PAIHIA WWTP, INNOVATIVE IN POND REMOVAL OF AMMONIA USING BIOSHELLS®

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ABSTRACT

Situated in the Waitangi Forest in the Bay of Islands, Paihia WWTP has a discharge that feeds into the sensitive Waitangi wetlands, home to the Northland Mudfish. To improve this habitat, it has been necessary to upgrade the plant that serves Paihia, Opua, Waitangi and Haruru to meet a 2 mg/l ammonia consent. Like many wastewater systems in New Zealand, Paihia WWTP is a pond based system built in the 1980s. not intended to meet nitrogen removal requirements.

To meet the tight standards the innovative technology of Bioshells® has been adopted to provide an in pond treatment system within the existing assets. With over 550 Bioshells® operating, this is the first NZ nitrifying plant and the largest of its kind outside of the USA. Performance monitoring over more than 1 year of operation has demonstrated that ammonia concentrations have been reduced from typically 50 mg/l to less than 2 mg/l. Total nitrogen has been reduced by 40% and additional benefits to BOD, TSS and E coli concentrations have been recorded.

Alkalinity has been identified as a major issue within pond treatment, resulting in the need for chemical addition to ensure full ammonia removal occurs and to maintain acceptable discharge ph.

By adopting this Innovative approach on a space restricted site, FNDC have achieved all required performance outputs at an affordable cost to the community in a tight capital programme. A capital saving of over $18m against a conventional solution has been realised.

KEYWORDS

Bioshells®, Paihia, In Pond, Ammonia Removal, Innovation, Mudfish

PRESENTER PROFILE

Andrew Springer, is a Technical Principal Wastewater Specialist with WSP in Auckland, bringing over 30 years wastewater treatment experience to projects across New Zealand. He has had roles as operator, asset manager, program manager, contractor and designer enabling him to embrace innovation and sustainable solutions to every challenge.

William Down, is a Senior Project Manager with Far North District Council in Northland, bringing over 35 years' experience in the water and wastewater industry, both as a Contractor and Principle across New Zealand and Australia. He has had roles as plant operator, operations manager, contracts manager, asset manager, project engineer, project manager and understands the value of innovation in providing sustainable solutions.

INTRODUCTION

Paihia Wastewater Treatment Plant (WWTP) in the Bay of Islands serves approximately 5000 residents in the communities of Paihia, Waitangi, Opua and Haruru. In summer, the population in the area can exceed over 11,000 FTEs. The WWTP was originally built in the 1980s in a remote location in the Waitangi Forest and has seen considerable growth in the catchment. The site is bounded by natural wetlands and forestry, with 2 drainage streams running the length of the site, Limiting the footprint of the site available for expansion. The discharge from the site is to a wetland area, part of the Waitangi Wetland system.

Within the Waitangi Wetlands, can be found the nationally Threatened Northland Mudfish, which is only found in a few localized lowland wetlands in New Zealand. This nocturnal fish of up to 130 mm in length is considered a maori taonga and an indicator of the health of these wetlands. As part of the protection of the habitat for the mudfish, the Paihia WWTP effluent resource consent required a change in performance to meet an annual median of 2 mg/l NH_3-N, 90%ile 4 mg/l NH_3-N, and to meet a total nitrogen median standard of 40 mg/l.

The Waitangi forest is an area being considered as treaty settlement. The land is owned by the Crown, managed by LINZ, Leased by China Forestry, and operated as forestry by PF Olsen. Additional, stakeholders in the area include Department of Conservation, Northland Regional Council Ngati Kawa and Ngati Rahiri. With significant numbers of stakeholders and uncertainty on treaty settlement outcomes, for several years additional land use could not be agreed. This meant the project was constrained to the area already occupied.

Like many wastewater treatment pond systems in New Zealand installed historically, the approach was a two stage pond designed to remove organic material, and by long retention time reduce bacterial numbers. Although the second pond in series may reduce ammonia, the primary mechanism for this has been by assimilation through the bacteria and algae growing in the pond. Linked to the accumulation of sludge and seasonal fluctuations from sludge decomposition, and seasonal population changes and the relative growth rates of the biota, the removal of ammonia has never been consistent and unable to get close to the tight standards required by the consented conditions.

