TREATING LANDFILL LEACHATE-IMPACTED STORMWATER WITH A NITRIFYING TRICKLING FILTER - NOT A LOAD OF RUBBISH

Liam Allan (Pattle Delamore Partners Ltd), Dr Mark Ellis (Pattle Delamore Partners Ltd), and Dr Sachin Narkhede (Timaru District Council)

ABSTRACT

Timaru District Council (TDC) has operated the Redruth Landfill, on the southern outskirts of Timaru, since the 1900s. Historic landfill cell designs and management practices did not fully comprehend that leachate would be generated in the landfill and seep from the landfill cells into stormwater drains and adjacent water bodies that bound the landfill. This, in turn, has negatively impacted the aquatic ecology of the lower stretch of the Ōtipua-Saltwater Creek. Improving the management of leachate and stormwater management practises at the landfill has been an ongoing task for TDC, specifically developing and implementing solutions to minimise the adverse effects on the aquatic ecosystem of the lower Ōtipua-Saltwater Creek. Timaru District Council have a vision of ultimately returning the creek into a valued cultural and recreational asset for the community.

To mitigate the adverse effects of ammonia in leachate-impacted stormwater, TDC engaged Pattle Delamore Partners Ltd (PDP) to identify and evaluate possible treatment solutions that could (1) mitigate the effects on the aquatic ecology, (2) required minimal supervision and maintenance, and (3) had a low capital or operational cost. The solution ultimately selected was to construct a nitrifying trickling filter (NTF) on the embankment of a historic landfill cell and the bank of a stormwater pond.

The design developed used locally sourced rock that provided a medium for the treatment biofilm to adhere onto. The structure of the NTF was achieved by constructing the walls from gabion baskets on three sides of the filter. The net result was an aesthetically pleasing structure that was readily visible from a nearby public walkway.

The NTF was constructed and commissioned in September 2020 and has routinely achieved a 93% reduction in total ammoniacal nitrogen concentration, resulting in an average treated total ammoniacal nitrogen concentration of 0.55 g/m^3. In addition, the NTF contributed to a 16% reduction in the total nitrogen concentration in the influent stormwater.

The discharge of treated stormwater into the downstream stormwater pond resulted in an unforeseen and beneficial benefit, specifically a noticeable improvement in the clarity of the pond, which has been attributed to the release natural coagulants, which has been attributed to extracellular polymeric substances in the NTF biofilms.

This paper demonstrates how the technology normally associated with the treatment of wastewater can be re-engineered and optimised to manage the impacts of elevated ammonia in leachate contaminated stormwater.

KEYWORDS

Ammoniacal Nitrogen, Leachate, Nitrifying Trickling Filter

PRESENTER PROFILE

Liam is a consultant with PDP with over 5 years of experience in environmental engineering. His primary focus is stormwater management both in terms of quality and quantity, and he has extensive experience in water quality monitoring and analysis of treatment performance.

1. INTRODUCTION

The Redruth Landfill in Timaru, South Canterbury, is owned by Timaru District Council (TDC) and serves as the primary solid waste landfill for the district. Historical landfilling practices, including unlined and uncapped landfill cells, have brought about the need for improvements to the management of leachate at the landfill site. Historical water quality monitoring (2004-2020) in the water bodies surrounding the landfill and its discharges have found elevated concentrations of ammoniacal-nitrogen (in the range of 4.9 to 66 g/m^3). These results indicate that leachate is entering surface waters at the site.

TDC has been undertaking an ongoing programme of upgrades to the legacy landfill cells including installing impervious capping and improving the leachate collection system to direct leachate away from stormwater. As part of these upgrades, Pattle Delamore Partners Ltd (PDP) were engaged by TDC to develop a low-cost treatment solution for ammoniacal-nitrogen that blends-in with the environment to reduce the ammoniacal-nitrogen concentration in the site's discharge.

The landfill also serves as a hub for environmentally sustainable practices and public education. The landfill site hosts a recycling and resale shop called 'The Crows Nest', which enables unwanted items to be reused and prevents these items from going to landfill. An additional facility, the South Canterbury Eco Centre, was constructed in 2022 and is designed to be a community space for hosting educational events to promote sustainability. Therefore, an opportunity has emerged for this project to provide public education on water quality and the improvements being made at the site.

