2021 NZLTC Conference Proceedings

Technical Session 41

PART 2

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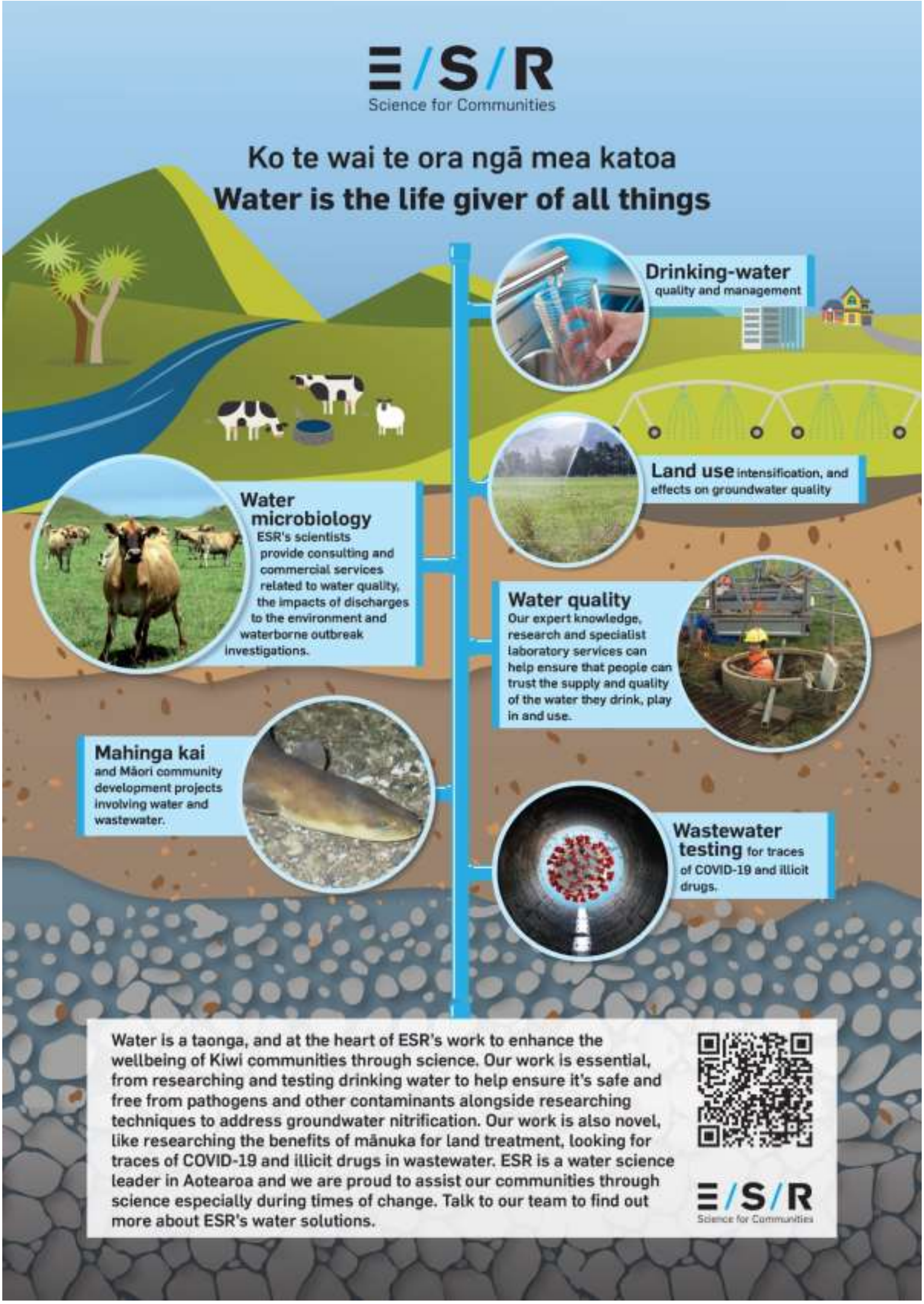

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CONTENTS

WHAT HAVE WE LEARNT ABOUT THE FUNCTIONING OF WOODCHIP BIOREACTORS?

G. Barkle [AE], A. Rivas [B], B. Maxwell [C], B Moorhead [B], R Stenger [B], L. Schipper [D],and J. Clague [B]

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ABSTRACT

Woodchip bioreactors have been proven to be effective in treating contaminant loads in a variety of applications. We have monitored over two seasons the mass fluxes of N and P in and out of a pilot-scale bioreactor, using a flow-based sampling scheme at the entry and exit points of the system. In addition, nitrate and carbon concentrations inside the bioreactor have been determined at a high frequency and at multiple locations, using an optical sensor connected to multiple wells installed through the bioreactor. This intensive sampling has allowed the treatment rates to be calculated for various flow rates and concentrations.

The understanding of how these low-cost treatment options function has been substantially improved through this better monitoring approach. This new knowledge has allowed us to determine the critical design parameters that should be used for these treatment options. Additionally, we can ascertain where modifications to enhance the performance of these systems via carbon dosing and/or woodchip surface modifications can be usefully employed.

Monitoring and performance of the trial bioreactor, design parameters and opportunities to enhance performance will be discussed in this presentation.

WOODCHIP BIOREACTORS – Design considerations

Greg Barkle[1], Aldrin Rivas[2], Brian Moorhead[2], Roland Stenger[2], Louis Schipper[3]

1 LaWR
2 Lincoln Agritech Ltd
3 The University of Waikato – Te Whare Wānanga o Waikato

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The Tatuanui (near Morrinsville) pilot bioreactor

Bioreactor volume	approx. 60 m^3
Woodchip material	Untreated Pine
Drainage area	0.65 ha

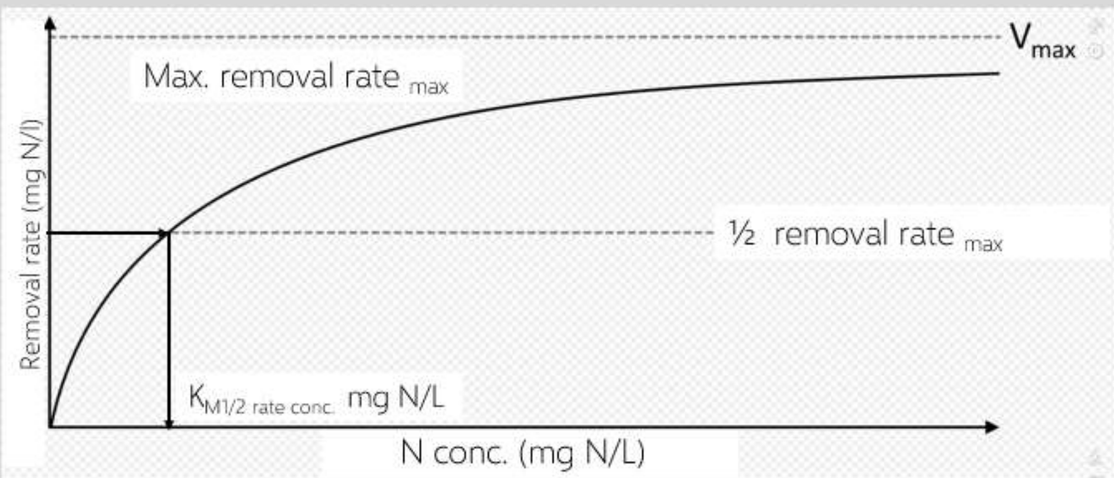
LaWR

The N removal of a bioreactor is a function of,

- The organic material that th... i.e. woodchip – ... etc., an...
- ...oad is delivered to the b... varies with site and season

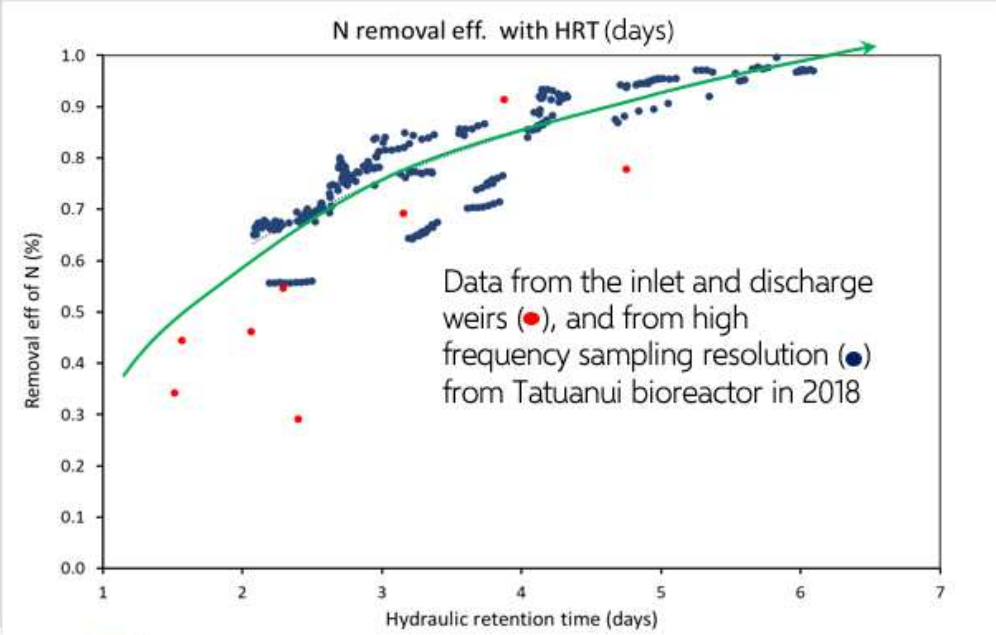
So how do we design bioreactors so they will consistently removed a minimum mass of N, which is "bankable" against a farm N discharge allowance?

Denitrification, is an enzyme reaction described by Michaelis Menten (MM) kinetics



LaWR

Effect of hydraulic retention time (HRT) on N removal



LaWR

Given a substrate, the N removal of the bioreactor achieved in a season will depend on;

1. The N concentrations and variability in the delivered N load.
2. The hydraulic variability.
3. The physical size of the bioreactor which controls the HRT in the bioreactor

LaWR

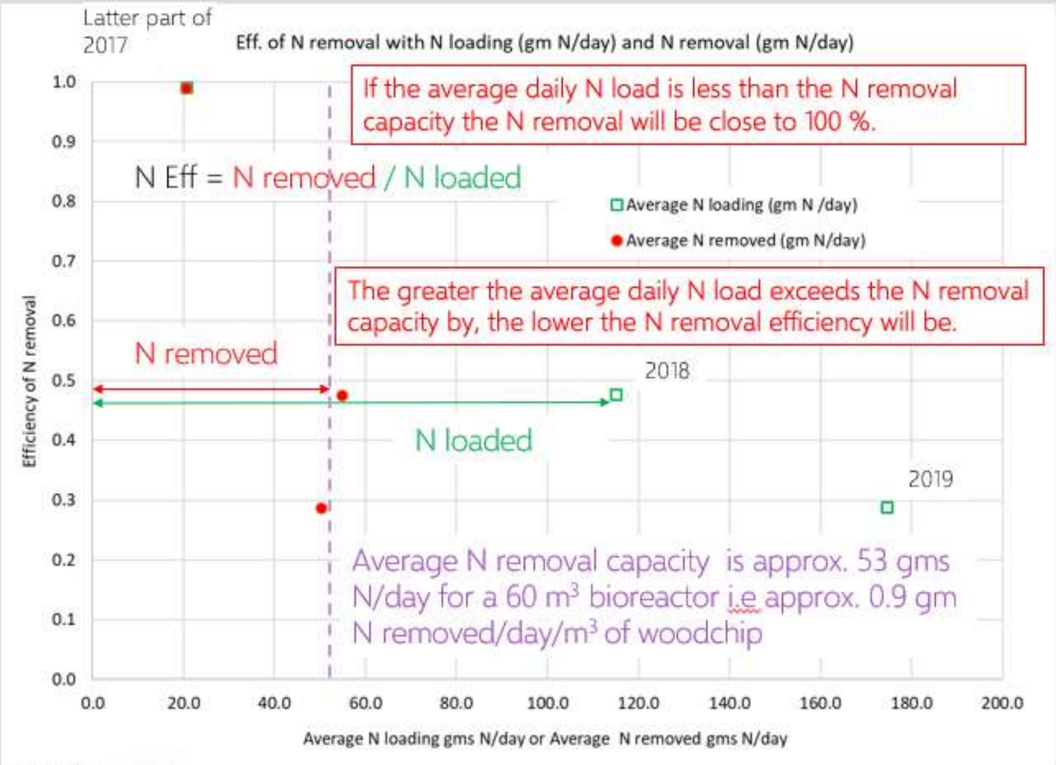
Nitrate removal from three years at Tatuanui bioreactor

Drainage year	Average daily load gms N/day	Average gms N/day removed	Average gms N removed/m3 of bioreactor per day (gm N/m^3 of woodchip/day)	Efficiency of N removal (%)
Latter half of 2017 drainage season	20.74	20.53	0.37	99.0
2018	115.13	54.78	0.98	47.6
2019	174.63	50.25	0.90	28.8

Increasing average daily N load

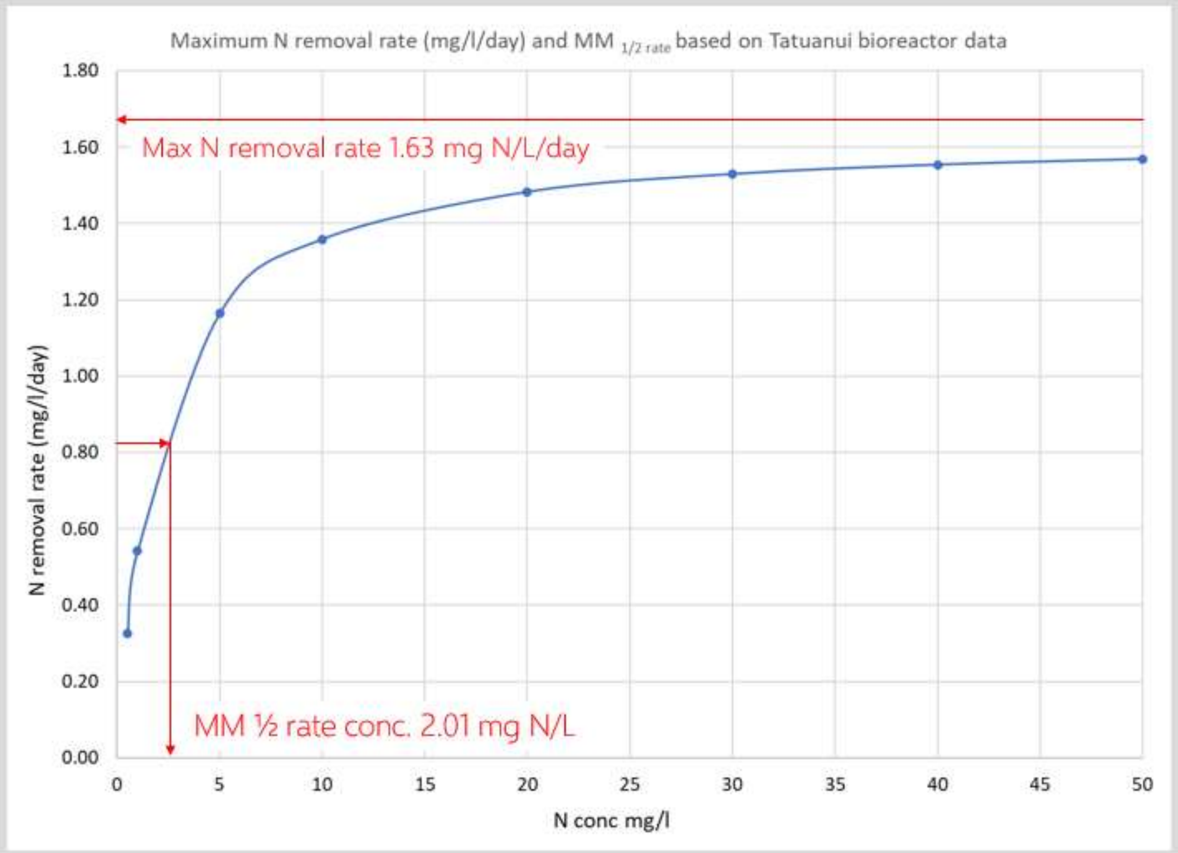
Approx. the same

Quite different !



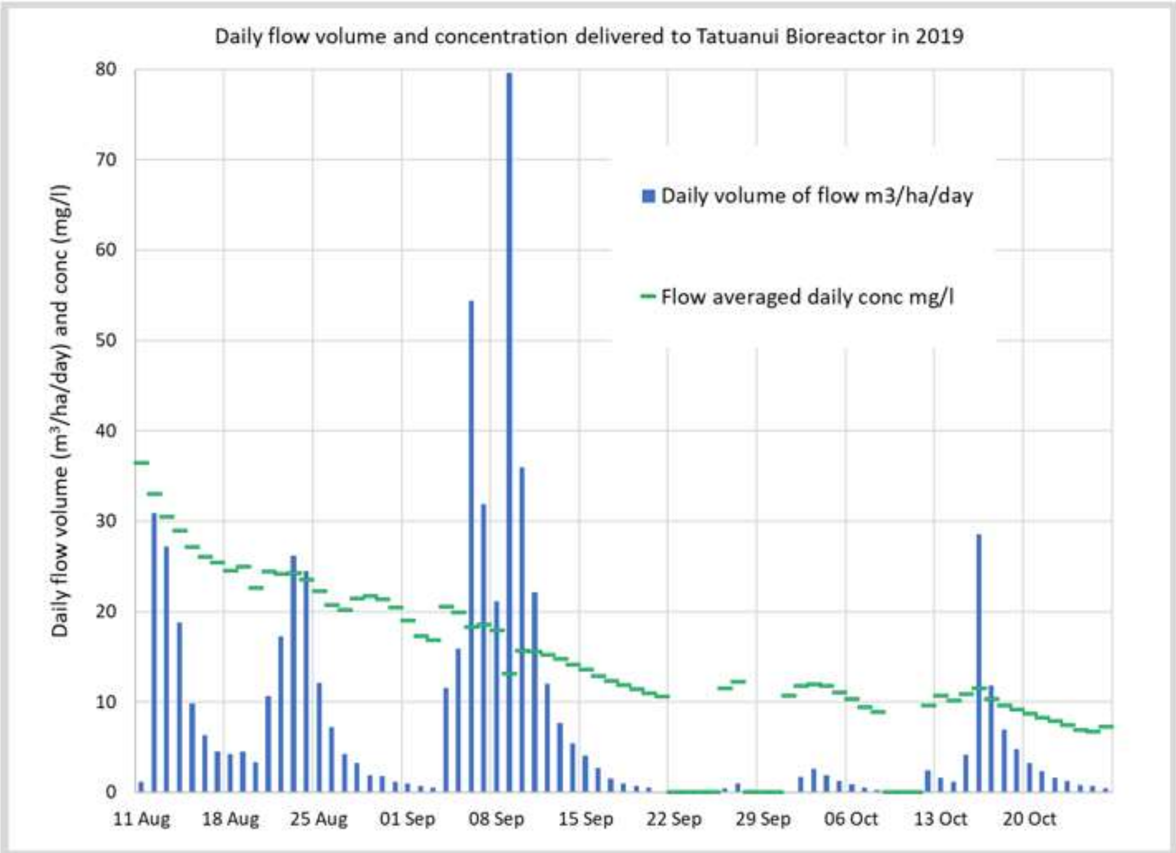
Design Process

1. Based on published laboratory data for substrate that you are going to use determine the aged N removal rate and the $MM_{1/2\ conc}$ parameters.



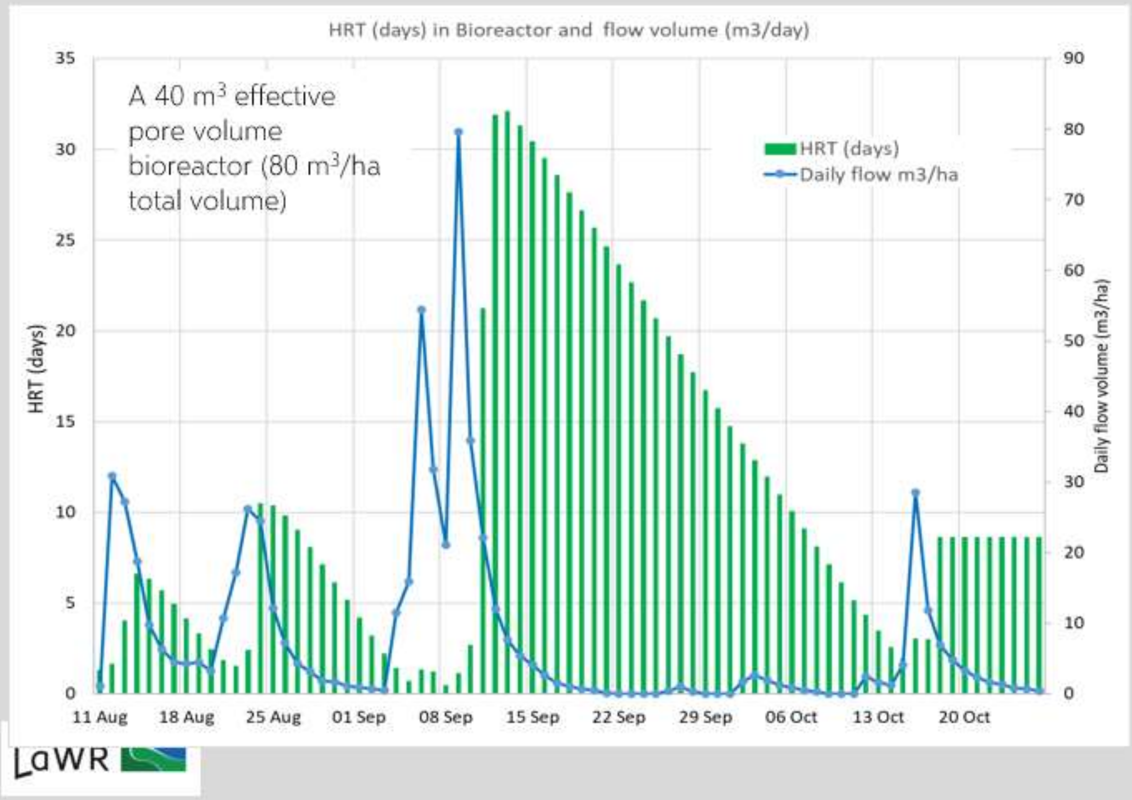
Design Process

1. Based on published laboratory data for <u>substrate</u> that you are going to use determine the aged N removal rate and the $MM_{1/2\ conc}$ parameters.
2. Determine the <u>daily hydraulic loading</u> to the bioreactor (L/ha/day) and the <u>N concentration (mg/l)</u> in the daily discharge over the season. (Note different for each year and site)



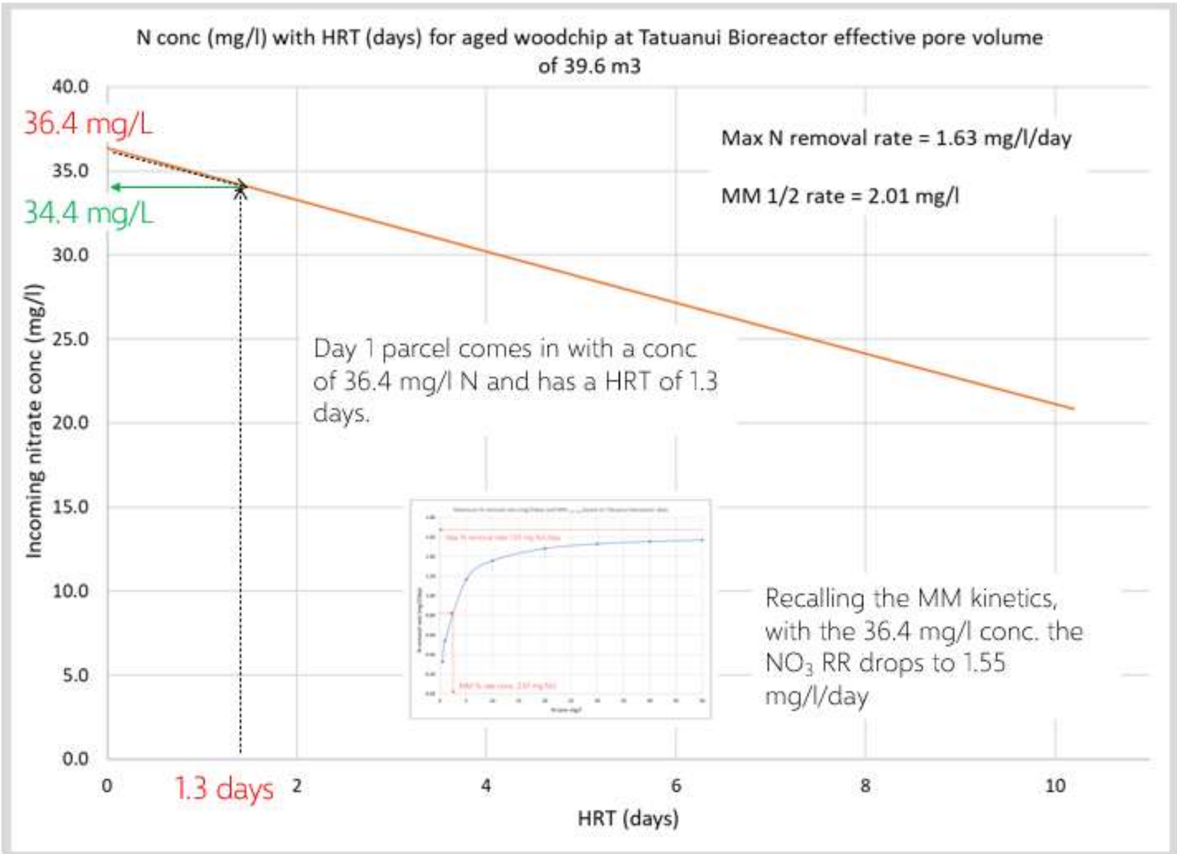
Design Process

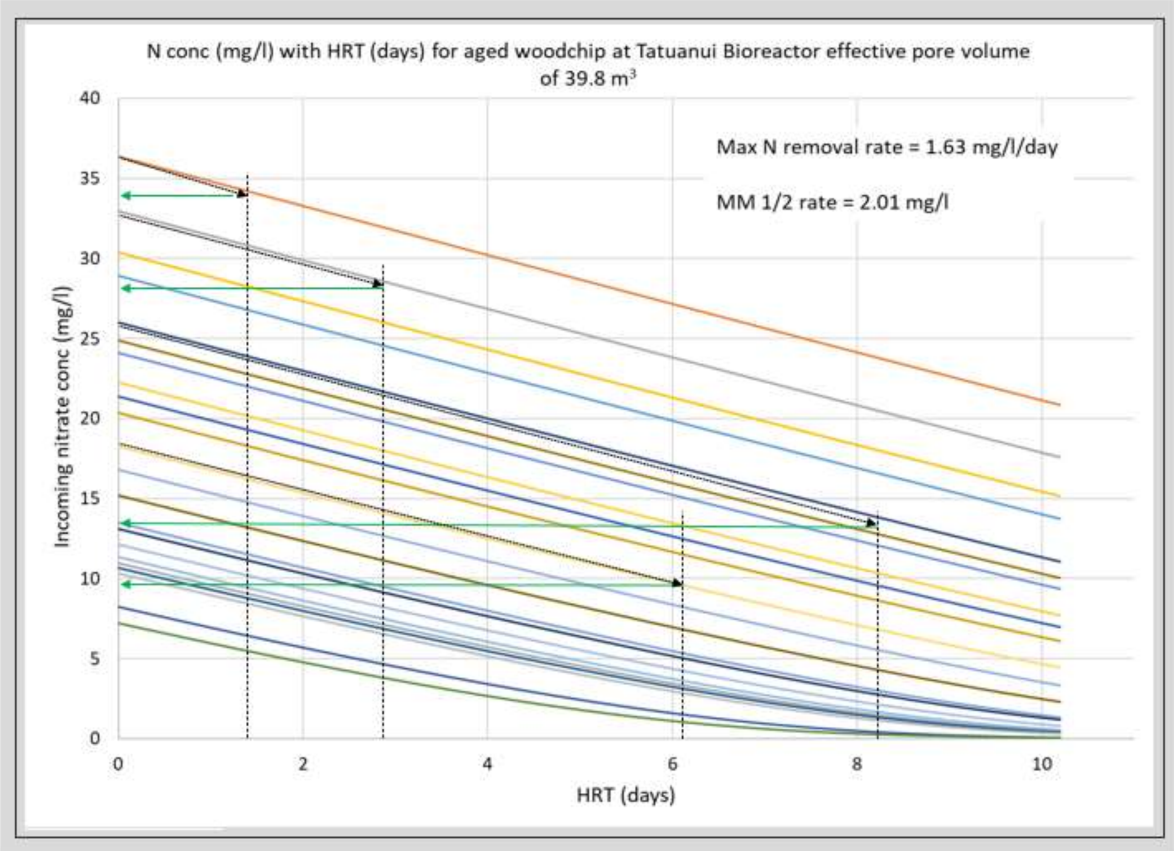
1. Based on published laboratory data for the substrate that you are going to use determine the aged N removal rate and the $MM_{1/2\ conc}$ parameters.
2. Determine the daily hydraulic loading to the bioreactor and the N concentration in the daily discharge over the season. (Note this different for each year and site)
3. Estimate a trial bioreactor volume and determine the hydraulic resident time (HRT) for each daily parcel.

