CAN PERFORMANCE OF WASTE STABILISATION PONDS BE IMPROVED?

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ABSTRACT

There are over 200 waste stabilisation pond treatment plants in New Zealand which represent a substantial asset value. Common criticisms of ponds include;

- Ponds have caused nuisance odours in some locations
- Faecal Indicator Bacteria (FIB) removal by ponds relies on natural processes and is too variable
- Algae in pond effluent cause colour effects in receiving waters
- Nutrients cannot be removed in ponds
- Sludge removal from ponds is difficult and expensive

These criticisms can be countered by describing the successful upgrading works that have been implemented at a number of pond sites in NZ, along with the subsequent performance improvements. This paper focuses on ponds which the author has first-hand experience of (at 50 WWTP sites with pond systems), but will also comment on other pond sites where problems have arisen.

KEYWORDS

Waste stabilisation ponds, oxidation ponds, odour emission, faecal indicator bacteria removal, membrane filtration, virus removal, nitrogen removal, pond sludge dredging, sludge dewatering geotextile bags

1 INTRODUCTION

While Waste Stabilisation Ponds (WSP) or oxidation ponds have been in service in New Zealand since 1960 and are viewed by some as ‘old technology’, there are modern and innovative methods for improving their reliability so that odour emissions are reduced and final effluent qualities are substantially improved. Improvements described in this paper can be summarised as follows:

- Significant odours have been emitted (on occasions) from ponds at Gore, Blenheim and Nelson. Odours were reduced by installing more mechanical aeration on those ponds, or by diverting high strength industrial loads from the domestic ponds and treating separately. From the 1994 Oamaru greenfield pond development onwards, CH2M Beca has installed multiple mixer/aerators on primary ponds at Blenheim, Rangiora, Tekapo, Fairlie, Gore, Leeston, Waimate, Patea, Nelson, Temuka, Geraldine and Timaru.

- Subdivision of ponds to form multiple ponds-in-series, or addition of wetland ponds-in-series, has achieved median FIB concentrations of 200 cfu/100ml at Christchurch, Invercargill and Blenheim. Significant reductions have been achieved at other ponds that have been subdivided, without increasing the overall pond area, at Patea, Twizel and Geraldine.

- It is now financially feasible for Membrane Filtration (MF) to completely remove algae and the green colour, as well as FIB, which avoids the need for UV disinfection. MF has been installed at ponds at Dunedin Airport, Dannevirke, Hikurangi, and Matamata, and is proposed for Motueka.

- Ponds located from Blenheim northwards, do remove significant nitrogen in summer and autumn, whereas ponds from Canterbury southwards, do not remove much nitrogen. This correlation with temperature agrees with the conclusion of Hurst and Connor (1997) that nitrification and denitrification were the major mechanisms for ammonia and total nitrogen removal, based on extensive studies of the large Western Treatment Plant ponds at Werribee near Melbourne Australia. Dissolved Phosphorus is not removed in ponds, but sludge removal, and algae removal by MF, can remove about 30% of Phosphorus.

- Sludge typically needs to be removed from primary ponds after 20 to 25 years' service. Ponds that have 30 years sludge accumulation normally emit odours and are unstable. If a pond can be taken out of service over summer, the sludge can be air-dried in-situ and removed by an excavator and trucks at low cost. If a pond has to remain in service, floating dredges and sludge dewatering using geotextile bags have recently been tendered at lower cost than centrifuge dewatering.

- Adoption of a Pond Management Plan (PMP), which incorporates operational guidelines for assessing the "pond health" and likelihood of odour release, plus mitigation measures that can be implemented by operators, has reduced the frequency and severity of odour emissions.

- For sustainability reasons, development of WSP can be encouraged where suitable land is available, because of low electrical energy inputs (and use of renewable wind and solar energy) and reduced solids processing costs. Furthermore, effluent qualities that match advanced "in-tank" processes can now be achieved.