2. SITE DESCRIPTION

2.1. LOCATION

As shown in Figure 1, Redruth Landfill is bordered on two sides by Ōtipua-Saltwater Creek and features a public walkway between the landfill boundary fence and the waterway. The remaining two boundaries consist of an industrial area and the Redruth Stormwater Drain, which receives runoff from a significant catchment of southern Timaru including parts of the Redruth Landfill.

The Redruth Stormwater Drain ends in a retention pond which discharges into Ōtipua-Saltwater Creek via a pump station.

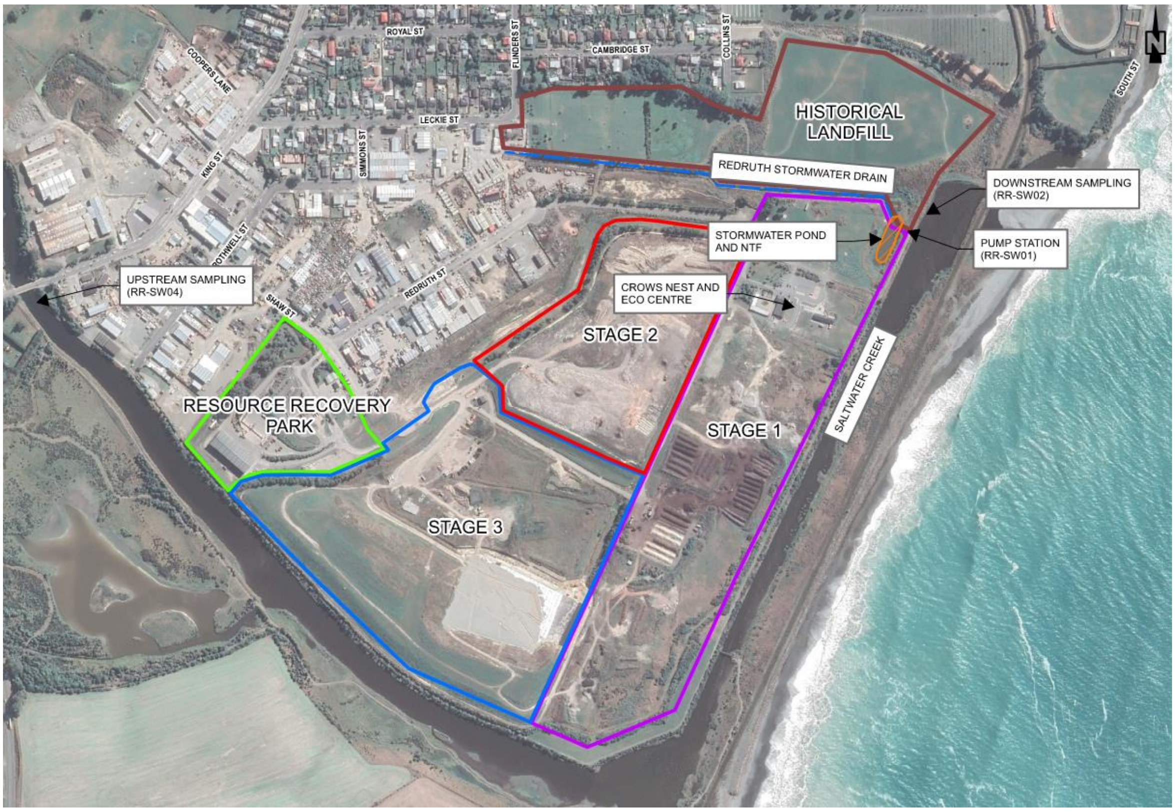

Figure 1: Overview of the Redruth Landfill site showing landfill stages, compliance monitoring locations referred to in this paper, and the location of the NTF.

2.2. LANDFILL PRACTICES

The "Historical Landfill" site north of the Redruth Landfill shown in Figure 1 was landfilled in the early 1900s, whilst landfilling has been occurring at the present Redruth Landfill site since the 1940s. The oldest landfill cells at the site, which were mostly unlined and uncapped, are referred to as Stage 1, which is adjacent to Ōtipua-Saltwater Creek and closed in 1996. Stages 2 and 3 began in 1996 and 2005 respectively, and both consisted of a base liner and a leachate collection system and will be capped upon completion.