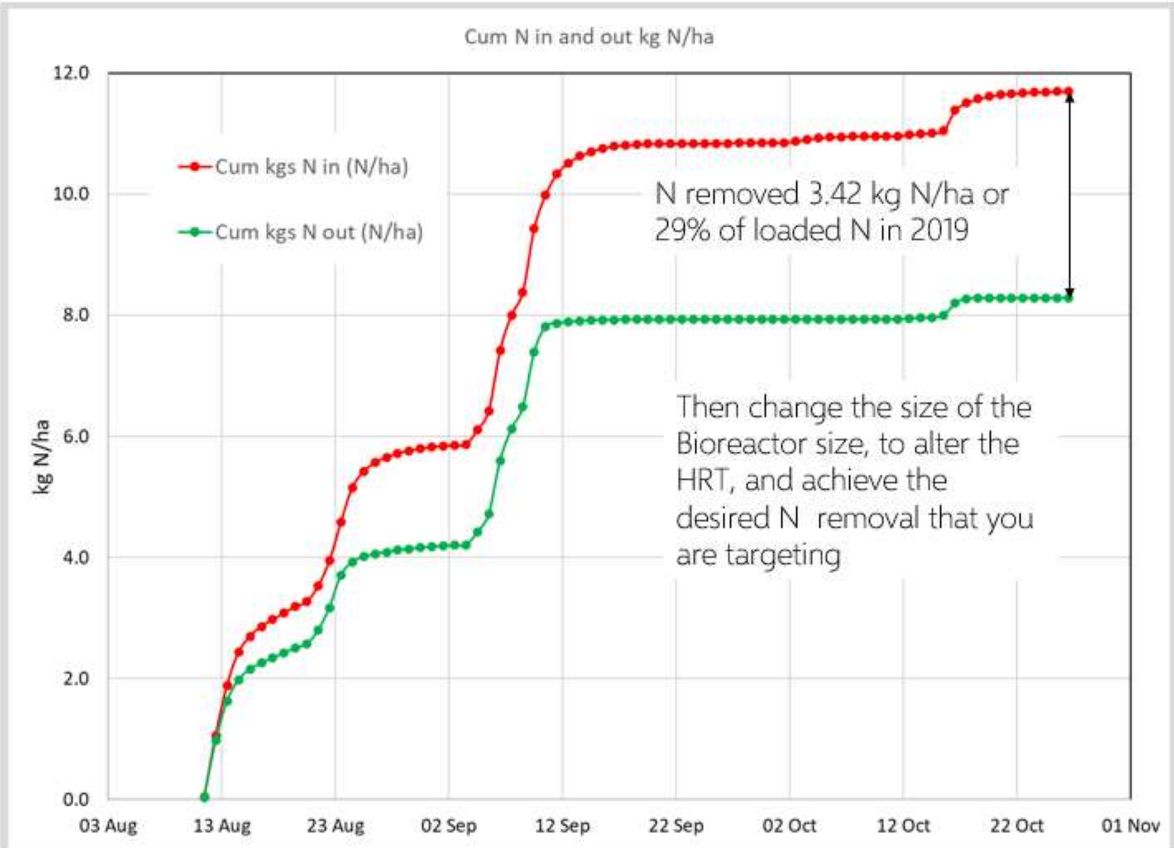


Design Process

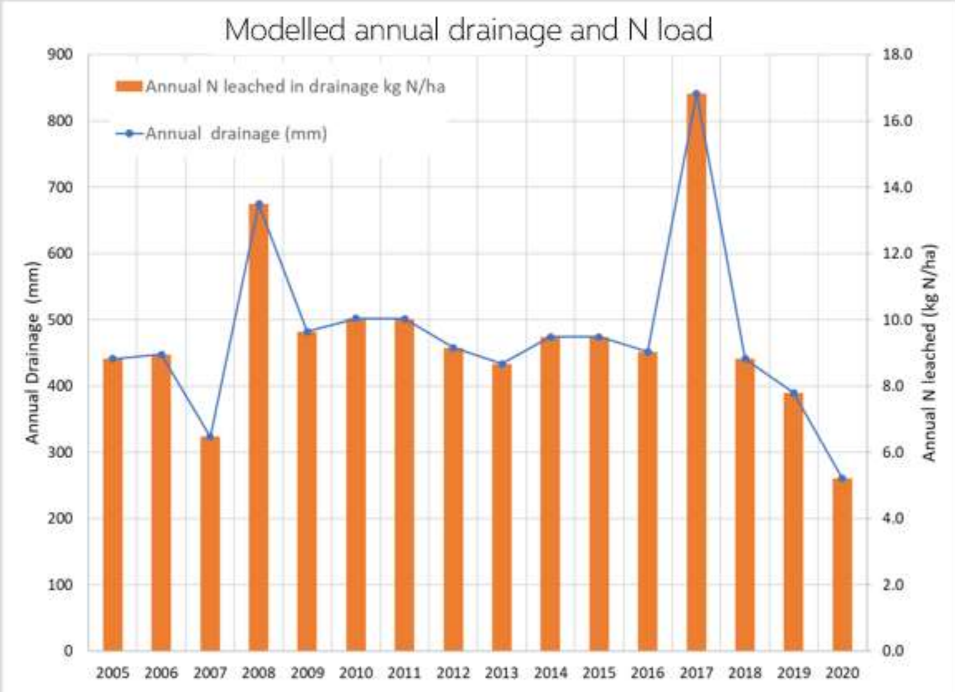
1. Based on published laboratory data for the substrate that you are going to use determine the aged N removal rate and the MM conc. parameters.
2. Determine the design daily hydraulic load to the bioreactor, and daily N concentration over the season. (Note different for each year and site)
3. Estimate a trial bioreactor volume and determine the hydraulic resident time (HRT) for each daily parcel.
4. For the N removal rate, and bioreactor volume determine the N removal achieved for each parcel.

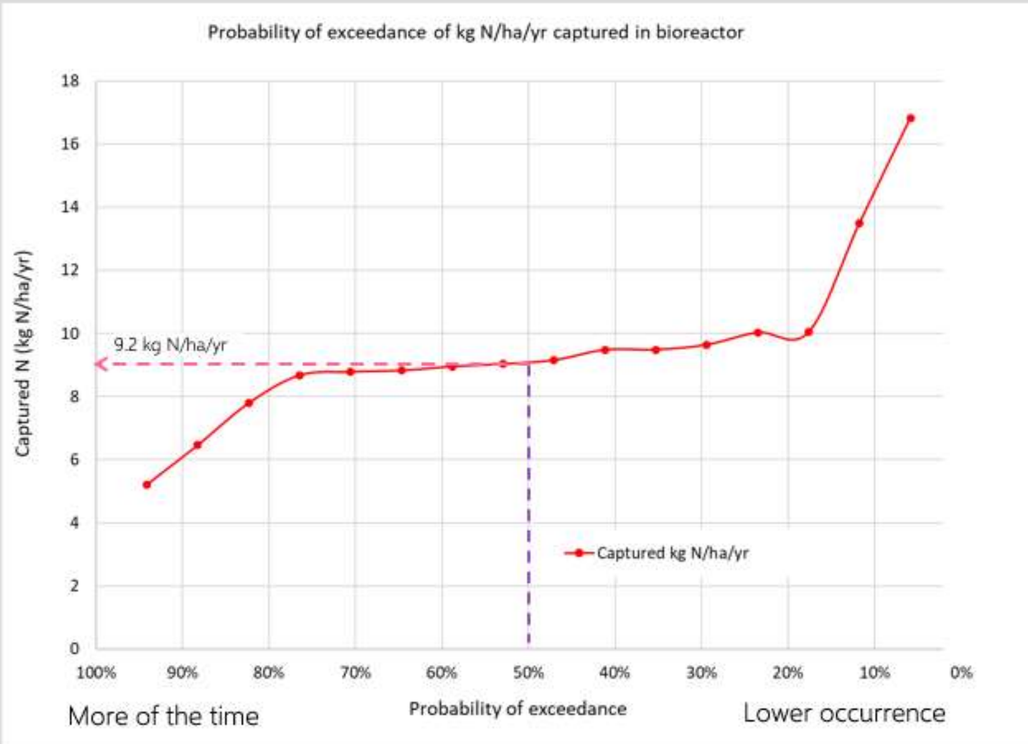



N conc (mg/l) with HRT (days) for aged woodchip at Tatuanui Bioreactor effective pore volume of 39.8 m3
Max N removal rate = 1.63 mg/l/day
MM 1/2 rate = 2.01 mg/l
Incoming nitrate conc (mg/l)
HRT (days)
0
5
10
15
20
25
30
35
40
2
4
6
8


Cum N in and out kg N/ha
Cum kgs N in (N/ha)
Cum kgs N out (N/ha)
N removed 3.42 kg N/ha or 29% of loaded N in 2019
Then change the size of the Bioreactor size, to alter the HRT, and achieve the desired N removal that you are targeting
kg N/ha
0.0
2.0
4.0
6.0
8.0
10.0
12.0
03 Aug
13 Aug
23 Aug
02 Sep
12 Sep
22 Sep
02 Oct
12 Oct
22 Oct
01 Nov

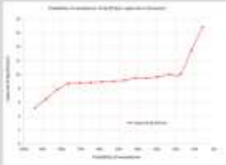
That's the design process for a single year ! However recalling even at the same site the N and hydraulic loading are different each year.



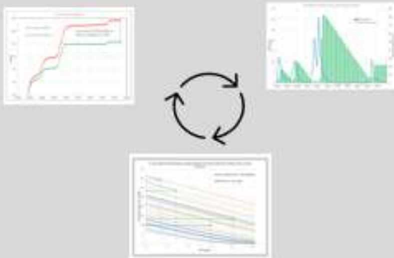


Designing for the long term i.e. including probability of performance over the long term

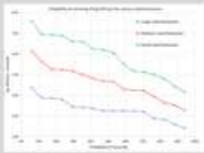
Determine the design N load (kg N/ha) – based on long term load probability

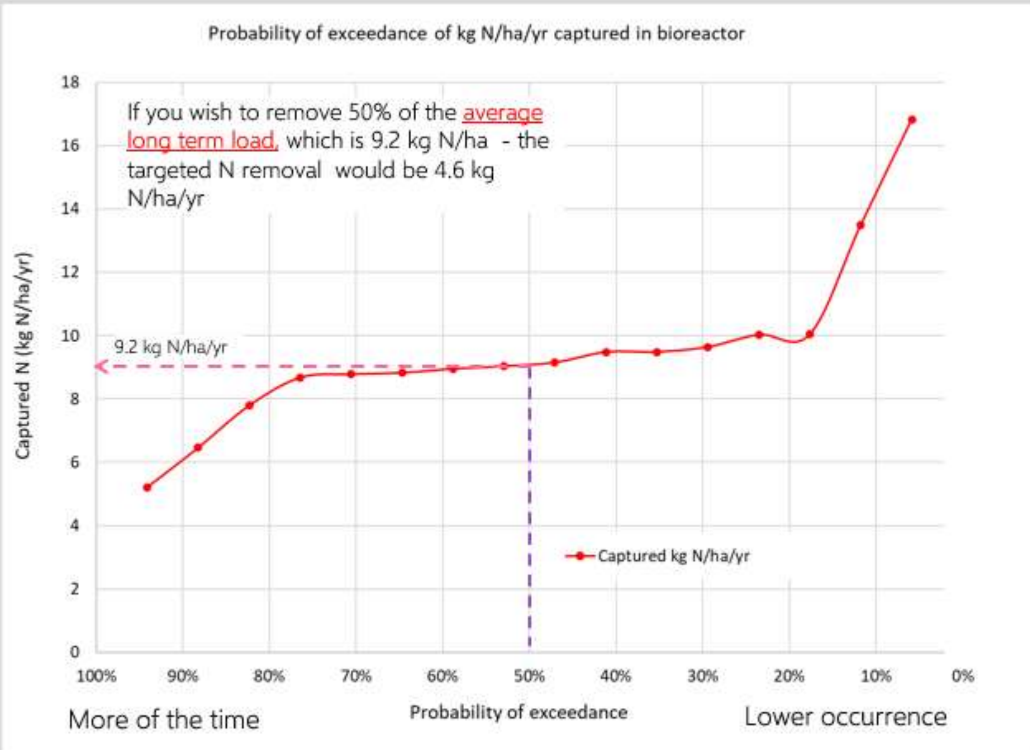


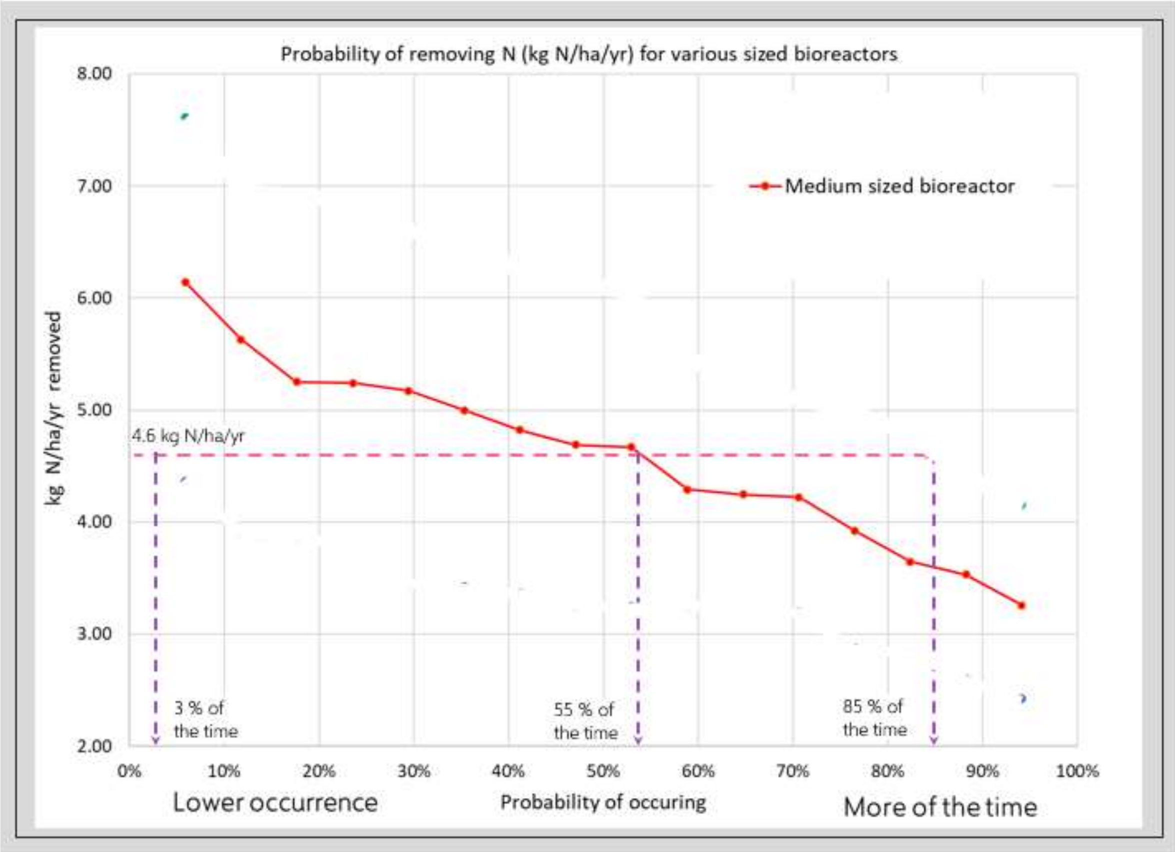
For the substrate, select a trial sized bioreactor and run the data for the number of years available

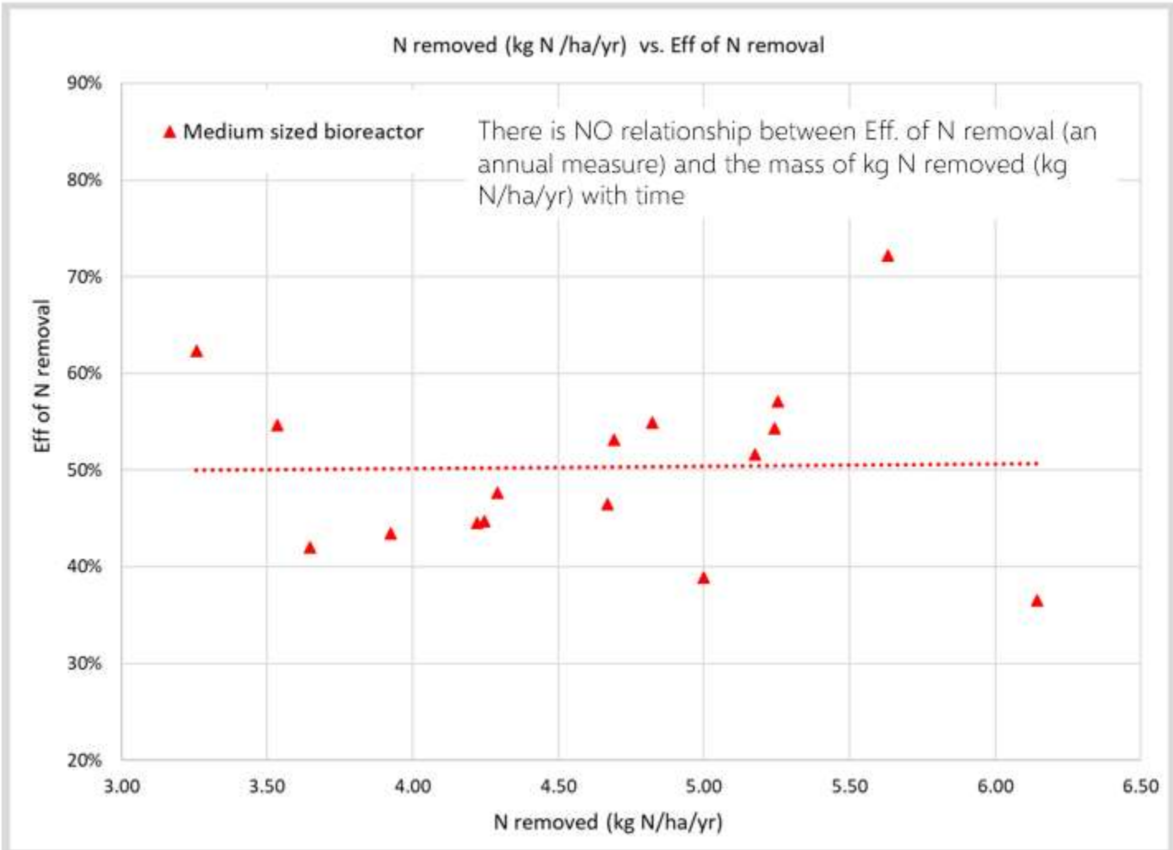


Examine the N removal performance and adjust size of bioreactor as required based on economics and performance






Probability of removing N (kg N/ha/yr) for various sized bioreactors
Medium sized bioreactor
4.6 kg N/ha/yr
3 % of the time
55 % of the time
85 % of the time
kg N/ha/yr removed
Lower occurrence
Probability of occuring
More of the time
8.00
7.00
6.00
5.00
4.00
3.00
2.00
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%


N removed (kg N /ha/yr) vs. Eff of N removal
Medium sized bioreactor
There is NO relationship between Eff. of N removal (an annual measure) and the mass of kg N removed (kg N/ha/yr) with time
Eff of N removal
N removed (kg N/ha/yr)
90%
80%
70%
60%
50%
40%
30%
20%
3.00
3.50
4.00
4.50
5.00
5.50
6.00
6.50

PHOSPHATE ADSORPTION ON ACTIVATED BIO-MEDIA

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ABSTRACT

Woodchip denitrifying bioreactors are an edge-of-field treatment technology to mitigate nitrate loadings from agricultural subsurface drainage. There is some evidence for low-level phosphorus removal by woodchip bioreactors, but no previous studies have investigated these processes to enhance P-removal in these systems. The objective of this study was to investigate the feasibility of incorporating iron-based materials in woodchip bioreactors to sequester phosphorus and reduce pollution in receiving waterways. We report a series of synthesis experiments of iron hydr(oxide) woodchip composites based on pine and manuka chips with particle sizes between 2 and 4 mm. Equilibrium studies were conducted to evaluate the adsorption capacity of activated woodchip composites and the data were fitted using Langmuir and Freundlich isotherms. P adsorption followed the Freundlich equation suggesting the formation of non-uniform multilayers of phosphate on the heterogeneous surface of iron hydr(oxide) coated wood chips. The maximum uptake of phosphate was 1 mg P g^{-1} at an equilibrium phosphate concentration of 55 mg P L^{-1} at pH 7 for the Fe-pine composites. Further research is aimed at creating a stable chemical environment within the anaerobic bioreactor environment to ensure the longevity of these composite materials.

Keywords: Phosphorus, Adsorption, bioreactor, iron hydr(oxides)

Activation of bio-media to remove phosphorus in denitrifying bioreactors

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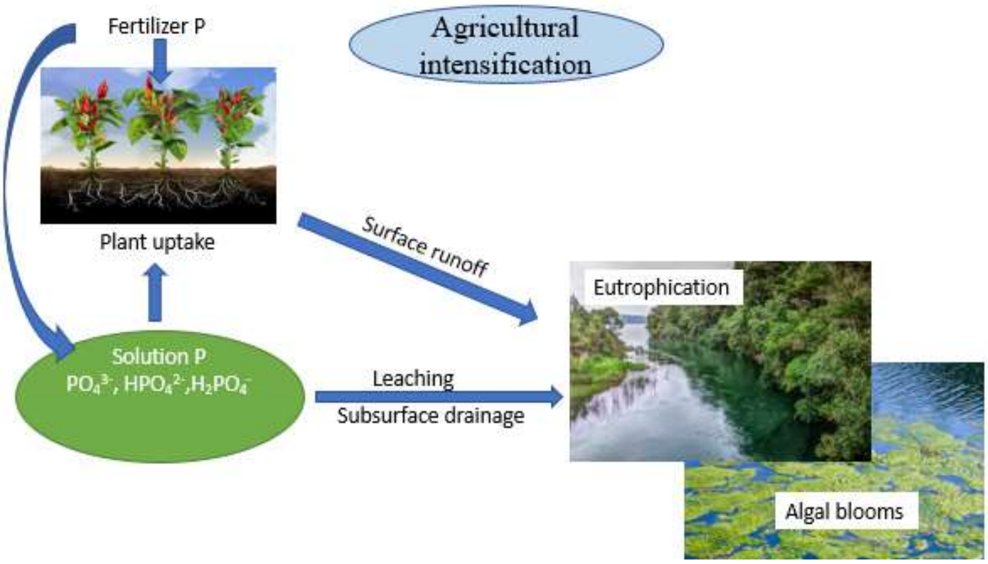
Water quality degradation



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Mitigation strategies

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Research objective

Investigate the potential of composite materials in woodchip bioreactors to prevent downstream phosphorus pollution of waterways

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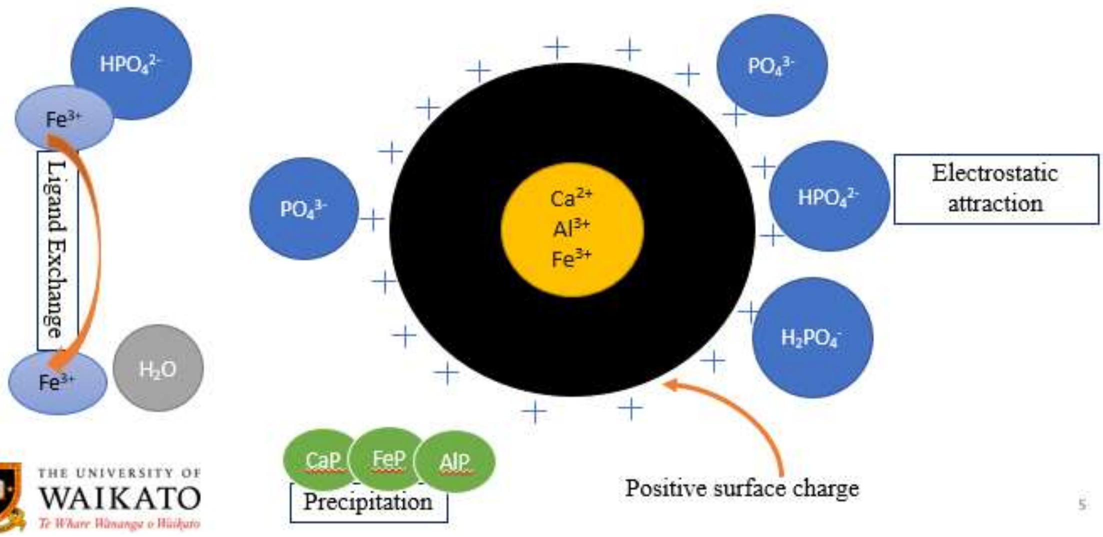
Mechanisms of phosphorus removal



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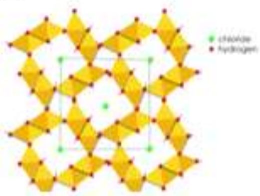
Iron (Fe)-based nanomaterials

- Magnetite (Fe_3O_4)
- Hematite (Fe_2O_3)
- Maghemite/lepidocrocite (γ- Fe_2O_3)
- Goethite (α- FeOOH)

- Akaganeite (β- FeOOH)

- Akaganeite is a mesoporous material with a tunnel-shaped morphology.
- Akaganeite has a high surface area and definite pore size distribution



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Synthesis of iron oxide and functionalized wood

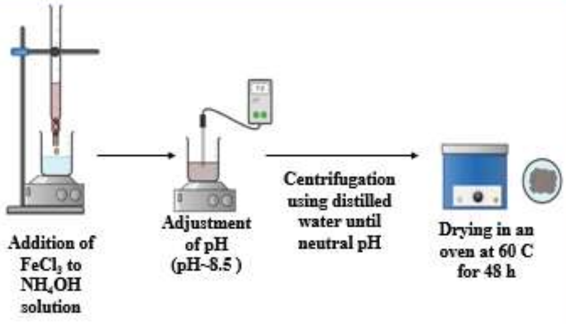

Figure 1. Akaganeite preparation (reverse co-precipitation technique)

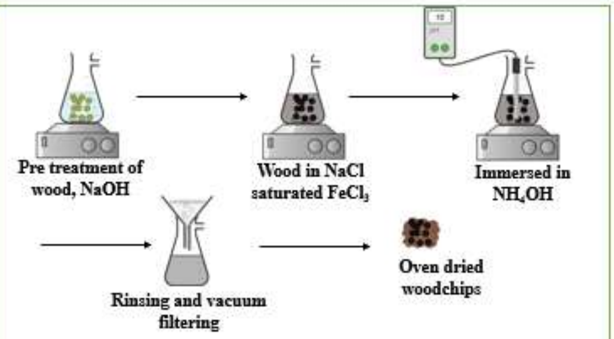

Figure 2. Functionalized woodchip preparation (reverse co-precipitation technique)

Iron oxide

Wood

Functionalized wood

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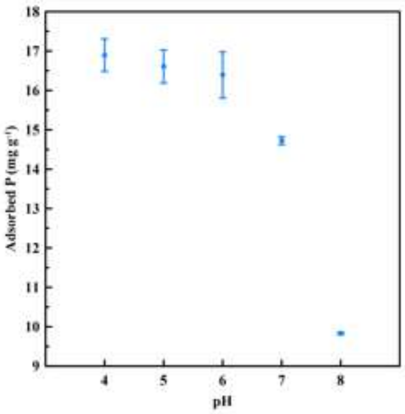
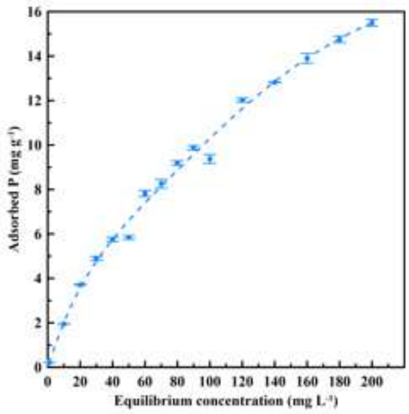
Adsorption isotherms of iron oxide



Effect of solution pH on adsorption of phosphate



Adsorption isotherm of phosphate on Iron oxide

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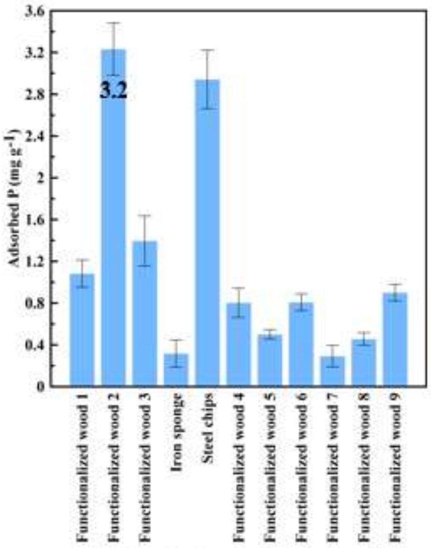
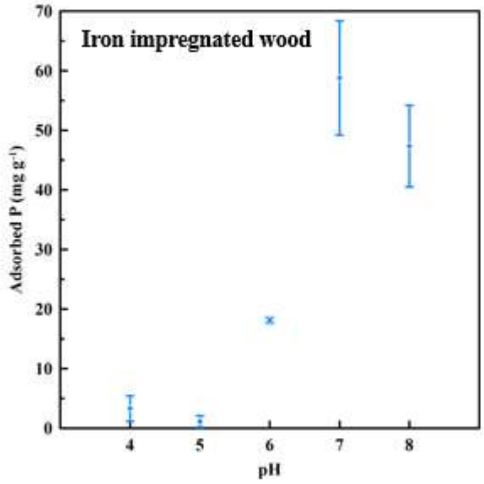
Phosphorus uptake by activated bio-media



P loading of various functionalized wood chips



Effect of solution pH on adsorption of phosphate

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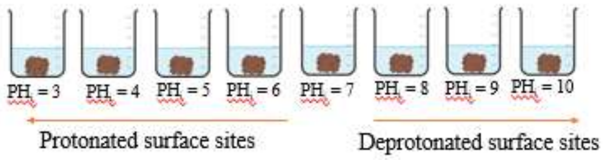
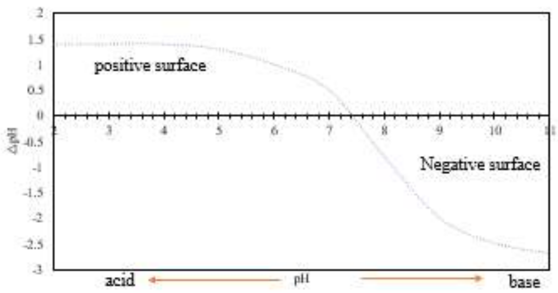
Surface charge





Point of zero charge (PH_{PZC}) is the pH at which the net **charge** of total particle surface is equal to **zero**

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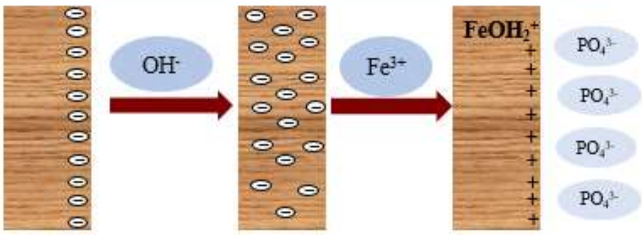
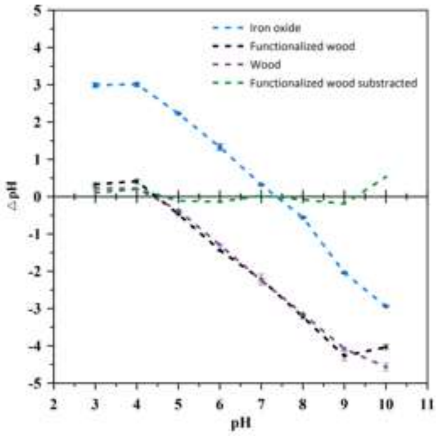
Synthesize and characterize iron hydr(oxide) functionalized woodchips for phosphorous removal

Activate the surface properties of bio-media with iron hydr(oxide)



Functionalization to inverse the surface charge of the wood, and thereby remove phosphorus



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Point of zero charge of Iron oxide, wood and functionalized wood

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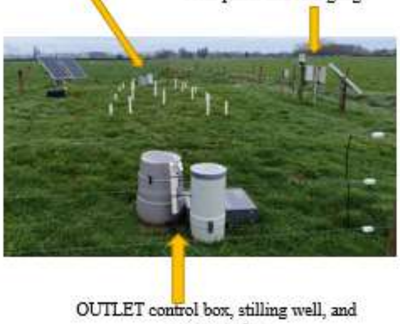
Functionalized woodchips to adsorb phosphorus in real world conditions

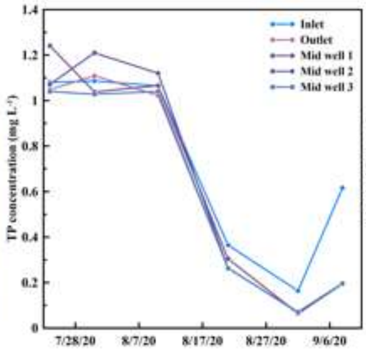
INLET control box, stilling well, and auto sampler

Instrument control panels, solar panel and rain guage

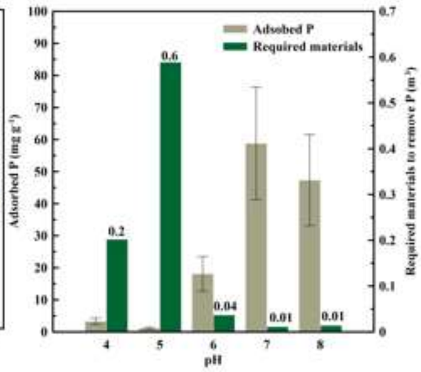


OUTLET control box, stilling well, and auto sampler

Study site



Total phosphorus concentration in 2020 drainage season



Required materials to remove P at high flow rates of bioreactor

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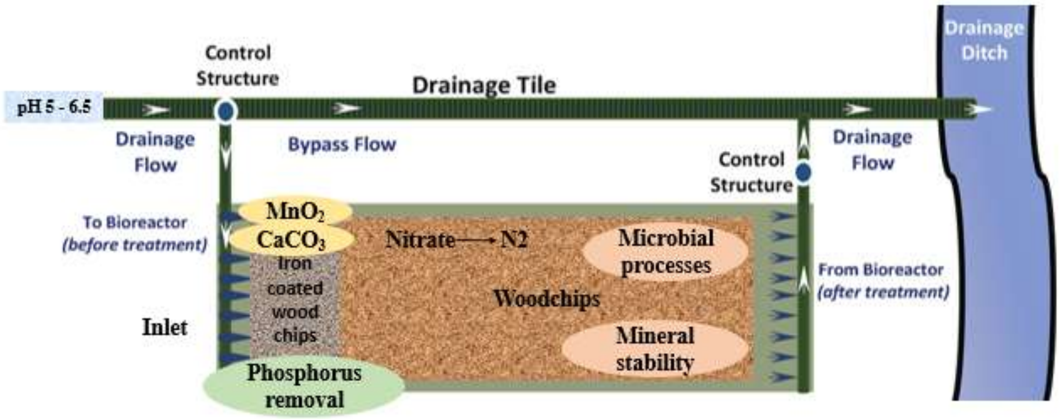
Ongoing research



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Conclusions

- The results of the batch adsorption experiments showed that 0.6 m^3 of iron oxide functionalized woodchips are required to remove phosphorus in our current bioreactor.