2 TERMINOLOGY

There are a number of descriptions used for treatment ponds (or lagoons). The IWA Specialist Group on Wastewater Pond Technology has adopted the term Waste Stabilisation Pond (WSP) as encompassing the following pond processes:

- Anaerobic

- Aerated (with substantial mechanical aeration and < 5 day retention)

- Facultative or primary or oxidation (without, or with minor, mechanical aeration and > 20 day retention)

- Maturation or polishing

- Wetlands (having more open water areas than planted areas)

This paper uses the terms "pond" or "WSP", while acknowledging that "lagoon" also has widespread usage, particularly in Australia. Facultative, maturation and wetland ponds are the focus of this paper.

3 SUMMARY OF POND ODOUR EXPERIENCE IN NEW ZEALAND

Most of the approximately 200 pond systems in New Zealand have operated without significant odour emissions. However, some ponds have created substantial odours. The key features of the experiences at larger pond systems are summarised in Table 1, including the reasons for the presence or absence of odour issues.

Table 1: Summary of Pond Operational Experience in New Zealand

Location	Odour Emissions	Comments
Nelson Regional Bells Island, near Richmond, which receives major industrial loads (three facultative ponds in parallel each 10ha, followed by two 10ha ponds in series – total area 50ha)	Major odour events up to about 2005 when the processes upstream of the ponds were upgraded.	Caused by high solids loading from aeration basin at the inlet and lack of mixing during calm conditions. Remedied by installing activated sludge process with secondary solids removal, and more recently with a primary clarifier upstream of activated sludge process.
Nelson North Wakapuaka (16ha primary pond and 10ha of maturation ponds)	Major odour events with odours detected at 2km to 5km from the plant, until 2012.	Caused by loss of algal populations, sludge belching, lack of wind mixing, and availability of only one brush aerator. Remedied by installing four extra brush aerators and removing sludge from primary pond.
Blenheim Municipal (three primary ponds in parallel 30ha total and three maturation ponds; total 8ha)	Some odour in 2003/04 due to rapid growth of centralised wineries in the Riverlands area causing pond overloading. No odours since staged upgrading of separate winery effluent treatment from 2006 to 2009.	High BOD loading (approximately 150kg BOD/ha.d) in autumn/early winter during vintage. Remedied by installing additional brush aerators on the primary ponds, and then diverting winery effluent to a separate industrial WWTP. Original 16ha pond was desludged in 2000 after 32 years of operation.
Oamaru (Two primary ponds in parallel, total 11ha, and three maturation ponds total 4ha)	Plant commissioned in late 1994. No nuisance odour emissions even though neighbours are 300 to 500m from the ponds.	Each primary pond has 3 x 15kW aerator/mixers which are operated when required. Frequent wind mixing due to proximity to coastline.
Gore	Major odour emissions in autumn 2004 due to overloading (250kg BOD/ha.d) of municipal pond with meat processing wastewater. Five small 2.2kW inclined aspiration aerators had been installed but were not reliable and were insufficient.	Installed 11 x 5.5kW inclined aspiration aerators in 2005. Odour emissions have not re-occurred.

4 ODOUR GENERATION IN PONDS AND MITIGATION BY MECHANICAL MIXING/AERATION – LITERATURE REVIEW

Pond odours are recognised in the literature and typically occur during spring and autumn. In spring, the pond temperature warms up, and once this reaches around 15°C, the sludge in the base of the pond starts to anaerobically digest more actively, and can release odours during the transition phases when volatile acid formers are active but methane formers have not multiplied sufficiently.

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 - refer to Brockett (1975).

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:

"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".

It is clear from the recommendations made by eminent researchers of ponds from overseas and New Zealand, that mechanical mixer/aerators should be installed on ponds. These recommendations date from 1970 and were included in the updated "Oxidation Pond Guidelines" issued as a draft in 2005 by NZWWA.

5 SUPPLEMENTARY MIXER/AERATOR USE

From the 1994 Oamaru greenfield pond development onwards, CH2M Beca has installed mixer/aerators on all primary ponds and some maturation ponds (to reduce blue-green algae growth caused by stratification). Our opinion is that multiple mixer/aerators are crucial to maintaining a healthy pond which is generally free from nuisance odour emissions.