The lack of capping and liners in Stage 1 has led to increased infiltration of rainfall and subsequent seepage of leachate from the landfill cell. A programme of improvements to the historical Stage 1 landfill cells is underway as part of efforts to improve overall water quality in the environment and management of leachate at the site. This work includes retrofitting impervious caps onto the old cells, capturing and redirecting leachate-impacted runoff, and efforts to treat stormwater before it leaves the site.

2.3. WATER QUALITY MONITORING

The leachate seepage resulting from the historical practices at the landfill has led to elevated concentrations of leachate-indicating contaminants in routine surface water monitoring at the site. Monitoring over the period of 2004-2020 has found consistently high ammoniacal-nitrogen concentrations at the SW01 pump station sampling site. Table 1 summarises the monitoring results for this period at the three sampling locations shown in Figure 1 and shows an increasing trend in concentration from the upstream site to the downstream site past the landfill.

Table 1: Summary statistics of concentrations of ammoniacal nitrogen in the 2004-2020 monitoring period.

	Ammoniacal-N (2004-2020)		
	RR-SW04 (Ōtipua-Saltwater Creek – Upstream)	RR-SW01 (Pump Station)	RR-SW02 (Ōtipua-Saltwater Creek – Downstream)
Trigger Value (g/m^3)		**0.7**	
Sample Size	30	41	43
Lower Quartile (g/m^3)	0.03	13.8	0.30
Median (g/m^3)	0.12	22	0.54
Upper Quartile (g/m^3)	0.27	32	2.00
Max (g/m^3)	3.20	66	7.00

The median ammoniacal-nitrogen at RR-SW02 meets the trigger value set out in the site's resource consent; however, there have been exceedances of the trigger value for some sampling rounds at both the upstream and downstream sites, as well as most samples at RR-SW01. The exceedances at RR-SW04 indicate that land-use activities upstream of the landfill is also contributing to elevated ammoniacal-nitrogen in Ōtipua-Saltwater Creek.

3. OBJECTIVES

The primary objective of the 'treatment system' is to mitigate the ecotoxic effect that ammoniacal nitrogen, in the leachate impacted stormwater, presents to the aquatic ecology in the lower stretch of Ōtipua-Saltwater Creek. As outlined in Section 2, the ammoniacal nitrogen concentration in the Redruth Stormwater Pond has a median of 22 g/m^3, reducing the ammoniacal nitrogen concentration to below 3.0 g/m^3 would comply with ECan's LWRP objectives for the Ōtipua-Saltwater Creek. Due to the proximity of the creek to the ocean, and specifically that this section of the creek is often brackish, the issues of elevated nitrate in the creek, resulting in the formation of periphyton slimes is likely to be less pronounced.

The preferred location of any treatment system would be in the vicinity of the Redruth Stormwater Pond. As the pond embankment forms part of a popular walking track in Timaru, any treatment system will need to be 'visually appealing' – due to the significant visual amenity potential. In addition, there is an opportunity to use the proximity to a public space to communicate or demonstrate the processes used in the design for education and environmental awareness.

TDC presented a desire that the solution should be sympathetic to the environment and specifically the neighbouring resource recovery centre, and an environmental education centre that operates in the vicinity.

The solution needed to be readily maintained, and no specialist skills should be required to maintain and operate the treatment system. In addition, whilst some limited electrical energy was available near the preferred site, a significant energy demand would require a significant capital expenditure in providing electricity to the 'treatment system'.

Other implicit objectives and considerations were that the 'treatment solution' should minimise both capital and operation expenditure, and the solution should manage treatment performance risks and the risk of detrimental contaminants entering the stormwater network.

4. DESIGN SOLUTION

4.1. FORM OF TREATMENT

Various treatment concepts were initially considered, including a variation of attached-growth and suspended-growth biological treatment systems, and combinations with and without active aeration systems. Ultimately, a treatment system comprising a nitrifying trickling filter and denitrifying optimised wetland was selected; this combination provided the best chance that the project objectives would be met.

Due to variability in the influent water quality, and the absence of a good understanding of the likely range of alkalinity that may be present in the untreated leachate impacted stormwater, it was identified that the treatment system should be staged.

Three stages were identified: (1) Nitrifying Trickling Filter Stage 1, (2) Nitrifying Trickling Filter Stage 2, and then ultimately (3) a Denitrifying Optimised Engineered Wetland. This approach has the benefit that the NTFs could be optimised, and the ammoniacal nitrogen and nitrate load assessed prior to completing the design and construction of the subsequent stages; in addition, it allowed capital expenditure to be optimised and invested only when required.