- Strategies need to be implemented to poise the redox in real world bioreactor conditions to prevent iron oxide dissolution

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Acknowledgement and funding

- A/Prof Adam Hartland – chief supervisor
- Dr Rupert Craggs – external supervisor
- Dr. Dorisel Torres Rojas – co-supervisor
- Professor Louis Schipper – co-supervisor
- Technical staff and colleagues

METHANOL DOSING OF A PILOT-SCALE DENITRIFYING BIOREACTOR TO ENHANCE NITRATE REMOVAL FROM TILE DRAINAGE WATER

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ABSTRACT

Denitrifying bioreactors are simple passive biofilters that can be used to reduce nitrate loads to receiving waters; however, their removal performance can be overwhelmed during high flow events. This work evaluated methanol dosing of a pilot-scale denitrifying bioreactor installed on a dairy farm to examine whether and to what extent, continuous methanol dosing could enhance nitrate removal rate while preventing excess methanol loss from the system. Without methanol dosing nitrate removal rates were 0.67–1.60 g N m^{-3} day^{-1} in 2019 drainage season. For the subsequent drainage season (2020), methanol dosing significantly enhanced volumetric nitrate removal rates to 12.8 g N m^{-3} day^{-1} in highly flashy nitrate inputs. Methanol concentrations decreased along the bioreactor by order of magnitude with varying removal rates of 24.91 to 180.94 (g C m^{-3} d^{-1}) and overall removal efficiency of >99% and well below concentrations of concern. The results suggest that methanol enrichment of the bioreactors can effectively stimulate denitrification rates but not be released to receiving waters even when nitrate concentrations were low.

Keywords: Denitrifying bioreactors, Tile drainage, Carbon dosing, Removal rate, Eutrophication

Passive Methanol Dosing of a pilot-scale Denitrifying Bioreactor to Enhance Nitrate Removal from tile drainage water

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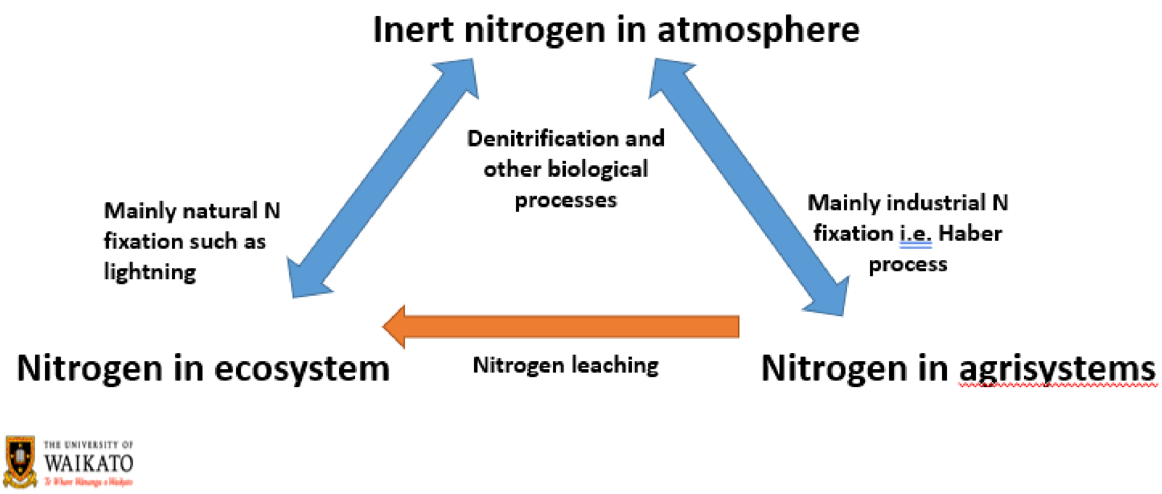
The nitrogen cycle



What operating conditions bioreactors limit N removal?

- High and flashy N load
- Labile Carbon Limitation

→ Low N removal rate

The overarching objective

- Enhancing the nitrogen (N) removal rate by adding constant relatively high dose of methanol while preventing excessive DOC from entering receiving waterways

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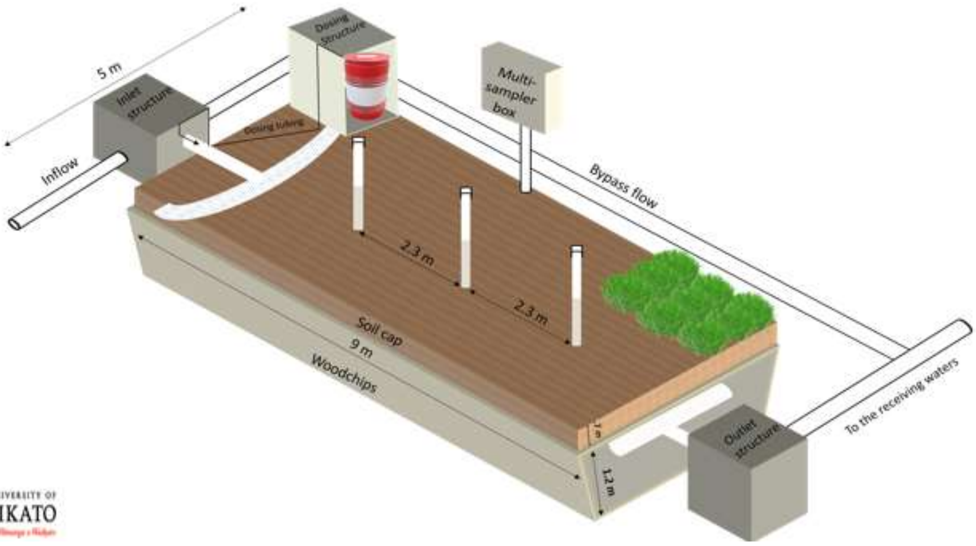
The schematic of the reactor



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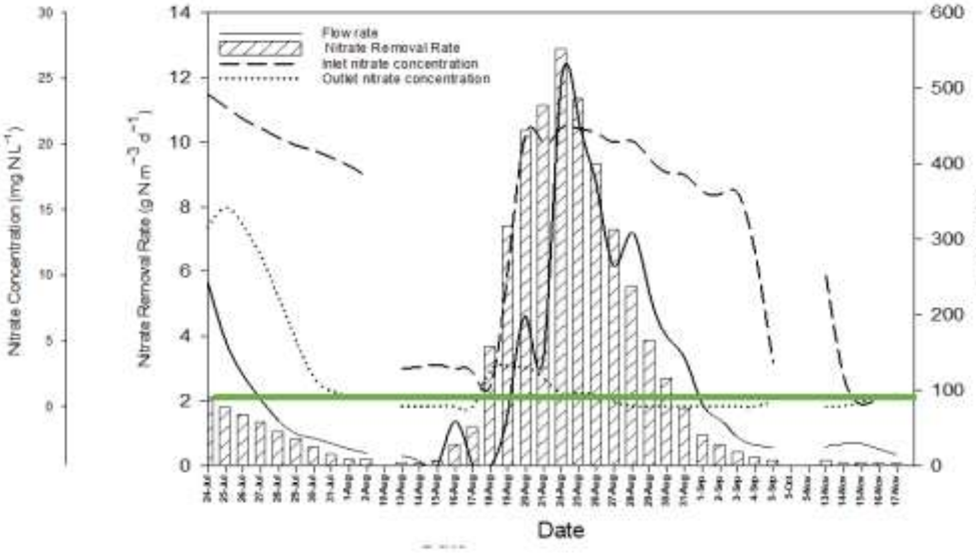
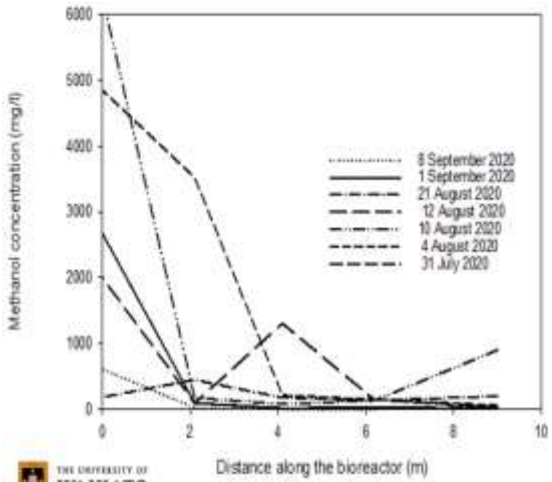
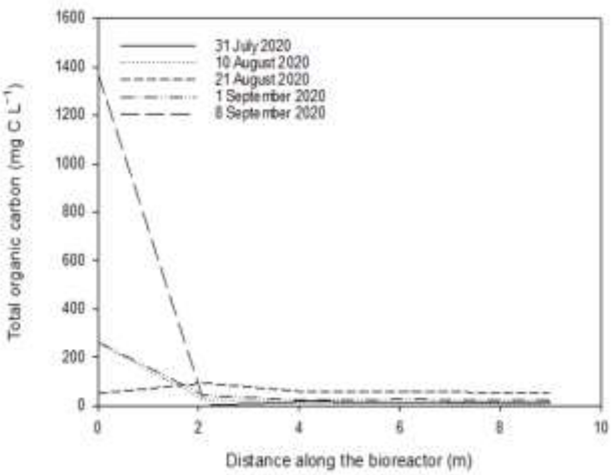
Temporal variations of nitrate inlet and outlet concentrations, removal rates and outflow rates

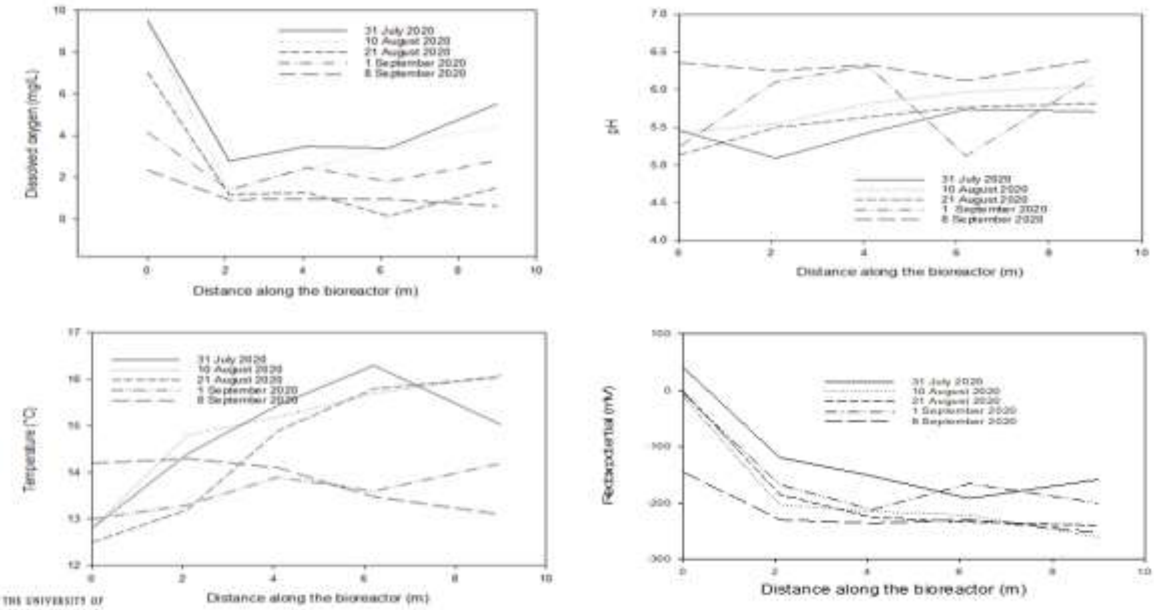


Methanol (left), and total organic carbon concentrations (right) along the bioreactor during the different sampling events





Environmental characteristics



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Conclusion and future plan

Overarching question: Can we enhance the nitrogen (N) removal rates by adding methanol while preventing excessive methanol from entering receiving waterways?

Answer: Methanol dosing increases denitrification rates in woodchip bioreactors while removed in nitrate limiting conditions

The plan (field): another year field methanol dosing to:

i. confirm 2020 drainage season data
ii. see the bacterial response to methanol at the startup phase

NITRATE ATTENTUATION BY THERMOCHEMICAL MODIFICATION OF WOOD SUBSTRATES

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[B] Corresponding author email: doriselt@waikato.ac.nz

ABSTRACT

Denitrifying woodchip bioreactors achieve significant reductions of nitrate (NO_3^-) levels during moderate drainage flows. Bioreactors are less effective at pollution attenuation at peak flows and high nutrient events, lowering their overall performance. The objective of this work was to investigate the potential for attenuation of nitrate in drainage water by using chemically and thermally modified woodchips.

Wood has a low affinity for anion retention due to net negative surface charge-- determined by functional group composition and ambient pH. Modifying the surface chemistry of woodchips to achieve a positive surface charge can increase nitrate retention by wood substrates, thereby providing a slow-release of NO_3^- for later denitrification. All chemical and thermal modifications resulted in an increase in positive surface charge at acidic-to-neutral pH. The maximum nitrate adsorption capacity was 1.22 mg NO_3^-N g^{-1} and 3.16 mg NO_3^-N g^{-1} for chemical and thermal modification at optimum pH. Compared to unmodified woodchips, chemically and thermally modified wood retains and retards (with respect to flow) a large fraction of NO_3^- which can be subsequently denitrified under moderate flow conditions, increasing the efficiency of bioreactors.

Keywords: water pollution, reactive nitrogen, charcoal, amine, bioreactors

WOODCHIP DENITRIFICATION WALL TRIAL IN A GRAVEL AQUIFER: RESULTS YEAR 1

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ABSTRACT

Gravel aquifers represent the most prolific and important groundwater systems in New Zealand (NZ). They are particularly vulnerable to nitrate leaching from intensive land-use practices. Woodchip denitrifying bioreactors are an 'end-of-pipe'/'edge-of-field' nitrate-mitigation tool that we think could have useful applications in NZ where nitrate pollution is a concern. To test this assertion, we are conducting a woodchip denitrification wall pilot study. In November 2018, we entrenched a 50/50 mixture of woodchip and gravel, 3 m below the water table, in a shallow gravel aquifer setting. Besides monitoring the efficacy of the woodchip wall at removing nitrate from the groundwater, we are also examining potential pollution-swapping phenomena, e.g., mobilisation of arsenic from aquifer sediments as a result of altered redox state and greenhouse gas emissions.

Over its first year we estimate the 375 m^3 wall passively filtered 152-230 m^3 of groundwater and completely removed 340-588 kg NO_3-N, converting it to di-nitrogen gas (N_2). Whilst operation of the wall did initially release arsenic into the groundwater, effects were localised and short-lasting. So far, greenhouse gas emissions have been insignificant. Whether this remains the case and how long the woodchip wall can sustain effective nitrate removal remains the focus of on-going study.

Keywords: nitrate; groundwater; gravel aquifer; woodchip denitrification wall

Woodchip Denitrification Wall Trial in a Gravel Aquifer: Results Year 1 and 2

<u>Lee Burbery</u>, Phil Abraham, Richard Sutton, Theo Sarris, Louise Weaver, Murray Close

Land Treatment Collective conference
Palmerston North
5 May 2021

ESR

Intro | Methods | Results> N-removal | >> pollution-swapping | >>>hydraulics | Conclusions

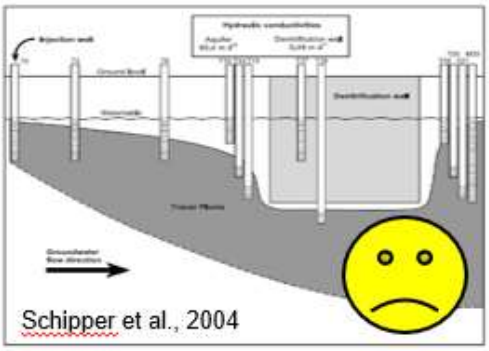
ESR

Woodchip denitrification walls - concept proven in sand aquifers

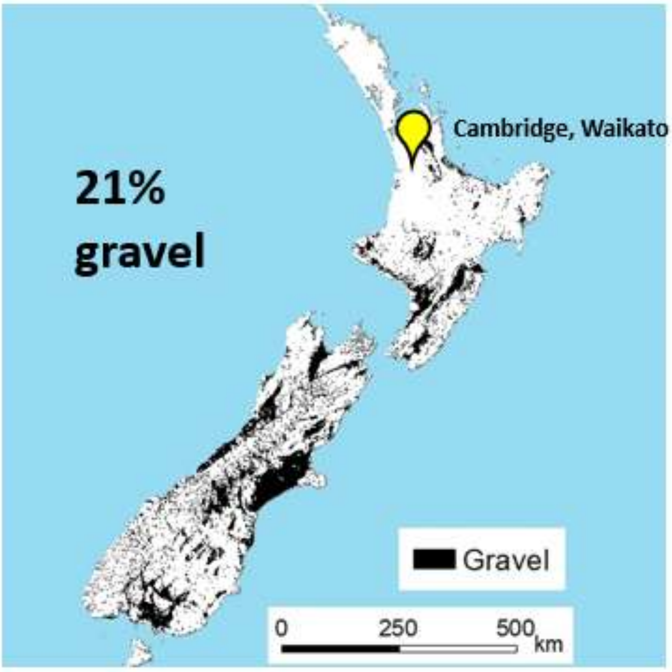
First trials 1990's:

- Robertson & Cherry (1995): Long Point, Ontario, Canada
- Schipper & Vojvodic-Vukovic (1998): Hautapu, Cambridge, NZ

Prognosis 30 years operational life



What about shallow gravel aquifers?



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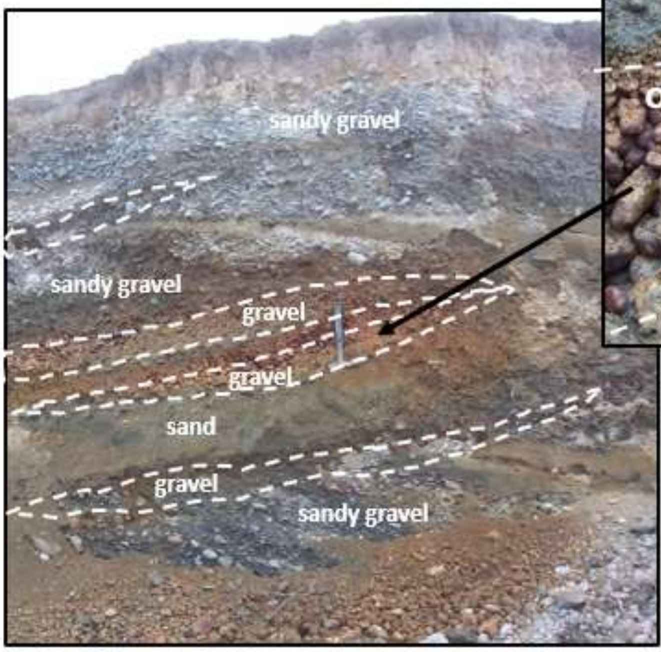
Alluvial gravel outwash is complex



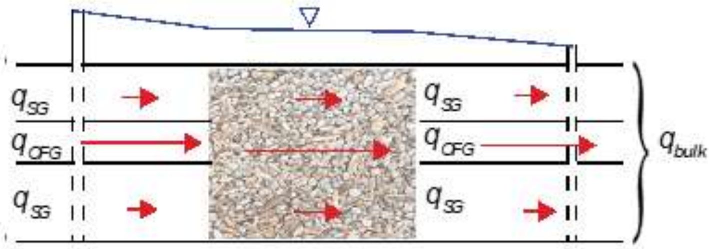
- Heterogeneous
- Highly permeable OFG
  - K_{gravel} ~10^4 m/day
  - K_{sand} ~10^2 m/day

Intro | Methods | Results> N-removal | >> pollution-swapping | >>>hydraulics | Conclusions

Are denitrification walls viable in gravel aquifers?

Fast-flowing
- velocities 10-100's m/day
- preferential flow via OFG

High mass fluxes
- water
- dissolved oxygen
- nitrate



Viability assessment:

1. Technical performance
   - hydraulic efficiency & denitrifying capacity
2. Any adverse effects (pollution-swapping phenomena)?
   - DOC export; arsenic release
   - GHG emissions
3. Pragmatism; cost-effectiveness

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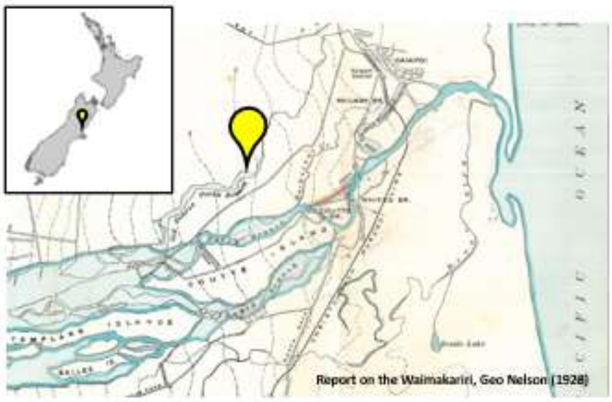
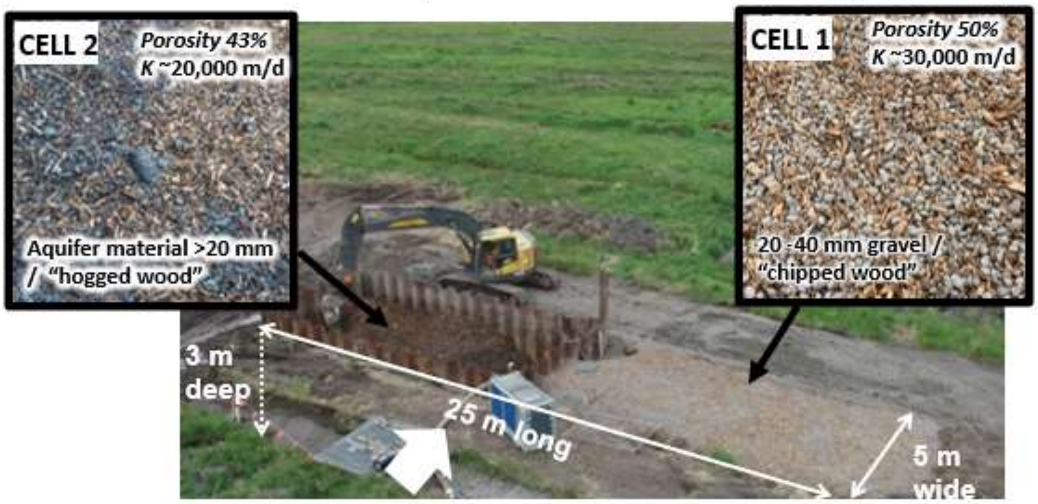
Study site: Silverstream, North Canterbury



- Old North Branch Waimakariri River
- Unconfined gravel aquifer ~5 m thick
- Water table within 0.5 m ground level
- Groundwater nitrate 6–7 mg/L NO_3-N

Wall construction (7th -14th Nov 2018)



- Excavation shored & dewatered = expensive
- 3 m deep; partially penetrates aquifer
- Initially, K_{wall} ~ 10 x $K_{aquifer}$; induced ~15% more flow
- 152-230 m³ water/day; 340-588 kg N/year

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Wall construction (7th -14th Nov 2018)

Specific discharge, q = 2.6 m/d
100 x flow at Long Point, Canada
12 x flow at Hautapu, Waikato

- Excavation shored & dewatered = expensive
- 3 m deep; partially penetrates aquifer
- Initially, K_{wall} ~ 10 x $K_{aquifer}$; induced ~15% more flow
- 152-230 m³ water/day; 340-588 kg N/year

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Monitoring:

Frequency	# wells	Parameters
Weekly-monthly	9 wells along flowline	**pH, temperature, DO, ORP, EC** **NO_3, NO_2, NH_4, DOC** **alkalinity, SO_4, DRP, Fe, Mn, As**
Quarterly	+13 wells distributed across site	pH, temperature, DO, ORP, EC NO_3, NO_2, NH_4, DOC **dissolved CH_4 & N_2O**
6 months	7 wells transecting woodchip wall	pH, temperature, DO, ORP, EC NO_3, NO_2, NH_4 alkalinity, SO_4, DOC, DRP, Fe, Mn, As **major ions** **DNA in water & biofilm extract** **stygofauna**

- Groundwater level (daily)
- Piezometric survey quarterly
- GHG emission - 12 months

Intro | Methods | Results> N-removal | >> pollution-swapping | >>>hydraulics | Conclusions

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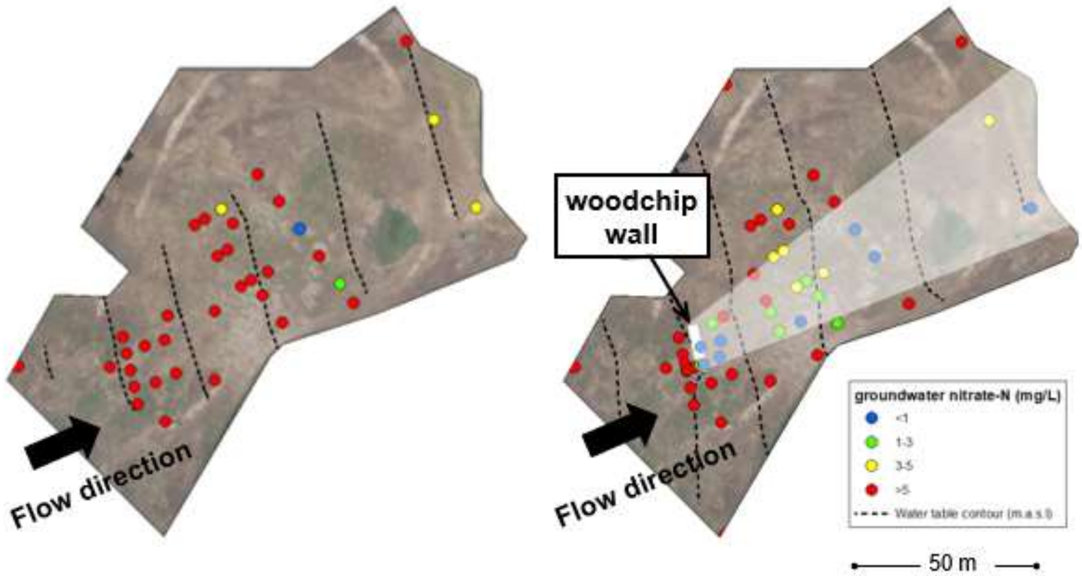
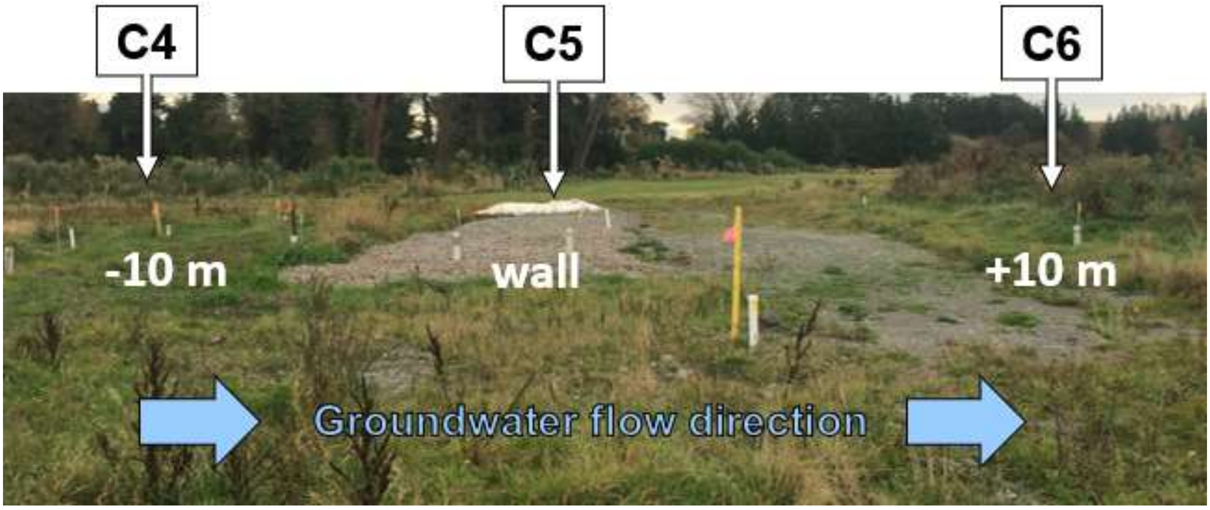
October 2018
Before installation