Brush (or paddlewheel) aerators are the most efficient type for shallow ponds. New Zealand made units have required significant maintenance, but more reliable units can now be imported from the USA at a similar cost to the New Zealand made units.

Figure 1 - Brush aerator at Nelson WWTP

At higher wind speeds, ponds are well mixed. However, during calm periods, the non-motile algae can be trapped below the zone of sunlight penetration (top 300 mm) and not receive a sunlight dose for photosynthetic oxygen production. Mechanical mixing can be very helpful during calm periods so that algae are brought to the surface for a dose of sunlight. The direct injection of oxygen by aerators is useful, but the mechanical oxygen supply is minor in comparison to the oxygen supplied by algae.

In smaller ponds or in calm conditions, stratification can develop which encourages the growth of blue green algae. Mechanical mixing can reduce the incidence of stratification and thus mixer/aerators may need to be installed on maturation ponds as well as primary ponds. Brush aerators, although more expensive, are more effective at breaking up algae scum mats and do not disturb the lower layers of facultative ponds.

The aerator mixers can also create favourable circulation patterns to utilise the full area of a pond to reduce the size of dead zones and avoid short circuit paths. Stub baffles can also be installed to prevent "bank hugging" currents from short-circuiting to the outlet – refer to Shilton et al (2002).

6 EFFECTIVENESS OF MULTIPLE PONDS-IN-SERIES FOR DISINFECTION

The significant improvements that can be achieved by increasing the number of ponds-in-series without increasing the overall pond area, was demonstrated at the Christchurch WWTP, New Zealand. Before upgrading, the 225 ha pond system comprised two parallel trains, each with three ponds-in-series. After upgrading in 2004, there is now one train with seven ponds-in-series. These ponds have a total of 17 days average retention and follow conventional primary sedimentation, trickling filter/solids contact and secondary clarification processes.

Table 1 – Examples of Pond Subdivision within the same footprint, Faecal Coliform (cfu/100ml)

Christchurch	Before with Three Ponds-in-Series	After with Seven Ponds-in-Series
Median	5,000	400
90 percentile	50,000	1,000
Patea	Before with One Ponds-in-Series	After with Three Ponds-in-Series
Median	26,500	51
90 percentile	146,000	168

The Christchurch ponds historically handled a portion of the BOD load but now are solely used as maturation or polishing ponds. The significant improvement in disinfection performance can be attributed to greater use of the available pond volume by reducing dead zones and short-circuit paths, plus higher average dissolved oxygen (DO) concentrations. Studies by NIWA (reported in Davies-Colley et al, 2002) demonstrated that disinfection by sunlight was significantly enhanced when DO was greater than 4 g/m^3, due to photo-oxidative damage.

It appears that four to seven ponds-in-series provides an optimal solution in terms of indicator bacteria reduction balanced against the cost of subdividing the pond.

7 ADD-ON DISINFECTION PROCESSES

If very low pathogen indicator numbers are required, then UV disinfection, or membrane filtration (MF), can be installed after the pond system. Some examples of typical performance improvements are:

Table 2 - Median Faecal Coliform In Pond Effluents and After Disinfection (cfu/100 ml)

Plant Location	Before UV	After UV
Byron Bay, NSW	1,000	10
Rangiora, NZ	2,800	160
	Before Membrane	**After Membrane**
Dannevirke, NZ	4,000	<1
Matamata, NZ	2,300	<2
Hikurangi, NZ	20,000	<10
Dunedin Airport, NZ	500	<1

It is noted that the results in Table 2 for membrane filtration are achieved by the membrane alone. There is no need for UV disinfection.

First generation UV lamps without mechanical wipers, required frequent manual cleaning to remove the algal film which quickly developed on the lamp sleeves and few UV systems were installed for pond effluents. Second generation UV systems with higher intensity lamps and automatic wipers, have proven to be practicable and can achieve a further 1 to 2 log order reduction of indicator bacteria as shown in Table 2.