It was elected to construct the NTFs adjacent to Redruth Stormwater Pond, and pump the leachate impacted stormwater from the Stormwater Pumpstation to the NTFs. Consequently, the NTF would be constructed on a 1970's landfill cell, which led to specific issues that needed to be addressed during design and construction. Many of the issues were addressed by designing the NTF to be structured like a retaining wall, stepping down the embankment of the landfill cell; restraining the filter media behind a series of gabion baskets allowed for the NTF to be flexible and accommodate differential settlement associated with constructing a structure on a landfill.

4.2. PROCESS DESIGN

The volume of the NTF, wetting rate, and likely treatment efficiency of the filter media to oxidise the organic and ammoniacal nitrogen load in the leachate impacted stormwater was evaluated both empirically and with a biological model

(BioWin). BioWin was specifically applied to model the complexity associated with varying media depth as the NTF stepped down the embankment of the landfill cell (Figure 2).

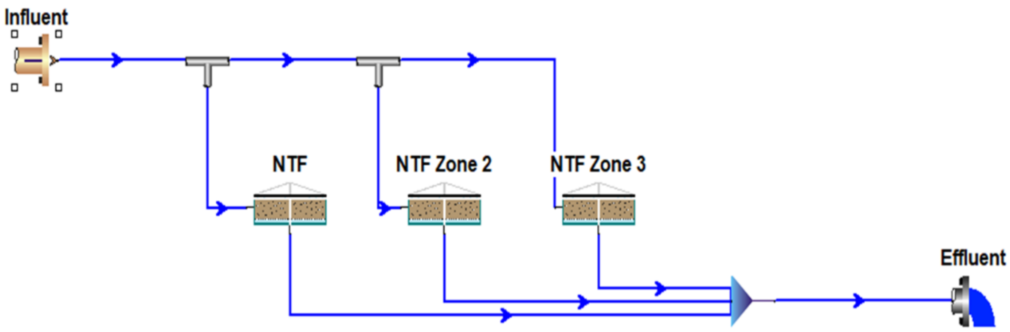

Figure 2: General configuration of the nitrifying trickling filter biological model (BioWin) in which the varying media depths were modelled as three cells.

Whilst the embankment added complexity to the process model, the 28° slope provided good management of biofilms that would slough off the media. Sloughed biofilms would gravitate to the toe of the NTF and settle on the bank of the stormwater pond. Wetland planting in this semi-wet zone would retain the biomass on the bank of the pond; where the biofilms provided a steady supply of natural sources of organics and nutrients, as well as an extracellular polymeric matrix of polysaccharides, liquids, proteins, and bacteria.

Regionally sourced rocks between 50 to 75mm formed the NTF media; this in conjunction with the gabion basket construction ensured that the media had a high void ratio, which in turn promoted the aerobic conditions in the media. Additionally, aeration vents ensure that fresh air is provided to the centre of the NTF, as well as providing a possible facility to flushing any biomass that may accumulate in the media.

Two single-phase fixed speed pumps, operating on a duty-standby arrangement in conjunction with a simple timer allowed the wetting and drying duration to be locally controlled. The pumps allowed up to 8 L/s of stormwater to be pumped to the top of the NTF; through a series of valves the wetting rate can be controlled, allowing a greater wetting rate onto the deeper sections of the NTF.

4.3. CIVIL DESIGN

The decision to construct the NTF on the landfill cell, required specific consideration of the stability of the structure and more importantly consideration on how to manage the risk that leachate may escape the landfill cell and/or stormwater enters the cell.

The solution adopted was to construct an anchor block, formed by a row of gabion baskets at the toe of the landfill cell, and just above the typical operating water level in the pond (Figure 3). From the anchor block, a compacted layer of AP65 was formed up the bank of the cells on which a layer of bedding sand and HDPE sheets were placed. The upper edge of the HDPE sheet was embedded into AP65 anchor trench. Gabion baskets and trickling filter media (stones) were then placed on the HDPE sheets and ultimately form the NTF structure, some 3m high, approximately 8m deep and 18m wide.

A geotechnical assessment of the final structure identified that an appropriately designed arrangement of gabion baskets at the toe of the structure would mitigate the risk that the irrigated stormwater would promote slipping, whilst the 2 sheets of 2.5mm textured HDPE would accommodate some differential settlement on the landfill cell embankment.

