerobic pond or a primary clarifier. The algae produce oxygen in the daytime with pond DO concentrations of 2-3 times saturation (over 20 g m^{-3}). This highly aerobic environment drives efficient bacterial decomposition of organic matter. The algae assimilate nutrients (NH_4-N and DRP) into harvestable algal biomass for beneficial use as fertilizer and biogas production. These large surface area and shallow ponds allow for a high level of natural disinfection, particularly sunlight-UV inactivation of faecal microbes, in combination with photo-oxidation of dissolved organic contaminants.

Figure 3-29 **Examples of High Rate Algal Ponds in California (a & b), New Mexico (c, d & e) and New Zealand (f & g)**

3.6.1.2 DESIGN PRINCIPLE

Since aerobic treatment usually only occurs in the top 500 mm of facultative ponds, HRAPs are shallow with typical depths of 300-600 mm. Moreover, aerobic treatment in HRAP occurs much faster than in facultative ponds so they have a much shorter HRT (typically only 4-8 days). Therefore, despite their shallow depth HRAP take up similar or less land area than an equivalent facultative pond. HRAP are constructed as raceway channels with constant gentle mixing (average horizontal water velocity of between 0.15-0.20 m s^{-1}) to circulate the algal laden pond water around the raceway, and up and down within the depth to ensure routine exposure to sunlight for algal growth and solar-UV disinfection. Mixing is cost-effectively provided by a single paddlewheel which has a low power requirement (~0.5 kW per ha of HRAP or, per 450-500 m^3d^{-1} wastewater flow) compared with mechanical aerators typically used on facultative ponds.

3.6.1.3 PERFORMANCE

A consequence of the higher algal growth rate in HRAP is that their average annual biomass productivity (8-12 g $m^{-2}d^{-1}$ VSS) is typically 2-4 times that of facultative ponds (2-3 g $m^{-2}d^{-1}$). In addition, HRAP biomass has a higher proportion of algae (up to 90%) than facultative pond biomass. The constant pond mixing, natural diurnal variation of HRAP conditions (sunlight, temperature, pH and dissolved oxygen) and lack of an anaerobic pond bottom, lead to far more efficient and consistent wastewater treatment. HRAP also tend to select for algal strains that are less susceptible to invertebrate grazing (a common cause of conventional pond crash). Importantly, HRAP only tend to grow green algae and diatoms as opposed to blue/green algae which commonly occur in late summer/autumn in New Zealand facultative ponds and can be toxic.

High levels of treatment can be achieved by HRAP systems with average annual effluent concentrations (g m^{-3}) of <15 BOD_5; <15 TSS; <10 TN; <5 NH_4-N; <6 TP; <4 DRP <100 E.coli), but removal declines during winter months due to lower algal growth, oxygenation and nutrient requirement.

3.6.1.4 CO_2 ADDITION

HRAP performance, (particularly nutrient removal and algal production) can be improved by daytime CO_2 addition, to overcome carbon limitation that is indicated by high pond water pH levels (typically above 9.5). Carbon limitation is due, in part, to the low C:N ratio of domestic wastewater (typically 3:1 to 4:1) compared to algal biomass (typically 6:1). More C must therefore be added to remove all the N (and P) by direct assimilation into algal biomass.

Addition of CO_2 to HRAP (Figure 3-30) increases carbon availability and enables pond water pH to be maintained at an optimum level (pH 7.5-8.5) for both algal and bacterial growth. The annual average biomass productivity of wastewater treatment HRAPs can potentially be doubled with CO_2 addition to 16 - 20 g m^{-2} d^{-1}. CO_2 addition further enhances nutrient recovery by assimilation into algal biomass. A readily available source of CO_2 for HRAPs can be found in either the CO_2-rich biogas (typically ~30% CO_2) captured by the cover of Covered Anaerobic Pond (CAP) that is used to pre-treat the HRAP influent or the flue gas (~10% CO_2) from use of the biogas in a generator to produce electricity.

Figure 3-30 Christchurch Demonstration HRAP CO_2 addition sump

3.6.2. ALGAL HARVEST PONDS (AHPS)

3.6.2.1 TREATMENT ROLE

Algal Harvest Ponds (AHPs) are gravity settlers and secondary thickeners that separate flocculated algal solids from the HRAP effluent. Colonial micro-algal species that often dominate in HRAPs can naturally bioflocculate when removed from the mixing of the HRAP, which assists the gravity sedimentation.

Figure 3-31 Cambridge Algal harvest Ponds (AHP)

3.6.2.2 DESIGN PRINCIPLE

AHPs are geomembrane lined earthen ponds which are shaped like an inverted pyramid. They are constructed with walls with a steep slope (at least 1:1 horizontal: vertical) to ensure settled solids slide down to a deep (ideally 4 m) central bottom sump. The hydraulic retention time (6-8 hours) is sufficient to enable efficient gravity settling of the solids. Additional pond volume allows for secondary thickening of settled solids.

AHP performance can be further enhanced by installing a surface baffle across the pond width to prevent short-circuiting and/or using lamella plates at the pond surface to promote more efficient gravity settling which would reduce the required HRT and volume.

3.6.2.3 PERFORMANCE

Provided the algae bioflocculate and settle out of the water column, AHPs typically achieve >60% and periodically 70-90% removal of TSS. Large flocs of bioflocculated algal cells will settle at rates of 30-50 cm/h and will concentrate to about 1-3% solids.

Addition of small amounts of cationic flocculent to the HRAP effluent can improve average algal settleability and consistency of BOD_5, TSS, TN and TP removal performance over that given in section 3.6.1.3, and is necessary if the HRAP effluent is pumped to the AHP as pumping will disrupt the flocs.

3.6.2.4 ALGAL BIOMASS USE

The harvested algal biomass can be recovered for fertiliser use due to its high nitrogen, phosphorus, and potassium concentrations. Alternatively, algal biomass can also be used as an energy source, by the production of biogas through anaerobic digestion using Algae Covered Digester Ponds, with the added bonus of the digestate also being beneficially used as a liquid fertiliser.

3.7 PETRO® SYSTEMS

Pond Enhanced Treatment and Operation (PETRO®) is a proprietary system that was developed in South Africa during the 1980s. The system effectively combines facultative pond pre-treatment with mechanical secondary treatment processes (either biological trickling filter (BTF) or activated sludge (AS) and is designed to overcome the shortcomings and promote the advantages of the individual components (Shipin et al 1998).

3.7.1. DESCRIPTION OF THE PETRO® SYSTEM

The PETRO® system (Figure 3-32) typically incorporates a primary facultative pond (with a deep anaerobic zone) which flows by gravity to one or more secondary facultative ponds. This primary stage of the process typically removes more than 70% of the raw wastewater organic load. The secondary facultative pond effluent flows into a mechanical secondary treatment process (either biological trickling filter (BTF) or activated sludge (AS) which is followed by a humus tank/clarifier.