Costs for MF have reduced significantly over the past ten years and the number of installations is increasing. Microfiltration membranes were initially used, but ultrafiltration membranes are now being supplied for pond effluents, e.g. Motueka upgrading where 3 log reduction of virus is required for protection of shellfish beds. Tube membranes rather than flat panel membranes have been favoured for pond effluents.

Micro and ultra-filtration after ponds produces a clear effluent (without the green colour) having low SS and indicator bacteria numbers. This development should see the continued viability of pond systems in situations where improved effluent quality is required for public health protection, rather than replacement of the ponds by "in-tank" processes.

8 NITRIFYING TRICKLING FILTERS

Ponds can reduce ammonia during summer conditions (water temperature 15°C to 30°C) but below 15°C, ammonia reductions are not reliable. For improved performance at lower temperatures, pond liquid can be pumped over gravel or plastic media trickling filters, which provide extra surface area for a nitrifying biofilm to develop.

Studies by Stone et at in 1975, at Sunnyvale California, demonstrated that nitrifying bacteria were present in pond liquid but populations were not stable. A trickling filter was used on pond effluent to reduce ammonia at Sunnyvale. Trickling filters have also been used in South Africa and in New Zealand at Paeroa and Rangiora (refer to Duncan 2002 and Archer 2004). If the nitrified effluent is recycled to the ponds, denitrification will take place due to the large anoxic zone at the base of the ponds. Studies by Hurse and Connor (1997) at the Melbourne Western Treatment Plant concluded that nitrification was the limiting process and that denitrification was not limiting.

Studies by NIWA from 1998 to 2000, showed that biofilm attachment surfaces could be added to dairy farm waste stabilisation ponds to increase the ammoniacal-N nitrification, especially in combination with mechanical aeration (refer to Craggs et al, 2000).

The Pano-Middlebrooks (1982) formula is widely quoted in WSP Design Manuals (e.g. Mara 1998). This empirically derived formula was based on a model for direct stripping of ammonia to atmosphere. Studies of data from ponds in New Zealand by Archer and O'Brien (2004) concluded that the Pano-Middlebrooks formula did not produce reliable predictions of ammonia reduction.

While some stripping of ammonia to atmosphere occurs, the major reduction of ammonia in summer is due to biological nitrification. There are sufficient data sets now available from France, Australia and New Zealand showing that when ammonia is substantially reduced, nitrate concentrations increase indicating nitrification. A consistent pattern is evident showing that nitrification does not commence until mid to late summer and continues through autumn into early winter. However, nitrification does not occur in spring and early summer at similar water temperatures. This suggests that time is needed for the nitrifying biomass population to establish in the pond liquid.

Thus for reliable ammonia reduction at lower temperatures, fixed film nitrifying biomass is required. This can be provided by curtains in deeper ponds usually with supplementary aeration, or by rock, or plastic media trickling filters. A lower cost approach is to utilise the rock protection on banks above waterline and using low pressure sprays to distribute the pond effluent – see Figure 2. A calculation method for the biofilm surface area required at lower temperatures can be found in Section 6.3.7 of USEPA (2011). Descriptions of the retrofits available for installation in ponds to increase attachment surfaces for biofilm can be found in Section 6.4 of USEPA (2011).

Figure 2 – Pond effluent being sprayed over internal rock baffles at Rangiora WWTP (from 2003 to 2006)

9 ALGAE AND PHOSPHORUS REMOVAL PROCESSES

For sensitive receiving environments where the green algae colour and suspended solids are issues, Dissolved Air Flotation (DAF) or Induced Air Flotation (IAF) processes have been used for algae removal. The chemicals dosed for flocculation purposes, or a supplementary chemical, can be added for phosphorus removal (refer to Armatec Environmental website for a description of the Waihi DAF and chemical dosing system).

Now that membrane filtration costs have reduced, this method of algae and SS removal is likely to be increasingly adopted, because pathogens are reduced at the same time.