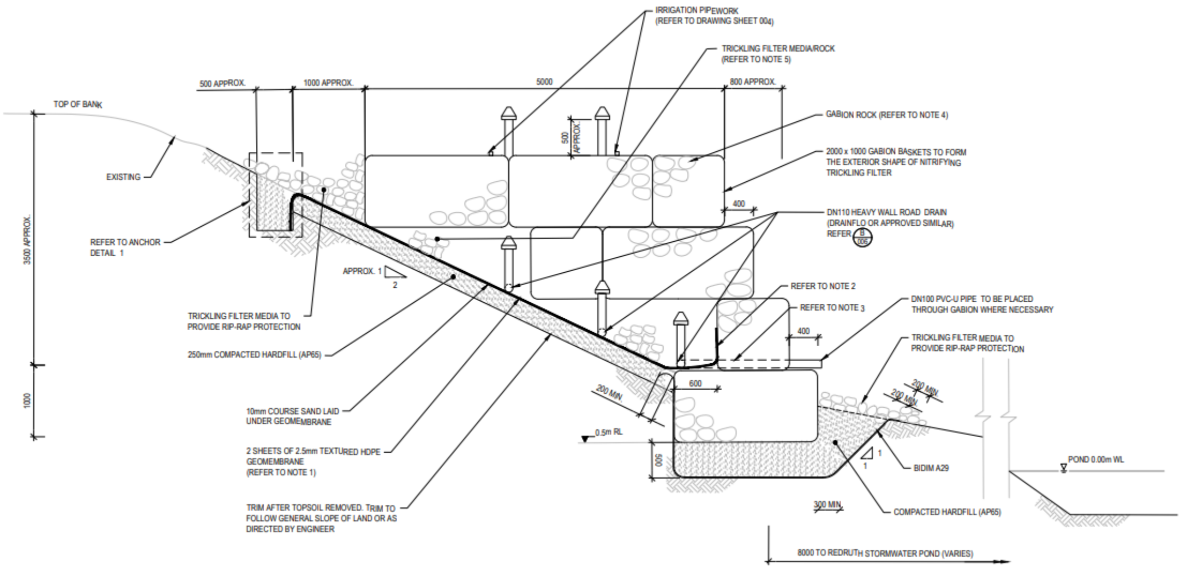

Figure 3: *Typical nitrifying trickling filter cross-section.*

4.4. FUTURE WORK

Future additions and improvements to the NTF treatment train and the Redruth Landfill stormwater management system are proposed to further improve water quality outcomes. Progressive planting of one of the main stormwater conveyance swales from the landfill, which receives some leachate-impacted runoff from a central pump station at the site, is currently underway in order to provide some nutrient uptake. Additionally, planting for nitrate uptake is proposed at the discharge from the NTF, with the potential to create a small treatment wetland within the stormwater pond area.

5. TREATMENT PERFORMANCE

5.1. MONITORING METHODOLOGY

A monitoring programme was developed as part of the NTF design to confirm and optimise the treatment performance of the NTF. Three locations were selected for monitoring and are shown in Figure 4:

- RR-SW16 – Within the stormwater drain, upstream of the NTF

- RR-SW01 – The existing stormwater pump station that is used for compliance monitoring
- RR-SW15_1 – Outlet of the first NTF