May 2019
6 months after installation





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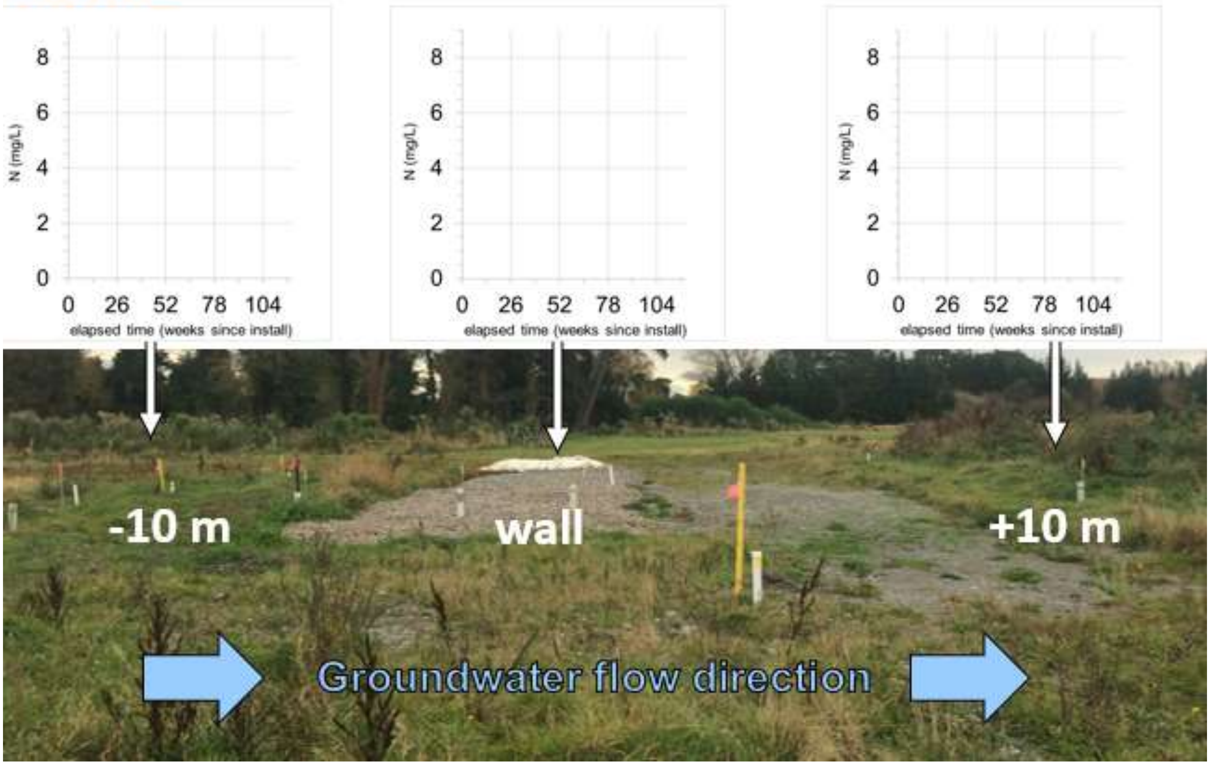
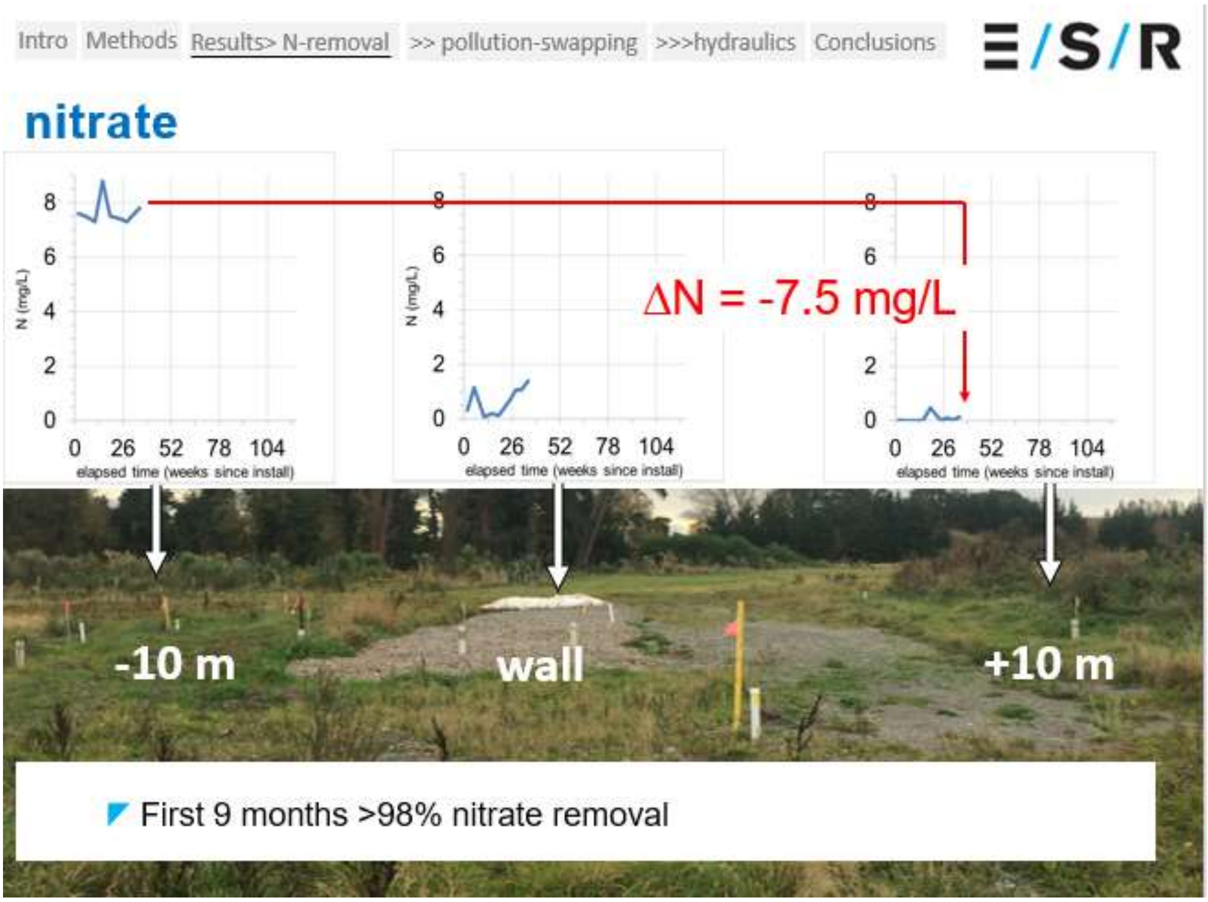
nitrate





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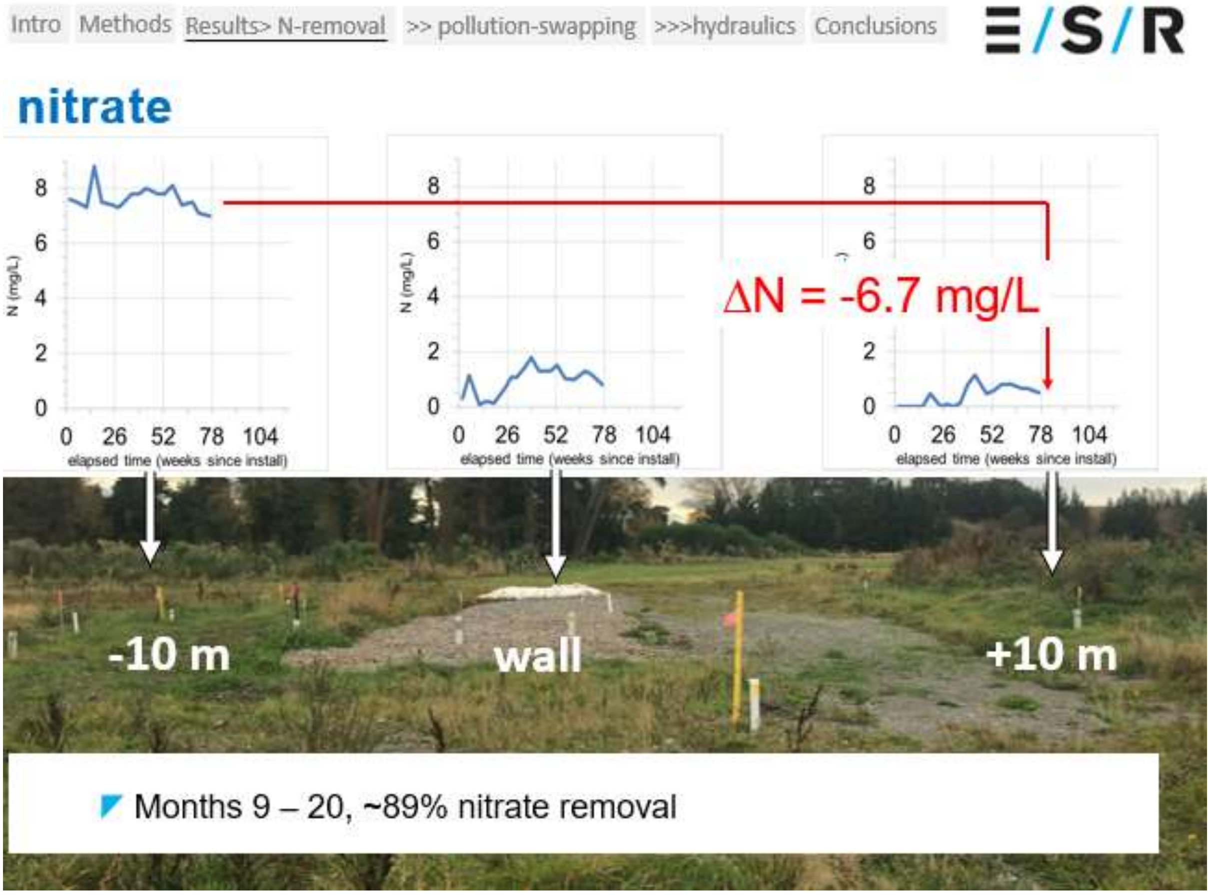
nitrate
N (mg/L)
elapsed time (weeks since install)
0 26 52 78 104
0 2 4 6 8
ΔN = -7.5 mg/L
-10 m
wall
+10 m
First 9 months >98% nitrate removal



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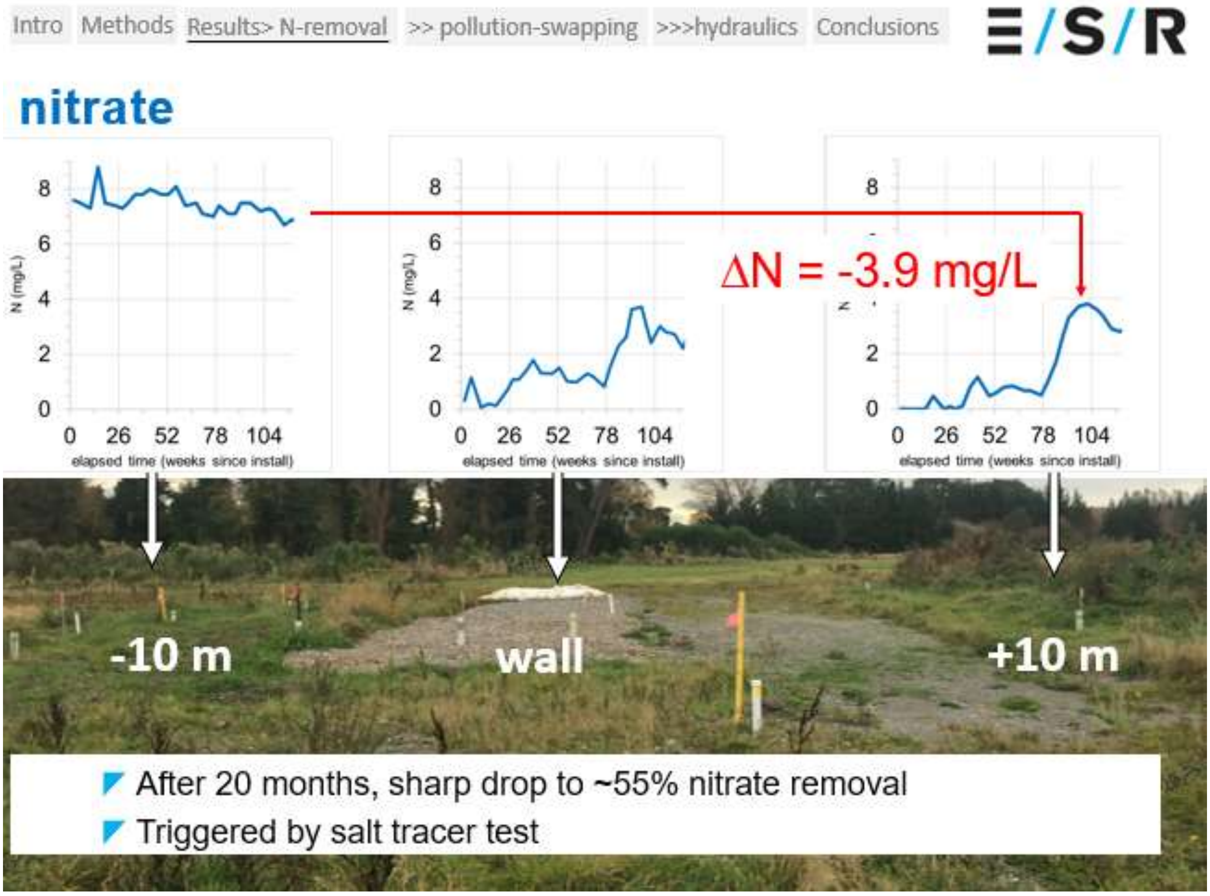
nitrate
N (mg/L)
elapsed time (weeks since install)
0 26 52 78 104
0 2 4 6 8
ΔN = -6.7 mg/L
-10 m
wall
+10 m
Months 9 – 20, ~89% nitrate removal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>>>hydraulics
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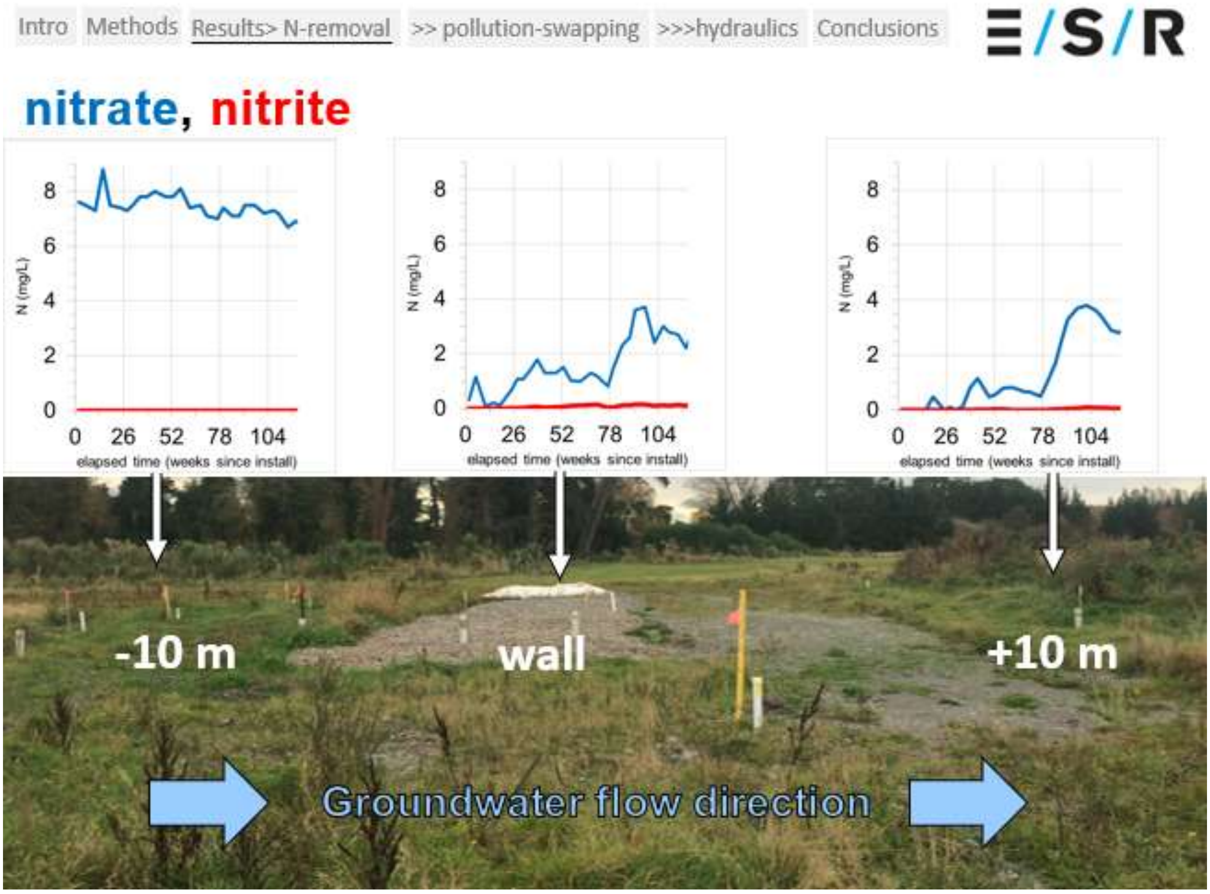
E/S/R
nitrate
N (mg/L)
elapsed time (weeks since install)
0 26 52 78 104
ΔN = -3.9 mg/L
-10 m
wall
+10 m
After 20 months, sharp drop to ~55% nitrate removal
Triggered by salt tracer test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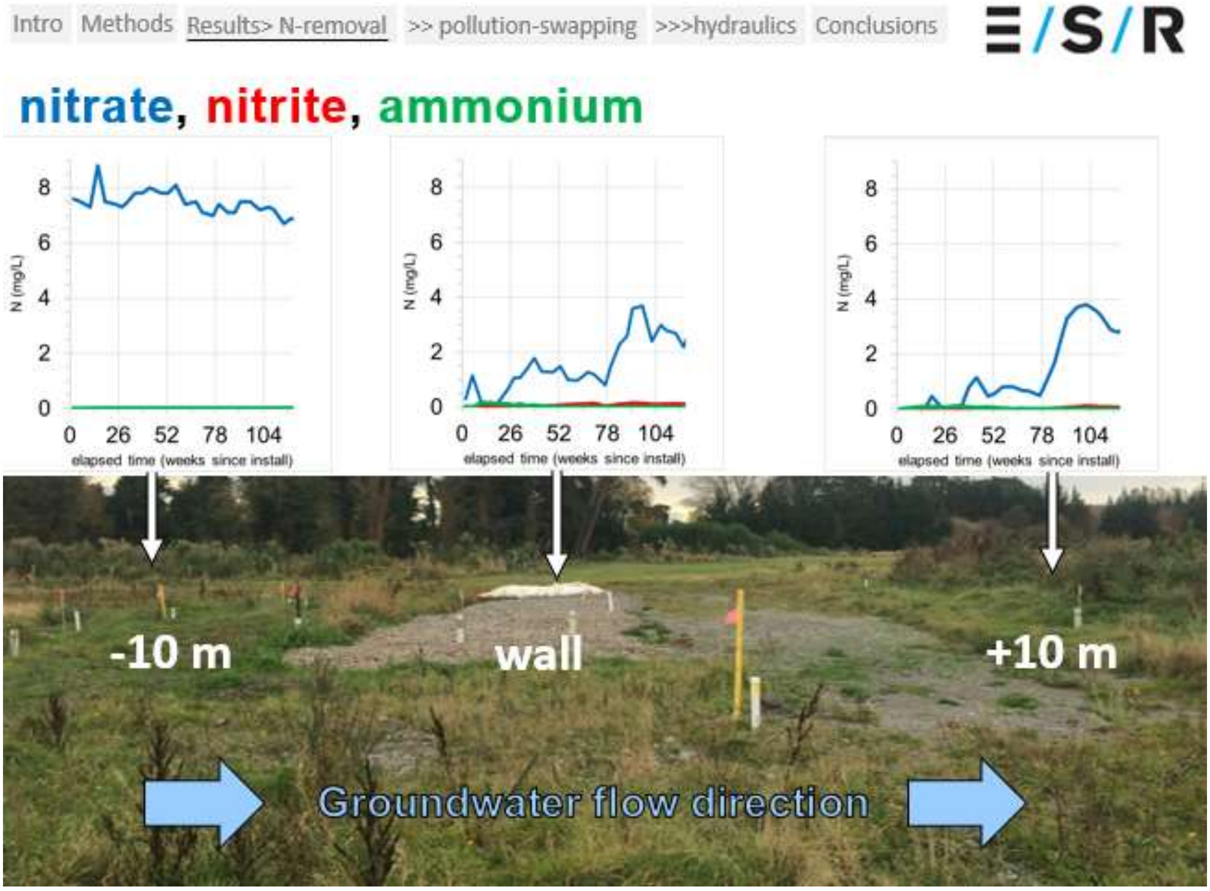
E/S/R
nitrate, nitrite
N (mg/L)
elapsed time (weeks since install)
0 26 52 78 104
-10 m
wall
+10 m
Groundwater flow direction


Intro
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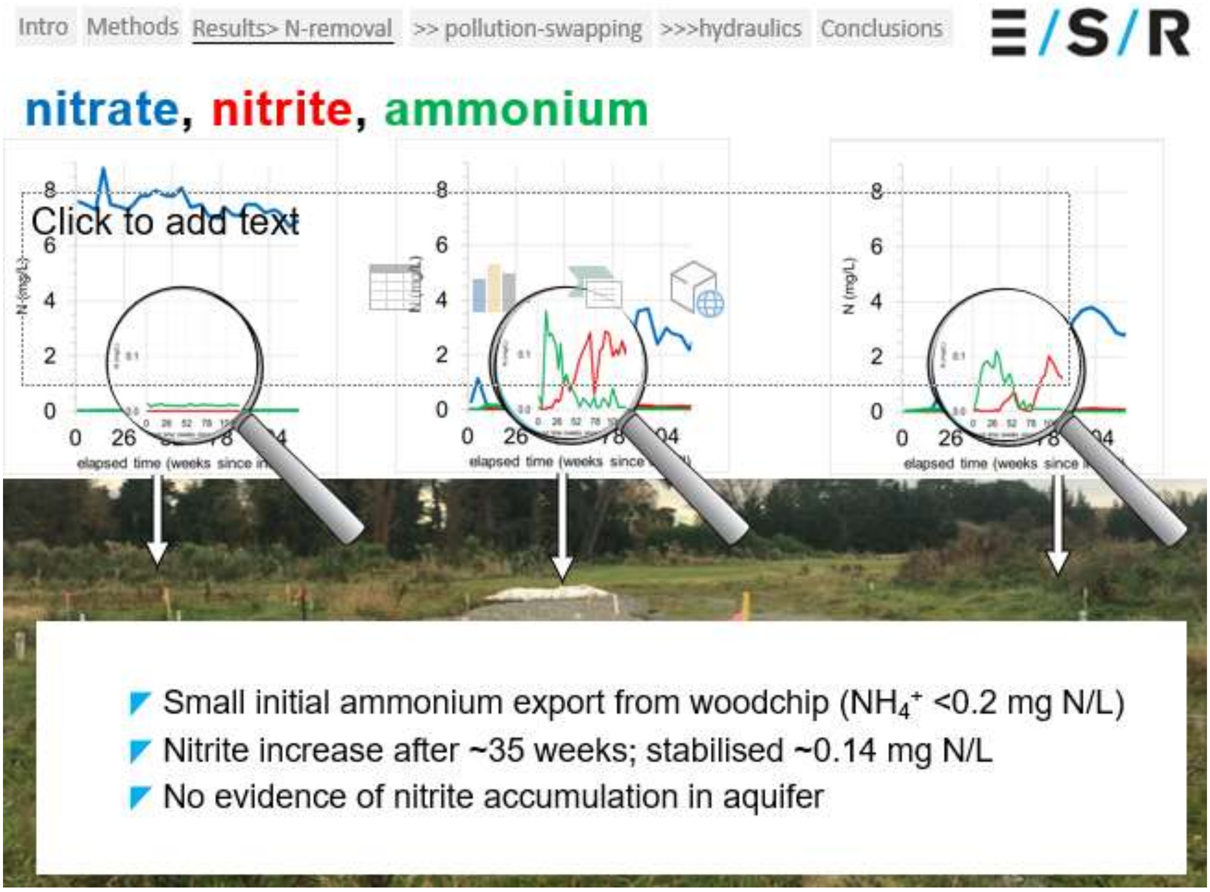
E/S/R
nitrate, nitrite, ammonium
N (mg/L)
8
6
4
2
0
0 26 52 78 104
elapsed time (weeks since install)
-10 m
wall
+10 m
Groundwater flow direction


Intro
Methods
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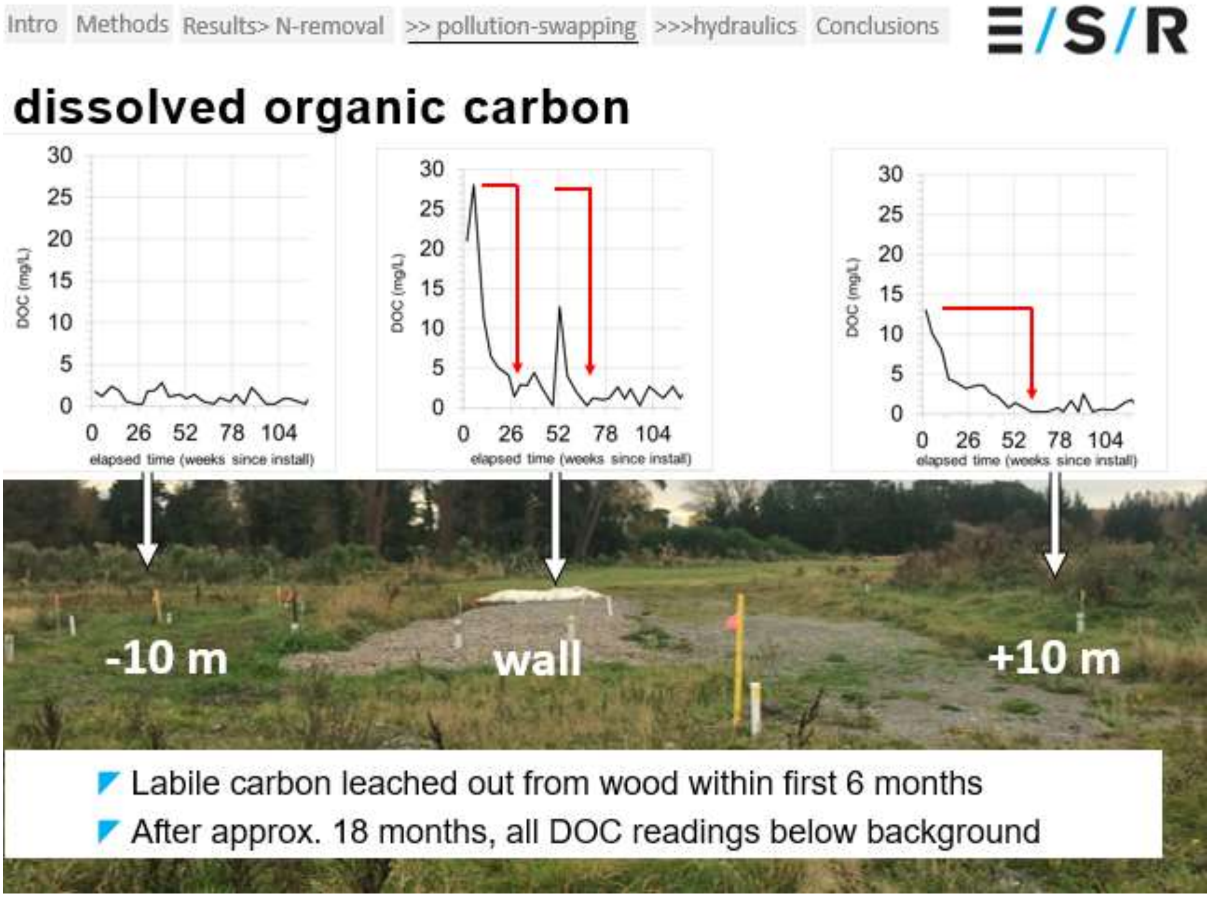
>> pollution-swapping
>>>hydraulics
Conclusions
E/S/R
nitrate, nitrite, ammonium
Click to add text
Small initial ammonium export from woodchip (NH_4^+ <0.2 mg N/L)
Nitrite increase after ~35 weeks; stabilised ~0.14 mg N/L
No evidence of nitrite accumulation in aquifer


Intro
Methods
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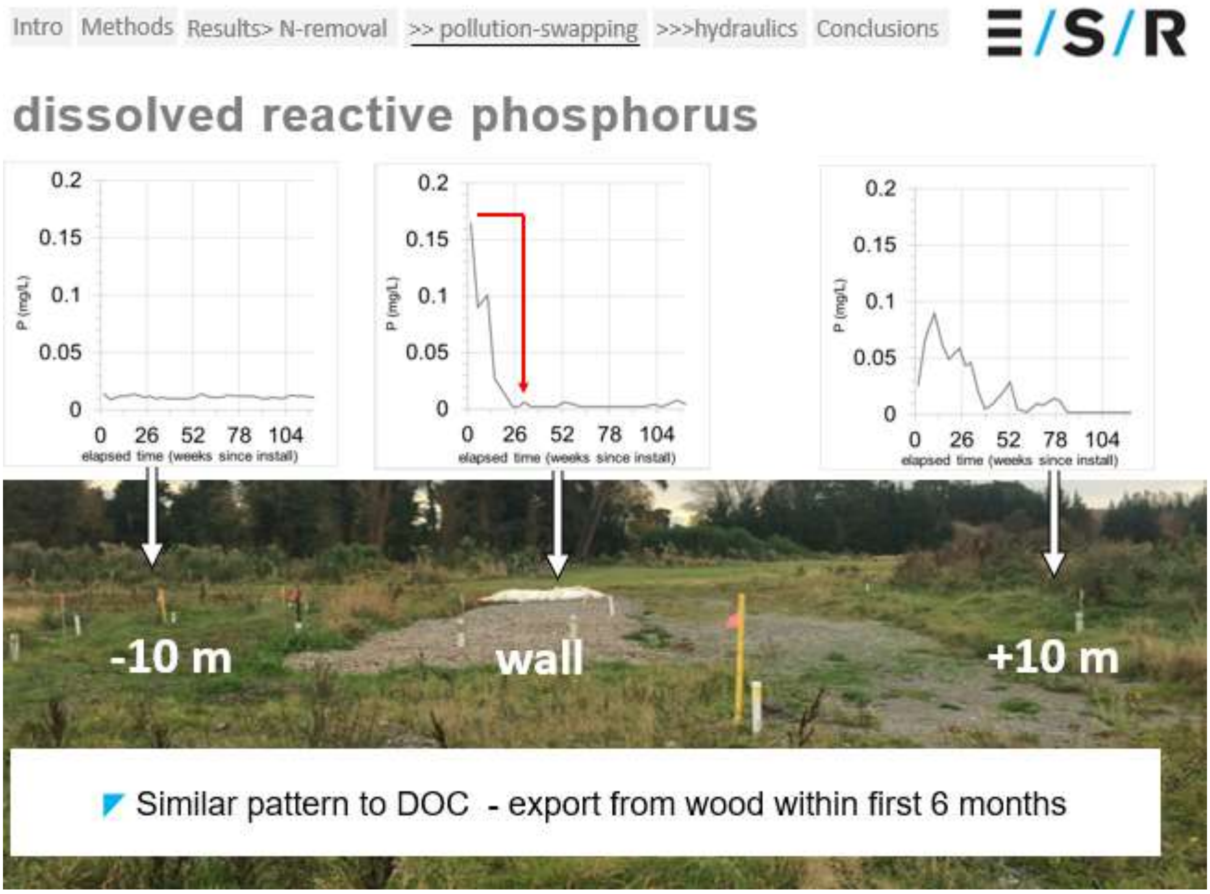
>>>hydraulics
Conclusions
E/S/R
dissolved organic carbon
DOC (mg/L)
elapsed time (weeks since install)
-10 m
wall
+10 m
Labile carbon leached out from wood within first 6 months
After approx. 18 months, all DOC readings below background


