Denitrification in a Rotoehu Stream, 2nd installation

Graeme Anderson
Landcare Research NZ Ltd
Private Bag 3127
Hamilton
NewZealand

Matthew Taylor
Environment Waikato (formerly Landcare Research NZ Ltd)
PO Box 4010
Hamilton East

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PREPARED FOR:
John McIntosh/Andy Bruere
Environment Bay of Plenty
PO Box 364
Whakatane

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Reviewed by:	*Approved for release by:*
Bryan Stevenson	Alison Collins
Scientist	Science Leader
Landcare Research	Landcare Research

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Contents

Summary

Denitrification beds have been successfully used to reduce nitrate levels of approximately 10 mg L^{-1} in municipal wastewater discharge. To test whether nitrate can be removed from stream water with a lower nitrate load, use of a woodchip-based denitrification bed was investigated. The test site was a spring-fed stream within the Rotoehu area carrying a consistent nitrogen level of approximately 2.3 mg L^{-1}. A bed was constructed to intercept and denitrify a proportion of the stream.

The bed removed approximately 50% of the nitrogen present. The denitrification rate varied over time but appears to have settled to about 2 g NOx m^{-3} (of bed) d^{-1}. Performance has been noted to be higher where input water has higher nitrate levels.

Organic nitrogen production was evident for several months after installation but decreased over time and current levels of organic N at the outlet are similar to inlet values.

Although stream nitrate levels were reduced by approximately 50%, expanding the installation to treat the entire stream flow would not seem to be economically or technically sensible as denitrification beds appear to be more applicable to water systems carrying higher levels of nitrate. Continued monitoring (bi-annually) of the existing set-up is encouraged as it would determine the longevity of the denitrification bed, if the denitrification rate settles to a constant level and if release of organic N proves to be a short term initial reaction.

1. Introduction

Excess nitrate nitrogen within waterways in the catchments of the Rotorua Lakes is one factor that may lead to undesirable levels of aquatic plant growth (Cooper & Thomsen 1987/1988). One method for removing excess nitrate is to pass the water through a denitrification bed. Denitrification beds are successfully employed in Taupo for municipal wastewater treatment, denitrifying nitrate levels of approximately 10mg/L, personal communication Nicola Church, Taupo District Council.

The removal of nitrate from stream water using a woodchip based denitrification bed was investigated for Environment Bay of Plenty in a Rotoehu stream.

2. Background

In a previous Landcare Research study (Taylor & Thornborrow 2006), a portion of the stream was diverted into a denitrification bed, which contained locally sourced bark from *Pinus radiata*. Results indicated that reduction of nitrate was taking place at a rate of 6.5 g day^{-1}; however, the leaching of organic N at 10 g d^{-1} appeared to be a by-product of the process. In discussions with EBOP it was elected to scale up the installation considerably and replace the bark with *Pinus radiata* woodchip to seek performance improvement.

3. Objectives

The objective was to determine the efficacy of employing woodchip-based denitrification beds to remove low level nitrate within stream systems.

4. Methods

A spring within a local farm adjoining Lake Rotoehu generates a stream carrying a consistent nitrate load of about 2.3 mg L^{-1} and volume of 100–200 litres per minute. This site had been used in a previous denitrification study using bark as the carbon source (Taylor & Thornborrow 2006). The old denitrification bed and bark were removed and about 10 metres of stream channel was cleared of debris to a width of about 2 m. A 1-m-high wooden retaining wall was fixed across the channel at the downstream end of the installation and a double layer of PVC liner (250 micron) spread over the base, banks and ends of the channel, to fully contain both water and woodchips. Approximately 18 cubic metres of *Pinus radiata* woodchip, screened to a size of 8–45 mm, was then placed in the lined cavity, resulting in an average chip depth of approximately 0.9 m (Fig. 1).

An upright riser, made from farmtuff piping, was placed at the head of the installation to intercept the stream piped from a culvert (Fig. 2). Flow into the denitrification bed was controlled by orifices drilled into the riser, while overflow was bypassed back to the stream bed (Fig. 3). Installation work was completed on 7 February 2007.

Duplicate samples of inlet and outlet flow were taken at several intervals over 13 months of operation. Levels of total nitrogen were measured after persulphate digestion, using colourimetry.

Ammonium and nitrate as NO_x, (being NO_3-N and NO_2-N) levels were measured directly on the water samples by colourimetry. Organic nitrogen was determined by the difference between total nitrogen and the sum of ammonium and NO_x.