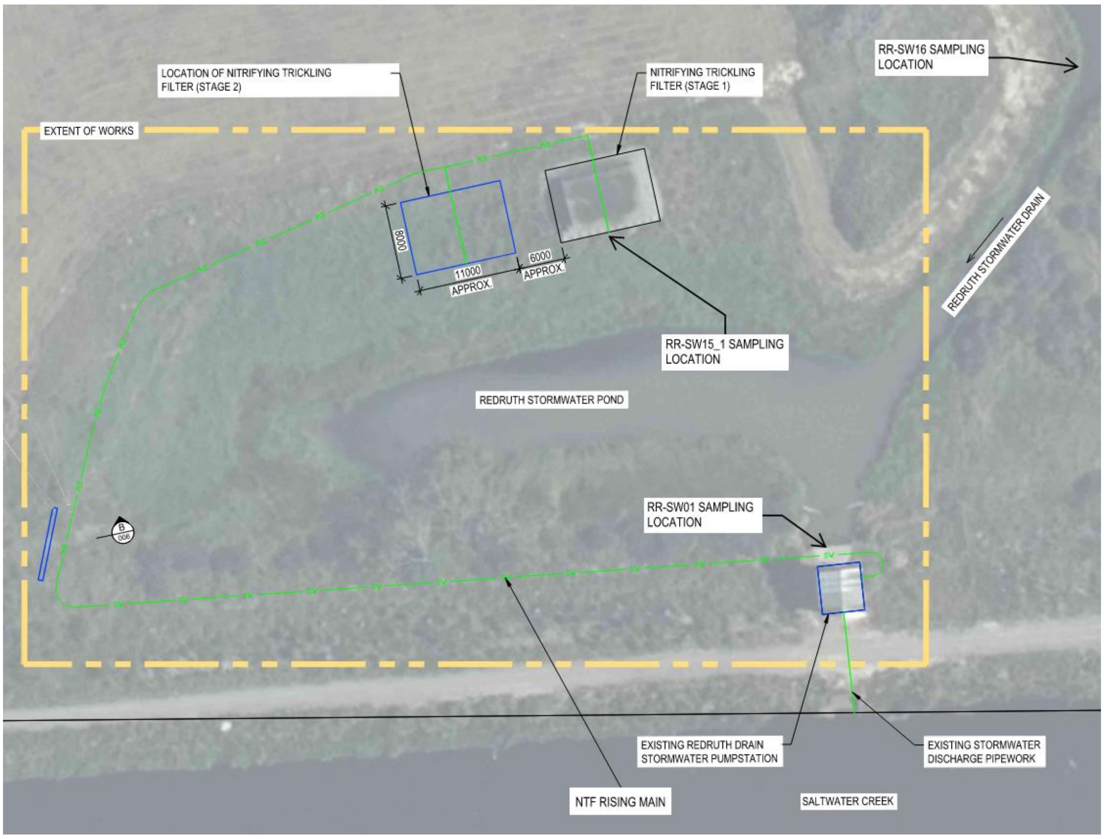

Figure 4: Redruth Stormwater Pond and NTF site showing NTF monitoring locations.

The NTF was commissioned on 1 July 2020, and the first water quality samples were taken on 7 September 2020. TDC undertook fortnightly monitoring during the first year of operation, before lengthening to monthly intervals. In-situ measurements of dissolved oxygen and temperature were recorded using a YSI ProSolo Dissolved Oxygen Meter. Grab samples were taken at the same time and sent to the laboratory for analysis of:

- Turbidity
- Total alkalinity
- Electrical conductivity
- Total ammoniacal nitrogen
- Nitrate-Nitrogen
- Nitrite-Nitrogen
- Dissolved reactive phosphorus
- Chemical oxygen demand

PDP and TDC compiled the laboratory results into a shared spreadsheet to keep track of the treatment performance and note any changes or issues with the NTF operation. This enabled any performance issues to be recognised and addressed quickly by the two parties.

5.2. PERFORMANCE RESULTS

5.2.1. NITRIFICATION PERFORMANCE

Figure 4 clearly shows the observed conversion of ammoniacal nitrogen in the influent to nitrate-nitrogen through the NTF. The results presented in this figure are with a single NTF system online, as insufficient data for the second NTF has been collected since commissioning. There is also a reduction in median ammoniacal nitrogen concentration from 4.95 g/m^3 to 3.8 g/m^3 from the inflow at RR-SW16 to the pump at RR-SW01, resulting from the treatment occurring at the NTF and the subsequent mixing with the influent from RR-SW16 prior to RR-SW01.