An alternative approach to reducing algae numbers is to dose ponds with chemicals so that phosphate remains precipitated and not available for algae growth. These methods are described in Section 6.5 of USEPA (2011).

10 INFLUENCE OF SOLIDS LOADING ON PONDS

Brockett (1975) who studied the Mangere ponds in the 1970's, makes this observation:

> *"The high solids loading leading to an upsurge of heterotrophic bacterial population, upsets the delicate bacterial – algal balance. Too high levels of bacteria in the ponds can disturb the algae in several ways viz:*
>
> - *Excess carbon dioxide production*
> - *'Crowding out' of the algae preventing the algae receiving light for photosynthesis and*
> - *Excess bacteria taking up all the available water so that the algae suffer death by plasmolysis."*

High solids loading on the algal overlying layer can occur when sludge accumulations are excessive and there is insufficient depth of aerobic liquid over the sludge layers, e.g.:

- During 'sludge belching' events when the sludge layer starts to digest actively in spring and early summer

- When wave action due to high winds, disturbs the sludge layer.

11 POND DESLUDGING

Primary ponds are typically desludged every 20 to 30 years, depending on sludge accumulation rates, with the aim of maintaining a water depth of at least 1m over the sludge, as this is normally a sufficient depth to strip out odours and reduce the incidence of wave action disturbing the sludge layer.

The most common reason for odour emissions from ponds that are not overloaded in BOD terms is sludge build-up. Comprehensive data on sludge accumulation rates in ponds in France is contained in Picot et al (2004).

Primary ponds should have overall depths of 1.5 to 2.0 m to allow for sludge accumulation, and also for the sludge to remain undisturbed under anaerobic conditions for effective digestion and consolidation.

Pond desludging can typically be undertaken in three ways: empty the pond and solar/air dry the sludge, dredge and dewater by centrifuge, and dredge and dewater by geotextile bags (O'Dempsey & Archer, 2011.

It is common to use floating dredges to remove sludge from a pond. Dredging itself is not a high cost item, but a separate holding pond and drying bed area is needed to handle the large volumes of water pumped. The alternatives to a drying bed, involve polymer dosing and dewatering using a belt press or centrifuge, and this is the more expensive operation. Geotextile bag dewatering is typically cheaper than centrifuging, but polymer dosing is needed and the bags may need to drain for up to one year.

It can be more economic if space permits, to construct an extra pond in parallel so that the original pond can be drained and sludge dried in-situ. Excavators and trucks can then be used to remove the sludge at 40 to 50% DS content without any polymer addition. All new or upgraded pond systems should incorporate two or three facultative ponds in parallel, so that one pond can be taken out of service in summer for sludge removal by drying in-situ.

Figure 3 – Pond sludge in geotextile bags at the Nelson WWTP 2014

12 POND MANAGEMENT PLANS

Based on regular measurements of DO and Chlorophyll a, plus visual observations of the pond surface, an "index of pond health" can be derived. Regular updating of trend plots can identify abnormal changes. Recommended values for key parameters are:

- Chlorophyll a should be normally >0.5g/m^3 and always >0.3g/m^3, as an indicator of adequate algae numbers.
- DO should be normally >4 g/m^{3}l and always >2 g/m^{3}l, when measured between 1100 to 1400 hours.
- DO can be allowed to reduce to zero overnight in primary ponds, because this prevents grazer growth, which can consume the valuable oxygen producing algae.

If trigger values are likely to be reached due to forecast calm/cloudy weather, mitigation measures can be actioned to a priority schedule, such as switching on aerators or diverting load to a more healthy pond.

When a pond 'crashes', temporary pumps can be used to reseed algae from adjacent ponds. It is recommended that permanent pipework is installed to allow recirculation to reseed a primary pond.

This Pond Management Plan concept has found favour with regulatory authorities and provides a more rational framework for operators to take proactive steps to prevent odour releases or in an extreme case, a "pond crash".