Figure 1: Aerial Views of Paihia WWTP showing surrounding Forest and Wetlands to existing Ponds (Images from Google Earth, Marshall Projects Ltd)

Figure 2: Northland mudfish, a threatened species found in the Waitangi Wetlands. (Images from DOC.govt.nz)

THE PROJECT

PROJECT APPROACH

Several project constraints were identified.

- Quality. To achieve a median of 2 mg/l NH_3-N would require substantial and consistent improvement from the previous median of 37 mg/l NH_3-N and be sufficiently robust to meet peak load events.
- Space. Only 10m x 40m was available for expansion. No additional land was available due to land ownership
- Power. Being over 3 km from the nearest mains power, a permanent supply had been quoted as over $700,000, so unaffordable. Local generation was preferred.
- Suitable technology. Several options had been considered and trials had been undertaken but none had met the constraints of space and performance.

Faced with these issues Far North District Council worked with WSP to deliver a project to meet compliance.

A review of historically considered options was undertaken. This considered the use of tertiary SAF (too large), conversion of pond to SBR (pond too shallow), floating reed beds, (unproven to this quality), in pond curtain type enhancement (unproven to this quality) and bioaugmentation. A bioaugmentation trial was undertaken with regular dosing of nitrifying organisms to Pond 2. Although an initial reduction in ammonia occurred, this was not sustained and may have been a result of seasonal performance variation. At high level options were considered for floating SAF using barges as a base but ruled out on cost. Construction in pond was considered, but unfavorable geotechnical conditions occur on the site from underlying basalt flows that would give differential settlement on any large structure.

This left a proven solution of construction of a new Activated sludge plant with total nitrogen removal to be considered. The budget price for this new plant was estimated at over $25m, and would require substantial new infrastructure, purchase of farmland, as land was not available in the Waitangi Forest and additional resource consents. This posed a very long programme project and not affordable to the community.

It was therefore decided to go to tender specifically to encourage an innovative solution from the New Zealand and international market.

Innovation was applied to the tender specification. The specification identified the goals of the project, its constraints and required outcomes of quality, focused particularly on ammonia removal. By careful wording the specification was open to all solutions that may be proposed.

Three tenders were received and evaluated, but none achieved fully the criteria given.

One solution proposed was through Marshall Projects Ltd, of Invercargill that proposed the use of an American solution from Wastewater Compliance Solutions. The “poogloo” has been developed and applied for enhancing pond performance in Utah and Montana where winter conditions prevent ammonia removal in the pond. The system is described below. A key feature of the system was that all loading and performance data demonstrated ammonia removal at < 10C, a condition not seen in Northland, so considered that the technology had some extra capacity. A technology evaluation was made, assessing the technology, comparing the system to other technologies and the project risks. After this evaluation a negotiated contract was agreed with Marshall Projects Ltd.

BIOSHELL®® SOLUTION

The Bioshells® is based on the “Poogloo” concept designed by WCS but is an adaptation for shallower ponds.

The figure below shows the principal of the Bioshells® system.

Figure 3: Diagram of Bioshells® (from Wastewater Compliance Systems)

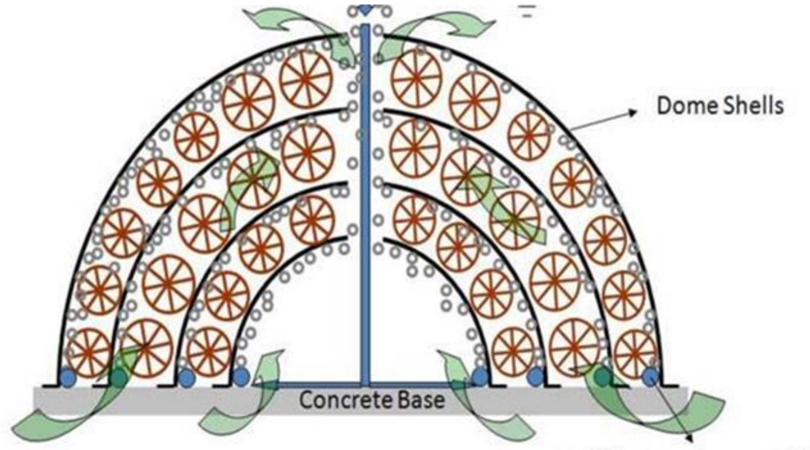


Figure 4: Bioshells® prior to Installation (from Marshall Products Ltd)

A series of plastic shells retain random plastic media. By providing an air supply to the base of the units, there is enough oxygen to enable a population of nitrifying bacteria to establish on the surfaces. A retaining mesh on the bottom is necessary to hold the media in place, and the whole assembly is fixed to a concrete subframe. This prevents buoyancy. To each assembly a stainless-steel lifting cable is provided for installation, or removal for maintenance. Each Bioshell®® unit is supplied with a dedicated air hose from a common air manifold.