Fig. 1 Bed overview on construction

5. Results

Technical challenges:
In the first month of operation the overflow pipe-work separated from the riser and water washed into the bed, flushing significant volumes of chips over the barrier. These chips were recovered and the pipe-work resecured. As algal growth was found to have blocked the feeder tubes to the point where the bed was drying out, it was decided to leave all but one of the feeders blocked and the remainder was simplified to a finger-size bore hole in the riser wall. A later problem with sediment build-up in the riser required that this hole be bunged and new holes drilled (diameter approx 25 mm) higher up on the lysimeter walls near the point of bypass flow. At this height, water turbulence was expected to alleviate sediment blockage and inhibit algal growth.

Fig. 2 Headworks March 2007

Fig. 3 Headworks October 2007

Table 1 Nitrogen analyses of Inlet and Outlet flow

Date	Total N Inlet mg L^{-1}	Total N Outlet mg L^{-1}	Nox-N Inlet mg L^{-1}	Nox-N Outlet mg L^{-1}	Organic N Inlet mg L^{-1}	Organic N Outlet mg L^{-1}	Ammonia N Inlet mg L^{-1}	Ammonia N Outlet mg L^{-1}	Est. Flow Inlet L min^{-1}	Est. Flow Outlet L min^{-1}
28/03/2007	2.38	0.95	2.52	0.78	0.00	0.15	0.01	0.01	29	47
10/05/2007	2.33	1.90	2.34	0.00	0.00	1.90	0.00	0.01	30	21
21/08/2007	2.29	0.82	2.33	0.00	0.00	0.79	0.01	0.02	27	19
19/09/2007	2.46	1.52	2.10	0.42	0.34	0.73	0.02	0.38	25	16
10/10/2007	2.29	1.32	2.31	0.79	0.00	0.35	0.04	0.14	27	18
14/11/2007	2.33	1.36	2.17	1.29	0.16	0.07	0.00	0.00	28	20
20/04/2008	2.44	1.06	2.29	0.89	0.16	0.16	0.01	0.02	20	19

(Compiled from Appendix 2)