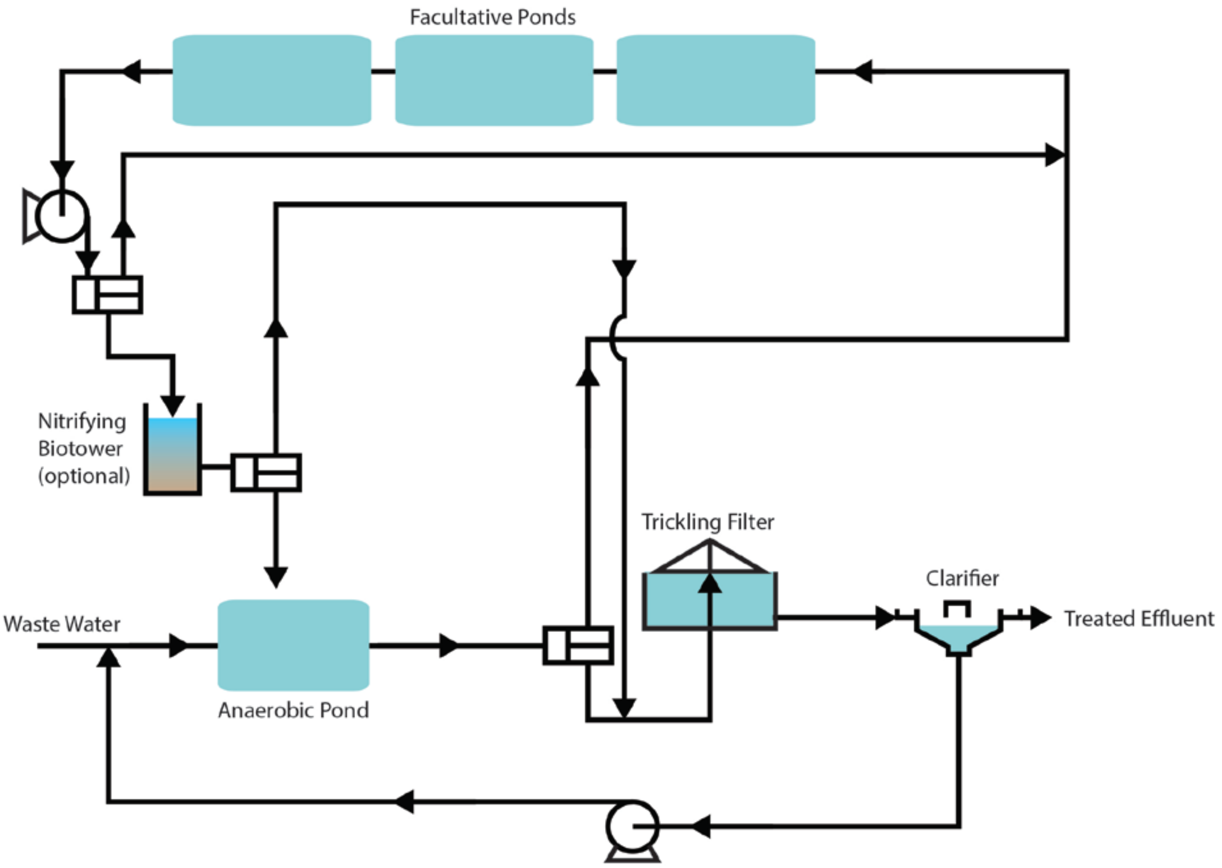


Figure 3-32 PETRO® Basic Flow Diagram

The name PETRO® is a proprietary name which is an acronym of the concept title **P**ond **E**nhanced **TR**eatment and **O**peration. The system sets out to make maximum use of anaerobic biodegradation followed by aerobic degradation in oxidation ponds prior to the polishing stage in a secondary unit. It was developed at a time when less knowledge existed of the exact biological processes occurring in each treatment unit and simpler variants are now possible as indicated in the preceding chapters.

All stages of the system are interlinked by multiple effluent recirculation pathways in which the required flow rates can be selected, these pathways include recirculation of:

- Oxygen-rich effluent from the secondary facultative ponds to minimize odour release from the primary facultative pond surface by sulphide oxidation.
- Humus tank solids to the primary facultative pond anaerobic zone for digestion.
- Bicarbonate alkalinity from the primary facultative pond to promote nitrification in the TF

The PETRO® system can be developed in a staged manner and is suited to upgrade an existing TF plant where land is available or to upgrade an overloaded WSP system.

3.8 PARTIALLY AND FULLY MIXED AERATED LAGOONS

Partially and fully mixed aerated lagoons are separate treatment processes which rely on mechanical aeration rather than algal processes. Algal processes become disrupted when introduced mechanical aeration reaches a level of about 1W/m^3. Information on lagoon aeration processes can be found at http://www.lagoonsonline.com/ . They can be provided by increasing the water depth of a conventional facultative pond and adding aeration and mixing, or by addition of a separate aerated basin upstream of the WSP. Fully mixed aerated lagoons can further be fitted with solids recycle, which makes them resemble an extended aeration activated sludge plant. However when any of these are provided the effect will be a high TSS effluent stream flowing to the next process which needs to be managed either by intermediate settlement and sludge management or ensuring the TSS loading on the subsequent facultative pond is within acceptable design limits.

Aerated lagoons operate at HRT between 2 and 6 days depending on their aeration and mixing efficiency. They have a higher TSS concentration due to the conversion of soluble BOD to TSS (e.g. 400mg/l) which can be increased further with solids recycle (e.g. 1,500mg/l). Partially and fully aerated lagoons are deeper (2.0m – 5.0m) than WSP and the amount of mixing and aeration energy ranges from 4 W/m^3 upwards depending on the efficiency and performance required. Addition of a solids recycle will increase this further.

Aerated lagoons can be added in front of a conventional WSP system to increase the system's overall capacity and nutrient removal rate. This will increase operating costs in form of kW/m^3 of wastewater treated and due to the higher sludge production. The effluent from an aerated lagoon will have a relatively high concentration in TSS, which will have to be settled out in a downstream facultative, maturation or settling pond.

A direct conversion of a facultative pond to a traditional aerated lagoon is difficult as an increase in water depth will directly result in a longer HRT making it difficult to achieve the conventional HRT versus W/m^3 requirements. The options between the aerated facultative ponds with a few aerators (< 1 W/m^3 aeration) and traditional fully mixed aerated lagoons (4 to 8 W/m^3 aeration) are variable regarding plant sizing for BOD or nutrient removal versus W/m^3 of aeration or mixing added. There are partially aerated lagoons in New Zealand operating at 3 W/m^3, which achieve considerable BOD and NH_4-N removal rates, but at HRT of between 8 and 16 days. Good nutrient removal rates can therefore be achieved by "in-between" aerated lagoons. But such designs are site specific and need to take into account a number of minimum requirements to prevent failure:

- Converted aerated lagoons should have a water depth of at least 2.0m, preferably more to provide the required space for sludge settling.
- Although some sludge accumulation at the base of the pond can improve denitrification, the sludge level has to be maintained below the level where it becomes lifted by aerators or mixers.
- The amount of aeration and mixing must relate to the necessary HRT for the required performance. Insufficient aeration and/or mixing will require a longer HRT.
- The aerated lagoon will require an optimised flow pattern for best performance.
- Provision has to be made for sludge settling within the converted aerated lagoon or in a downstream facultative or settling pond.
- Overall sludge production is typically greater than a standard facultative pond, partly related to the amount of BOD and nutrients removed. This will therefore increase the need for and frequency of desludging.
- Aerated lagoons should not be directly followed by a wetland as the latter would rapidly clog up through the settling out of solids. This would result in a breakdown of the wetland's flow pattern and increase the risk of weed growth as well as odour generation.

4 OPERATION AND MAINTENANCE

4.1 GENERAL

One of the major advantages of WSP is that they require relatively little operation and maintenance (O&M) in comparison to mechanical wastewater treatment processes. However, some O&M is still required to:

- Monitor the health of the WSP process.
- Undertake general housekeeping around the site.
- Maintain the structural integrity of the WSP.
- Collect samples for resource consent compliance.

4.2 MONITORING AND SAMPLING

4.2.1. RESOURCE CONSENT MONITORING

The minimum amount of monitoring to determine the performance of WSP will be stipulated in the resource consent. However, this resource consent monitoring may not provide sufficient information to really understand the health of the WSP process, or to identify trends in performance which may indicate imminent process failure. Therefore, it is recommended that sufficient monitoring should be undertaken, regardless of whether it is required by the resource consent.

The frequency of monitoring, and the determinants to be monitored, will be site specific depending on factors such as the size of the WSP, the population served, and the resource consent conditions to be achieved. For further information on resource consent monitoring refer to Section 5. Other recommended monitoring is discussed in the following sub-sections.

4.2.2. INFLUENT MONITORING

Any wastewater treatment plant is designed to treat a defined wastewater flow and load, and WSP are no exception. If the flow and/or load exceeds the design capacity, the WSP process could fail.

As communities change over time, so the nature and quantity of wastewater produced can also change. To understand these changes in flow and load, it may be appropriate to periodically characterise the raw wastewater entering the WSP. This is particularly true for WSP serving areas with expanding populations, either permanent or seasonal, or where industrial wastewater is sent to the municipal WWTP for treatment. Separate monitoring of significant industrial or other non-domestic e.g. leachate, septage discharges should also be undertaken to police against any toxic shocks as well as spikes in load to be treated. Oils and greases as well as any non-biodegradable chemicals should not be discharged into the wastewater system.

4.2.3. SEPTAGE AND INDUSTRIAL DISCHARGE MONITORING

Many WSP in NZ are located in rural towns where a high proportion of dwellings are often not connected to the municipal wastewater reticulation and treatment system. Such dwellings are serviced by septic tanks, or in some cases, by advanced on-site effluent treatment systems (OSET). Periodically, septic tanks, and the primary settlement tank in OSET systems, need to be desludged. The resulting “septage” comprises the concentrated faecal and other organic material which has been discharged into the septic tank or OSET system over time.

Septage is much more concentrated than raw domestic wastewater. Therefore, tanker loads of septage discharged into WSP can add a significant wastewater load and should be monitored and controlled, both in terms of volumes and characteristics.

Many industrial and trade wastes are highly concentrated and may have extremes of chemical concentrations, some of which are toxic to WSP biology. NZS 9201.23:2004 Model general bylaws - Trade Waste provides guidance on how a Territorial Authority can and should manage these discharges safely. The standard also gives concentration limit guidance on specific chemicals so that their WWTP performance is not compromised. All wastewater discharges from other than domestic premises should be monitored and managed in accordance with the advice within NZS 9201.23.