At Paihia to meet the Peak summer loading condition of 120 kg NH_3-N/d, 553 Bioshells® have been installed, with air supplied by duty standby Roots Z Series screw blowers. Photographs of the project installation are shown below.

Figure 5: "Land Based" Installation of Blowers. Air Manifold and Generator/Control Room (from Marshall Projects Ltd)

Figure 6 Bioshells® Zone showing location of Bioshells® by air pattern prior to cover installation (from Marshall Projects Ltd)

WCS advised that algal competition could occur on the media, so a floating cover system was installed. This was the first use of Hexacovers in NZ, which provide an interlocking flexible cover across the Bioshells® zone.

INNOVATION IN INSTALLATION

Prior to this project a small number of Bioshells® had been installed in South Island on small ponds for enhanced BOD removal. As the pond was small a crane had been used for installation. However, for Paihia, with nearly 0.4ha of pond area for the installation, and limited access, a 110m crane reach would have been required. Marshall Projects innovated by designing and using a twin hulled barge with permanent lifting frame. By setting up guide wires across the pond, it was then possible to transport Bioshells® across the pond and install in lines.

Figure 7: Innovative installation barge (from Marshall Projects Ltd)

Innovation was also demonstrated in managing fabrication logistics. MPL have manufacturing facility in Invercargill but transporting over 500 completed units this distance was a logistics problem and very costly. To overcome this challenge MPL rented a local workshop facility and supported the local community by employing more than 20 local staff for the fabrication and installation of the Bioshells®. Components were shipped direct to the workshop, and concrete bases fabricated locally, enabling a production line of fabrication and installation.

Figure 8: Local Fabrication Facility ((from Marshall Projects Ltd)

Figure 9: Complete Installation (Image from A Springer)

PERFORMANCE OF BIOSHELLS®

AMMONIA REMOVAL

The performance of the Paihia WWTP has been monitored through routine compliance monitoring and through the following additional testing periods.

1. Handover Testing 28 days Jan-Feb 2020
2. Performance Testing 14 Days Aug 2020
3. Additional Monitoring Period Sep 20-Dec 20
4. Performance Testing 14 day period Jan 21

Bioshells® were commissioned with air from October 2020, with significant nitrification achieved by December 2020.