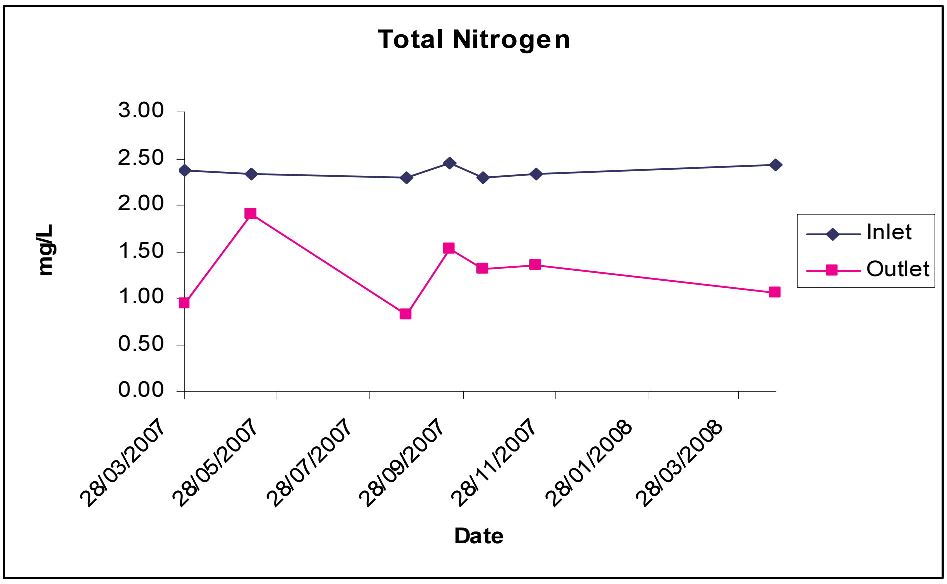

Fig. 4 Total Nitrogen levels entering and leaving the denitrification bed

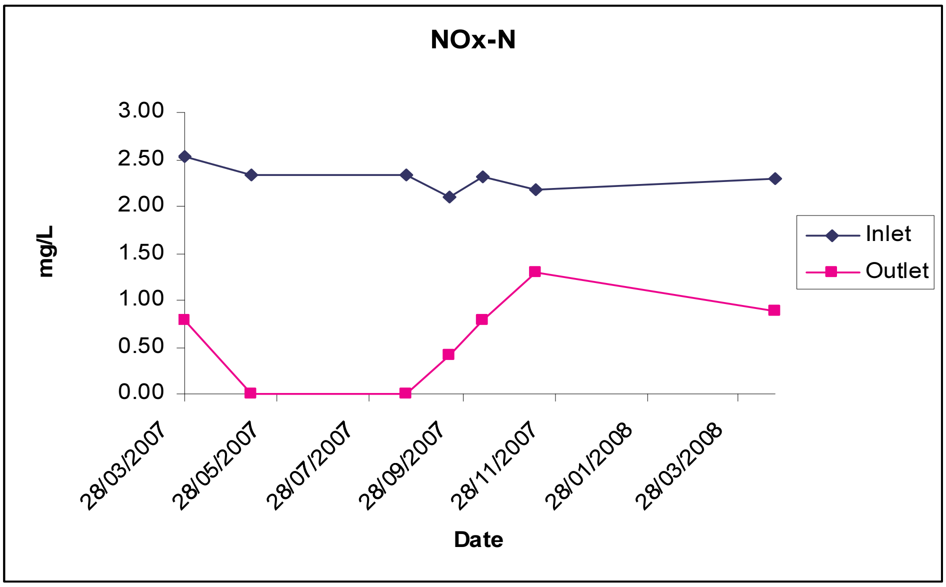

Fig. 5 Nitrate levels entering and leaving the denitrification bed

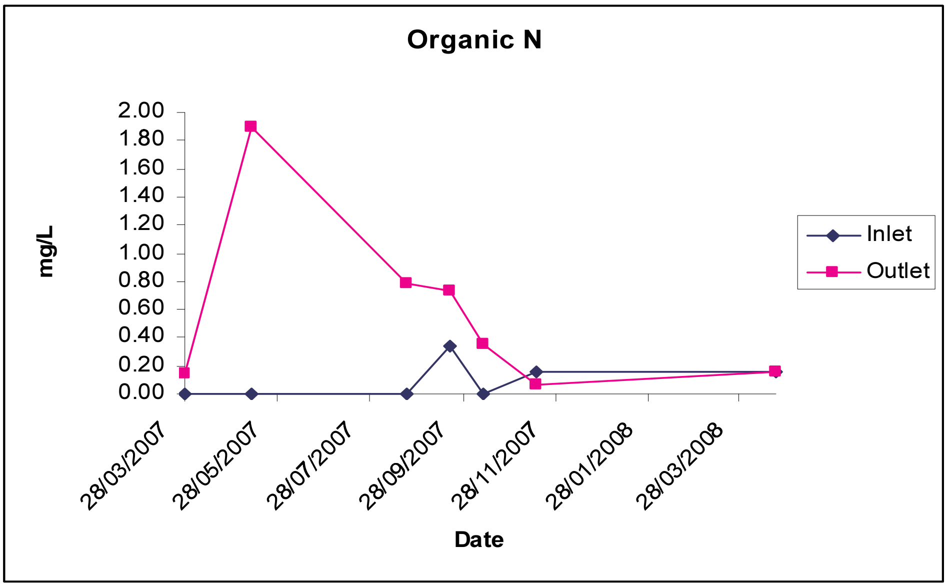

Fig. 6 Organic Nitrogen levels entering and leaving the denitrification bed

Overall, the denitrification bed removed about 50% of total N (Fig. 4) but, the beds nitrate removal efficiency deteriorated over time (Fig. 5). Total nitrogen levels in the stream varied little in level over time and nitrogen is almost wholly in nitrate (or partly nitrite) form. The nitrate removal per day is in the order of 5 to 6 times that observed by Taylor and Thornburrow (2006) at the site, which is in line with the increased size of the bed. The denitrification rate per cubic metre therefore appears to be similar for bark and woodchip. Nitrogen reduction of 1 mg L^{-1} from a flow of 25 L min^{-1} represents a removal rate of 36 g N d^{-1}, from an 18-m^3 denitrification bed. This yields a removal rate of 2 g NOx m^{-3} d^{-1}. Higher removal rates have been observed at Taupo municipal wastewater tertiary treatment beds where nitrate inputs have been higher, personal communication Nicola Church, Taupo District Council.