4.2.4. PROCESS MONITORING

The recommended monitoring of WSP will be site specific, depending on factors such as:

- Resource consent conditions.
- BOD loading rate.
- Pond size.
- Number of ponds.

Monitoring, particularly effluent sampling should be taken at a similar time each day for comparison; ~2 pm is typically peak treatment, ~9 am often provides a good 24 hour average effluent sample.

As a minimum, regular (daily-weekly) monitoring of DO, pH, conductivity and temperature of WSP should be undertaken, with additional monitoring, such as algae density (measured as either TSS, VSS, chlorophyll or absorbance at 630 nm) and algal diversity potentially providing valuable additional information. The importance of monitoring these parameters is discussed below:

pH; The pH of a normal, healthy WSP will fluctuate diurnally from ~6.5 in the early morning to ~8.5 in the early afternoon of a warm, sunny day. These fluctuations in pH are caused by changes in pond water carbon dioxide concentration as carbon dioxide dissolves in water forming carbonic acid. Pond water pH is lowest at dawn and rises during the day when algae take up more carbon dioxide through photosynthesis than the algae, bacteria and other pond organisms produce by respiration. Pond water pH declines again at night as carbon dioxide production by respiration occurs continually. pH changes outside of this normal diurnal trend could occur if wastewater with high or low pH is discharged into the system. If pH is monitored manually, this should be undertaken at roughly the same time each day to allow results to be comparable. Automatic pH monitoring at the plant inlet can help detect industrial loads.

DO; The DO concentration in normal, healthy WSP will fluctuate diurnally due to the higher production of oxygen by algal photosynthesis during the day than that required by algae, bacteria and other pond organism respiration. Pond water DO concentrations will normally be lowest at dawn (1 mg/L or less), and highest (15 mg/L or more) in the early afternoon following peak algal photosynthesis. As with pH, If DO is monitored manually, this should be undertaken at roughly the same time each day to allow results to be comparable. Manual DO spot testing may not give sufficient information to determine if a pond is in a healthy condition or not. An automated probe used over an extended time period is best for this. These probes should be fitted with an efficient auto-cleaning system to avoid erroneous high readings during day-time. For pond health monitoring the DO concentration during night-time is valuable as the trending of the DO level every night at the same time will give a good indication of the overall health of the pond. If a downward DO trend is noted over a period of a few days (when sunlight and temperature conditions have been stable), this could also indicate the process is on the way to failure.

Conductivity; Since many pH meters also measure conductivity, it is useful to also record it, since conductivity of wastewater typically declines with wastewater treatment, particularly assimilation of ammonia into algal biomass. Conductivity can also increase with increase in influent trade waste discharges.

Temperature; While it is not realistically possible to control the temperature of WSP, regular monitoring and recording of pond temperature provides useful information. In particular, if upgrades or modifications to ponds are likely to be considered in the future, understanding the long-term temperature trends will be invaluable when assessing the suitability and sizing of different upgrade technologies.

Algae; Green algal growth is critical for healthy pond function, with the algae providing the bulk of the oxygen for the process. Regular monitoring of the concentration of algal biomass, as well as the relative abundance of algal species, can provide valuable information on WSP health. Such monitoring is generally most valuable if the WSP comprises more than one pond and with ponds in parallel, where operation of individual ponds can be adjusted based on algal identification and counting. For example, if algal concentration is falling in an individual pond, it may be improved by reducing the pond loading or recirculating effluent from other ponds with higher algal concentration.

A depth integrated sample is important for algae sampling as the algae often migrate within the pond aerobic layer.

Chlorophyll; Chlorophyll *a* is a pigment found in algae, blue-green algae and plants and is critical to the process of photosynthesis. Chlorophyll concentrations therefore give an approximation of the amount of living algae present in WSP. As with algae monitoring, chlorophyll monitoring is most valuable if the WSP comprises more than one pond, where the operation of individual ponds can be adjusted based on the results of chlorophyll monitoring. A depth integrated sample is also important for chlorophyll *a* sampling. Handheld meters are available to measure chlorophyll based on absorbance of selective optical wavelengths.

Sludge Level; Sludge accumulates in the bottom of WSP over time. Increasing sludge depths result in:

- Reduced effective pond volume available for treatment.
- Reduced hydraulic retention time (HRT).
- Increased risk of odour nuisance and sludge rising to the surface
- Increased risk of botulism outbreaks.

The quantity of sludge should be monitored periodically to understand the rate of accumulation. At the same time, the sludge should be characterised in terms of total and volatile solids content. This will allow effective planning and budgeting for sludge removal.

Table 4-1 Recommended Monitoring Schedule

Parameter	Method	Frequency	Comments
DO	In-situ or on-line	Daily or continuously	Remote sites may be visited once or twice per week
pH	In-situ or on-line	Daily or continuously	Remote sites may be visited once or twice per week
Conductivity	In-situ or on-line	Daily or continuously	Remote sites may be visited once or twice per week
Temperature	In-situ or on-line	Daily or continuously	Remote sites may be visited once or twice per week
Algal TSS	Laboratory		Depending on WSP complexity
Algal Species	Laboratory		Depending on WSP complexity
Chlorophyll *a*	Laboratory or on-line	Weekly or continuously	Depending on WSP complexity
Sludge level	In-situ	1 – 5 yearly	Depending on rate of accumulation
Sludge characteristics	Laboratory	1 – 5 yearly	For desludging purposes

4.2.5. BETWEEN PONDS MONITORING

Where a WSP comprises more than one pond in series, it may be beneficial to periodically undertake between-pond monitoring to determine performance trends. Performance trends can be useful, for example, to determine the impact of sludge accumulation on pond performance. The appropriate frequency of such monitoring will be site specific, depending on factors such as resource consent conditions, pond size, short-circuiting and loading rates.

4.2.6. MONITORING OF EXTERNAL PARAMETERS

In addition to the process monitoring detailed above it is often useful (but not mandatory) to measure and record the following external parameters, particularly if a pond is experiencing loss of performance.

- Septage and Industrial discharges; see sections 4.2.2 and 4.2.3 above.
- Air temperature; large differences in pond and air temperature together with low wind speed can explain overturning of a pond. Refer 4.4.3.
- Wind speed and direction; this can indicate trends in wave action, contribute to pond overturning and sources of odour complaint. Refer 4.4.1 and 4.4.3.
- Solar radiation; this can explain trends in effluent disinfection when the final ponds have low algal levels.
- Sewerage catchment and pond rainfall and evaporation records.

4.2.7. SAMPLE METHOD – EFFLUENT

Treated effluent samples should be collected from the discharge weir, discharge manhole or discharge pipeline, rather than directly from the pond. It will be difficult to ensure that representative samples are collected if taken directly from the pond. It is appropriate for effluent samples to be collected as spot (grab) samples, rather than composite samples. Samples should be collected at a similar time on each sample day (ideally in the morning, between 9-10 am). This will usually also ensure that samples can be delivered to the laboratory the same day.

The frequency of sampling the treated effluent will largely be dictated by resource consent requirements. However, as a minimum, treated effluent samples should be collected monthly, unless the resource consent stipulates more frequent sampling. By sampling WSP effluent monthly, seasonal trends in performance can be determined. However, weekly sampling will give a greater understanding of performance, particularly with infrequent trade discharges or weather patterns such as storm events.

The contaminants to be analysed will also largely be dictated by resource consent requirements. At a minimum, analysis for the following determinants is recommended:

- cBOD5
- TSS
- Ammoniacal nitrogen
- TKN
- Total nitrogen
- DRP
- Total phosphorus
- *E. coli*

Sampling, sample preservation, labelling protocols, site identification, means and timing of transport etc. should be agreed with the testing laboratory beforehand.

4.2.8. SLUDGE LEVEL MONITORING

Periodically checking the sludge levels in the WSP can be performed to assess sludge accumulation, and to assist with planning and budgeting for sludge removal. Ideally sludge depth profiles should be undertaken at least every 5 years. The evaluation of sludge accumulation is complicated, in that sludge build up within WSP varies both over the pond area and with depth. Sludge levels are often found to be higher near the inlet, outlet and in the corners of the WSP. Older, more compacted sludge is found on the base of the pond, while newer and less dense sludge is found at the sludge-water interface. When the depth of sludge is significant (e.g. approaching 0.9 m from the water surface), it can potentially impact treatment performance, and sludge depth profiling should be undertaken more frequently.

4.2.9. WSP SLUDGE MEASUREMENT TECHNIQUES

Wet sludge volume, sludge solids concentrations and inert fraction of dry solids are the main considerations when quantifying or surveying the accumulated sludge in a WSP. All survey levels should be referenced to a clear fixed datum nearby. Ideally this survey datum should be identifiable against the WSP as-built drawings.