Figure 10: Effluent ammonia-N mg/l 2015-2021

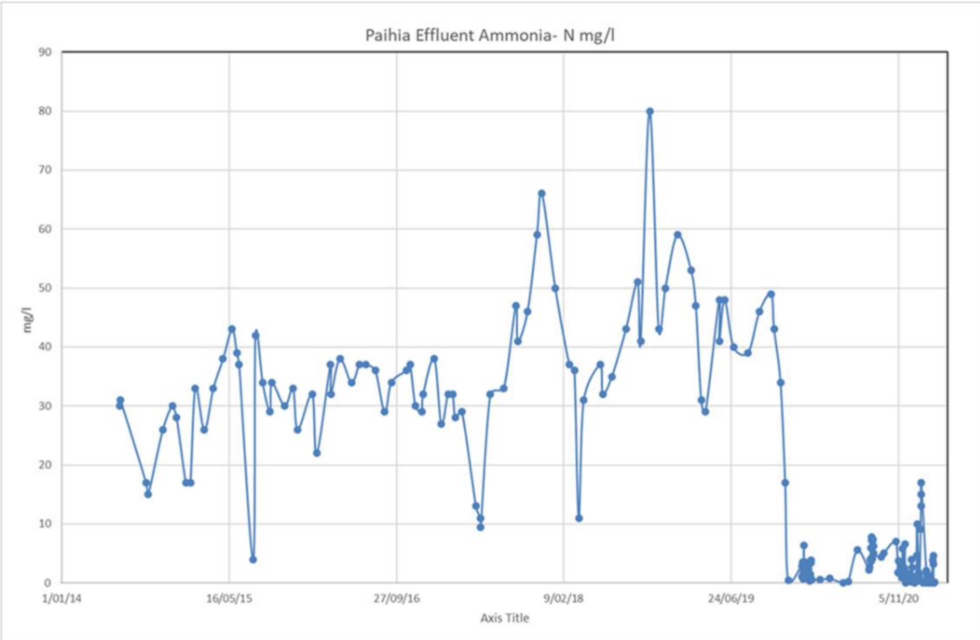
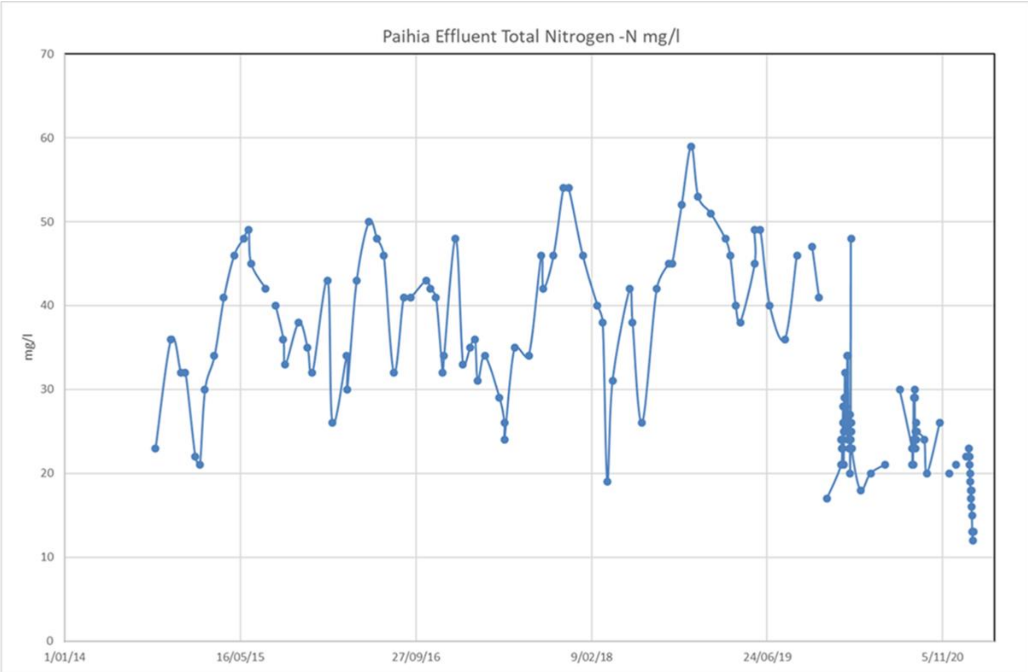


Figure 11: Effluent Total Nitrogen-N mg/l 2015-2021



Prior to commissioning the effluent ammonia in the Paihia Effluent had a median of 37 mg/l and a total nitrogen of 41.5 mg/l. In 2020 to Feb 2021 this reduced to median 1.9 mg/l NH_3-N and 25 mg/l TN-N a reduction of 95% NH_3-N and 40% TN.

A number of factors have had significant impact on the performance observed.

ALKALINITY

Alkalinity is required for the process of nitrification. In conventional plants it is recognized that 7.13 Alkalinity is required for every 1 NH_3-N removed, and that a residual concentration is required to prevent rate limitation. This is usually regarded as 100 mg/l.

Hence, in summer at Paihia with an influent to Bioshells® of 50 mg/l NH_3-N it would be expected to require 456 mg/l alkalinity. Monitoring data showed alkalinity to be typically 280-300 mg/l, meaning that only 25 mg/l of NH_3-N removal should occur.

Similarly, in winter with 30 mg/l NH_3-N it would be expected to require 313 mg/l alkalinity, but monitoring showed that only 200 is available.

Performance has been better than predicted for conventional nitrification relationship with alkalinity.

To understand this effect, it need be considered several factors.

The Bioshells® installation at Paihia occupies a shallow section of Pond 2 and is separated from the bulk of Pond 2 by a curtain baffle. Part of this area is not used for Bioshells® due to underlying bed rock being, too shallow for their installation. It is considered that in summer conditions denitrification is occurring in this zone, recovering some alkalinity. However, in winter, the rate of denitrification becomes limited by temperature and does not recover enough alkalinity for additional nitrification although similar retention time.

Long retention time in the Bioshell® zone, typically at average flow is over 3 days, much longer than in a conventional plant with < 1 day retention. This means the limited alkalinity is around longer and can be utilized. This has resulted in alkalinity results < 20 mg/l.