Similar to the results of Taylor and Thornburrow (2006), a flush of organic N (Fig. 6) was seen at the outlet in the early months of the experiment. This did correspond with the period of greatest reduction in nitrate. As nitrate levels at the outlet increased, organic N decreased and current levels of organic N at the outlet are now similar to inlet values.

6. Conclusions

The bed removed approximately 50% of the nitrogen present in the stream flow, equating to a nitrate removal rate of about 2 g NOx m^{-3} (of bed) d^{-1}.

Lower levels of denitrification were obtained treating stream water with about 2.3 mg L^{-1} nitrate than those obtained treating sewage effluent with about 10 mg L^{-1} nitrate in a similar denitrification bed, personal communication Nicola Church, Taupo District Council.
In the present case, denitrification rates appear to be limited by the amount of N in the streams as higher denitrification rates were observed where input water has higher nitrate levels.

Organic nitrogen production, as described by Taylor and Thornburrow (2006) was evident but as nitrate levels at the outlet increased, organic N decreased and current levels of organic N at the outlet are now similar to inlet values.

7. Recommendations

We recommend further monitoring of the bed at longer intervals, such as twice per year, to determine:

- the longevity of the denitrification bed
- whether the denitrification rate settles to a constant level over time or fluctuates
- whether the release of organic nitrogen proves to be a short-term initial reaction.

Expanding the installation to treat the entire stream flow may not be economically or technically sensible, and denitrification beds may be more applicable to water systems carrying higher levels of nitrate.

8. Acknowledgements

Andrew Fitchett, Landcare Research, for photos and endless woodchip shovelling; and Rob Reeves, GNS Science, for sampling and bed maintenance.

9. References

Cooper AB, Thomsen CE 1987. Nitrogen and phosphorus in stream waters from adjacent pasture, pine and native forest catchments. New Zealand Journal of Marine and Freshwater Research 1988 22: 279–291.

Taylor MD, Thornburrow D 2006. Removal of nitrogen from a stream flowing into Lake Rotoehu using a denitrification box. Landcare Research Contract Report LC0506/130 to Environment Bay of Plenty.

10. Appendices

Analytical results and site visit notes are appended.

Appendix 1 – Rotoehu records

Flow 1 - 28/3/07

Graeme,
I sampled the bed today. All looks good - the best I've ever seen it. There appears to be no leaks at all.
The samples are being sent by overnight courier to Palmy tonight. Could you let the lab manager know they will arrive tomorrow + the required analyses.

Bed inflow = 8.3 l/17 sec
Bed outflow approx 5.5 l/7 sec

There are clearly reducing conditions in the bed. There is a faint sulphur smell from the water at the outlet, and white (Sulphide ?) deposits on the bark at the outlet.

Rob

Flow 2 - 10/5/07

Graeme,
Samples collected 10/5/2007. Brian will receive the samples tomorrow.
The denitrification bed looks good and no apparent leaks.
Inlet flow = 10l/20 sec
Outlet flow = 10l/30 sec

The outlet flow measurement contains about 95% of the outlet flow. Visually, it does look as if the out outlet is flowing at a slower rate than the inlet. Possible leak in the bottom of the bed?

Some white deposits observed on wood chips @ the outlet and on the plastic at the outlet.

The outlet water sample does contain some sediment. Would you like me to field filter (0.45 micron) all samples next time?
Rob

Flow 3 - 21/8/07

Graham,
Sampled the Rotoehu Denitrification Wall today. Sent samples on tonight's courier.
Stats below.
Rob

Zero inflow and zero outflow on arriving at 9:00am due to high sediment levels in the lysimeter.

Cleaned out lysimeter and waited over an hour.

Inlet flow @10:15 = 10l/22 sec

Outlet flow = 10l/32 sec

Samples collected at this time.
Structure looks in good shape. Minor leakage at the culvert - pipe to lysimeter join. Nothing to worry about yet.

I will go back out next month.
Rob

Flow 4 - 19/9/07

Graeme,
I have just got back from the sampling. Bad news is that sediment has again clogged the lysimeter outlet, so there was no water entering the bed. However, the level in the bed wasn't very low - it only took about 15 - 20 mins of water running into the bed to get it overflowing again. This suggests the blockage may have occurred within the last week - but who knows.

On leaving the site:
outlet flow = 8l/30 sec
inlet flow = 8l/19 sec

I did collect samples at both inlet and outlet. Outlet water had an H_2S odour.