4.2.9.1 MEASURING WET SLUDGE VOLUME

A systematic methodology should be used when determining the quantity of sludge in WSP. The WSP should be divided up using clear and repeatable transect lines across both the length and the width of the pond. For repeatability, the location of these transects could be marked using stakes or permanent markers on either the waveband or fence posts. Graduated ropes pulled taught across the pond or GPS can then be followed to position the measurement and sampling boat.

The number of locations at which sludge depth should be measured to allow a reasonable estimate of total sludge quantity to be made will be influenced by the size of the pond. Larger ponds will require more measurements to be taken. As an example, for a WSP 100m by 100m, transects at 20m intervals in both directions would give a total of 16 locations for sludge depth measurement. This would allow a reasonable estimation of sludge volume to be determined.

Calm weather is essential and a rope line pulled tight across the pond can be used to hold the survey vessel stationary while measurements and samples are taken. The depth probe used to measure total depth should have a blunt end so that it does not damage a geomembrane pond liner or penetrate into a clay pond liner. The water level on the day of the survey must be recorded in relation to a fixed height if it is used as the datum for all measurements. This will then need to be compared to the water level in following surveys and any difference subtracted or added accordingly.

Many techniques have been used to measure to the sludge-water interface (top of sludge layer) with varying degrees of accuracy.

A simple and effective method for measuring both the sludge depth and total pond depth is through use of a graduated “sludge judge”. A sludge judge allows a “core” of WSP liquid and sludge to be brought to the surface for visual determination of the depth of water above the sludge layer. The total pond depth can be determined by pushing the sludge judge to the base of the pond.

There are a number of different infrared sludge blanket detectors available that are relatively inexpensive, simple to use and accurate.

The accuracy of using sonar depth sounding to measure to the top of the sludge layer can depend entirely on the nature of the sludge, turbidity, type of sonar device and depth of the sludge below the transducer. Sonar has the advantage of being able to produce a highly detailed survey but that detail is of little use if inaccurate. A sonar device should be calibrated in each pond at multiple points against a sludge judge or infrared sludge blanket detector.

Sludge measurement accuracy and repeatability of +/- 25mm is possible and should be targeted. All data should be made available to the operator in hard and electronic format for reference as part of the plant history records. With the data gathered, 3D computer software can then be used to calculate volumes and create plans and cross sections.

4.2.9.2 MEASURING SLUDGE SOLIDS CONCENTRATIONS

Solids concentrations are an important consideration when calculating dry mass, dewaterability, space and costs needed for disposal.

Undisturbed in-situ sludge samples need to be taken to be analysed for dry solids content. The depth at which the sludge sample is taken also needs to be considered. A comprehensive sludge survey should include a representative number of sample locations and ideally samples taken at up to three different depths at each location (depending on the depth of the sludge layer). The reason for this is that sludge accumulations deeper than about 1 metre can sometimes show compaction with higher solids concentrations nearer the base than in the upper sludges. This stratification in solids concentration needs to be considered when calculating dry solids volumes. An example of 3 differing layers in the sludge column is shown below.

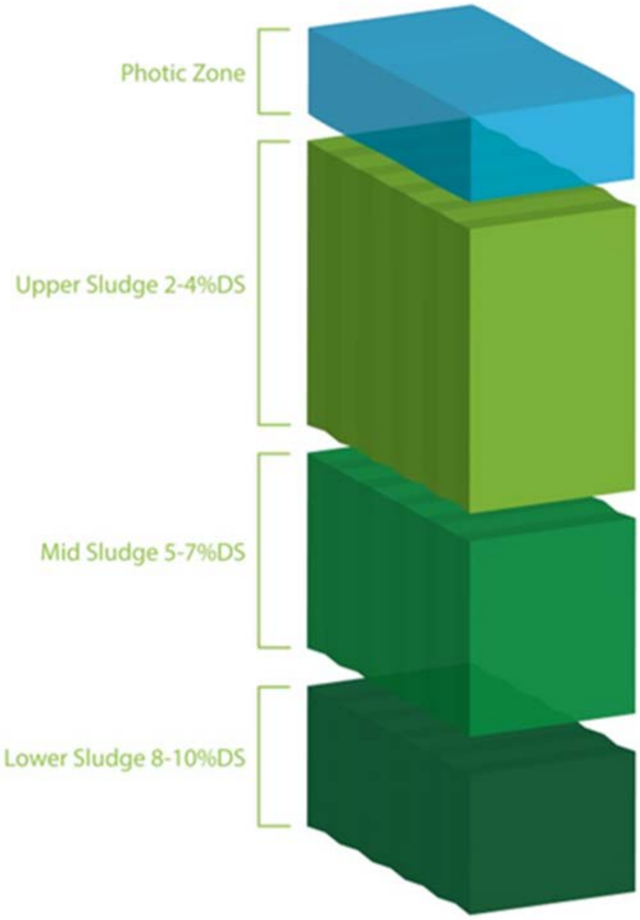


Figure 4-1 **Example Sludge Column Layers**

Any stratification in solids concentration will show up in the sample analysis at which point it can be determined whether there is a significant difference in total dry solids calculated by either applying an overall average dry solids percentage to the wet volume of sludge or splitting that volume into two or three layers and applying the corresponding average dry solids percentages to each layer. If there is a significant difference, it would be more accurate to separate out the layers and apply the appropriate average dry solids percentage to each layer. It is also important when comparing the solids concentrations to the depths at which the samples were taken to note that the thickness of each layer could vary throughout the pond especially where the base profile is inconsistent.

In summary, to provide a more accurate approximation of the dry mass present, it is important to consider variation in sludge solids concentration relative to depth. However, it is recognised that specialist sampling equipment is required to be able to effectively collect discrete samples from different sludge depths.

If such specialist sampling is not possible, an alternative is to homogenise a sludge core collected through the depth of the pond. The resulting TSS concentration, multiplied by the depth of sludge, provides a reasonable estimation of the mass of dry solids present. Examples of sludge core collection include use of a ‘sludge judge’ and use of an open tube with a valve on top.

When using a sludge judge to collect a core sample, care should be taken as the sludge may not enter the tube at the same rate as the tube is lowered like water does. This means that the tube will collect sludge at the sludge surface but may begin to push sludge out of the way instead of letting it enter the tube as it proceeds through the sludge column. This may mean that you do not capture the whole sludge column.

When using an open tube that has a valve on top, the valve is open when lowering the tube and closed when the tube has reached the base. The tube is then raised up with the entire sludge column inside, including any layer of grit or soft clay from the base. Depending on the weight of the water on top and the depth of the sludge, the grit and clay can often drop out before you have a chance to close off the bottom of the tube when it is just below the pond water surface.

4.2.10. SAMPLE METHOD – SLUDGE

When sludge depth profiling is undertaken, sludge samples should be collected and sent to a laboratory for analysis. It is recommended that all sludge samples collected from WSP should be analysed for TSS. In addition, a selection of the samples (e.g. 10 – 20%) should also be analysed for volatile suspended solids (VSS).

When collecting samples of the sludge, the location and depth should be recorded for repeatability and the sample should be undisturbed when taken. When taking samples at more than one depth in the same location, take the upper sample first and work downwards so that each sample is undisturbed. Some sludge survey contractors have proprietary equipment which allows discrete sludge sampling at different depths, typically using vacuum pumps.

Sludge surveys should preferably be undertaken at the same time of year to avoid seasonal effects on comparative volumes.

Sludge cores through the depth of the pond can be collected using a sludge judge or open tube as noted above. To collect a homogenised sludge sample in this way, slowly pour the pond water from the top of the sample, taking care to minimise mixing of the pond water and sludge layers. After the pond water has been removed, pour the sludge into a bucket. It will be necessary to send only a relatively small portion of the sludge sample to the laboratory for analysis. Therefore, it is critical that the sludge in the bucket is mixed well to ensure homogenisation before removing the sub-sample to send for laboratory analysis.

If beneficial reuse of the biosolids is being considered, a selection of sludge samples should also be analysed for heavy metals, organics and pathogens. The Guidelines for the Safe Application of Biosolids to Land in New Zealand (NZWWA, 2003) detail the contaminants which should be tested for, and the contaminant levels to meet the various biosolids grades.

Note: These biosolids guidelines are currently being reviewed and updated as “Guidelines for Beneficial Use of Organic Materials on Productive Land”. The revised version is expected mid 2018.

4.2.11. RECOMMENDED SAMPLING SCHEDULE

Table 4-2 Recommended Sampling Schedule

Parameter	Method	Frequency	Comments
DO	In-situ or on-line	Daily or continuously	Remote sites may be visited once or twice per week
pH	In-situ or on-line	Daily or continuously	Remote sites may be visited once or twice per week
Conductivity	In-situ or on-line	Daily or continuously	Remote sites may be visited once or twice per week
Temperature	In-situ or on-line	Daily or continuously	Remote sites may be visited once or twice per week
Algal TSS	Laboratory		Depending on WSP complexity
Algal Species	Laboratory		Depending on WSP complexity
Chlorophyll *a*	Laboratory or on-line	Weekly or continuously	Depending on WSP complexity
Sludge level	In-situ	1 – 5 yearly	Depending on rate of accumulation
Sludge characteristics	Laboratory	1 – 5 yearly	

4.3 TROUBLESHOOTING

Common operational problems encountered and their solutions are listed below.