13 POLISHING WETLANDS

A frequently adopted method for final polishing of a pond effluent is the use of constructed wetlands. The USEPA Design Manual for Constructed Wetlands, September 2000, is targeted mainly for WSP effluents. This Manual strongly advocates an alternating series of deeper open water ponds and shallower planted zones, to create optimum conditions for each. The USEPA now does not favour fully planted wetlands (that were recommended 20 years ago) because of insufficient oxygen supply. The open water pond areas function exactly like maturation ponds, with algae-supplied oxygen and sunlight disinfection. The planted zones mainly reduce suspended solids. Thus WSP and wetlands can be designed as a continuum.

Important lessons have been learned regarding selection of plants for the local climate, and the need for minimal submergence while the plants are young. Also predator control is essential because foraging birds can destroy young plants.

The combination of open water ponds and planted areas create a more natural wetland effect with a wide range of habitat values. Thus wetlands can greatly enhance a WSP system.

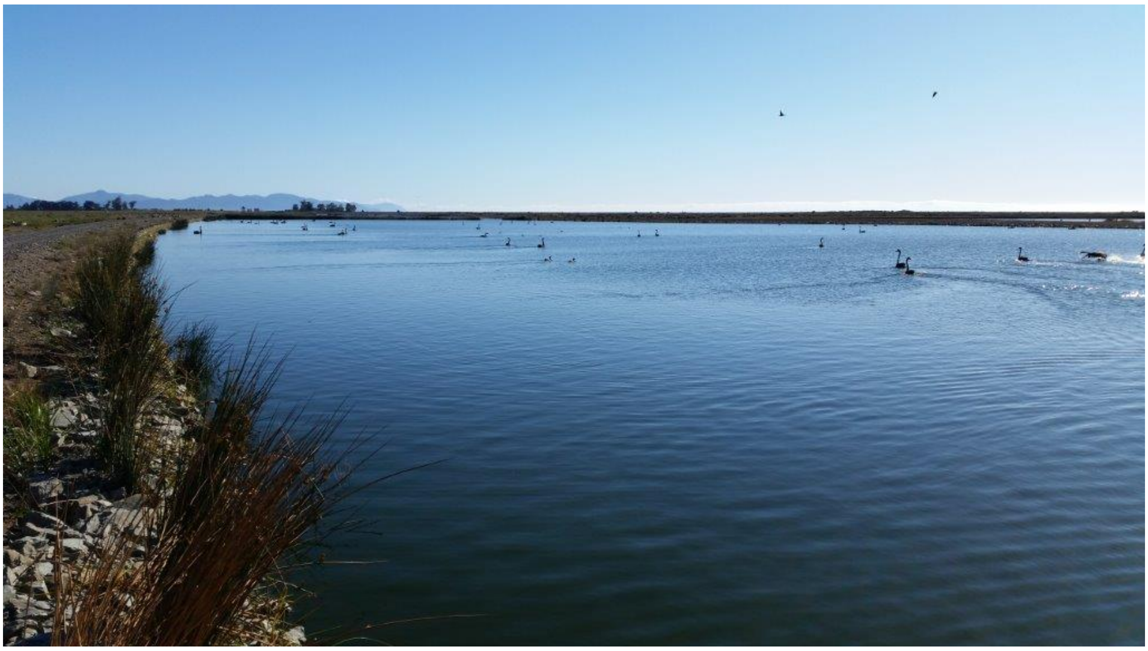

Figure 4 - Blenheim STP wetlands

14 CONCLUSIONS

It can be seen from the suite of available upgrading technologies that the State of the Art in 2015 for Waste Stabilisation Ponds, is at the forefront of wastewater treatment developments.

- Much improved operational reliability can be achieved by using mechanical aerator assistance.
- Very reliable disinfection can be achieved by creating multiple ponds-in-series, or adding UV disinfection, or membrane filtration, after a pond system.

Thus, to answer the question posed in the title: Waste Stabilisation Ponds performance can be significantly improved using affordable methods.

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The studies carried out by Dr Dinah Brockett on the Mangere ponds in the 1970's and 80's contributed greatly to our understanding of the complex processes that take place in ponds. I have included most of her publications in the list of references as a reminder of that work.

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