Do you think I should pay a "maintenance" visit in 2 weeks to clear sediment from the lysimeter (without collecting a sample - or collect a sample anyhow given that I would be going there)?

Other alternatives could be:
1) Install another hole higher up the lysimeter - this could buy us more time between visits.
2) Increase frequency of visits, clearing the lysimeter each time.
3) Install a "sediment trap" before the lysimeter. This could take the form of the current lysimeter installed upstream from the current lysimeter.
4) Design a baffle system in the current lysimeter that ensures the water is always flowing past the lysimeter outlet, therefore not allowing sediment to settle around the hole.

Rob

Flow 5 – 10/10/07

Graeme,

Bad news. Inlet and outlet flow = 0 when I arrived. It appears we have a new enemy - algae. It appears as if a build-up of algae somehow blocked the lysimeter outlet, therefore no water to the bed!! The sediment level was about 10cm below the lysimeter outlet hole.

A small leak has developed around the culvert/pipe join. Will be worth keeping an eye on this.

As discussed, I performed some modifications.

1) I cut about 4cm off the end of the inlet pipe to the lysimeter to "move" the location of where the flow hits the lysimeter. Previously, most of the flow was going directly into the bypass pipe. It has now moved back about 1cm, hitting the join between the lysimeter and the by-pass pipe. I did this in order to generate more turbulence near the lyismeter - by-pass pipe join. I did this without discussion with you.

2) I bunged up the existing lysimeter outlet.

3) I drilled 2 holes further up the lysimeter, near the bypass pipe. This is just below the water level in the lysimeter and in an area of turbulence. Hole 1 = 27mm, hole2 = 25mm diameter. I needed both holes to obtain a flow equivalent to the old hole. I will drill more holes when you want to increase the flow later. I am hoping that the larger hole will be less prone to blocking by anything!!
4) Cleaned out another batch of sediment. Want to start a beach feature somewhere?

I took samples. Note that samples were collected about 1.5 hours after the flow in the bed had been restored. I used plastic bottles we normally use for nutrient analysis, and not the pink-lid bottles. There is less chance of damage to these bottles from couriers and/or samplers.

Flow from hole1 = 9l/31 sec
Flow from hole2 = 9l/58 sec
Outlet flow = 9l/30 sec
Samples collected about 11:15, NZDT

Rob

Flow 6 – 14/11/07

Graham,
All systems operational!!!
Details:
Samples collected 14/11/2007 at about 14:15
Inlet flow hole 1 = 9l/29 sec and hole 2 = 9l/56 sec
Outlet flow = 9l/ 27 sec

I cleaned the sand out of the lysimeter.

We have an algae ecosystem in the making. Brown algae at the surface at the water inlet, and green algae near the outlet (see pictures).

Rob

Flow 7 – 20/4/08

Graeme visits – all operational with leakage from culvert now not evident.

Inlet – flow now 15 litres in 45 secs in total from both.
Outlet – 9 litres in 29 secs.

Samples collected around 3 pm.
Needed weeding and sediment had half filled the lysimeter but not restricting any flows.
Sediment removed within reach. Algae present but no major.

Appendix 2 -Analytical Results

Analysis Results

Environmental Chemistry Laboratory

Manaaki Whenua
Landcare Research

Client: **Graeme Anderson, Landcare Research, Hamilton** **Date In:** **29/03/2007**

Job No.: **LJ06156** **Date Out:** **04/04/2007**

Client ID	Sample No.	Ammonia-N (method 316) mg/L	NO_x-N (method 316) mg/L	Total Nitrogen (method 326) mg/L	Organic Nitrogen (calculation) mg/L
Inlet #1 28/3/7	M6/5968	0.016	2.51	2.38	0.0
Inlet #2 28/3/7	M6/5969	0.007	2.52	2.38	0.0
Outlet #1 28/3/7	M6/5970	0.011	0.84	0.98	0.1
Outlet #2 28/3/7	M6/5971	<0.004	0.72	0.92	0.2

Water Analysis Results

Environmental Chemistry Laboratory

Manaaki Whenua
Landcare Research

Client: **Graeme Anderson, Landcare Research, Hamilton** **Date In:** **11/05/2007**