4.3.1. SMELLS AND ODOURS

Odours can potentially be generated from two areas on a WSP site; the influent screening area, and the WSP itself. If odours are being generated by the inlet screening, this can be minimised by use of a washing system prior to dewatering and covering both screen and screening bins. This has the additional benefit of reducing the attraction to vectors such as flies, rats and seagulls. Figure 4-2, below, shows an example of effective covering of a screenings bin.

The main water body of a WSP should be aerobic, with anaerobic conditions restricted to the sludge layer at the bottom of the pond. Localised odour at the pond inlet can occur with high influent load and insufficient initial mixing. Providing a WSP remains aerobic, minimal odours should be generated from the WSP pond itself. If a WSP does generate objectionable odours, this is likely to be due to low DO, pond turnover, and/or excessive floating matter. These problems are discussed in subsequent sections.

Figure 4-2 Covering of Screenings

4.3.2. LOW DO

The DO concentration in a WSP will fluctuate considerably over a diurnal (24-hour) period due to the combined effects of algal photosynthetic oxygen production and oxygen consumption by the respiration of all pond organisms. DO concentrations will be at their lowest at, or shortly after, sunrise rising to their peak towards the early afternoon. Low DO concentrations early in the day are not necessarily cause for concern, however if low DO (<2 mg/L) is measured in the early afternoon this may be of concern. Nitrification is much less likely to occur under low DO conditions.

Low DO in WSP can be caused by the following factors:

- Excessive BOD loading, for example due to a seasonal or permanent increase in wastewater flow and load.
- Loss of algae, either due to seasonal fluctuations in algal concentrations, or due to other factors such as grazing by invertebrates.
- Failure of or inadequate use of mechanical aeration, if mechanical aeration is used to supplement the oxygen produced naturally by photosynthesis.
- Pond turnover, resulting in the release of organic matter (BOD) from the sludge layer into the surface layers and increasing oxygen demand.

If low DO concentrations occur, it may be possible to provide supplementary aeration by:

- Mechanical aeration. Note: it is important that the anaerobic sludge layer is not disturbed by aeration as organic matter will be released from the sludge, increasing the oxygen demand.
- Sodium nitrate. This could be introduced at a fixed point in the pond, for example with the influent, or released from a boat moving around the pond surface.
- Where the WSP comprises more than one pond, through recirculation of effluent from a pond with relatively high DO to the surface of a pond with lower DO. This can be particularly effective if the low DO in one pond is caused by loss of algae, and other pond(s) still have a healthy algae population.

Note: Previous Guidelines and industry perception is that jet boats or outboard motors can be used to provide supplementary aeration and mixing in WSP. While this is possible, care must be taken because they have the potential to stir up the sludge layer, potentially compounding the situation. The health and safety requirements for boats also need careful consideration. This option should therefore only be used in emergencies and not as a regular operation.

4.3.3. STRATIFICATION AND POND TURN-OVER

Stratification in WSP occurs mostly during spring and summer months during periods of high sunshine and low wind velocity. During this time the water on the surface of the pond is exposed to sunlight and heats up more quickly than the water at the bottom, resulting in warmer less dense surface layer above a much cooler denser deep layer. The change in water temperature and density at the boundary between the two water layers prevent mixing of the surface water into the deeper rest of the pond. Stratification can trap the pond algae and daytime oxygen production near the pond surface, reducing its availability to promote aerobic treatment in the rest of the pond water.

Pond turn over occurs mostly during late summer and autumn during cold nights when the pond surface cools down more quickly than deeper pond water which remains warm. At some stage the density difference is sufficient for the cooler denser surface water to sink to the pond bottom and displace warmer lighter bottom water and sludge that may have low DO or even be anaerobic and can release nuisance odour.

The risks of both stratification and pond turn-over can be reduced by installing some mechanical aeration and mixing using surface aerators which minimise disturbance of the sludge layer.

If stratification does occur and low DO concentrations result, refer to Section 3.4.4 for methods to increase DO concentrations.

4.3.4. UNEXPECTED POND CRASHES

This issue is covered in sections 4.3.2 on “Low DO” and 4.3.5 on “insufficient algae growth”.

4.3.5. INSUFFICIENT ALGAL GROWTH

As WSP rely on the photosynthetic action of algae to provide most of the oxygen required for effective aerobic breakdown of contaminants, a WSP requires a healthy algal population to function effectively. When the algae population is vibrant, a WSP is dark green in colour.

Insufficient algal growth can occur due to the following:

- Natural variations in the algal growth rate due to seasonal fluctuations in temperature, sunlight intensity, and sunlight hours. This results in WSP often turning brown, particularly during winter.
- Excessive grazing, for example due to rotifer or cladoceran (particularly *Moina* sp.) blooms.
- Toxicity entering the plant through the raw influent or through incorrect pond maintenance introducing algaecides.

Blooms of the cladoceran *Daphnia* sp. should not occur in WSP that are functioning well. The pH in WSP with healthy algal growth will fluctuate diurnally due to the photosynthetic effects of algae. During sunlight hours when algae consume carbon dioxide (CO_2) for photosynthesis, the pH in WSP rises. At relatively high pH values, more of the ammonia present in the wastewater is present in the unionised (ammonia gas) form, which is toxic to daphnia (Crites et al. (2014)).

If there are insufficient algae to maintain adequate DO concentrations, supplementary aeration can be provided. Refer to section 3.4.4 for further details.

4.3.6. EXCESSIVE ALGAL GROWTH

Excessive algal growth does not adversely affect the function of a WSP, however it can cause elevated concentrations of TSS in the treated effluent. During summer, high algal growth rates can result in TSS concentrations in WSP of 150 mg/L or more. At such times, higher daytime DO concentrations will increase the treatment capacity of the WSP.

The concerns around excessive algal growth are usually due to the visual impact (green plume) of treated effluent with a high algal concentration when it is discharged into a stream or river.

Rather than control algal growth in the main WSP, reductions in TSS concentration in the discharged effluent could be achieved by either providing shade around the outlet, or through modification of the discharge structure. Refer to section 3.4.2 for further details of these potential solutions.

4.3.7. BLUE-GREEN ALGAE (CYANOBACTERIA) BLOOMS

Blue-green algae, or cyanobacteria, blooms can occur in WSP in particular, during warmer summer and autumn months when pond HRT is often longer (due to lower inflow and higher evaporation) and there is less wind mixing which enables blooms to accumulate on the pond surface. This is often the case in ponds with an outflow surface baffle that prevents these surface floating algae from being washed out of the pond. A blue-green algal bloom in a WSP is shown in Figure 4-3.

Figure 4-3 Cyanobacteria

Cyanobacteria in WSP is potentially of concern due to:

- The release of toxins by some species of cyanobacteria under certain conditions, with the cyanobacteria and/or toxins being released into the environment with the WSP discharge. These toxins can be fatal in mammals such as dogs and cattle, and can cause anaphylactic reactions in humans.
- The creation of rafts of cyanobacteria on the surface of WSP, reducing the amount of sunlight which penetrates into the pond. This can limit the growth and oxygen production of beneficial green algae.

The growth of blue-green algae can be reduced by ensuring all Maturation ponds have a short HRT to minimise their growth, a surface outflow weir to wash them out of the pond, and mixing the pond surface to avoid them concentrating there and out competing other algae.

4.3.8. COLOUR OBSERVATIONS

Table 4-3 Connection between colour of the pond and operational characteristics

Pond Colour	Interpretation
Dark green and partially transparent	Unimportant presence of other microorganisms in the effluent High pH and DO values Pond in good condition
Orange red	Bloom of *Daphnia* or *Moina* which will reduce pond algae and DO concentrations
Yellow green or excessively clear	The result of a rotifers, protozoa or cladoceran bloom which graze on the algae and can decimate their population in days If the conditions persist, there will be a decrease in DO and the potential for odour nuisance.
Greyish	Overload of organic matter and/or short detention time Incomplete anaerobic digestion in the sludge layer The pond should be put out of operation
Milky green	The pond is in a self-flocculation process as a result of high pH and temperature causing flocculation of algae with magnesium and calcium hydroxides.
Blue greenish	Excessive proliferation of cyanobacteria The bloom of a certain species forms a scum that decomposes easily, leading to bad smells, reduction of light penetration and green algae, as a consequence, reduction in oxygen production
Brownish red	Overload of organic matter Presence of photosynthetic sulphide-oxidising bacteria (they require light and sulphides, use CO_2 as an electron acceptor, do not produce oxygen and do not help in BOD removal).