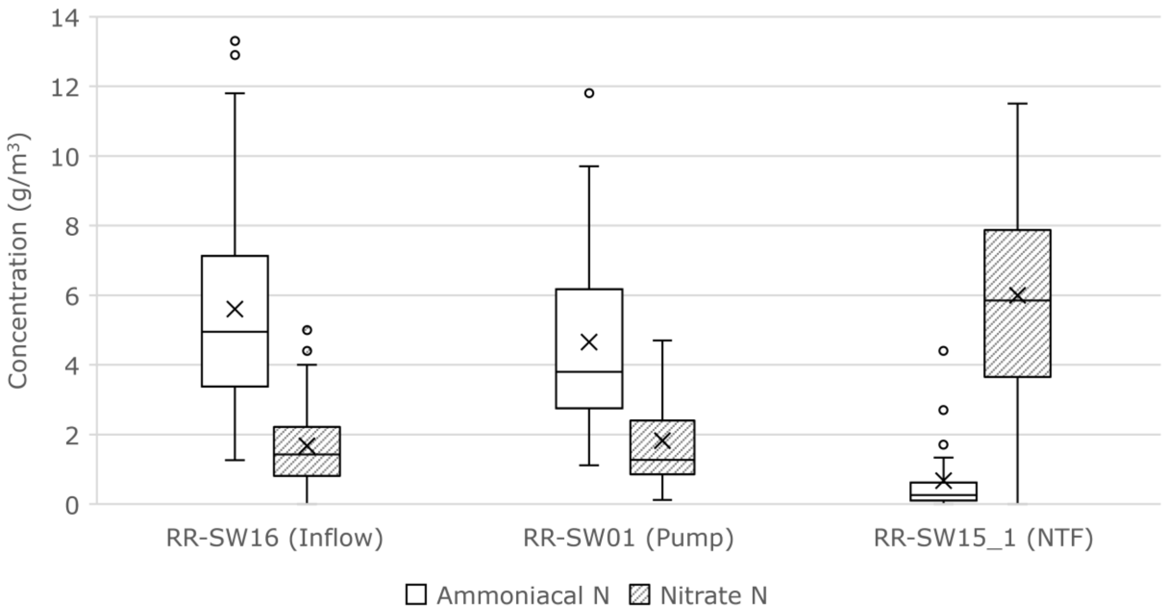

Figure 4: Box and whisker plots of ammoniacal nitrogen and nitrate-nitrogen concentrations across the three monitoring locations.

5.2.2. WATER QUALITY

A key performance indicator for the NTF is the concentration of ammoniacal-nitrogen and nitrate-nitrogen at the discharge into Ōtipua-Saltwater Creek from the SW01 pumpstation. Figure 5 compares the concentration of ammoniacal nitrogen in samples taken at SW01 prior to the installation of the NTF with concentrations taken after the NTF was commissioned. The figure shows a consistent reduction in concentrations after the NTF was commissioned, with no concentrations exceeding 12 g/m^3. The highest concentrations occurred when one of the pumps serving the NTF was temporarily out of action during the middle of 2022, resulting in reduced treatment.

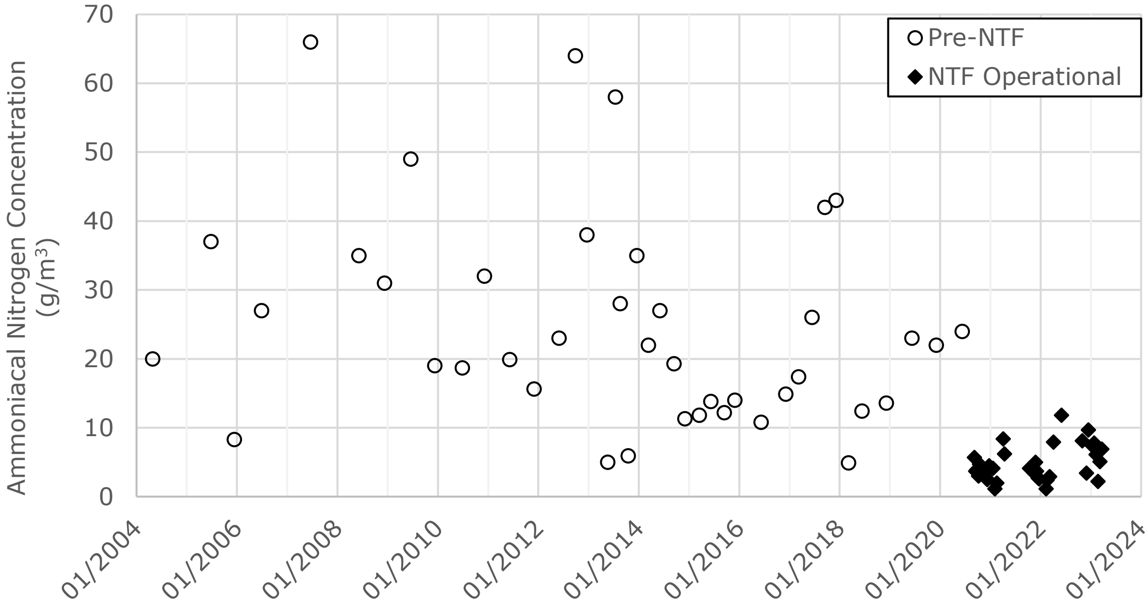

Figure 5: Scatter plot of ammoniacal nitrogen concentrations measured at SW01 (pump station) comparing concentrations before and after NTF commissioning.