Job No.: **LJ06193** **Date Out:** **17/05/2007**

Client ID	Sample No.	Ammonia-N (method 316) mg/L	NO_x-N (method 316) mg/L	Total Nitrogen (method 326) mg/L	Organic Nitrogen (calculation) mg/L
Inlet #1 10/5/07	M6/7804	0.005	2.34	2.32	0.0
Inlet #2 10/5/07	M6/7805	<0.004	2.34	2.34	0.0
Outlet #1 10/5/07	M6/7806	0.008	<0.005	1.66	1.6
Outlet #2 10/5/07	M6/7807	0.010	0.007	2.13	2.1

Water Analysis Results

Environmental Chemistry Laboratory

Manaaki Whenua
Landcare Research

Client: **Graeme Anderson, Landcare Research, Hamilton** **Date In:** **21/09/2007**

Job No.: **LJ07039** **Date Out:** **02/10/2007**

Client ID	Sample No.	Ammonia-N (method 316) mg/L	NO_x-N (method 316) mg/L	Total Nitrogen (method 326) mg/L	Organic Nitrogen (calculation) mg/L
Inlet #1 21/8/07 1	M7/2347	0.008	2.36	2.31	0.00
Inlet #1 21/8/07 2	M7/2348	0.008	2.31	2.26	0.00
Outlet#2 21/8/07 1	M7/2349	0.020	<0.005	0.59	0.57
Outlet#2 21/8/07 2	M7/2350	0.017	<0.005	1.04	1.0
Blank (N bubbled)	M7/2351	0.010	<0.005	<0.01	0.00
Blank (N bubbled)	M7/2352	0.010	<0.005	<0.01	0.00
Inlet #1 19/09/07 1*	M7/2386	0.017	2.10	2.46	0.34
Inlet #1 19/09/07 2**	M7/2387				
Outlet #1 19/09/07 1	M7/2388	0.380	0.416	1.53	0.74
Outlet #1 19/09/07 2	M7/2389	0.377	0.422	1.50	0.71

* container cracked, sample still present
** container smashed, no sample present
Containers being screwed too tight?

Water Analysis Results

Environmental Chemistry Laboratory

Manaaki Whenua
Landcare Research

Client: Graeme Anderson, Landcare Research, Hamilton **Date In:** 11/10/2007

Job No.: LJ07057 **Date Out:** 29/10/2007

Client ID	Sample No.	Ammonia-N (method 316) mg/L	NO_x-N (method 316) mg/L	Total Nitrogen (method 326) mg/L	Organic Nitrogen (calculation) mg/L
Inlet #1 10/10/07 1	M7/2848	0.04	2.31	2.28	0
Inlet #1 10/10/07 2	M7/2849	0.04	2.31	2.29	0
Outlet #2 10/10/07 1	M7/2850	0.14	0.79	1.28	0.3
Outlet #2 10/10/07 2	M7/2851	0.14	0.79	1.36	0.4

Water Analysis Results

Environmental Chemistry Laboratory

Manaaki Whenua
Landcare Research

Client: Graeme Anderson, Landcare Research, Hamilton **Date In:** 15/11/2007

Job No.: LJ07080 **Date Out:** 28/11/2007

Client ID	Sample No.	Ammonia-N (method 316) mg/L	NO_x-N (method 316) mg/L	Total Nitrogen (method 326) mg/L	Organic Nitrogen (calculation) mg/L
Inlet #1 14/11/07 1	M7/4322	<0.004	2.16	2.35	0.19
Inlet #1 14/11/07 2	M7/4323	<0.004	2.17	2.30	0.13
Outlet #2 14/11/07 1	M7/4324	<0.004	1.28	1.35	0.07
Outlet #2 14/11/07 2	M7/4325	<0.004	1.30	1.36	0.06

Water Analysis Results

Environmental Chemistry Laboratory

Manaaki Whenua
Landcare Research

Client: **Graeme Anderson, Landcare Research, Hamilton** **Date In:** **22 April 2008**

Job No.: **LJ07163** **Date Out:** **28 April 2008**

Client ID	Sample No.	Ammonia-N (method 316) mg/L	NO_x-N (method 316) mg/L	Total Nitrogen (method 326) mg/L	Organic Nitrogen (calculation) mg/L
Inlet 1 20/4/08	M7/7675	0.007	2.28	2.39	0.12
Inlet 2 20/4/08	M7/7676	0.005	2.29	2.49	0.20
Outlet 1 20/4/08	M7/7677	0.021	0.89	1.03	0.14
Outlet 2 20/4/08	M7/7678	0.020	0.89	1.08	0.18