Intro
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>> pollution-swapping
>>>hydraulics
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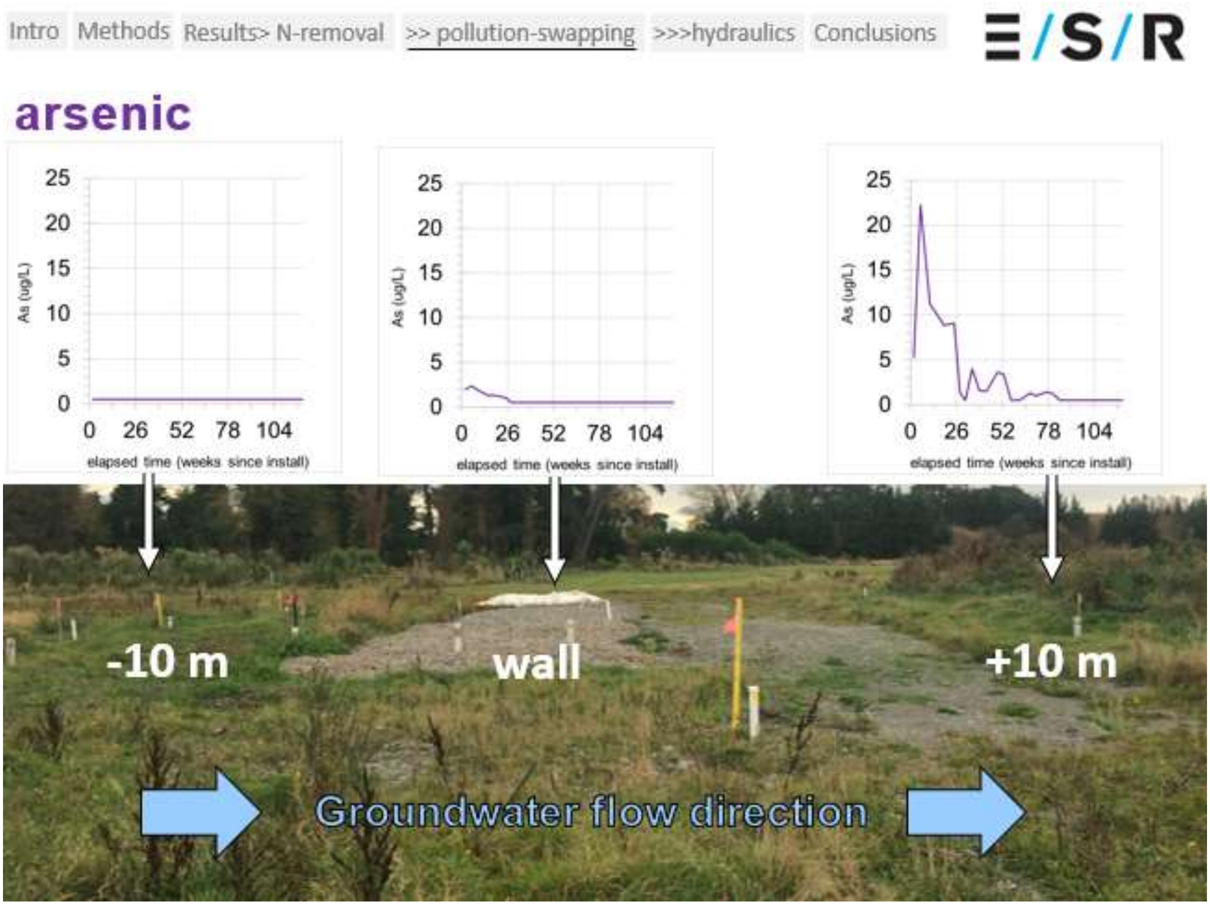
E/S/R
dissolved reactive phosphorus
P (mg/L)
elapsed time (weeks since install)
-10 m
wall
+10 m
Similar pattern to DOC - export from wood within first 6 months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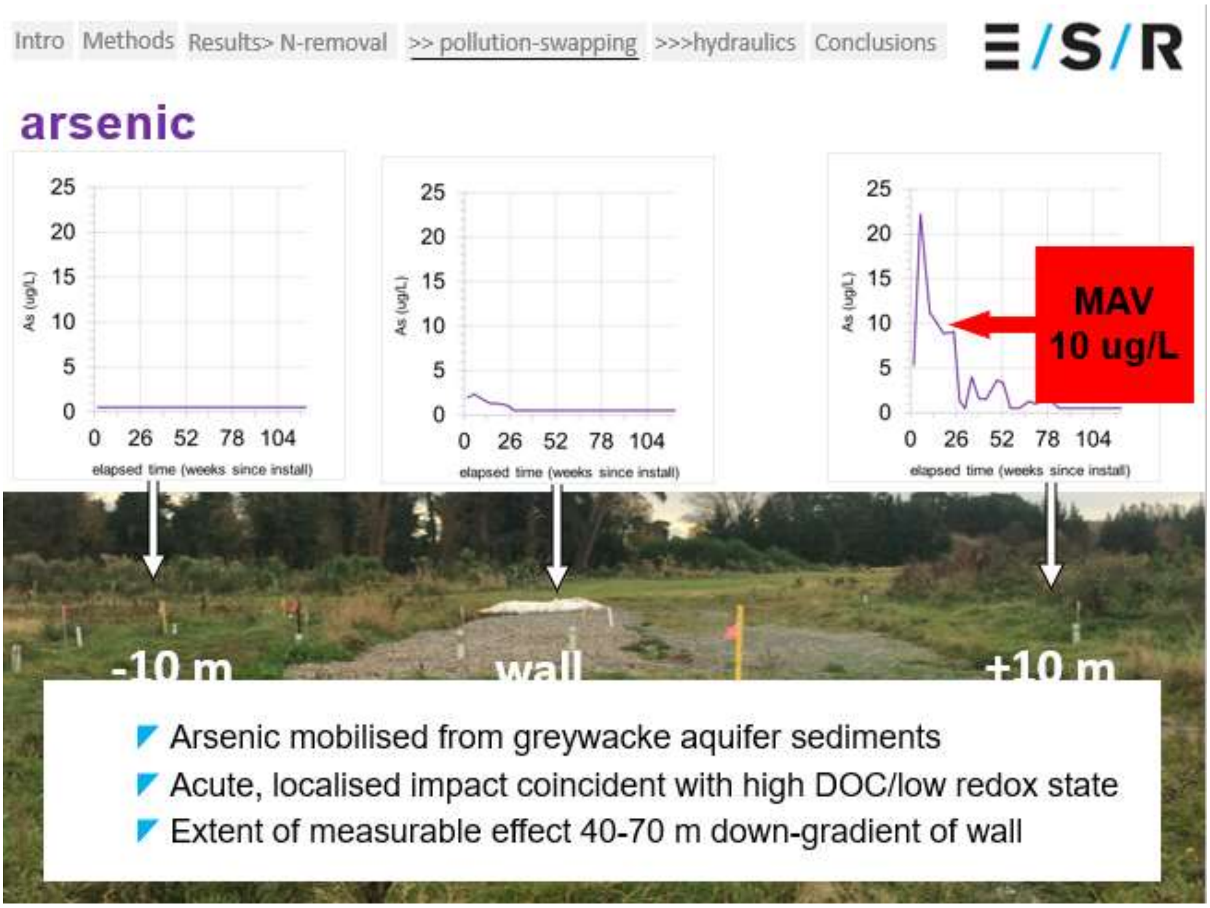
>> pollution-swapping
>>>hydraulics
Conclusions
arsenic
As (ug/L)
25
20
15
10
5
0
0 26 52 78 104
elapsed time (weeks since install)
-10 m
wall
+10 m
Groundwater flow direction


Intro
Methods
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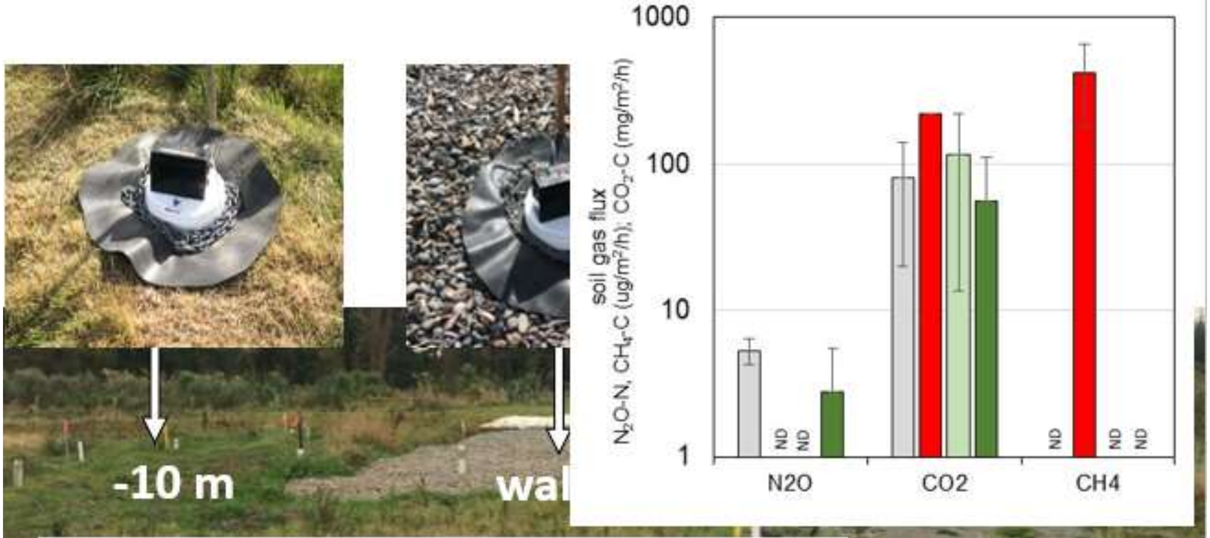
>> pollution-swapping
>>>hydraulics
Conclusions
arsenic
As (ug/L)
25
20
15
10
5
0
0 26 52 78 104
elapsed time (weeks since install)
MAV
10 ug/L
-10 m
wall
+10 m
Arsenic mobilised from greywacke aquifer sediments
Acute, localised impact coincident with high DOC/low redox state
Extent of measurable effect 40-70 m down-gradient of wall

Greenhouse gas emissions



- Denitrification wall emits less N_2O than pasture
- Positive CH_4 flux – not significant

Hydraulic efficiency declined since install

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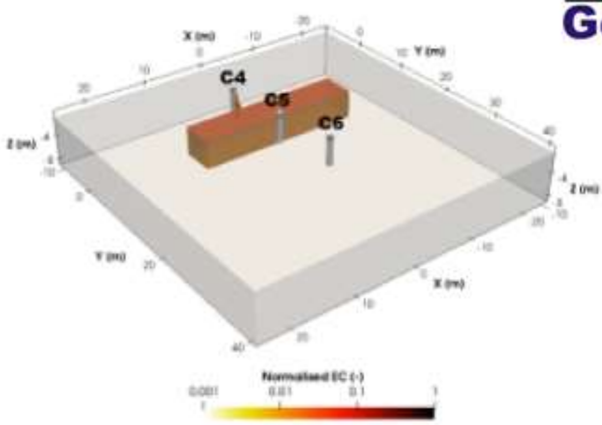

- Saline tracer tests with time-lapse ERT show clogging effect
- Evaluation of mass fluxes through wall = work in progress
- Nitrate removal efficiencies t.b.c.

E/S/R

Summary & Conclusions

1) Woodchip denitrifying walls proven concept for gravel aquifers
2) Use of sheet-piling in construction is costly – alternative methods being explored
3) Woodchip wall highly effective at reducing nitrate for about 18 months
4) Subsequent drop in nitrate-reduction efficiency can be attributed to experimental artefact (salt)
5) Acute pollution-swapping phenomena (DOC & P-export; As-leaching) are a real hazard
6) No evidence of significant GHG-production
7) Some clogging effect inferred from hydro-geophysical tests
8) Quantification of what drop in hydraulic efficiency translates to in terms of N-mass removal is a work in progress

Thank you

lee.burbery@esr.cri.nz


Silverstream Reserve denitrification wall, May 2019

E/S/R Lancaster University Università degli Studi di Padova Southern Geophysical Ltd

USING PLANT UPTAKE TO DETERMINE CUT & CARRY WASTWATER-NITROGEN LOADING RATE

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[B] Corresponding author email: selvarajah@enviroknowledge.co.nz

ABSTRACT

It is well known among the wastewater treatment professionals that the cut and carry systems are the best land treatment systems and arguably the best wastewater treatment systems to treat most wastewaters under conducive and well managed environments with little or no nitrate leaching and impacts on water quality. However, most such systems require discharge permits under the Resource Management Act (RMA) from the regional councils. One of the critical factors encountered in the consent application, consent process and compliance performance management is the determination of suitable wastewater-nitrogen loading and estimating potentially leachable nitrate.

In the absence of specific wastewater loading models to determine wastewater-N loading, there has been an emerging practice among the RMA practitioners of using nutrient models such as Overseer for the purpose. At the last NZ Land Treatment Collective conference (2019) I presented a paper in discouraging the use of unvalidated nutrient models such as Overseer for consenting or compliance monitoring wastewater discharge to land and proposed the use of plant uptake of wastewater-N as an alternative approach.

This technical paper assesses the feasibility of using plant uptake of nitrogen as a critical factor to determine wastewater-N loading rate for wastewater discharge consenting and compliance performance monitoring purposes.

Keywords: wastewater, plant uptake, wastewater-nitrogen, cut & carry, nitrogen leaching, discharge permit

Plant Nitrogen To Manage Cut & Carry Land Treatment System Effectively

Selva Selvarajah
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Cut & carry land treatment systems

- Well managed cut & carry wastewater irrigation systems are the best LTSs and arguably better than many sophisticated wastewater treatment systems to treat small to medium scale wastewater discharges
- However, wastewater-N loading rate and N leaching estimate may be required to apply, grant or monitor consents
- Technically defensible models can be used for the above purpose
- In my 2019 LTC conference paper I discouraged the use of models which were not fit for purpose
- In the absence of credible models, I proposed the use of plant-N uptake to determine wastewater-N loading and to minimise nitrate leaching
- This paper considers the above concept

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Key processes affecting wastewater-N transformations in cut & carry system

- The past 100 years of research mainly in the context of productive system has recognised ammonia volatilisation, N-immobilisation & mineralisation, nitrification, denitrification, N leaching, plant-N uptake and biological N fixation (BNF) as key N transformations
- Of the above plant-N uptake followed by N-immobilisation & mineralisation are significant N fluxes
- Owing to laborious ^{15}N stable isotope techniques, N-immobilisation has been studied seldom and understood poorly hence beyond the use of models such as Overseer
- Whilst N-mineralisation has been studied extensively, since it has been linked intricately with N-immobilisation it has been poorly understood with no universal method to monitor

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Key processes affecting wastewater-N transformations in cut & carry system

- In 1987 at Lincoln University ten widely used N-mineralisation methods were studied using 295 Canterbury cropping surface soils and 7-day anaerobically mineralizable-N and boiling KCl-hydrolysable-N were recommended as most reliable methods (Selvarajah et al. 1987)
- Since then, the 7-day anaerobically mineralizable-N has been used extensively but accurate quantitative prediction of mineralizable-N for a growing season has not been possible
- With the limited wastewater-N transformation studies in soil, plant-N uptake and immobilisation have also been recognised as significant N fluxes

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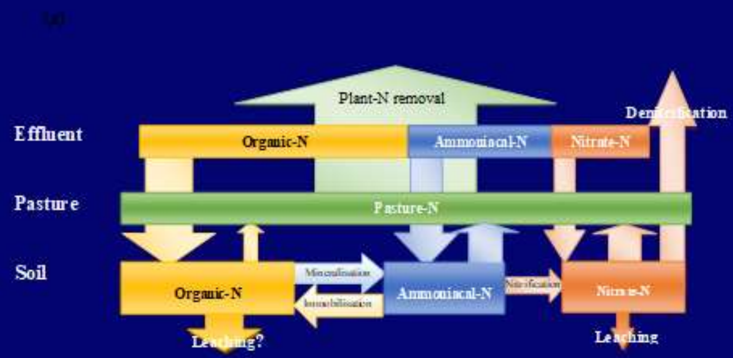
Diagrammatic representation of N fluxes in the cut & carry system (Selvarajah, 2019)



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Plant-N yield/removal is easy to monitor, and it integrates other factors

- In the context of this paper, 'plant-N removal' is a better terminology than 'plant-N uptake'
- Plant-N removal can be estimated from dry matter (DM) x total-N, where DM can be monitored by direct methods such as the use of quadrats
- Indirect methods such as rising plate meter (RPM), C-Dax meter (CDM) attached to a vehicle, calibrated eye visual methods, satellite methods or drone methods are not accurate
- Except for seasonal effects, plant-N removal is a product of:
  - Soil moisture levels
  - Soil structure and porosity
  - Soil and plant nutrient status including micronutrients of soil
  - Soil pH
  - Frequency and timing of plant harvest
  - Soil toxicity or anaerobiosis by contaminant accumulation (e.g., heavy metals) and/or heavy BOD loading
  - Plant type and variety/hybrid
  - Plant population density

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The relationship between DM and herbage-N

- It is crucial to understand DM and herbage-N are not related linearly
- Increasing DM may result in low herbage-N%
- When the above phenomenon was studied under non-limiting N and soil moisture conditions a reduction in herbage-N% was observed as DM yield accumulated for vegetative crops (Mills et al. 2009)
- Thus, for effective N removal from soil, the combined performance of DM and herbage-N% is critical, ideally high herbage-N% scenarios
- For example, 8 t DM with 4.5% herbage-N would have removed similar N (i.e., 360 kg N) as 12 t DM with 3% herbage-N.

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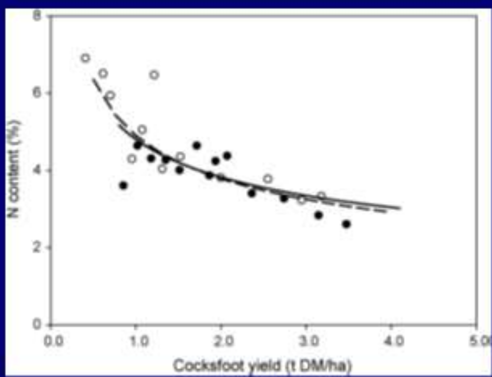
N dilution curve for cocksfoot under unlimited N and soil moisture from Mills et al. (2009) (● 2003/2004 trial ○ 2004/2005 trial) (Solid line from Lemaire et al. 1989)



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Plant type is a critical factor affecting plant-N removal

- The selection of plant type in a cut & carry system need not necessarily be based on herbage-N% and can also be based on the following factors:
  - Ease of management
  - Compatible with specific situation (e.g., high soil moisture or high sodium tolerant)
  - High financial returns (high monetary value of the harvested product or profitability)
  - Deep rooted to reduce N leaching and resilient to unplanned soil moisture deficits (e.g., lucerne)
  - Nutritious or environmental benefits (e.g., plantain can improve milk solid production whilst reducing N leaching and GHGs)
- Plant-N removal potential can be derived from the literature
- N removal potential varies between plant types and within plant type between cultivars

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Annual plant-N removal potential for selected plants under optimal conditions (i.e., trials held under irrigation and with N fertiliser applications)

(some Herbage N% derived from crude protein values converted to total-N)

Plant	Potential annual DM yield (tonne/ha)	Herbage N%	Annual plant-N-removal potential	Product Use	Reference
Lucerne ('Grassland Kaituna') (*Medicago sativa*)	17-28	4.6%	780-1280	Hay/silage	Brown and Moot (2004)
Red clover ('Grassland Pawera) (*Trifolium pratense*)	13-20	4%	520-800	Hay/silage	Brown and Moot (2004)
Chicory ('Grassland Puna) (*Cichorium intybus*)	13-20	2.8%	360-560	Hay/silage	Brown and Moot (2004)
Cocksfoot ('Grassland Wana') (*Dactylis glomerata*)	22	2.7-3.4%	590-750	Hay/silage	Mills et al. (2006)
Maize (Hybrid CF1) (*Zea mays*)	20	1.1-1.2%	220-240	Silage	Villaver, 1996
Plantain ('Ceres Tonic') (*Plantago lanceolata*)	16-20	3% (derived from young stem & leaf)	480-600	Hay/silage	Lee et al. 2015

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Principles in setting cut & carry wastewater-N loading based on plant-N removal

- A large proportion of the wastewater-N is removed by plant-N export
- Wastewater-N loading < plant-N removal potential
- Long-term wastewater-N soil accumulation and any future N mineralisation cannot be ignored
- Owing to less-than-ideal conditions experienced in cut & carry treatment systems compared to fertiliser-based field trials, lower range of plant-N removal potentials can be used
- To be further conservative, 75% of the lower range plant-N removal can be set as wastewater-N loading despite some gaseous-N losses
- This means, if red clover annual plant-N removal range is 520-800 kg N/ha, wastewater-N loading of 390 kg N/ha can be considered based on 75% of the lower range of plant-N removal potential of 520 kg N/ha.

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Other matters for consideration

- Setting annual wastewater-N loading alone is not sufficient to minimise N leaching unless the N leaching limit is defined and monitored, which is problematic
- The alternative is to set plant-N removal trigger or target level
- In a cut & carry system it is unreasonable to set plant-N removal limit at wastewater-N loading limit because of N wastewater-N losses via gaseous-N and minor N leaching
- Thus conservatively 75% of the annual wastewater-N can be set as plant-N removal trigger
- Owing to seasonal variations, the plant-N uptake trigger can be estimated based on a 3-year rolling average, which will also promote adaptive management to optimise plant uptake
- Because of not monitoring N leaching, groundwater quality must be monitored for N upgradient and downgradient of the system (i.e., piezometers or bores)

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Conclusions & Recommendations
In the absence of fit for purpose models, plant-N removal potentials based on agronomic field trials can be used to set wastewater-N loading limits for cut & carry wastewater irrigation systems
To minimise N leaching, annual plant-N removal trigger (kg N/ha) based on 3-year rolling average can be set
The above approach will promote conducive management practices towards high plant/crop performance and adaptive management to correct poor plant performance regularly
Plant-N removal trigger approach will result in effective cut & carry system management, less N leaching and less onerous consent conditions and monitoring
Regional councils could co-ordinate the collation of technically defensible annual wastewater-N loading rates and plant-N removal triggers based on plant-N removal potentials for a range of cut & carry plants/crops by peer reviewed expert desktop research (e.g., Envirolink)
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FLOOD AND RAINFALL MOBILISATION OF E. COLI AND FAECAL SOURCE TRACKING MARKERS FROM DECOMPOSTING COWPATS – THE IMPLICATIONS FOR WATER QUALITY MONITORING

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ABSTRACT

The intensification of dairy farming on the agricultural landscape in NZ has raised concerns about pollution sources from dairy faecal runoff into waterways. An important step for mitigation of pollution is the identification of the sources of faecal contamination to enable optimal land treatment options.

This study using amplicon-based metagenomic approaches describes the changes in the bacterial community in cowpats monitored over five months of decomposition under field conditions. Mobilised fractions from the cowpat, simulating flood conditions, showed major bacterial community shifts from the anaerobic bacteria that dominate the cow rumen and fresh cowpat, to environmental bacterial groups which dominate the latter stages of decomposition. Over the same time period and field conditions, the bacterial community composition of rainfall runoff from the cowpats was analysed and compared with the communities from the simulated flood conditions. The impacts of the bacterial shifts in the cowpats are discussed in terms of their effects on the faecal indicator *Escherichia coli* used for water quality monitoring and the markers used for faecal source tracking (FST).

The results from these bacterial community analyses will be incorporated into emerging tools that use computational programmes to track sources of faecal contamination such as the Bayesian classifier, SourceTracker.

Keywords: dairy, faecal bacterial persistence, faecal source tracking

ESR photo

Wikimedia

Flood and rainfall mobilisation of *Eschericia coli* and faecal source tracking markers from decomposing cowpats- the implications for water quality monitoring

Megan Devane, Pierre Dupont, David Wood,
Bridget Armstrong, Louise Weaver,
Jenny Webster-Brown, Brent Gilpin
Environmental Science and Research Ltd. (ESR)

Aim:

To investigate the impact of aged sources of faecal contamination on the markers we use for faecal source tracking

Toolbox of Faecal Source Tracking (FST) markers

Faecal indicator bacteria: *Escherichia coli*

Host-specific quantitative Polymerase Chain Reaction qPCR markers

- General faecal marker, GenBac3
- Ruminant, BacR
  (cows , sheep, goats and deer)
- Bovine specific, CowM2

Chemical markers: Faecal sterols n = 10

ESR photos

Faecal Sterols (n = 10)

Each animal type has a similar range of sterols but at different concentrations

Sterol ratio analysis

$$\frac{\text{Coprostanol}}{\text{24-ethylcoprostanol}} = \frac{\text{human sterol}}{\text{cow sterol}}$$

>1.0 indicative of human pollution

<1.0 indicative of pollution from herbivores

Wikimedia cartoons and photos

Faecal Sterols (n = 10)

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Sterol ratio analysis
Coprostanol / 24-ethylcoprostanol

>1.0 indicative of human pollution

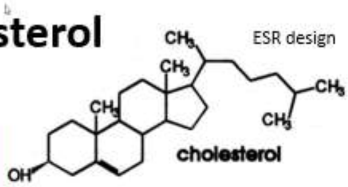
<1.0 indicative of pollution from herbivores

Wikimedia cartoons and ESR photos

Sterols degrade over time

Degradation pathways of sterols in the gut

Cholesterol



Plant sterol
24-ethylcholesterol

Human intestine

Microbial reduction

Ruminant intestine

Major Human sterol
coprostanol

Major Cow sterol
24-ethylcoprostanol

Hypothesised that there would be changes in the bacterial community of decomposing cowpats

Physical changes to the cowpat:

- **water and nutrient loss**
- **encrustation of the cowpat surface**
- **temperature fluctuations**

Decreases in concentration of markers mobilised by flood or rainfall events:

PCR markers

Ruminant:

(cows , sheep, goats and deer)

Cow specific

Faecal indicator: *Escherichia coli*

Faecal sterols

Fresh cowpats and dried out cowpat at 5 ½ months ESR photos

Mobilisable faecal source markers under two conditions

1) Flood simulation = flood runoff

Re-suspend entire (1 kg) cowpat in 2 kg of sterile water.

Stir gently for 10 minutes. Collect supernatant for analysis

2) Rainfall runoff event:

20 mm/hr, representing light rainfall with the formation of <2 mm raindrops at terminal velocity

ESR photos

Three cowpats per treatment per sampling interval

Triplicate cowpats subjected to rainfall, and runoff collected

Sampling regime for mobilised FST markers from cowpats

- 10 sampling events over 5½ months
- Weekly for first four weeks, at the seven week mark, then monthly
- Samples of simulated flood event and rainfall runoff from triplicate cowpats for each condition

analysed for:

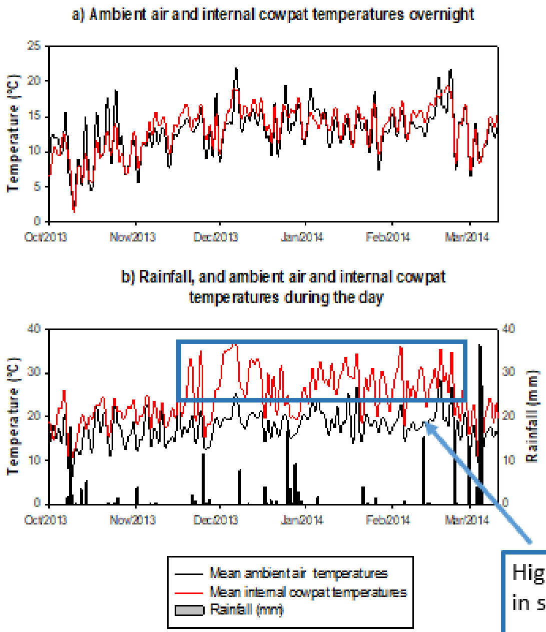
Faecal source markers

Bacterial community :16S rDNA amplicon metagenomic assay

Using the "cake tin" to lay out 1 kg simulated cowpats

ESR photo

Temperatures of internal cowpat (n= 5) and ambient air



Air Temperatures :

Daytime : mean of 18ºC and range of 6 to 28ºC

Overnight : mean of 13ºC and range of 2 to 22ºC

Internal Cowpat Temperatures

Daytime : cowpats had a mean of 24ºC and mean daily range : 9 to 37ºC

Overnight : cowpats had a mean of 13ºC and mean range : 1 to 19ºC.

173 mm Rainfall in few days before last sampling in March

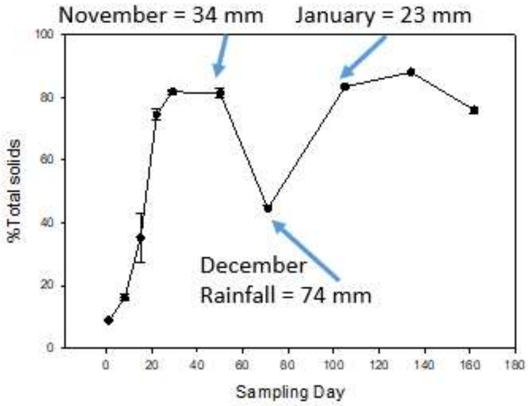
Highest average temperatures within cowpat were recorded in summer, Nov to Feb with temperature ranges of 45-52°C

Moisture fluctuations in the cowpats over time

5 month old cowpat

Day 1 fresh simulated cowpats

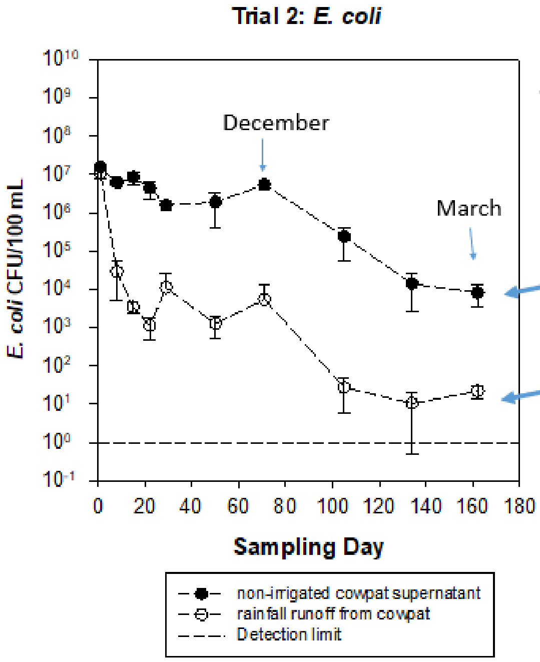
ESR photos



Total solids increased in cowpats as moisture content reduced during summer conditions

Triplicate samples from a single cowpat at each sampling interval

E. coli concentration decreases over time

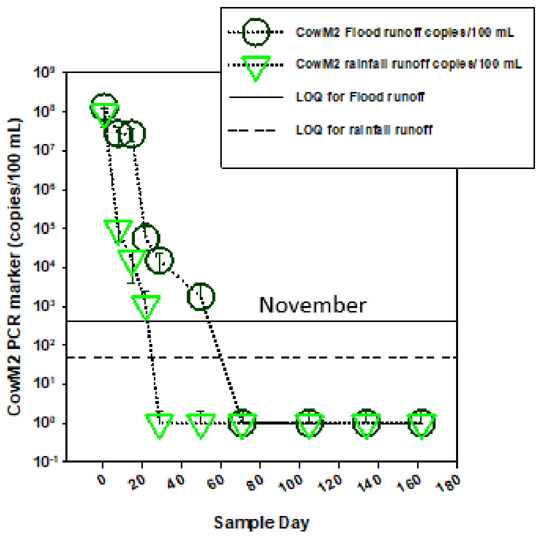


Still a significant reservoir of *E. coli* able to be mobilised from the cowpat over time during a flood event

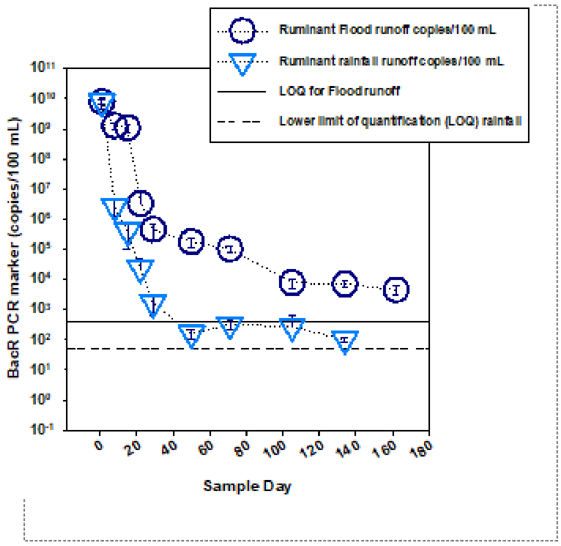
Flood simulation
>10³ CFU/100 mL

Rainfall runoff
<30 CFU/100 mL

Persistence of Faecal source quantitative PCR markers



Cow specific marker disappears after Day 50 in flood runoff and after Day 22 in rainfall runoff