Source: Arceivala (1981) and CETESB (1989)

4.3.9. INVASIVE PLANT GROWTH

Excessive plant growth does not normally occur in WSP, however it does happen on occasions, as shown in Figure 4-4. When excessive plant growth occurs, this can impact on the normal function of a WSP by affecting the flow through the ponds, potentially increasing short circuiting.

A WSP does not normally provide opportunity for weed growth due to:

- The depth of WSP, which are typically ~1.5 m deep. This generally prevents sunlight penetration through the depth of the pond, minimising the potential for weeds to grow from the bottom towards the surface. Accumulation of a sludge layer to the pond surface can increase the risk of excessive plant growth.
- The turbidity and suspended solids of WSP, which further reduces sunlight penetration to the bottom of the pond.
- Impermeable embankments with little opportunity for root development.

Figure 4-4 Weed Growth (Photo courtesy of Sam Murphy, Buller District Council)

Weed growth should be eradicated promptly as excessive weed growth can be difficult to control. The bulk of the weed can be removed by dredging, however some roots will remain which is likely to result in regrowth.

4.3.10. FLIES, MOSQUITOS AND MIDGES

WSP can provide a breeding ground for flies, in particular midges. Significant midge outbreaks have occurred at some WSP and can cause major public nuisance. Midge adults' swarm and mate at the pond margins at dawn and dusk and the females lay their eggs into the pond water attached to surfaces. The larvae migrate to deeper water where they eventually settle on aerobic surfaces where they build a cocoon and pupate. The mature pupa swims to the pond surface, from which a new adult midge emerges and flies away. It has been found that outbreaks of midges are most easily minimised by controlling the population of larvae within the pond. This can be done by:

- Ensuring the pond base is sufficiently anaerobic e.g. by temporarily increasing pond loading.
- Temporarily lowering the water level to dry out the margins where eggs have recently been laid.
- Use of approved pesticides and insect hormones, providing such chemicals can be used within the terms of resource consents.

Flies will mostly be found around the inlet works if a screen system is not fitted with a screenings washing mechanism and faecal matter is accumulating in the discharge bin. They can best be controlled by removing their breeding ground.

Mosquitos develop when vegetation is allowed at the WSP margins and acts as their breeding ground.

Installing a strong light source at a pond system with midge issues can be an effective method to keep midges away from the neighbours; the midges stay at the plant rather than seeking out the light sources in the neighbourhood.

4.3.11. FISH

Eels often naturally colonise WSP in New Zealand, and in some cases are present in high numbers. The presence of eels is generally not of concern, however they can cause blockages in outlet chambers and pumps, and could impact on downstream treatment processes such as membrane filtration.

If eels do cause problems, their impact can be reduced through appropriate design of outlet structures and screening. This is discussed further in sections 3.3.1, 3.4.2.

4.3.12. BIRDS

WSP are often inhabited by large transient populations of birds such as ducks, geese, and swans. This is generally not of concern, although they can create public nuisance, equipment damage and Operator Health and Safety issues. Public nuisance caused by birds can occur if houses are located in close proximity to the WSP. Operator Health and Safety issues can result from trespassers deploying firearms around WSP.

The main concern regarding birdlife on WSP is the potential for outbreaks of avian botulism which can result in the death of birds, in particular ducks, on a large scale in and around WSP. Avian botulism is caused by a toxin produced by the bacterium *Clostridium botulinum*, producing paralysis in affected birds. *C. botulinum* is most prevalent in anaerobic environments, such as the sludge layer on the bottom of WSP. The risk of outbreaks of avian botulism appears to be increased by:

- Modification of WSP from a traditional WSP to a buffer pond, storage pond or sludge pond. This reduces flow through the ponds, increasing the potential for the toxin to accumulate in the pond.
- Increased sludge depth, and/or reduced clear water depth between the anaerobic sludge and the surface of the pond, for example by operating ponds at low levels to provide buffer capacity. This allows the birds easier access to the sludge.
- An outbreak at a plant nearby or in the natural environment with local introduction by infected birds.

If an outbreak of avian botulism occurs on a WSP, it is important to remove and dispose of affected birds as quickly as possible. Transmission of avian botulism occurs through concentration of the toxin in maggots which feed on dead birds, with the maggots then being consumed by other birds. If an outbreak of avian botulism occurs on a WSP, Fish & Game may assist with control. It is increasingly common for Regional Councils to require avian botulism management plans for WSP.

WSP provide an attractive environment for birdlife, so it can be difficult to minimise the numbers of birds on WSP. Ducks seem to' know' when their hunting season starts and their numbers often increase at many WSP at that time since duck shooting is illegal there. The following control methods may assist:

- Culling of birds around WSP, although this will likely require approval by Fish & Game, who are often reluctant to give such approval.
- Deployment of LPG “scarecrow guns” around the perimeter of WSP. The effectiveness of such guns is limited, particularly on larger ponds and when used over an extended period of time.
- Use of explosive cartridges fired from shotguns, for example “Birdfrite”. The effectiveness of such cartridges is also limited, particularly on larger ponds.

4.3.13. EFFLUENT DETERIORATION

Deterioration in WSP effluent quality could result in an increased concentration of many different contaminants, with multiple potential causes. The principle causes of effluent quality deterioration are summarised in Table 4-4.

Table 4-4 Principal causes of effluent quality deterioration

Contaminant	Typical Effluent Concentration	Deviation	Potential Causes	Potential Solutions
TSS	10 – 150 mg/L	> 50 mg/L	Algal growth Sludge build-up	Outlet shading Desludge
BOD	15 – 110 mg/L	> 40 mg/L	Algal growth Sludge build-up	Outlet shading Desludge
NH_4-N (winter)	0.5 – 30 mg/L	> 15 mg/L	Cold temperatures Sludge build-up Low DO Overloading	- Desludge Add aeration Reduce load
NH_4-N (Summer)	0.1 – 10 mg/L	> 5 mg/L	Sludge build-up Low DO Overloading	Desludge Add aeration Reduce load
DRP	2 – 12 mg/L	> 6 mg/L	High influent concentrations Sludge build-up	- Desludge
TP	4 – 16 mg/L	> 8 mg/L	High influent concentrations Sludge build-up	- Desludge
E. coli	2,000 – 50,000 cfu/100mL	> 10,000 cfu/100mL	Short-circuiting	Improve hydraulics
Faecal coliforms	5,000 – 100,000 cfu/100mL	> 20,000 cfu/100mL	Short-circuiting	Improve hydraulics

Depending on the potential causes of the deterioration in effluent quality, refer to the relevant section.

- Algal growth – refer to section 4.3.5, 4.3.6.
- Sludge build-up – refer to section 4.3.15.
- Low DO – refer to section 4.3.2.
- Overloading – refer to section 4.3.14.
- Short-circuiting – refer to section 3.4.3.

4.3.14. OVERLOADING

Overloading occurs when the wastewater load, in kg BOD/day, exceeds the capacity of the WSP at the current temperature and operational regime. As a result, DO concentrations fall, and the treatment process fails. The detailed reasons for overloading should be thoroughly investigated prior to committing to remedial action. However overloading can potentially be mitigated by:

- Increasing oxygen availability in the WSP – refer to section 4.3.2.
- Reducing the BOD load onto the WSP – refer to section 4.3.14.

4.3.15. SLUDGE ACCUMULATION

While WSP do provide some ongoing breakdown of organic solids in the anaerobic sludge layer at the bottom, the depth of the sludge layer will build up over time. This is due to the presence of some inorganic (inert) solids in raw wastewater, and because it is not possible to break down all of the organic solids deposited on the base of the WSP.

As the sludge level in a WSP rises, the following problems can potentially occur:

- The increase in sludge depth reduces the depth available for wastewater treatment, reducing the HRT and WSP performance.
- Sludge can form pockets in certain areas of WSP, increasing the potential for short-circuiting to occur.
- The reduced clear water above the sludge layer can provide the environment for problems such as weed growth and avian botulism to occur.
- Anaerobic digestion of the organic material can result in the release of nutrients, in particular NH_4-N and DRP. The rate of anaerobic digestion occurs more quickly during warmer summer temperatures.

For desludging options, refer to 3.4.12, 4.4.7.

4.3.16. EXCESSIVE FLOATING MATTER

Floating matter could be in one of a number of forms:

- Rags and other debris.
- Blue-green algae mats.
- Sludge.

Rags and other sewage debris can accumulate on the surface of WSP, particularly if the raw wastewater is not effectively screened before it enters the WSP. While this is visually undesirable, it is not of undue concern unless debris leaves the WSP in the treated effluent, or clogs aerators or mixers. It is recommended that raw wastewater is screened before it enters a WSP. Screening is discussed in section 3.3.1.