A secondary effect witnessed is an impact on pH. pH was measured as low as pH 6.0 in the effluent, below the 6.5 consented range. This coincided with alkalinity < 20 mg/l due to nitrification stripping.

In the data presented not all samples have associated alkalinity data due to the sampling programs in place.

Figure 12: Relationship between effluent ammonia and affluent alkalinity

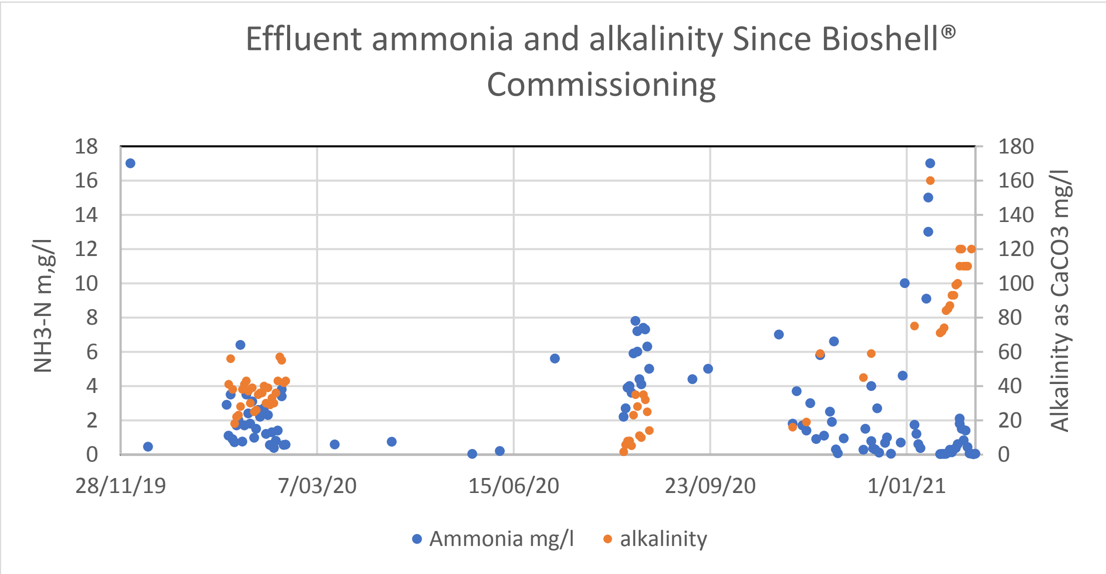


Figure 12 demonstrates the shortfall in alkalinity in the effluent and the relative performance in the plant.

The single elevated ammonia result in January 2020 testing is a result of generator down time and subsequent loss of air. Despite this abnormal result the 4 week testing period achieved a median ammonia < 2 mg/l with low alkalinity levels. Performance remained good through the summer and autumn. In July routine monitoring showed an increase in ammonia concentration. A two week survey undertaken to demonstrate winter performance in August continued to show elevated ammonia results, and very low alkalinity results.

Additional chemical alkalinity was added to the pond system by manual dosing of sodium bicarbonate, and so increased the alkalinity and pH commencing in October 2020. As seen in the data, the alkalinity rose slowly in available concentration, but once elevated, significant improvement in ammonia

Despite increased alkalinity in early January 2021, a few elevated ammonia results occurred. At this time a reliability issue was occurring with the site generator, causing periodic loss of aeration so stopping nitrification.

At the end of January 2021, the power reliability had been improved giving reliable aeration and alkalinity residual greater than 70 mg/l, ammonia removal was capable of reduction of ammonia from incoming 50 mg/l to < 2 mg/l consistently. Several results were at ammonia detection level of 0.01 mg/l.

Long term it is intended to dose magnesium hydroxide to the Paihia WWTP to seasonally top up the alkalinity needed for nitrification so

OTHER PARAMETERS

For comparison of performance all data acquired from Jan 16 to Nov 19 have been used for pre Bioshell® data, and all monitoring data and testing data has been used for post installation data. No data cleansing to remove outliers or known mechanical failures has occurred in this data.