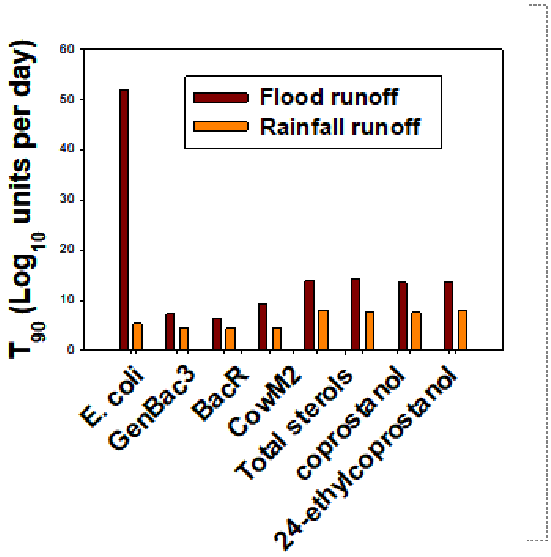


Ruminant Marker is more persistent compared with Cow specific marker CowM2

Mobilisation decline rates of faecal source markers

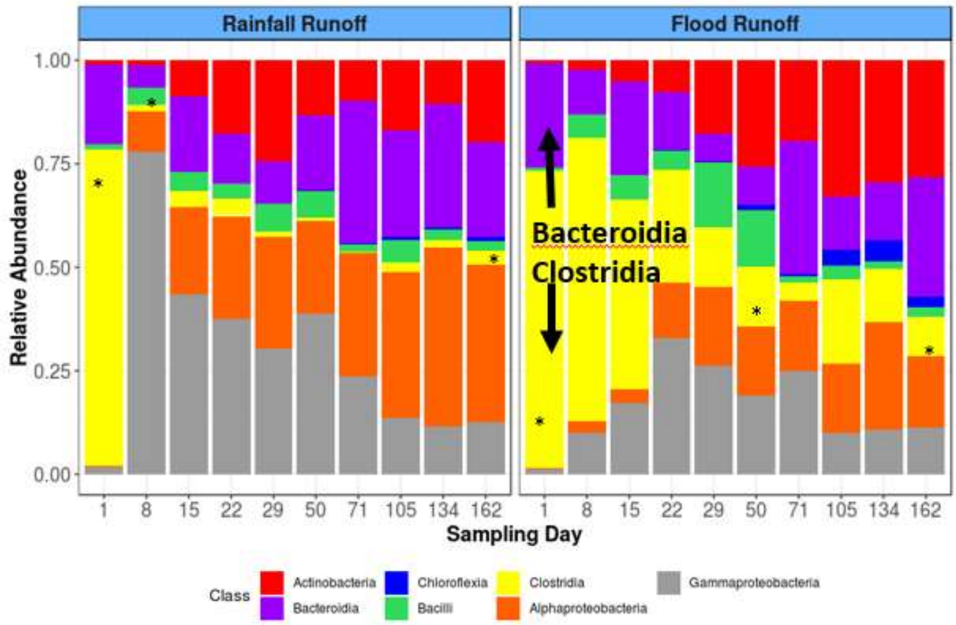
- *E. coli* more persistent in cowpat flood runoff compared with quantitative PCR/DNA markers
- Decline rates for individual sterols such as the bovine indicative 24-ethylcoprostanol were similar between each of the ten sterols.
- Stability between sterols meant that the Faecal sterol BOVINE signature in the cowpat runoff was stable over the six months of field decomposition

T90 values for selected faecal source markers



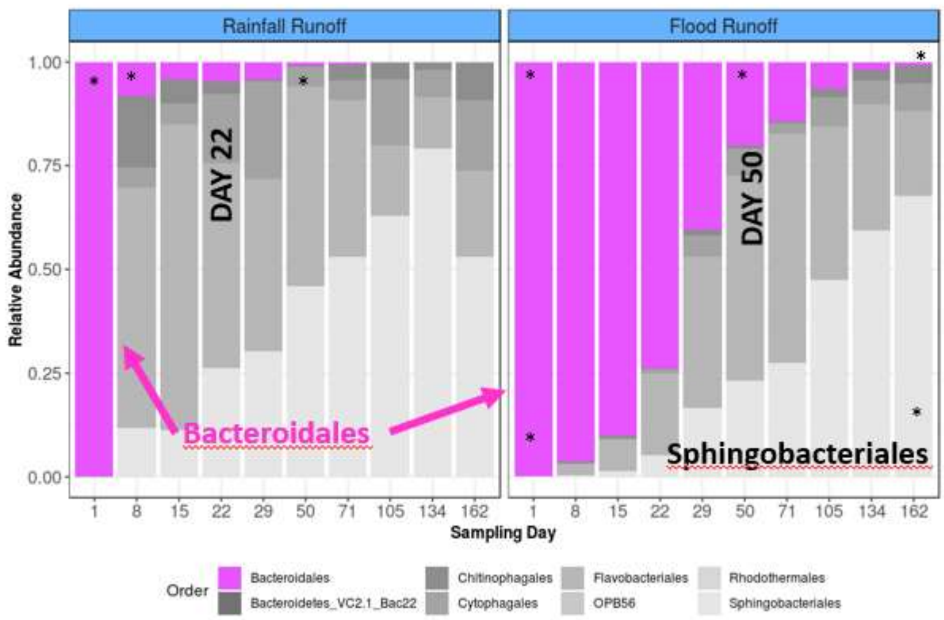
Mobilisation decline rate in Log_{10} units/day;
T_{90} = time (days) taken for one log reduction in concentration

Bacterial community analysis of the Classes of Bacteria in the Rainfall and Flood runoff



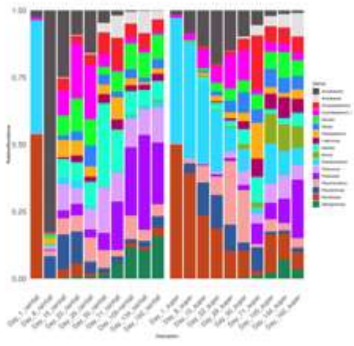
Clostridia and Bacteroidia dominate on Day 1 in both flood and rainfall runoff

Disappearance of the Bacteroidales cow PCR markers as the cowpat decomposes



DAY 22 and DAY 50 when cow-specific marker is no longer detected

Conclusions



Changes occurring in the bacterial community of the cowpat

Shift from bovine faecal bacteria to non-faecal environmental bacteria

There is a **significant reservoir of *E. coli*** available for mobilisation by heavy rainfall from the cowpat months after deposition >10^3 *E. coli* /100 mL in flood runoff

Ruminant marker is less persistent than *E.* *coli*

CowM2 Host-specific PCR marker is useful as an indicator of recent faecal inputs.

Stable Faecal sterol BOVINE signature in cowpat runoff over the six months of cowpat decomposition. Useful for aged sources of bovine contamination, e.g. dairy shed effluent applied to land.

[**Devane et al. (2020)** Bacterial community shifts in decomposing cowpats and the subsequent impacts on fecal source indicators for water quality monitoring. **Ecological Indicators 113.]**

- **MBIE: Ministry of Business Innovation and Employment**
- **University of Canterbury Scholarship**
- **Waterways Centre for Freshwater Management,**
  - **Jenny Webster-Brown (OLW Director)**

Brent Gilpin, Louise Weaver, Pierre Dupont, Bridget Armstrong

David Wood, Susan Lin, Beth Robson,

Phil Abraham, Paula Scholes

Erin McGill, Margaret MacKenzie

CONFOUND IT E. COLI! IMPROVING UNDERSTANDING OF MICROBIAL WATER QUALITY AND PERFORMANCE MONITORING OUTCOMES FOR LAND TREATMENT OF WASTEWATERS USING NATURAL TREATMENT SYSTEMS.

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ABSTRACT

Agricultural runoff and drainage waters can transfer high loads of faecal microbial contaminants to waterways affecting water quality and values. Constructed wetlands are a land-based mitigation option offering great potential to attenuate microbial losses from agricultural land use and reduce diffuse pollution impacts.

However, event sampling from a surface flow constructed wetland intercepting and treating intermittent tile drainage from grazed pasture revealed interesting but unexplained new export of the faecal indicator bacteria *Escherichia coli* (*E. coli*) in treated wastewaters.

Further investigation into the diversity of *E. coli* in water, sediment, soil and faecal material from the constructed wetland and adjacent pasture, found evidence of naturalised cryptic clades of *Escherichia* species phenotypically indistinguishable from faecally-derived *E. coli* but divergent at the genetic level. *E. coli* is routinely used for water quality monitoring to assess the potential health risks from presumed faecal contamination. However, conventional regulatory monitoring methods do not distinguish naturalised non-faecal sourced *Escherichia* from faecal *E. coli*. The presence of an environmental source of *Escherichia* has implications for confounding health-based water quality monitoring and challenges for assessing the performance efficacy of wetland systems for land treatment and water quality improvements.

Further work is underway as part of a bigger project to identify genetic and phenotypic traits to resolve differentiation of naturalised *Escherichia* species and develop novel discriminatory tests for *E. coli* to improve water quality assessments. The discovery that some "*E.coli*-like" strains can persist in the wetland provides new impetus for investigating the maintenance and relative survival and removal of faecal and naturalised strains. This will help to determine the impact of environmental sources of *Escherichia* species on poor water quality and to investigate whether the environmentally-adapted bacteria are diluted with faecal-sourced *E.coli* as waterways pass through farmland.

Keywords: constructed wetlands, E. coli, microbial water quality


Confound it E. coli!
Improving understanding of microbial water quality and performance monitoring outcomes for land treatment of wastewaters using natural treatment systems
Rebecca Stott[1], James Sukias[1],
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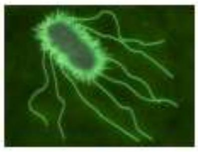
Improving outcomes for land treatment
NZ Land Treatment Collective Conference,
Palmerston north,
4-6 May 2021
NIWA
Taihoro Nukurangi

Constructed wetland treating subsurface drainage from grazed dairy pastures

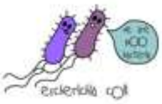
- Toenepi catchment flat to gently rolling, 76% dairy farming, (~3 cows ha^{-1})
- Constructed Wetland (Surface flow)
  - 2 shallow surface-flow cells in series, each ~5m wide x ~26m long , planted with *Typha orientalis*
  - Water depth typically ~30cm (total volume 80-130m^3 per cell)
  - Dries out completely during dry summer periods
  - Receives subsurface drainage water from grazed dairy pasture
  - Discharges into an open (surface) drain

CW: Microbial removal *Escherichia coli*

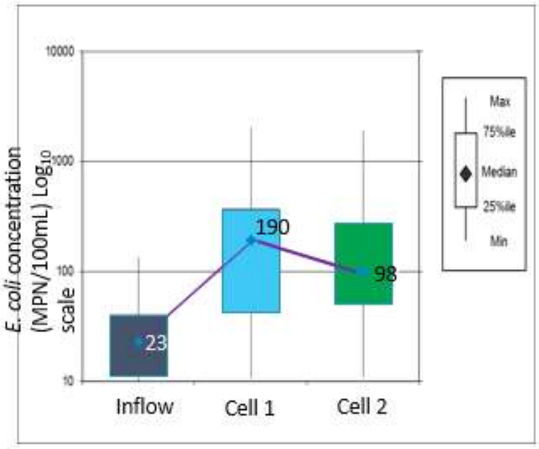


- Periodic monthly sampling over 5 years
- Grab samples Inflow (Cell 1), outflow (Cell 1), final outflow (Cell 2)
- Sampled typically after high flow events and predominantly taken on falling limb of flow events
- Culture based enumeration for E. coli (Colilert)

CW: Microbial removal
Escherichia coli



- Periodic monthly sampling over 5 years
- Grab samples Inflow (Cell 1), outflow (Cell 1), final outflow (Cell 2)
- Sampled typically after high flow events and predominantly taken on falling limb of flow events
- Culture based enumeration (Colilert)
- For relatively low influent concentrations, effluent concentration can sometimes **exceed** influent value
  - Inflow 1-134 *E. coli*/100mL
  - Outflow ~10-2000 *E. coli*/100mL
- Sampling biased towards receding flows
  - Inflow samples biased ***low*** (receding tail of storm events)
  - Outflow *E. coli* biased ***high*** (passage of contaminated plume)



Event-based monitoring

- Sample *E. coli* concentrations, flux (MPN/s) and loads (MPN/event) over rainfall driven flow events using autosamplers
  - Time basis for 3 rainfall events (e.g. ½ or hourly sampling based on expected time of rainfall)
  - Flow basis for 4 rainfall events (changing stage height)

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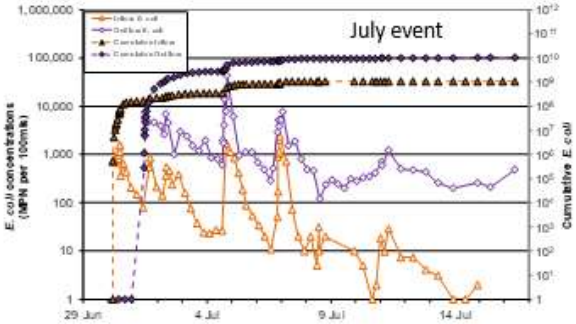
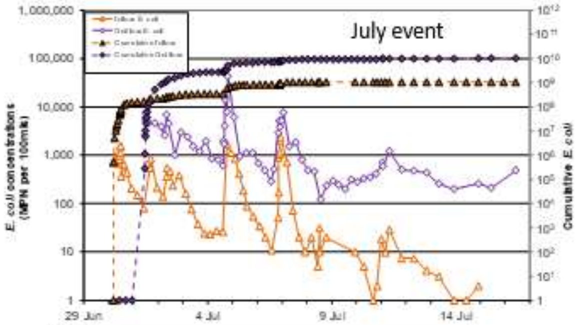
Event-based monitoring

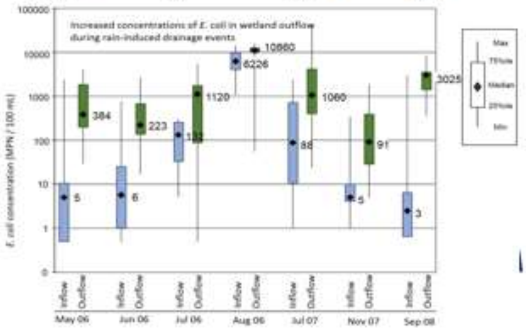
- *E. coli* concentrations consistently higher in final effluent than influent



Event-based monitoring

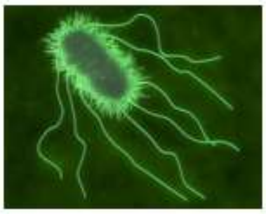
- Similar trends for both time and flow triggered sampling
- Higher concentrations *E. coli* in outflow compared to inflow for all events sampled
- Average *E. coli* concentrations (and yields) **higher on rising limb** of hydrograph for inflow and outflow
- Median *E.coli* concentrations in **outflow typically ~x10 higher than inflow** during rising and falling hydrograph limbs
- *E. coli* net export (MPN/event) ranged **2-34 fold** (typically 14 fold)



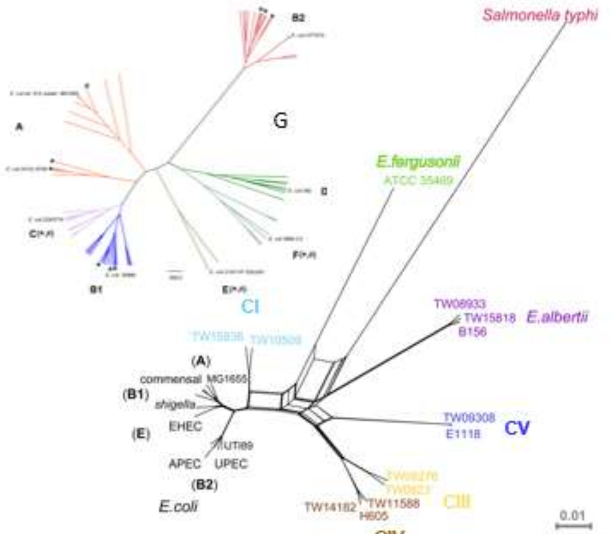


Causes of net *E. coli* export?

- **Mobilisation** of bacteria from CW sediment due to increased flow velocity?
- **Liberation** of accumulated *E.coli* flushed from 'dead zones' by Increased water levels?
- **Wildlife** faecal inputs – eg avian?
- Resuscitation of **VBNC** in effluent?
- Persistence/ growth of **environmentally adapted *E. coli*** types in high carbon environment?



Whole genome phylogeny of *Escherichia coli*



Luo et al., 2011

Molecular genetic profiling of *E. coli*

- *E. coli 'sensu stricto'* separated into 8 phylogroups based on molecular sequence data
- Genome sequencing of environmentally adapted strains
  - Cryptic *Escherichia* clades CI to CV are **genetically distinct but phenotypically 'identical'**
  - CI gut associated & closer affiliation with typical *Escherichia coli strains (now considered as E. coli)*
  - CIII, CIV, CV more divergent from typical *E. coli* strains
- Sampling and genetic analysis suggests CIII, CIV and CV environmentally adapted
  - Form biofilms more readily
  - Outcompete typical *E. coli* strains at low temperature.
  - Negligible health hazard (found very infrequently in human clinical samples)

What is the *E. coli* population diversity in our CW?

- Environmental (naturalised) *Escherichia* clades can be differentiated from 'faecal' strains using
  - whole genome sequence analysis and
  - unique *gnd* sequence types (to establish community diversity)
- Sites of contrasting anthropogenic impact:

  Toenepi constructed wetland,

  Manawatu River catchment; Pūkaha Mount Bruce, Makakahi River, Mangatera Stream Mākirikiri stream,
- Water, sediment, soil, periphyton (biofilm), faeces
- 6 sampling occasions – every 2 month over 1 yr
- *E. coli* enumeration, colony isolation, DNA extraction, PCR (gnd, cryptic clades), WGS

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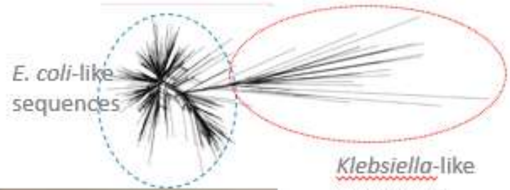
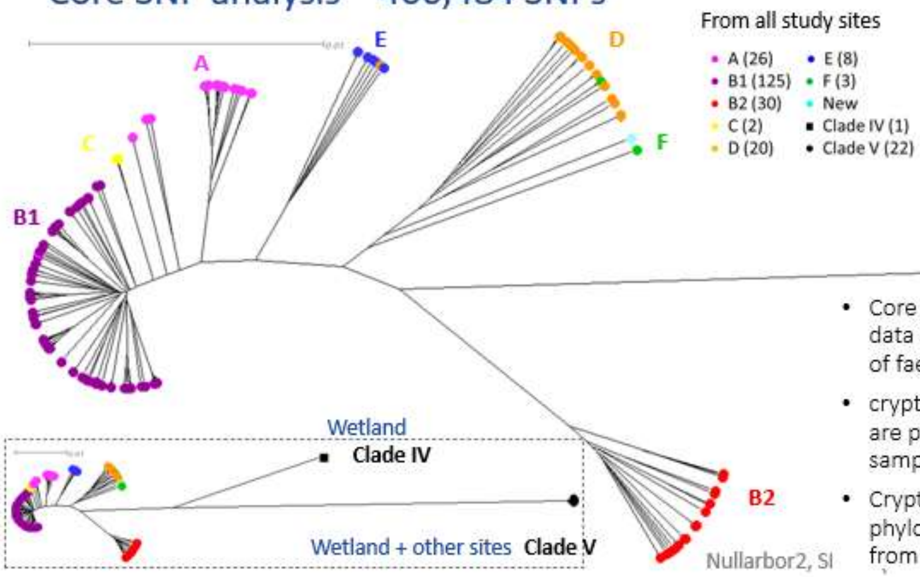


Pūkaha Mt Bruce

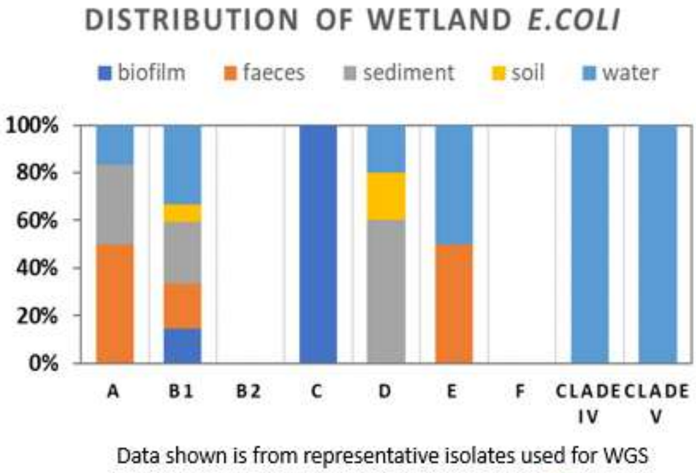
WGS study – 238 isolates total (n=58 isolates from the wetland) Core SNP analysis – 400,484 SNPs



- Core SNP analysis of WGS data shows broad diversity of faecal *E. coli* phylotypes
- cryptic *Escherichia* clades are present from diverse samples and different sites
- Cryptic clades are phylogenetically distinct from *E. coli*

Constructed wetland *E. coli* diversity

- 243 *E. coli* wetland isolates
- Subset of 58 isolates selected for WGS
- 5 *E. coli* phylotypes identified (A, B1, C, D, E)
- Phylotype B1 present in all sample types
- 2 cryptic clades (IV, V)
- Cryptic clades present in water samples only



Data shown is from representative isolates used for WGS

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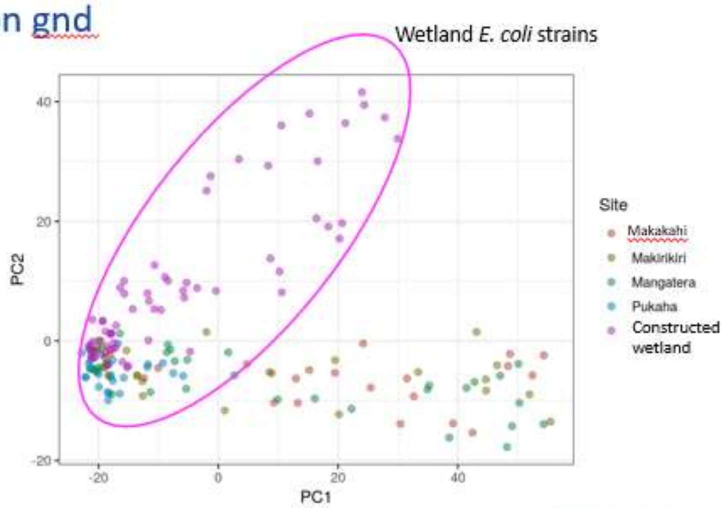
Spatial variation of *Escherichia* populations using PCA on gnd sequence types (gSTs)

- Site and sample type contributed to the most variation in *Escherichia* population
- *Escherichia* population from the wetland differentiated from other sites
- Wetland *Escherichia* population distinct from river/stream sites



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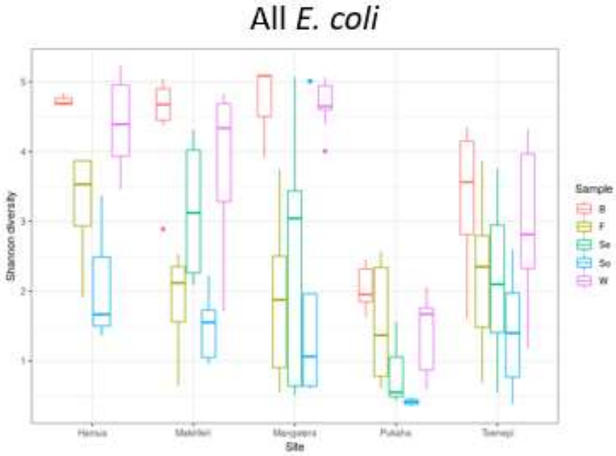
Population diversity using *gnd* amplicon sequence data (gSTs)

- Shannon diversity analysis: contrasting diversity levels between sites
- Different *E. coli* populations associated with different sites
- Mt Bruce has least diverse *E. coli* populations
- Wetland has lower *E. coli* population diversity than surface waters in Manawatu river catchment area
- Water and periphyton samples associated with most diverse *Escherichia* populations



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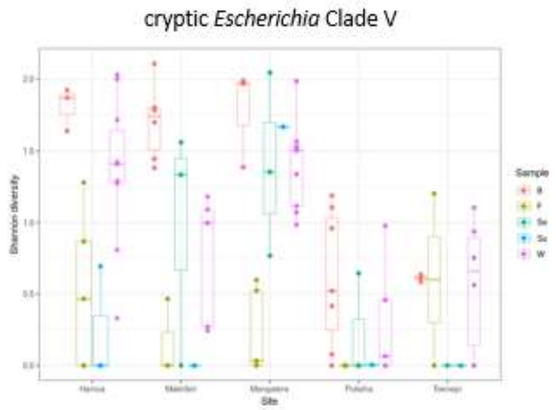
Population diversity using *gnd* amplicon data (gSTs)

- Wetland and Mt Bruce samples have reduced diversity of cryptic clade V positive samples compared to waterways
- Cryptic Clade V most abundant in water and periphyton samples
- Wetland: overall sample prevalence of Clade V positive samples =27.4%
- Mt Bruce = 78.6%



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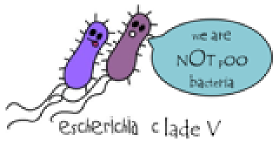
Conclusions: cryptic *Escherichia* clades



- Environmentally adapted *Escherichia* clades (IV, V) found in wetland water samples
  - Other sites: most abundant in water (84.1%) and in periphyton (84.6%) samples
- Functional analysis found cryptic clades possess characteristics potentially advantageous for maintenance and growth in freshwater habitats
- Lack *E.coli* factors associated with intestinal colonisation
- Phylogenetically distinct from other *Escherichia* sp.

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Summary: Constructed Wetland

- In most instances, CW's effective in removing microbial contaminants during episodic events when inflow concentrations moderate-high (>10^3 *E. coli*/100mL),
- Net export of *E. coli* highlights our limited understanding of microbial survival, fate and behaviour in organic rich environments such as wetlands
- Evidence of naturalised cryptic clades of *Escherichia* ("*E.coli*-like" strains) in wetland – persistence and/or growth contributing to "*E. coli*" export
- Implications of environmentally adapted *E. coli*-like strains for interpretation of E. coli based water quality monitoring & health risk downstream from wetland environments.

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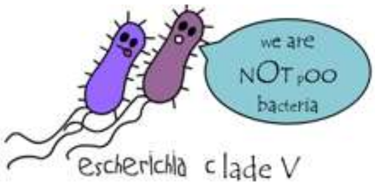
Next Steps



- Investigate differential survival of *Escherichia coli*/"*E.coli*-like" species – understand relative maintenance/removal of faecal and naturalised strains (MBIE-funding)
- Use 3 isolates collected from the Wetland
- water sample clade V,
- bovine faecal sample,
- sediment sample
- **Hyp**: the water and sediment isolates will persist and survive in the constructed wetland for a longer time-period than the faecal isolate.
- provide clues on the apparent role of "*E.coli* – like" strains on microbial water quality and human health assessments.
- Determine impact of environmental sources of *Escherichia* species on performance monitoring outcomes of natural treatment systems e.g. wetlands for land treatment of wastewaters

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Acknowledgements

Toenepi wetland - George Howie
NIWA: John Nagels, Tom Headley, Vernon Bevan, Margaret Bellingham

agresearch ātā mātai, mātai whetū
pukaha MOUNT BRUCE
MANAWATU CITIZEN SCIENCE
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MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT HIKINA WHAKATUTUKI

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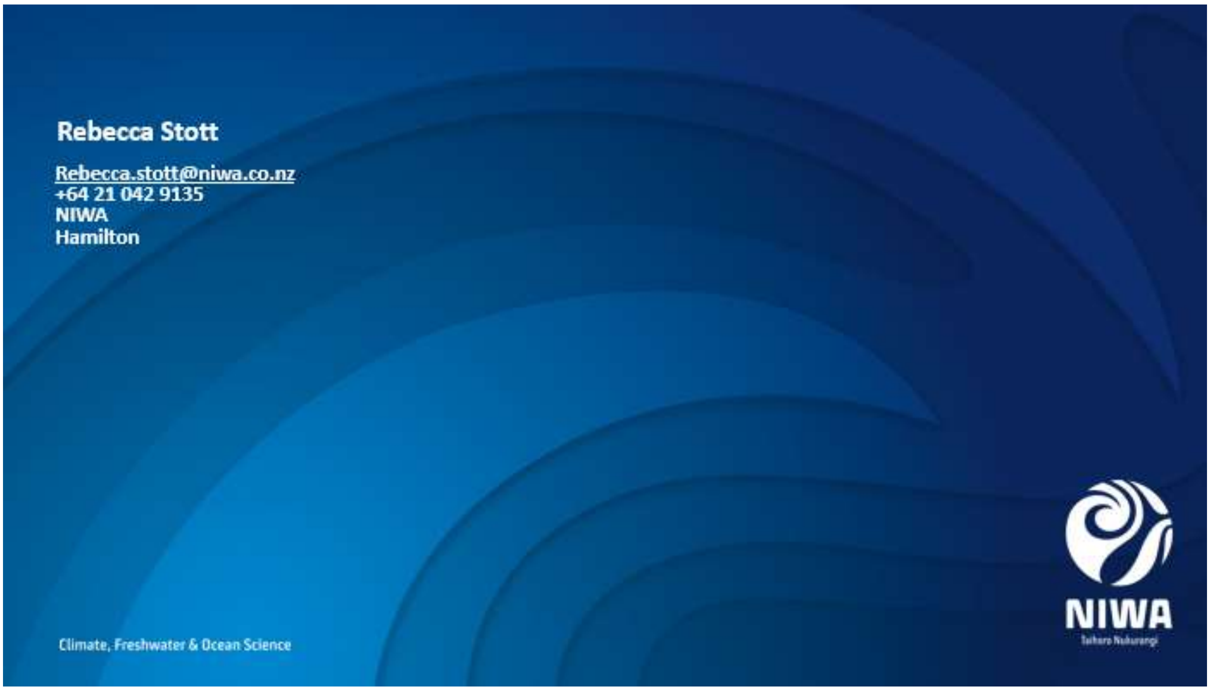
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GEOSPATIAL METHODS FOR THE EFFICIENT IDENTIFICATION OF POTENTIAL LAND TREATMENT SITES

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ABSTRACT

The use of geospatial software for the analysis and presentation of significant amounts of data is an increasingly common method to gain efficiencies on many projects, and the development of land treatment schemes is no exception. A process applying geospatial methods for the preliminary identification of land treatments sites has therefore been developed.

This paper will discuss the methodology applied to identifying potentially viable sites for land treatment schemes with the use of geospatial analysis, and some case studies in which this has been successfully used to identify suitable locations for land treatment schemes.

The methodology described allows for the analysis of several sets of data that govern the feasibility of a land treatment scheme such as soil properties, land coverage, and property ownership. The end result being a spatial Multi Criteria Analysis (MCA) of the desired region that can be customised by implementing and varying weightings applied to the criteria included in the analysis, based on the needs of the project and land treatment scheme.

This methodology has provided significant efficiencies on multiple projects, particularly those that involve large land treatment schemes and large areas of potential land, including areas located far from the site or across multiple locations.