Growth of blue-green algae, or cyanobacteria, can result in the formation of mats on the surface of WSP. This is undesirable because some cyanobacteria can release toxins, and a floating mat can block sunlight penetration, reducing the potential for algal photosynthesis. For further information on blue-green algae, refer to section 4.3.7.

Natural WSP processes result in some sludge floating to the surface, lifted by gases produced by anaerobic digestion within the sludge layer. Such floating sludge typically falls back to the bottom of the WSP due to the agitating effects of both wind and wave action and is not a concern. Sludge will normally only form a layer on the surface of a WSP if there is excessive sludge accumulation or if there is little surface movement by wind or waves. As discussed in Section 2.4.1, good design of WSP promotes wind and wave action on the surface. If floating sludge occurs on existing WSP that are in sheltered locations, aerators can be used to provide mixing and break up the surface sludge layer. Refer to section 3.4.4 for discussion on appropriate types of aerators to use in WSP.

Note: If a stable sludge layer does accumulate on the surface of a WSP, this will quickly turn green due to the growth of algae on the surface of the sludge layer. It is also a clear indication of WSP overload over a long period of time.

4.4 MAINTENANCE

4.4.1. GENERAL HOUSEKEEPING

As with all WWTP sites, WSP should be kept clean and tidy. To achieve this, grass will need to be mown, weeds controlled, and any floating debris should be removed from the surface of the WSP. Rodent traps may also need to be installed. Any operator facilities, such as laboratory, office, shower and toilet, should also be kept clean and tidy.

Data collection, transmission and recording should also regularly be checked.

4.4.2. EQUIPMENT MAINTENANCE

While a traditional WSP has minimal mechanical equipment on site, equipment such as pumps and aerators do require maintenance. A greater range of mechanical equipment is likely to be present on modified WSP.

A maintenance schedule for all mechanical equipment should be developed and followed. The manufacturers or suppliers O&M manuals will provide details of the specific maintenance that should be undertaken on any piece of equipment. All maintenance, both planned and unplanned, should be recorded. Access points e.g. jetties, cranage, should also be maintained available.

4.4.3. INSTRUMENTATION MAINTENANCE

All instrumentation, such as pH or DO probes, require regular cleaning and calibration. The supplier's manuals should provide details of the required maintenance for all instruments, including cleaning and calibration procedures.

4.4.4. INLET AND OUTLET STRUCTURES

Inlet zones should be regularly cleared of any floating debris to avoid odours and ensure that a clear inlet flow path is maintained to assist efficient hydraulic circulation patterns.

Outlet zones should also be regularly cleaned and maintained to limit excess algae being discharged and ensure flow measurement is accurate.

4.4.5. WAVEBAND MAINTENANCE AND REPAIR

Wavebands provide essential protection for the embankments of WSP. Proactive maintenance is required to ensure the WSP structure will have a long life. Routine maintenance of wavebands will differ depending on the waveband material. However it is likely to include:

- Removal of weeds to prevent weed roots damaging the waveband.
- Filling of holes that have been dug in behind the waveband, for example by rats, or rabbits.
- Repair of broken waveband sections.

In addition to waveband maintenance, damage to wavebands can be reduced by ensuring the water level in WSP is not too high, preventing waves passing over the top of the waveband and causing scouring. For information on the required waveband freeboard for different waveband types and pond sizes, refer to section 2.8.

4.4.6. POND LINER MAINTENANCE AND REPAIR

It can be difficult to effectively repair WSP liners without draining and cleaning the pond. Attention to detail and construction as a 'preventative maintenance' is better. Refer to design section 2.8 for further information.

4.4.7. DESLUDGING METHODS

Desludging is the most important long-term maintenance requirement for WSP as sludge accumulation affects pond operation in multiple ways, especially by increasing the emission of odours. Sludge levels should be measured regularly (5 yearly initially and 2 yearly after 15 years operation), to understand the rate of deposition, any irregularities formed e.g. shoals of sludge, and when it is necessary to desludge, or commence enhanced microbial digestion, or similar operational programs. Councils and plant operators should not be surprised by the need to desludge a pond, but should put the finances required in long term plans, and then an annual plan when the time for desludging is approaching.

Once the decision is made to desludge the WSP, based either on sludge inventory measurements, or degradation of WSP performance, sludge removal options are evaluated. Common methods to remove excess sludge include:

- Empty the pond, solar or air dry the sludge in-situ, followed by removal by excavator and trucks. The disadvantage of this method is that the pond must be taken out of service, and this is not possible in many situations. If space is available to construct a parallel pond (taking advantage of higher loading rates in summer), this may prove to have similar or lower costs than the expensive desludging methods, plus the extra pond will provide future flexibility.

- Dredge the sludge from the base of the pond, dewater the sludge externally, then transport the dewatered sludge for reuse or disposal. Dredging does not usually require removing the pond from service, which is a main advantage. However, care must be taken with returned liquors from dewatering and allowing for some variations in pond effluent quality.
- Sludge dewatering methods include trailer-mounted centrifuges, dewatering containers (similar to shipping containers), or geotextile bags located in a lined basin (for collection of filtrate and return to the pond). All the dewatering methods rely on polymer or other chemical dosing, to allow liquid to be separated from the sludge floc. Centrifuges generally can achieve a cake Dry Solids (DS) between 15% and 19%. Geotextile bags can achieve between 17% and 40% DS, with the dewatering performance varying significantly depending on the geotextile fabric selected and the chemical dosing rate. Desludging contracts may need to have an incentive mechanism whereby the contractor receives more payment for DS contents greater than the target value. Alternatively, a special retention could be held and released if the target DS is achieved (within a nominated time in the case of geobag dewatering). This would reimburse the contractor for the use of greater amounts of chemicals, and minimise ‘skimping’ on the amount of chemical used.
- Pond desludging may appear to be a simple operation, but significant documentation and quality assurance is required for :
  - the sludge surveys before and after desludging, and
  - cake DS achieved (in the case of geobags, monitored over a 6 to 12 month period) .
- Pond sludge survey data needs to be collected on a 20m x 20m grid for moderate size ponds, and down to a 10m x 10m grid for small ponds. Samples need to be collected from various positions in geobags because a drier crust can form near the outer surface which ‘hides’ a lower DS content in the centre of the geobag. The data gathering requires adequate contract monitoring resources to check on the validity of the data provided by the contractor. Independent sampling and testing may also be required.
- Dewatered sludge cartage from the pond to remote sites can be a substantial portion of the overall cost. Consequently, dewatered sludge can be used on larger WWTP sites as landscaping mounds to minimise the cartage cost. Often geobags have been buried on the WWTP site if space allows. Alternatively, dewatered sludge can be taken to a landfill and used for surface restoration which may avoid the ‘tipping charge’. Because pond sludge is normally very well stabilised with a lower organic content compared to other sludges, it may be less attractive for commercial beneficial reuse options such as composting. However, local uses in high volumes such as -- landfill, mine, or quarry restoration, could be an economical solution.
- Undertake a form of enhanced microbial digestion. Refer section 3.4.12.

All methods have a significant cost and each has a different timeframe, payment and resources profile. Therefore selection should be based on a specific comparative assessment.

4.4.8. OTHER

Attention should be given to observing whether rodents, other animals or birds are causing issues. Ducks generally prefer cleaner water such as maturation ponds and numbers can markedly increase during duck shooting season as they seem to know they are safe within the plant confines. This can cause a surge in effluent faecal indicator bacteria and virus concentrations.

In cold weather some animals e.g. rabbits, can dig burrows against plastic liners for warmth. Unfortunately sometimes they gnaw through the liner causing leaks.

5 RESOURCE CONSENT AND POND MONITORING

5.1 RESOURCE CONSENT CONDITIONS

Useful guidance on how to set sensible consent conditions and how and why they should be monitored can be found in the NZ Wastewater Monitoring Guidelines, 2002. The following sections summarise a compendium of criteria being usefully applied in the different regions of New Zealand, for WSP discharge consents.

5.1.1. SUPPORTING DOCUMENTATION

Refer to the supporting documentation, especially the Assessment of Environmental Effects (AEE) report, and require that key criteria: location, volumes, rates of discharge and character of the discharge, be as described in the AEE. When applying for a new consent, ensure that the new AEE accurately describes the current and proposed future situation including changes over time and desludging programme.

5.1.2. MITIGATION

Require steps to be taken in the event of a failure of the WSP that could result in any deterioration in quality of effluent discharging to the receiving water, including: remedy and mitigate adverse effects, notify the Medical Officer of Health, notify the Regional Council, provide follow up reporting. Useful tools include troubleshooting flow charts, e.g. for odour control. Acknowledge a timetable necessary for each type of remediation.