Table 1: Performance *Improvement at Paihia WWTP with Bioshells® – Unedited Statistics*

	Flow	pH	DO	NH3-N	TSS	BOD	TN	E.coli
	m3/d		mg/l	mg/l	mg/l	mg/l	mg/l	Cfu/100ml
Stats Jan 16-Nov 19								
mean	1281	7.7	7.1	38.1	38	16.9	40.6	6799
median	1137	7.6	6.3	37.0	38	18	41.5	3784
90%ile	1725	8.4	12	50	66	26.6	50.5	21596
Max	3852	8.9	17	80	94	37	59.0	24196
Min	504	6.4	2	9	2	2.8	19.0	20
Stats Dec 19-Feb 2021								
mean	1289	7.1	6.6	2.6	13	5.7	23.8	662
median	1123	7.1	6.9	1.5	11	5.55	24.0	207
90%ile	2219	7.8	8.8	6.3	24	8.1	29.0	2779
Max	2503	8.9	9.6	17.0	32	9.4	48.0	4884
MIn	712	5.8	2.8	0.01	2	2	12.0	13
Improvement								
% median			-10%	96%	71%	69%	42%	95%
% 90%ile				87%	64%	70%	43%	87%

As discussed above with regards alkalinity, pH has been decreased as a result of nitrification. Additional alkalinity is required to maintain the required standard of consent and to enable full nitrification.

Dissolved Oxygen has statistically decreased. This is a direct effect of the floating covers, as these have suppressed algal activity in the Bioshells® zone of the pond. The statistics before installation show concentrations of DO above saturation, characteristic of the effect of very active algae in summer daytime conditions, which are unable to occur with the covers that block sunlight. This is offset by the continuous aeration of the Bioshells®.

Despite operational problems with power supply and suppression of nitrification by shortfall of alkalinity, across all monitoring data since the commissioning of the Bioshells®, the media of 1.5 mg/l NH_3-N has been achieved an improvement of 96% on previous performance.

Improvement to reliability of power supply is expected to improve performance and reduce the risk of 90%ile exceedance.

Total Nitrogen has been reduced by 42%. Reduction is not as great as seen with ammonia as the nitrogen remains as nitrate and only partial denitrification is occurring.

The floating covers have suppressed algal activity, but due high solids are still entering the Bioshells® zone. From the reduction of over 70% observed in compared to previous pond performance, significant reduction in solids is occurring and it is unlikely that algal solids are passing through the zone. BOD is similarly suppressed.

E coli has shown significant improvement with a reduction of median by over 95%. In pond systems the E coli level is principally affected by sunlight and retention time. In this situation retention has not changed and sunlight has been reduced, so an increase in E coli would have been expected. It is considered that the presence of the media not only provides a home for nitrifying bacteria but will offer a home for sessile protozoa like Opercularia spp., and similar organisms. WCS report large colonies of protozoa observed other plants. The presence of these filter feeders will enhance capture of small solids including bacteria and algal cells, resulting in the improved solids and E coli removal observed.

LESSONS LEARNT

Several lessons have been learnt that can be applied to other in pond ammonia removal systems.

Noise.

The air flow required for the Bioshells® was over estimated. Each blower is 55 kw, but the required aeration was achieved at < minimum speed, resulting in a low operating pressure on the blower. This caused the integral control system to cycle creating a loud whine. This was rectified by artificially increasing the back pressure on the manifold so that the system could operate in the required pressure range.

Alkalinity.

As discussed above alkalinity is essential to achieving low ammonia results from any treatment system. Shortfalls in alkalinity were recognized before construction, but a lack of advanced data meant that this risk was not fully managed until late in the project. Additional capital is required for supplementary dosing.

A short fall in alkalinity will result in poorer ammonia removal and can cause issues with effluent ph.

CONCLUSIONS

Compared to a conventional solution of new treatment works, this project using Bioshells® for in pond ammonia removal has achieved a saving of over $18m for FNDC.

This cost saving has been achieved by applying several innovations in contract management, choice of technologies, fabrication processes and installation resulting in a reliable system achieving very low ammonia quality in the pond effluent.

The Bioshells® system can be applied successfully to existing ponds to meet challenging ammonia standards, with additional improvement to BOD, TSS, Total Nitrogen and E coli being observed and can achieve 2 mg/l NH_3-N from an existing pond-based treatment system.

This makes Bioshells® technology an affordable choice where tighter effluent standards are required to meet increasing water quality standards.

The media system provides a suitable habitat for nitrifying bacteria that normally cannot be established in pond systems, and a suitable habitat for filter feeding protozoa that contribute to solids and bacterial reduction.

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