Keywords: Geospatial, Multi Criteria Analysis, Efficiency, Preliminary, Location

NEW ZEALAND LAND TREATMENT COLLECTIVE CONFERENCE - 2021

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GEOSPATIAL METHODS FOR THE EFFICIENT IDENTIFICATION OF POTENTIAL LAND TREATMENT SITES

PRESENTED BY
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Presentation Overview

2

- Background to the problem
- Refresher on Multi Criteria Analysis (MCA)
- Explanation of the Geospatial MCA methodology
- Example Project 1
- Example Project 2
- Example Project 3
- Conclusions

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Background

- Lots of drivers for discharges to go to land
- Requirement for robust Best Practicable Option (BPO) assessment

Assessment radius of 10 km > 30,000 ha assessment area

- Thousands of properties in assessment area
- Some schemes require > 1,000 ha irrigable area

There is a requirement for an efficient way to perform a robust desktop assessment of land treatment feasibility

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MCA Refresher

- Robust selection tool
- Score options based on set criteria and requirements
- Scoring criteria can be weighted depending on perceived importance
- Scoring and weighting dependant on personal opinion
- Can be as simple or complex as the user/problem requires

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Geospatial MCA Methodology

- A tool to analyse many large data sets and produce a useful output
- Steps
  - Identify required assessment criteria
  - Collect geospatial data into project data base
  - Set scoring criteria and weightings

Geospatial MCA Methodology

- Automated data analysis and scoring
- MS Excel (or other) data handling allows changes to be made easily
- Manual scoring or fatal flaws can be incorporated if required

	Usable Drainage Areas (m2)				
Parcel ID	Moderately well drained	Poorly drained	Well drained	Total Drainage Area	Drainage Score
4,508,264.00	-	-	11,352.95	11,352.95	100%
4,509,635.00	-	-	330,089.18	330,089.18	100%
4,510,191.00	1,782.33	-	1,770.96	3,543.50	80%
4,510,892.00	-	-	512,437.98	512,437.98	100%
4,512,119.00	4,488.46	-	257,754.82	261,225.50	99%
4,512,755.00	-	-	0.06	0.06	100%
4,512,781.00	8,945.61	7,000.58	-	15,846.48	51%
4,513,844.00	53,825.95	-	68,028.75	121,854.70	82%
4,514,877.00	117,177.28	39,771.86	16,618.85	173,567.99	59%
4,515,366.00	-	-	1,032.43	1,032.43	100%

Geospatial MCA Methodology

7

- Assessment can be parcel based or grid based
- Outputs
  - Land parcel ranking list
  - Land parcel suitability map
  - Suitable areas heat map

MCA	Parcel
Overall Rank	ID
4.41	7831248
4.36	4667804
4.32	7288517
4.27	7933209
4.27	4274944
4.27	4499746
4.27	7211930
4.27	7445129
4.23	6843814
4.23	4331487
4.23	7914581
4.18	4379840

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Example Project 1

8

- 5 km assessment radius
- More than 2,000 property lots
- 140 ha land required

	ASSESSMENT CRITERIA	WEIGHTING
1	Usable Land Area	20
2	Land Suitability	20
3	Land Use	10
4	Operability/Engineering	5
5	Distance to WWTP	15
6	Proximity to Receptors	15
7	Community Consideration	15
		100

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Example Project 1

9

- 11 preferred feasible sites identified
- Manual scoring allowed a level of realism to be applied to scoring
- Output map allows clearly feasible regions to be identified

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Example Project 2

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- Very large assessment area
- Assessment based on 2 km x 2 km grid
- Grid system allows area to be targeted for more detailed assessment
- New criterion – Number of properties in grid square

Score	5 (Best)	4	3	2	1 (Worst)
Useable Land	> 80 %	60 - 80 %	40 - 60 %	20 - 40 %	< 20%
Suitability of Land	High i.e. <5% slope and well rained	M-High	Med	M-Low	Low i.e. >20% slope & poorly drained
Distance	<9.5 km	9.5 km – 18.5 km	18.5 km – 27.5 km	27.5 km – 36.5 km	> 36.5 km
Receptors	> 80 %	60 - 80 %	40 - 60 %	20 - 40 %	< 20%
Number of Lots	<4 lots	5 - 10 lots	11 - 18 lots	19 - 30 lots	>31
Existing Land Use	High i.e. exotic forestry, exotic shrubland	M-High	Med i.e. high production farmland	M-Low	Low i.e. orchard, vineyard

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Example Project 2

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Criteria	Assessment 1 Weightings	Assessment 2 Weightings
Usable Land Area	25	25
Land Suitability	50	40
Distance to WWTP	0	5
Proximity to receptors	25	15
Existing Land Use	0	10
Number of individual properties	0	5
Total	**100**	**100**

Example Project 3

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- Area > 40 ha
- > 80% well drained or moderately well drained

Example Project 3

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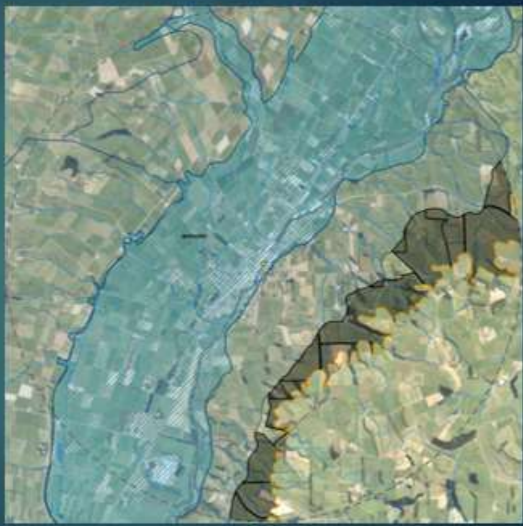
- Exclude flood zones
- Exclude groundwater management
- Exclude elevations > 100 m



Example Project 3

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- Separation distance from surface water = 20 m
- Separation distance from dwellings = 150 m

Conclusions

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- Geospatial MCA can process significant amounts of data
- Enables a robust desktop land treatment feasibility study
- Produces useful outputs
- Assessment can be objective and transparent
- Assessment criteria can be adjusted through the project

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ASSESSING THE EFFECTIVENESS OF A COMPOST TOILET SYSTEM AND COMPOST ACTIVATORS FOR PATHOGEN DIE-OFF RATES IN AN EMERGENCY CONTEXT

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[B] Institute of Environmental Science and Research Limited (ESR), Wellington

[C] Corresponding author email: matt@greenearth.net.nz

ABSTRACT

The greater Wellington region is highly vulnerable to large earthquakes as it is crossed by active faults, both on- and offshore. A future earthquake on the Wellington Fault is expected to cause extensive damage to water supply and wastewater networks, which is likely to result in prolonged service outages to households. Widespread landslides may also affect road access and isolate households, implying that residents may have to manage human waste disposal onsite.

A concept emergency composting toilet system has been trialled in Wellington through 2012 with positive user feedback but little is known on the public health risks of this system. The isolation of households may require many to dispose of waste to land onsite.

This paper presents the research results from an experiment in which different composting activators and carbon cover materials were used in the toilet system and tested these systems for indicator *Escherichia coli* die off rates. The results indicate that untreated *Pinus Radiata* wood shavings enhanced the die off of E. coli to safe levels within 9 weeks compared with the other variables.

Keywords: Emergency, Sanitation, Bio-waste, composting toilet, disaster, Human waste

How effective is a composting toilet system for protecting human health in an emergency context?

M. Brenin, M.J. Gutiérrez-Ginés, J. Horswell, C. Stewart, K. Bohm, D. Johnston

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Impacts of earthquakes on sanitation
The Christchurch Experience……..

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Christchurch Feb 2011 Earthquake → about 40,000 people unable to flush their toilets

Damage to wastewater collection system → public health risk of water faecal contamination

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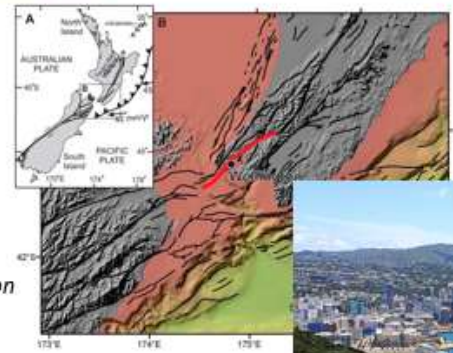
The Wellington Situation



"The hilly terrain of the Wellington region makes the provision of emergency sewage disposal particularly challenging and the community may be expected to be ***self-sufficient for a longer period*** *than that experienced by Christchurch residents following the Christchurch earthquakes"*

Wellington Lifelines Group. (2019). https://www.wremo.nz/assets/Uploads/Wellington-Lifelines-PBC-MAIN-Combined-20191009.pdf

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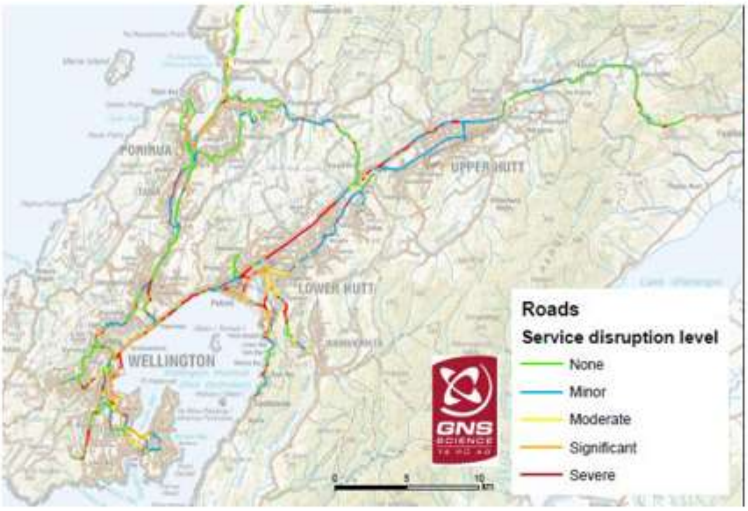

- Sewage and/or drinking water interruptions
- Closed road access
- Isolation → need for self-sufficiency

Resilience of communities post-earthquakes

WREMO (2013) Wellington Regional Emergency Management Office
https://wremo.nz/assets/Publications/Compost-Toilet-Trial-Report.pdf.

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Dilute pee and pour on your garden

On-site composting of solids?


Experimental design
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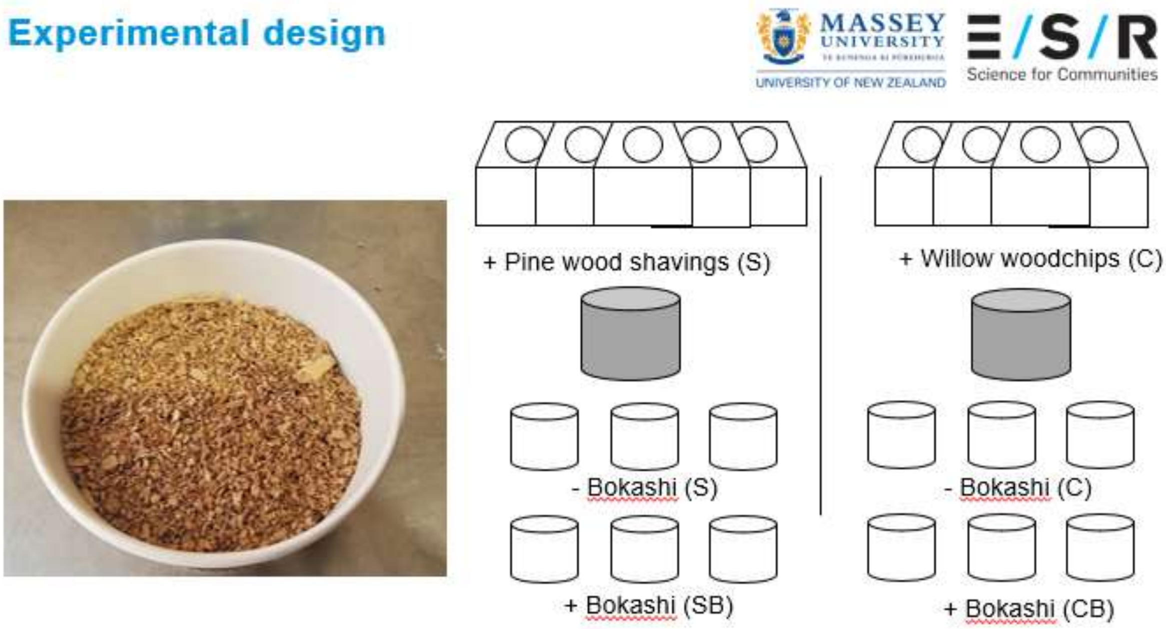
+ Pine wood shavings (S)
+ Willow woodchips (C)


Experimental design
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Science for Communities
+ Pine wood shavings (S)
+ Willow woodchips (C)
- Bokashi (S)
- Bokashi (C)
+ Bokashi (SB)
+ Bokashi (CB)

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Pine wood shavings (S) Willow woodchips (C)

+ Bokashi (SB) + Bokashi (CB)

Sampled weekly, *E. coli* enumeration and moisture. Three times over the experiment: TC, TN, inorganic N, and P

Results

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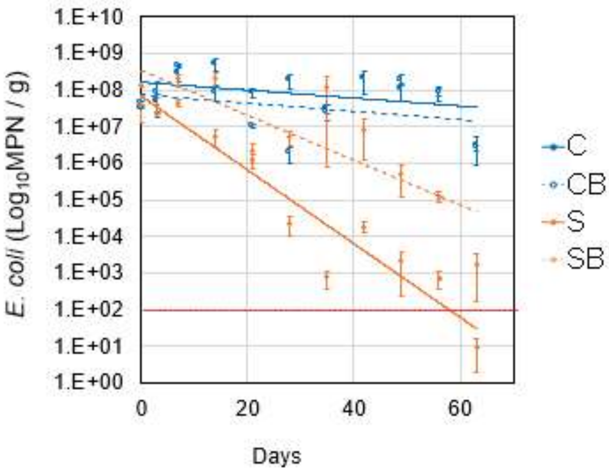
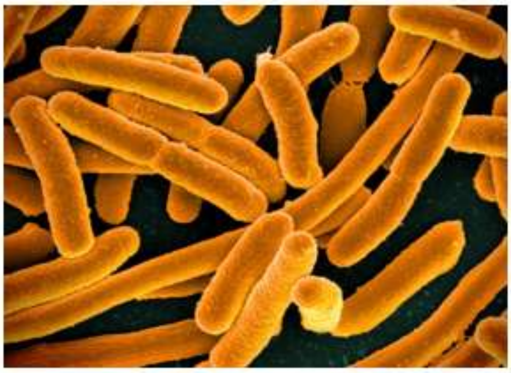
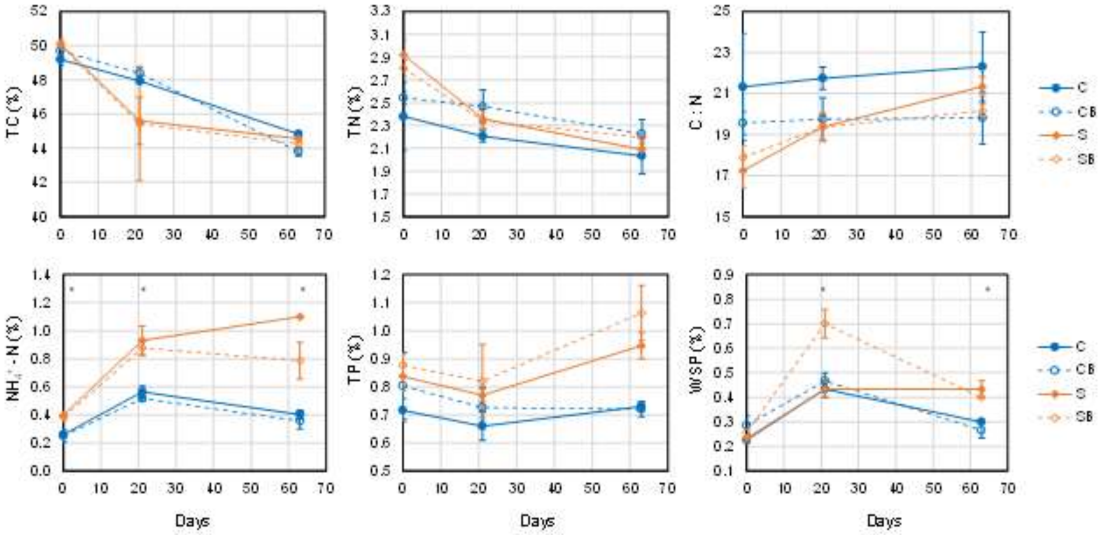




Results



Conclusions

The experimented emergency composting toilet which used pine shavings alone produced the greatest *E. coli* reduction (7 log_{10}), and the treated faecal waste complied with the New Zealand standard for microbiological safety for composts, soil conditioners and mulches. These findings indicate that treated faecal waste could be managed onsite using the normal precautions for handling potting mix. Given that it is unlikely that this experiment followed a conventional composting process (with increasing temperatures up to 65 °C for certain periods of time, oxidation and stabilization of the organic matter), as shown by chemical analysis (TC, TN, C:N, NH_4^+ and NO_3^-), the reduction of pathogens could be a consequence of either the antimicrobial properties of pine shavings and or an increase in toxic ammonia formation. This suggested that the final compost was not stable (or mature) and that there may be the potential risk of re-growth of pathogenic organisms. Further research is required to investigate the potential regrowth of *E. coli* or other pathogenic organisms after the compost is applied to the soil.

BIOSOLIDS LAND TREATMENT – CONSENTED BUT NOT IMPLEMENTED

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ABSTRACT

The land treatment of municipal biosolids in New Zealand faces a number of constraints, including a lack of suitable land areas, which can often be driven by opposition from neighbouring property owners due to the negative perception of biosolids, as well as the effects from nutrient leaching, pathogens, and heavy metals and other contaminants present in biosolids. However, even where these constraints are overcome, and resource consent is granted, land treatment may still not be implemented.

This paper will discuss a case study, where dewatered and stabilised biosolids from a small community wastewater treatment plant were to be incorporated into land operated as cut and carry. Resource consent was sought and granted, but an alternative disposal method is now being pursued.

This project highlighted the challenges around:

- The assessment of effects from nutrients and heavy metals present in biosolids,
- Consultation and the obstacles of the perception of biosolids.
- The long term sustainable management of the activity.

The drivers for the consent holder not giving effect to the consent will also be investigated, including the concerns of ongoing commitments for operation, potential for future emerging contaminants to create a legacy issue, and the availability of an alternative vermicompost facility for disposal.

Keywords: Biosolids, Perception, Constraints, Alternatives.

1

Biosolids Land Treatment Consented but not Implemented

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Background

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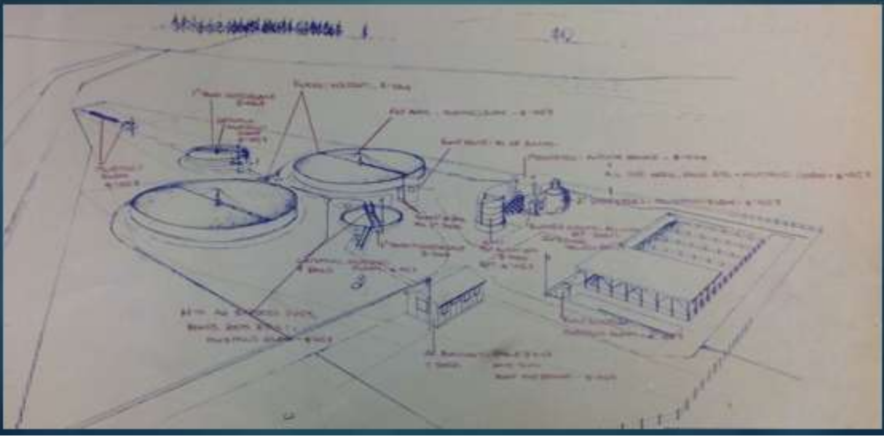
- Small community sewage treatment plant built in 1954 under-going upgrades.
- Existing drying beds with disposal to local landfill.



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Drivers for Project
4
Sewage Treatment Upgrades producing more solids.
Drying beds remediation.
Local landfill closure.
More sustainable management.
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Project Timeline

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- 2013 - Solids management and disposal optioneering.
- 2013 - Geobag and drainage bed installed.
- 2014 - Land treatment system outlined.
- 2014 - Disposal site 1 investigations.
- 2014 - Pathogen risks summary work and consultation.
- 2014 - 15 draft AEE preparation.
- 2015 - 2016 Disposal site 2 investigations.
- 2017 - 18 – Further Site Visit, Operational Concerns, Pathogen Risk Discussions.
- 2018 - 19 updated AEE preparation.
- 2019 - AEE granted 2019.

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Solids Management Optioneering

6

- Solids Dewatering Options:
  - No Dewatering (Irrigation to land).
  - Mechanical dewatering.
  - Drying beds.
  - Geobag dewatering.

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Solids Management Optioneering

7

- Disposal:
  - Land treatment:
    - forestry,
    - grazed pasture (sheep/beef),
    - Undeveloped land.
  - Landfill.

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Preferred Option: Geobags + Land Treatment

8

- Multiple Geobags on rotation over drainage bed (remediated drying beds).
  - Provides dewatering and required stabilisation storage for biosolids.
- Application to land, incorporation into soil in conjunction with grazed pasture or cut and carry.

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Geobag and Drainage Bed Installation

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Proposed Land Treatment Operation

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- Stabilization through 12+ months storage to achieve Grade B biosolids required for consent.
- Approximately 300 m^3 dewatered biosolids per year, single annual application.
- Spreading (Muck spreader) and incorporation to depth of 100mm.
- Application to 5ha per year rotating through 20 ha of land.
- Cut and carry pasture – ryegrass or lucerne.
- Cut product removed and feed to sheep without direct grazing.

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Biosolids Land Treatment Challenges

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- Pathogen risks.
- Perception issues - neighbour/community opposition.
- Stakeholder concerns.
- Heavy metal contaminants.
- Nutrient management.
- Operability and management commitments.

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Pathogen Risk

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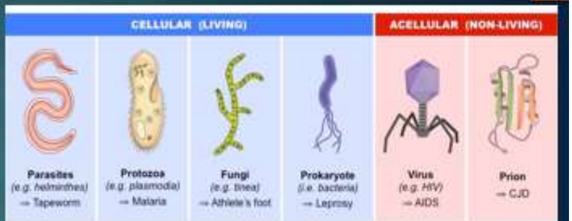
- Biosolid Pathogen of Concern:
  - Bacteria (*Salmonella, listeria* and *campylobacter*)
  - Protozoa (*Giardia entestinalis, Entamoeba histolytica, Cryptosporidium* and *Balantidum coli*)
  - Parasitic helmiths (*Taenia saginata*).
  - Viruses (*Hepatovirus A*, Norovirus and the *Adeno* virus).
- Direct human exposure risk –Limited by restricted access to land area.
- Exposure via food chain key potential risk.



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Perception Risk
13
Examples of opposition - Generally focused on direct human exposure and odour issues, not food chain exposure via sheep and beef stock.
MPI Animal - no restrictions on use of biosolids or sewage effluent.
Fonterra – Does not allow material to be feed to lactating cows grown on land receiving sewage wastewater (unless meeting very strict treatment requirements).
Number of existing sewage wastewater treatments operating cut and carry systems for stock feed (Taupo District Council).
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Key Risk Mitigation - Breaking Exposure Pathway
14
Feed Offsite
Ingestion of Soil
Pathway Removed
Incorporation into Soil
Cut and Carry
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Land Treatment Location 1 – Undeveloped Land

Land Treatment Location 2

Environmental Effects - Soil

Analysis		Level Found	Medium Range	Low	Medium	High
pH	pH Units	5.8	5.8 - 6.3			
Olsen Phosphorus	mg/L	8	20 - 30			
Anion Storage Capacity*	%	57				
Potassium	me/100g	0.16	0.50 - 0.80			
Calcium	me/100g	2.2	6.0 - 12.0			
Magnesium	me/100g	0.43	1.00 - 3.00			
Sodium	me/100g	< 0.05	0.20 - 0.50			
CEC	me/100g	11	12 - 25			
Total Base Saturation	%	25	50 - 85			
Volume Weight	g/mL	0.79	0.60 - 1.00			
Total Carbon	%	5.1				
Total Nitrogen	%	0.35	0.30 - 0.60			
C/N Ratio*		14.7				
Dry Matter*	%	68.3				
Moisture*	%	31.7				
Base Saturation %		K 1.4 Ca 19	Mg 3.9 Na 0.3			
MAF Units		K 3 Ca 2	Mg 8 Na < 2			

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Environmental Effects - Metals

Table 6: Biosolids Characterisation and Minor Grade Classification

Parameter	Grade a Biosolids Limit (mg/dry kg)	Grade b Biosolids Limit (mg/dry kg)	Biosolids Concentration (mg/dry kg)
Cadmium	1	10	1.3
Copper	100	1,250	455
Mercury	1	7.5	4
Zinc	300	1,500	820

Table 7: Soil Capacity at Biosolids Application Site

Contaminant	Soil limit (mg/dry kg)	Existing soil concentrations (mg/dry kg)	Available capacity of soil (kg/ha)	Biosolids load (kg/ha/yr)	Years to reach ceiling limit
Cadmium	1	0.18	0.8	0.005	183
Copper	100	16	84	1.64	51
Mercury	1	< 0.10	1.0	0.014	66
Zinc	300	10	291	2.95	98

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Environmental Effects - Nutrients

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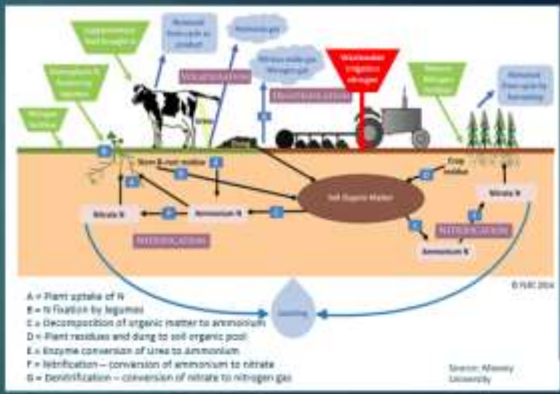
- Nutrient loading of 200 kg-PAN/ha/yr, 55 kgP/ha/yr.
- Nitrogen leaching rate of 13-14 kg-N/ha/yr. In line with typical sheep farm.
- Phosphorus runoff limited by low Olsen-P and minimal runoff risk.



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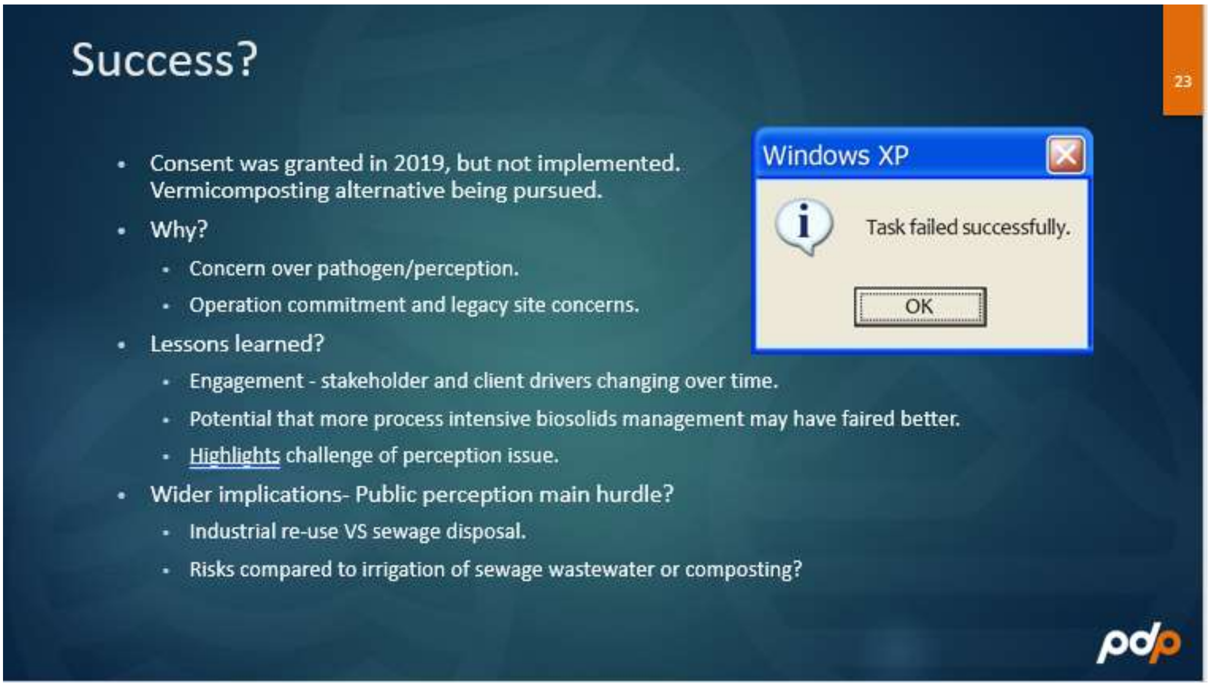
Test Run – Landfill Application

20

pdp


21


Test Run – Landfill Application
22


Success?
23
Consent was granted in 2019, but not implemented. Vermicomposting alternative being pursued.
Why?
Concern over pathogen/perception.
Operation commitment and legacy site concerns.
Lessons learned?
Engagement - stakeholder and client drivers changing over time.
Potential that more process intensive biosolids management may have faired better.
Highlights challenge of perception issue.
Wider implications- Public perception main hurdle?
Industrial re-use VS sewage disposal.
Risks compared to irrigation of sewage wastewater or composting?
Windows XP
Task failed successfully.
OK
pdp

NATIVE VEGETATION TO MANAGE NUTRIENTS IN WASTEWATER LAND APPLICATION SCHEMES

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Native vegetation could be an alternative for the land application of treated municipal wastewater (TMW), with potential to create zones of ecological value. However, not much is known about the fate of nutrients applied with TMW in native soil-plant systems.

Long-term field trials were set up in Duvauchelle (Banks Peninsula) and Levin to study the effect of native plants on the mobility and speciation of nutrients applied with TMW. We aimed to determine if TMW irrigation onto native vegetation would result in accumulation, depletion or leaching of nutrients in the underlying soil. We monitored the survival and growth of native plants at the sites and analysed the composition of the plants.

Results from Duvauchelle indicate that there was no significant soil degradation or nutrient imbalances following the application of TMW. Irrigation of TMW improved the growth of native plant species. However, individual species responded differently, and some species were not well adapted to the sites. Accelerated weed growth in both Duvauchelle and Levin was observed due to TMW irrigation and needed to be controlled.

The field trials support the viability of native vegetation for the land treatment of TMW. They highlight the importance of species selection and weed management as critical success factors.

Hi, my name is Alexandra and I'm doing my PhD in Environmental Science at the University of Canterbury. My research focuses on the use of native vegetation for the land application of wastewater. Today I want to give you a bit of an update on what we were and are doing at our field sites in Duvauchelle and Levin.

In today's presentation, I would like to move away from common wastewater land application schemes such as cut and carry pasture or commercial pine forest and talk about native vegetation.

...to native vegetation?

It might be possible to combine the land application of treated municipal wastewater with the restoration of native ecosystems throughout New Zealand. Wastewater could potentially even be used to accelerate the production of valuable native products, such as manuka honey. Now as such schemes are not very common yet, there are some open questions.

First, we need to know how native plants respond to wastewater irrigation and elevated nutrient concentrations as many natives usually thrive on poor soils.

Second, native plants are typically not harvested. This means that there is no removal of nutrients from the system through plant biomass. It is possible that nutrient losses would therefore be greater than from wastewater irrigated pasture or commercial forest. Of particular concern is the movement of nitrate and phosphorous from irrigated soils into waterbodies, where these elements can lead to eutrophication.

We were able to set up a couple of field trials in two different environments to study native land treatment schemes. Our two main aims were to determine how wastewater irrigation affects the growth of native plant species AND if wastewater irrigation onto natives would lead to excess nitrate leaching, and accumulation or depletion of phosphorus, sodium and other elements in the soil.

Duvauchelle field trial

The first field trial is located in Duvauchelle on Banks Peninsula. We can see the local wastewater treatment plant on the left side, right next to Akaroa harbour, where the wastewater is currently discharged.
Some of the wastewater is now pumped over the hill to our field site over here.
The trial consists of 27 vegetated blocks, including 12 irrigated and 12 non-irrigated control plots. There are 11 native species, divided into 3 different vegetations types. These were manuka and kanuka, a flax dominated mixture and a broadleaf dominated mixture. The soil at the site is a Pawson Silt Loam.