This trend is summarised statistically in Table 2. The most notable change occurs for ammoniacal-nitrogen, where the median concentration reduced from 22 g/m^3 to 3.8 g/m^3 between the monitoring period before and after the NTF was commissioned. There is little change in the nitrate-nitrogen concentration observed in this data, although overall a slight reduction is observed.

Table 2: Summary statistics of concentrations measured at SW01 before and after NTF commissioning.

	Ammoniacal-N		**Nitrate-N**	
	Pre-NTF	Post-NTF	Pre-NTF	Post-NTF
Trigger Value (g/m^3)	**0.7**		**1.70**	
Sample Size	41	36	40	36
Lower Quartile (g/m^3)	13.8	2.85	0.80	0.93
Median (g/m^3)	22	3.8	2.05	1.28
Upper Quartile (g/m^3)	32	6.125	3.68	2.40
Max (g/m^3)	66	11.8	10.30	5.20

Despite the significant reduction in concentration, none of the samples to date for ammoniacal-nitrogen meet the trigger value set out in the consent for Redruth Landfill. However, the commissioning of the second NTF is anticipated to further reduce ammoniacal-nitrogen concentrations, and as the median concentration at the SW15_1 sampling site is 0.265 g/m^3, as indicated on Figure 4, it may be possible to meet the trigger value with a greater volume of water being treated.

Figure 4 also shows an increase in nitrate-nitrogen through the NTF, and it is anticipated that the introduction of the second NTF and the subsequent increase in treatment volumes will result in some increase in nitrate-nitrogen without additional treatment from a wetland/other denitrification process. Therefore, the future work for this project proposes providing a denitrification process after the NTF.

5.2.3. OTHER BENEFITS

The microbial films that form on the media are expected to be similar in composition to wastewater treatment plant microbial films; an assemblage of microbial cells enclosed in a matrix of bacterial self-generated extracellular polymeric substances (EPSs). It is these EPSs that have been attributed to the noticeable improvement in the clarity of the Redruth Stormwater Pond. Specifically, it is thought that these molecular-weight polymers (Mw = 10,000) are binding to the colloidal silts in the pond and forming flocs that deposit in the pond.

6. PUBLIC EDUCATION

The NTF is becoming a part of the education programme for schools at the South Canterbury Eco Centre. A presentation outlining the system and its use was developed for school groups that visited the site during TDC's Seaweek event in March 2023, with around 150 children learning about the system over that period. This information has been used by the centre for additional school visits as part of wider talks on environmental sustainability.

To provide a more permanent and accessible educational platform, TDC plans to install an NTF information board on the walkway for the public. PDP is currently developing the layout and content of the information board, which will communicate how the NTF works including a schematic picture and flow diagrams, as well as explaining the reasoning behind treating the water. The intention is for the NTF and associated information board to become part of the education programmes provided by the South Canterbury Eco Centre for schools, tour groups, and the public.

7. CONCLUSIONS

Nitrifying trickling filters can be simplified and utilised in treating leachate-impacted stormwater in a manner that uses low-cost construction materials and techniques. The technology has been adapted in a way that strives to blend in with the surrounding environment and is simple to operate and maintain.

The proximity of the NTFs to a public walkway and an education centre has created an opportunity to provide education on the treatment offered by the NTF and water quality improvements occurring at the Redruth Landfill. Rather than attempting to obscure the NTFs from public view, they have been made into an example of the ongoing work undertaken by TDC to improve water quality.

Photograph 1: Drone photo of the trickling filters following the recent completion of NTF number 2 (on left).

The commissioning of the second NTF is expected to further improve water quality outcomes, as it is acknowledged that a greater volume of water needs to be treated in order to ensure the water quality outcomes for the receiving environment are consistently met. The addition of a denitrifying wetland or similar additional treatment process will be required to manage the increase in nitrate-nitrogen resulting from the nitrification occurring through the NTF.

ACKNOWLEDGEMENTS

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