5.1.3. RISK COMMUNICATION STRATEGY

Develop a risk communication strategy to notify potentially affected persons of the existence and potential health effects of the discharge. Include: identification of key community groups (e.g. recreational and food gathering users of receiving waters), organisations to consult with (e.g. Ministry of Health, Iwi), development of strategy, adherence to strategy, provision of signs at points of discharge and downstream, notification of downstream landowners and occupiers.

5.1.4. MONITORING

Specify:

- locations of sampling points; typically discharge and receiving water impact sites (upstream and downstream). Dissolved oxygen (DO) should preferably be measured at the same time each day and between 0900 and 1400 hours which is typically an average of diurnal variation. It is possible for DO to reduce to zero overnight. DO should be greater than 2 g/m^3 in 90 percent of samples (i.e. 10th percentile of data set >2 g/m^3. Continuous recording will demonstrate the diurnal curve and can demonstrate healthy biology even when periodic daily spot measurements are different (refer 4.3.2).
- frequency and method of sampling,
- methods and procedures for analyses, (typically the current version of "Standard Methods for the Examination of Water and Wastewater"),
- frequency of advising results and format of reporting,
- requirements for flow monitoring, (typically continuous inflow and outflow monitoring),
- testing for pond sealing, if a likely risk.

5.1.5. RECORDS

Keep operational records of system changes, operating procedures, troubleshooting etc. and report annually, or as required by the consent authority. Agree the format of reporting, especially of data minimum accuracy, presentation, trending and percentiles.

5.1.6. MINIMISING ADVERSE EFFECTS

After reasonable mixing discharges should not exceed RMA default criteria e.g. specified limits for indicator bacteria, suspended solids, filtered BOD_5, or affect receiving water macro-invertebrate populations. For WSP with modifications or additional treatment steps, possibly add other parameters within their performance capabilities. Compliance should be based on a running geometric mean and ninety percentiles calculated using specified numbers of test results. Performance criteria may need to be seasonal i.e. different conditions for winter vs summer.

5.1.7. REVIEW OF CONDITIONS

Consent authorities may at scheduled intervals initiate a RMA section 128 review and may also review conditions to deal with any adverse effects on the receiving environment, review the adequacy of the monitoring requirements or reduce the monitoring requirements when the effects of the effluent discharge are adequately established.

The term of consent is to be specified, including any scheduled dates or milestones for upgrading, or system replacement.

It is useful to schedule a periodic review meeting with the consent officer and local community representatives to ensure everyone understands the performance achieved and especially any deviations and their cause. Often deviations are caused either by unusual weather patterns or community events.

6 FREQUENTLY ASKED QUESTIONS

If you are using an electronic copy of these guidelines, holding down the control key plus a left mouse button click on any of the questions below will take you to the relevant section.

How often should I measure the sludge depth?

My ponds have an odour problem!

Is the colour of the pond important?

What are Blue-Green Algae?

How do I design a pond?

How do I build a pond?

What operational records should I keep?

What effluent quality should a pond produce?

What effluent quality can an upgraded pond produce?

How can I improve the discharge quality?

Can I treat the pond effluent with UV light?

I'm confused by the different names used to describe ponds.

APPENDIX A: INDICATIVE EFFLUENT QUALITY FROM IMPROVED POND SYSTEMS

Contaminant	**BOD_5** **g/m^3**	**SS** **g/m^3**	**TN** **g/m^3**	**NH4-N** **g/m^3**	**TP** **g/m^3**	**DRP** **g/m^3**	**FC** **cfu/100 ml**	***E. coli*** **cfu/100 ml**
Facultative (Primary) Pond	40	50	40	15	8	6	20x 10^3	$10x10^3$
Maturation (Tertiary), Pond	30	40	35	13	8	6	$10x10^3$	$5x10^3$
Multiple Maturation (Tertiary), Ponds in Series	30	40	25	10	8	6	2 x 10^3	1 x 10^3
Membrane-Filtration	5	1	5	10	4	4	Detection limit	Detection limit
Rock Groynes	30	35	30	10	8	6	$5x10^3$	$2x10^3$
Growth Media Ponds	20	30	12	4	6	4	$5x10^3$	$2x10^3$
Coagulation and Sand Filtration	5	5	20	10	5	3	50	10
Wetlands	15	15	25	5	6	4	$5x10^3$	$2x10^3$
Wetlands and UV Light	15	15	25	5	6	4	200	100
High Rate Algae Pond Systems	15	15	10	5	6	4	200	100

APPENDIX B: POND RECORD SHEET

		Pumps		**Sewage Flow**		**Waste Stabilisation Ponds**												
Day of month	**Plant inspected**	**Meter Reading (Hr or KwH)**		**Pump Hours**	**Daily Flow (m^3)**	**Time of Test**	**pH**		**Dissolved Oxygen (mg/L)**		**Temp of Ponds (°C)**		**Appearance of Ponds**		**Odour**		**Weather**	**Comments**
		No. 1	No. 2				No. 1	No. 2	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2		
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Note: A template for this record sheet is available as an excel download at http://www.waternz.org.nz/WSP

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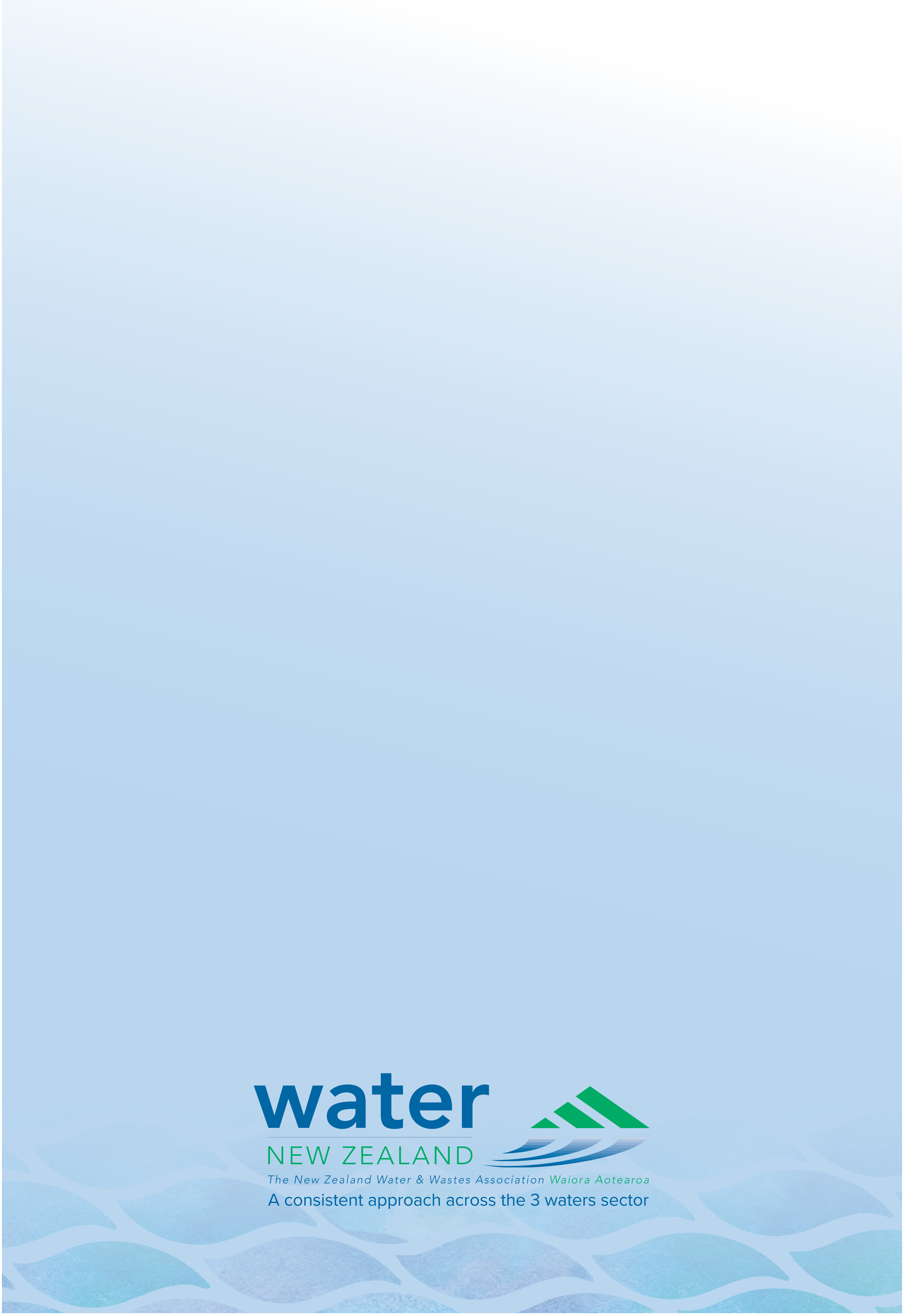

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