2015 - 2021

1000 mm/yr

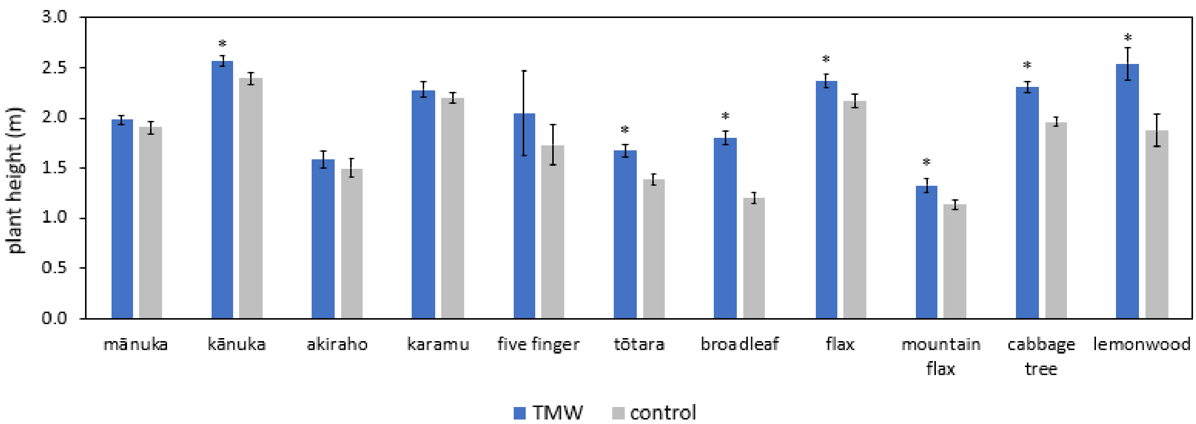
The trees were planted in July 2015 and are receiving wastewater at a rate of 1000 mm per year through surface drip irrigation. Nearly 6 years later the trial looks like this, with plants now more than 4m high.

Elements applied with wastewater

Element	Application (kg/ha/yr)
N	200
P	110
K	220
S	250
Ca	590
Mg	190
Zn	1.7
Cu	0.4
Cd	<0.01
Na	950

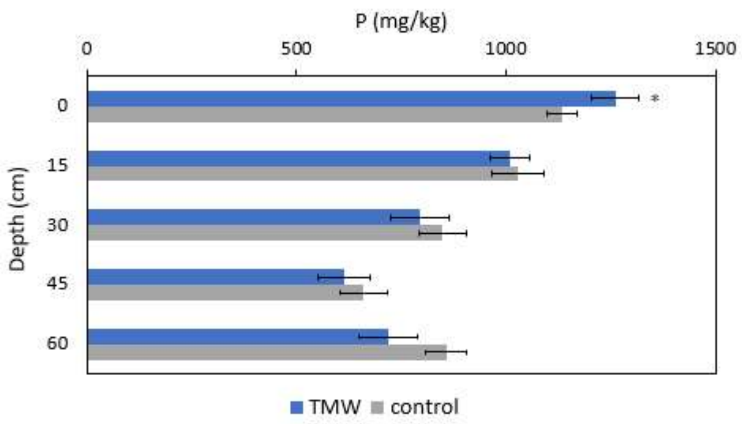
The amount of nitrogen and phosphorus applied in the trial is similar to what is typically applied to pasture in agriculture. The application of heavy metals is low. The amount of sodium applied is 950 kg per ha per year.

Wastewater increases native plant growth



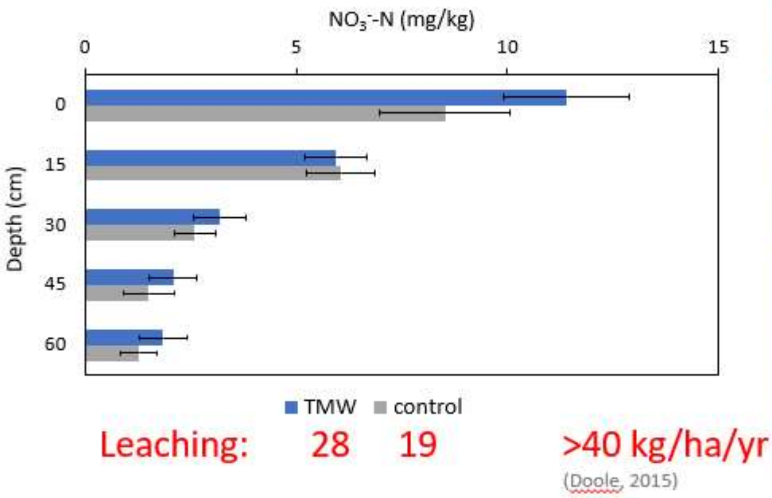
To study plant growth at the site, we measured the height of each individual tree. We found that across all species the average height of the vegetation receiving wastewater was significantly greater than the controls. But there were clear differences between individual species. Cabbage tree and lemonwood, for example, performed particularly well at the site and responded very well to wastewater irrigation. In contrast, manuka and five finger were not well adapted to the site. They showed signs of stress and disease in both the control and wastewater-irrigated plots.

Phosphorus accumulates in the topsoil

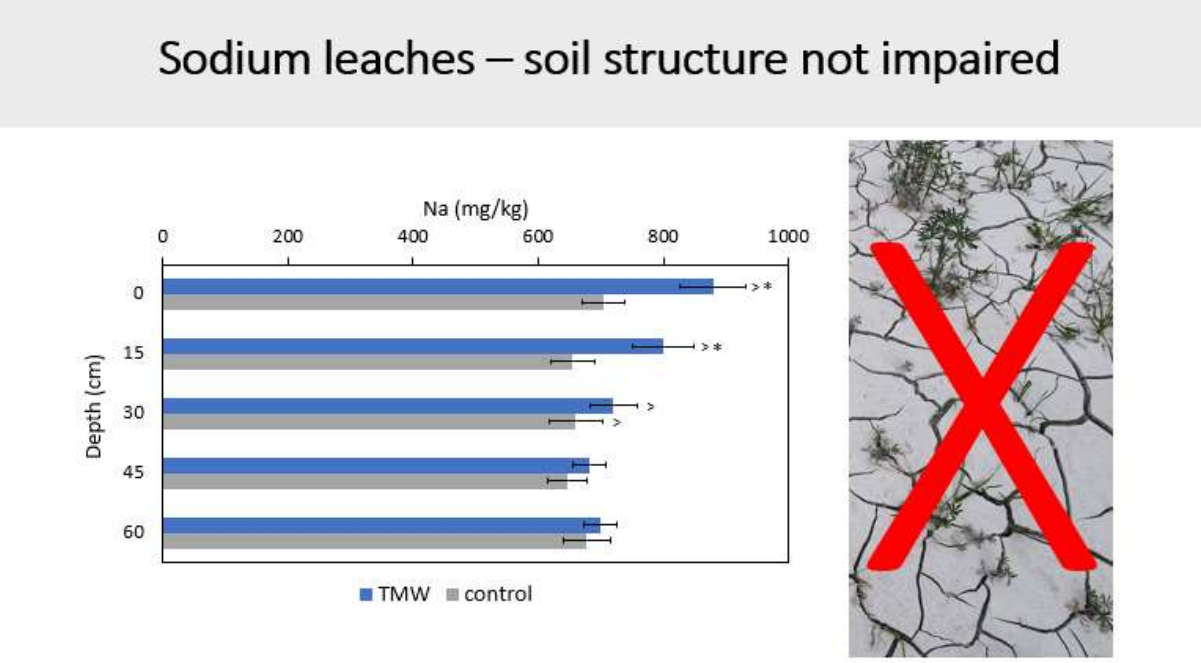


To study the distribution and speciation of nutrients in the soil profile, we dug soil pits down to 60 cm and took soil samples at 5 different depths. The phosphorous concentration was significantly increased in the topsoil. The strong adsorption of phosphorous in soil means that only a small part of the applied phosphorous is taken up by plants or leached. There were no signs of increased erosion that would result in phosphorous entering the nearby stream. It is expected that phosphorous losses will be lower from wastewater irrigated native vegetation than from grazed pasture as there is no mechanical disturbance of soil by animals.

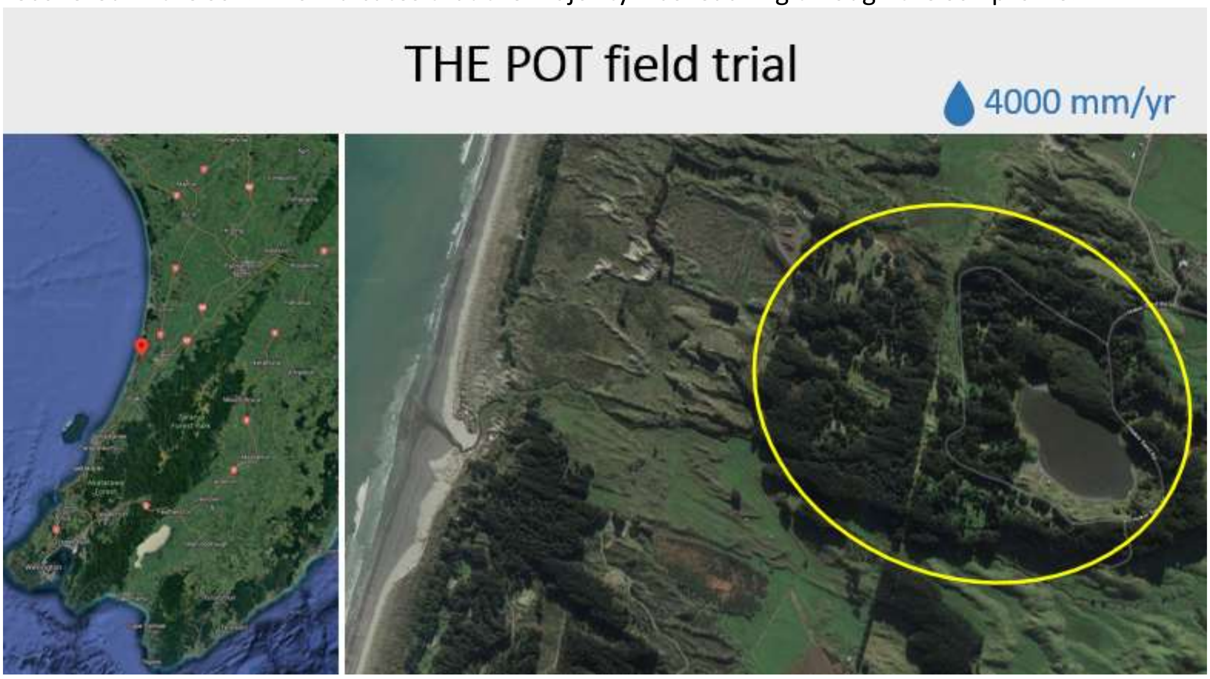
Nitrate leaching lower than from grazed pasture



Nitrate was also increased in the topsoil, with smaller differences between the irrigated and control plots at greater depths. We estimated nitrate leaching based on the assumption that all nitrate at 60cm is leached, as this is below all but the deepest roots. The results show that 28 kg of nitrate-nitrogen per ha per yr was leaching from the irrigated plots, compared to 19 kg from the control plots. Both these values are lower than nitrate leaching from a grazed pasture, which can exceed 40 kg/ha/yr.

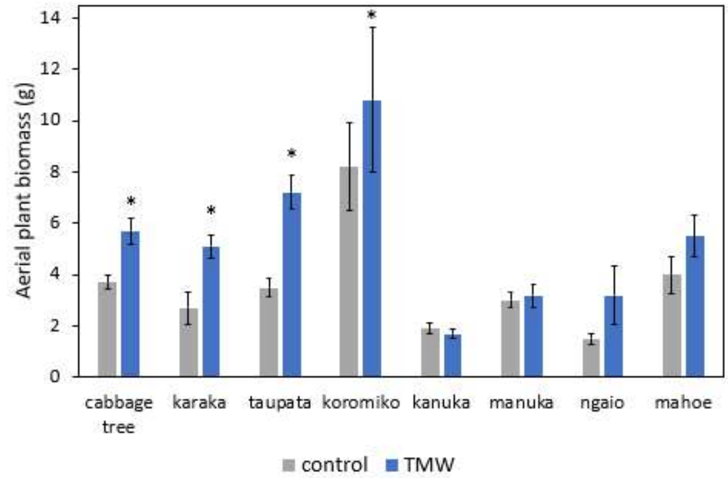


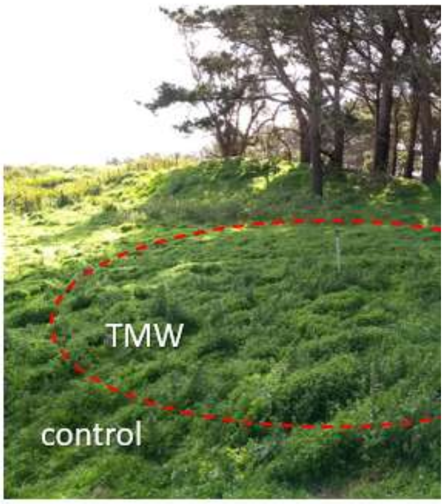
Throughout the trial, there was no evidence of ponding or runoff. This indicates that the soil structure and infiltration were not impaired following the irrigation of high sodium wastewater. While sodium significantly increased in the topsoil, we have strong evidence that it is not continuing to accumulate in the system. Only 20% of the sodium applied in the 3 years until sampling was recovered in the soil. This indicates that the majority was leaching through the soil profile.



The second field trial I want to talk about is called THE POT. It is located just outside of Levin and receives wastewater from the Levin wastewater treatment plant. It is right next to the ocean and, compared to Duvauchelle, the soil is mainly sand with only little organic matter. This site has been operating for over 30 years, applying the wastewater onto 40 ha of pine trees. Most of these have been harvested and native vegetation, dominated by manuka and kanuka, was planted on 10 ha and is receiving wastewater irrigation. The wastewater is stored at the pond here and the middle and then irrigated onto land at a rate of 4 m a year through sprinkler irrigation. Today I would like to present 4 experiments that were performed at the site.

Wastewater increases native plant biomass





The first experiment was a preliminary plant growth trial that we harvested in 2018. In this trial we analysed the performance of 8 species under irrigation compared to a non-irrigated control treatment. Similar to Duvauchelle these results were very encouraging, showing that half of the species produced significantly more biomass with irrigation and none of the species was adversely affected by wastewater irrigation.

Weed control trial

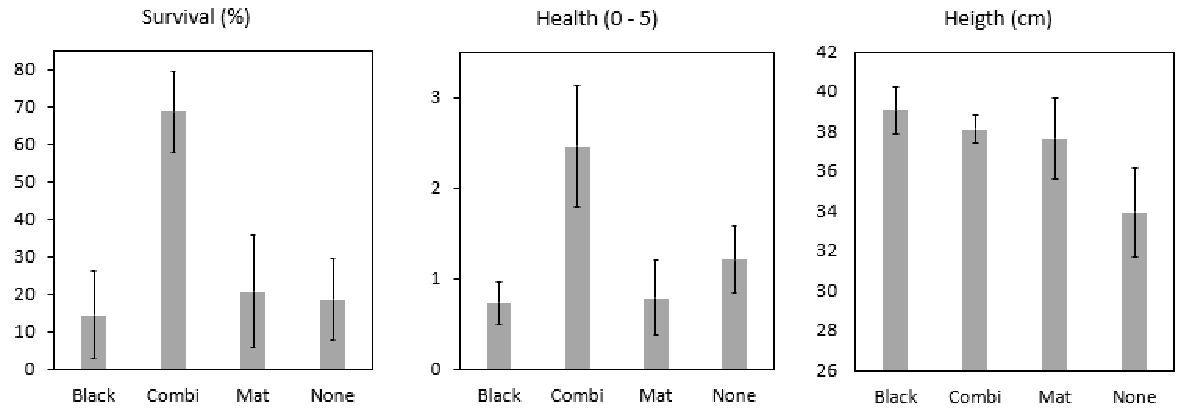
However, during the establishment of the native plants at The Pot we encountered some serious issues with weed growth. We had to learn the hard way that wastewater can massively increase the growth of weeds if these are not controlled very rigorously. This leads me to the second experiment. Following this challenge we set up a weed control trial last year where we compared the growth of manuka seedlings with different weed control treatments.

The trial consisted of three irrigated plots subdivided into four areas of different weed control treatments:

a) No weed control (none)
b) Weeds controlled with black weed mat (black)
c) Weeds controlled with wool mats around the seedlings (mat)
d) Weeds controlled by combiguards and wool mats (combi)

The survival of each mānuka seedling was monitored and height and health were recorded.

Best survival and health with CombiGuard



Results showed that the best survival and plant health was achieved when a combination of wool mats and combiguards was used. The height of the plants did not differ between treatments.

Lysimeters

The third experimental part is all about nutrient leaching. We set up some lysimeters at the site to monitor nitrate leaching under natives compared to pasture. We've installed 8 of these devices to sit 30 cm below the surface and planted 4 each with kanuka and pasture.

2019 - 2021

The lysimeters were installed and planted in 2019. The planted kanuka established well and we are currently in the process of completing the leachate sampling that will be followed by nitrate analysis.

Soil and plant sampling

For the fourth experimental part we aimed to quantify the movement of N, P and other elements in the soil and plant system based on plant type and rate of irrigation. We selected a total of 51 plants, 17 manuka, kanuka and pasture. The selected plants receive a varying amount of irrigation. We took soil samples at two different depths under these plant as well as a foliage sample. We measured the trees and determined the biomass of the pasture in a defined area. The irrigation for the selected plant was recorded with a rain gauge. We are in the process of analysing the soil and plant samples for nitrogen, phosphorus and trace elements and will have results ready within the next two months.

Conclusions

In conclusion, our trials have so far shown that applying wastewater to NZ natives might be a viable option for wastewater land treatment. Results from Duvauchelle show that the soil structure was not impaired and nutrient losses were small compared to losses from agricultural land. Plants at both sites responded well to wastewater irrigation, but species selection is important to grow plants that are well adapted to the local environment. Equally important for the successful establishment of native vegetation is the control of weeds, as their growth can be accelerated by wastewater irrigation. It is likely that native land application systems can create zones of ecological value throughout New Zealand.

Acknowledgements

Christchurch City Council

Horowhenua District Council

Ministry for the Environment Manatū Mō Te Taiao

Freshwater Improvement Fund

Centre for Integrated Biowaste Research

UC University of Canterbury Te Whare Wānanga o Waitaha

BIOSOLIDS AS A VALUABLE SOURCE OF PLANT NUTRIENTS WITH HIGH POTENTIAL AS SOIL CONDITIONER AND SOIL FERTILIZER

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ABSTRACT

More than half of the biosolids produced in NZ is still sent to landfills or oceans. In this paper, we will present opportunities for beneficial use of sludges and solids.

A field trial showed the potential of sludges and biosolids to be used as a soil ameliorant for winter crop production, which increased the growth and nutrient status of pasture and oats for longer periods compared with mineral fertilizers with negligent risk for human health or livestock.

Although the potential content of pathogens and trace elements is one limiting factor for the beneficial reuse of biosolids into land, a composting trial with different mixtures of biosolids and greenwaste demonstrated the possibility of obtaining a high quality product graded Aa, which has a high potential to be reused without restriction.

These experiments were carried out as part of a Waste Minimisation MfE funded project led by LEI in collaboration with ESR, Massey University, and ten lower North Island Councils, to develop a biosolids strategy that included the potential collective management of municipal wastewater treatment sludge, with a focus on beneficial use.

Keywords: Biosolids, winter crops, composting, plant nutrients, trace elements. Escherichia coli

Biosolids as a valuable source of plant nutrients

Maria Gutierrez, Hamish Lowe

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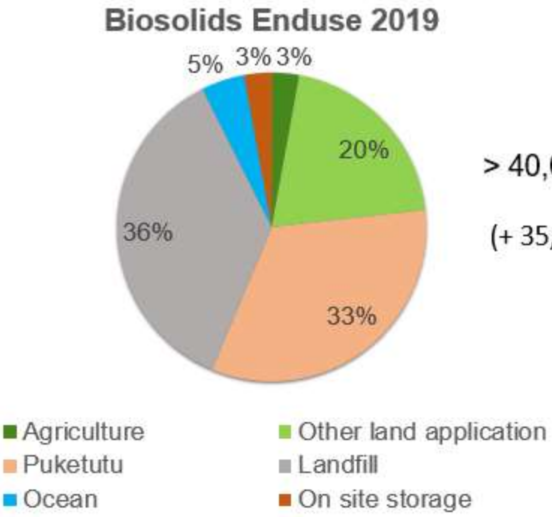

> 40,000 dry tonnes per year

(+ 35,000 dry tonnes biosolids sitting in ox ponds)

Data of production of biosolids from ANZBP2019: https://www.biosolids.com.au/
And WWTP inventory Water NZ 2019

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Recycling nutrients?

Properties	Units	Biosolids 1	B 2	B 3	B 4	B 5
pH		6.4	8.1	7.2	6.8	4.3
Total Org. Carbon	%	20	34	39	30	23
Total N	%	1.89	6.0	4.9	3.9	2.3
Ca	%	2.1	1.8	2.4	3.1	1.1
Mg	g/kg	3.1	11	2.0	5.0	3.9
P	g/kg	13	27	8.9	16	5.7
K	g/kg	10.2	2.0	0.8	2.2	3.8

→ 1600 + 1400 tonnes N

→ 560 + 490 tonnes P

Data of biosolids composition from our own database

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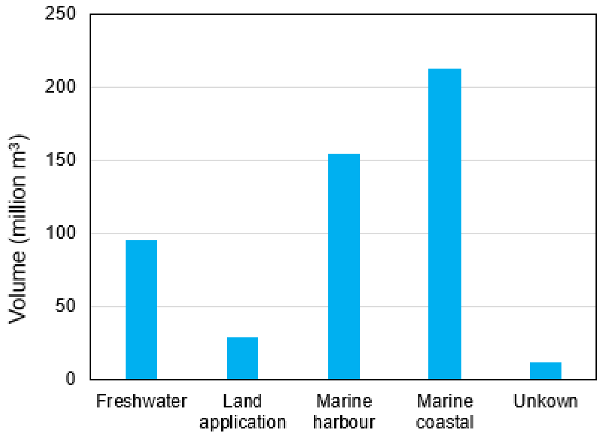
Wastewater – recycling of nutrients?

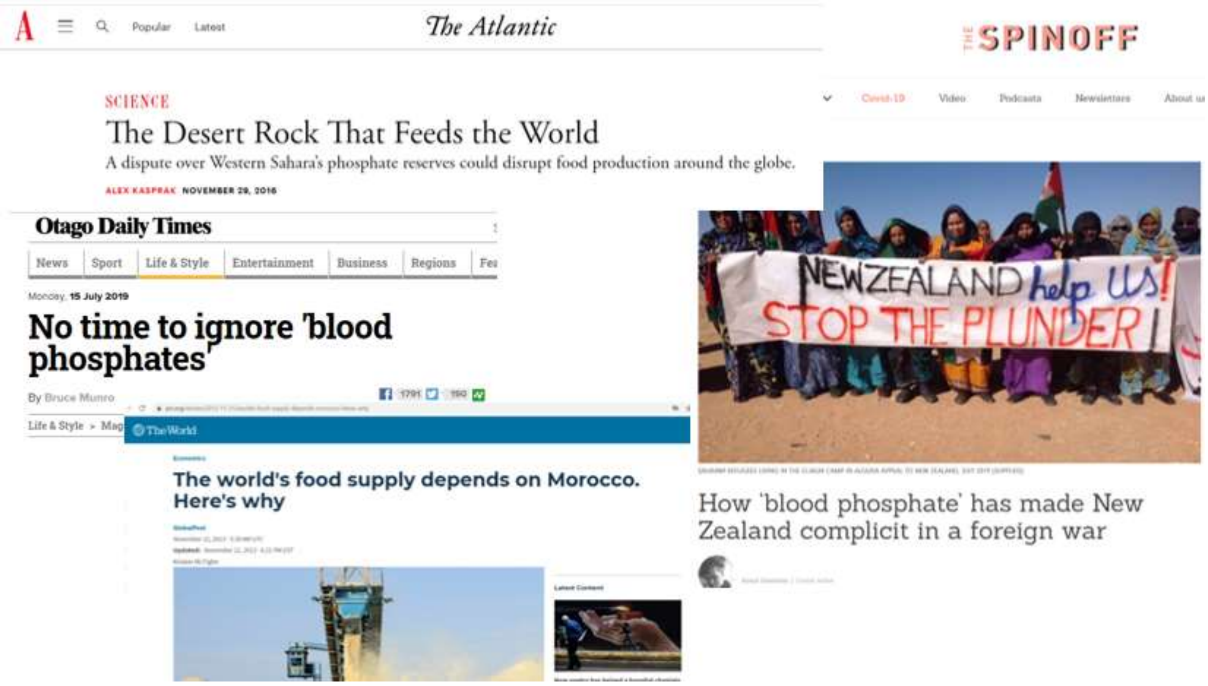


460 million m^3 going to water bodies

20 mg N / L
10 mg P / L

9200 tonnes N per year
4600 tonnes P per year

Data from WaterNZ 2021. WWTP Inventory: https://www.waternz.org.nz/WWTPInventory



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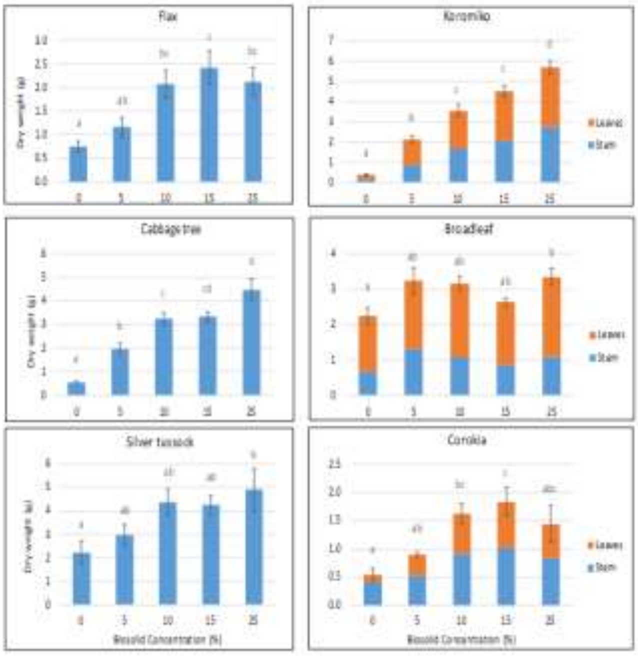
Manawatu District Council
Whanganui District Council
horizons regional council
Palmerston North City Council
Tararua District Council
Ruapehu District Council
Masterton District Council
Rangitīkei District Council
Centre for Integrated Biowaste Research
Massey University
Horowhenua District Council

Biosolids as potting mix

720 seedlings – 6 species – 4 biosolids – 4 blends



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Biosolids to grow winter crops

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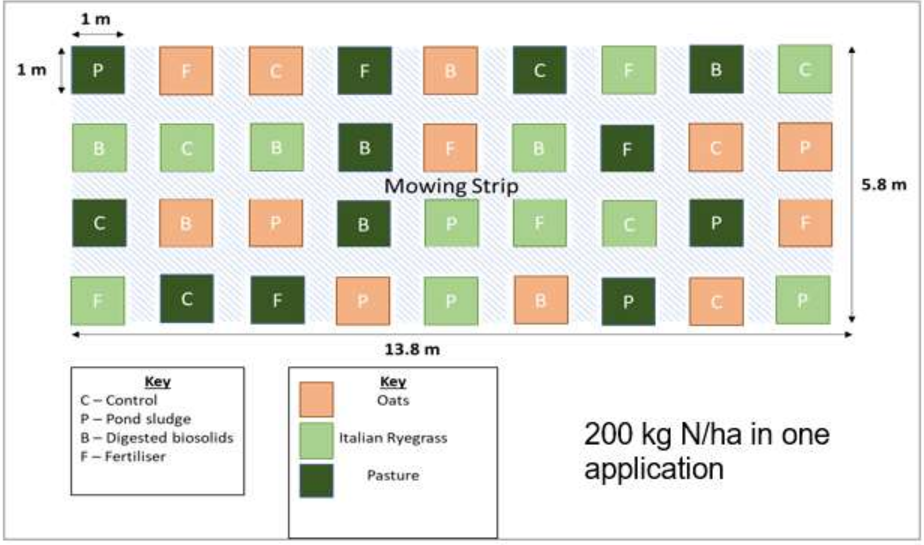

200 kg N/ha in one application

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Properties	Units	Pond Sludge	Digested Sludge	Soil	Biosolids Guidelines*
E. coli	MPN/g	4.4×10^4	1.8×10^7	5.4×10^4	< 100
pH		6.9	7.3	5.8	-
TOC	%	19	29	3	-
Total N	%	2.3	3.6	0.27	-
C:N		8.2	8.0	11	
NH_4^+-N	mg/kg	1,260	6,300	< 5	-
NO_3^--N	mg/kg	< 10	< 5	1.6	-
P	mg/kg	4,650	16,300	750	-
K	mg/kg	1,380	1,200	540	-
Cd	mg/kg	1,9	0,7	0,16	1 - 10
Cu	mg/kg	220	164	4	100 – 1,250
Zn	mg/kg	1035	680	27	300 – 1,500

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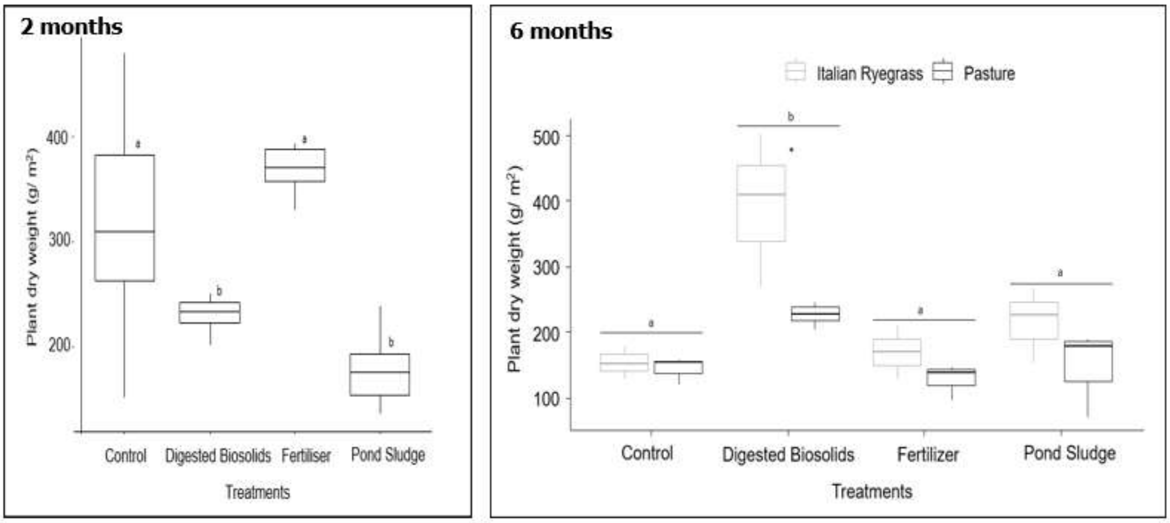

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Plants

Parameter	Unit	Pasture				Italian Ryegrass			
		Control	Digested Biosolids	Fertiliser	Pond Sludge	Control	Digested Biosolids	Fertiliser	Pond Sludge
N	%	2.27 ± 0.21	2.20 ± 0.00	2.23 ± 0.06	2.23 ± 0.35	2.50 ± 0.10	2.17 ± 0.23	2.10 ± 0.14	2.63 ± 0.25
P	%	0.45 ± 0.02	0.47 ± 0.04	0.43 ± 0.03	0.49 ± 0.02	0.43 ± 0.04	0.43 ± 0.02	0.52 ± 0.05	0.43 ± 0.02
Zn	mg/kg	29 ± 2.1^{a}	34 ±4.36^{ab}	23 ± 0.6^{c}	37 ± 2.1^{b}	26 ± 3.2^{a}	34 ± 3.6^{b}	33 ± 2.8^{b}	37 ± 2.6^{b}
Cu	mg/kg	8.00 ± 1.00	9.00 ± 1.73	7.33 ± 0.58	9.67 ± 1.53	8.33 ± 1.15	8.00 ± 0.00	8.50 ± 0.71	7.67 ± 0.58

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Increasing quality by composting with green waste

Treatment number	Description
1 - 2	Bunnythorpe pond sludge + green waste
3 - 4	PNCC alum sludge + green waste
5 - 6	PNCC digester sludge + green waste
7 - 8	Bunnythorpe pond sludge + PNCC alum sludge + green waste
9 - 10	PNCC digester sludge + Bunnythorpe pond sludge + green waste
11 - 12	PNCC alum sludge + PNCC digester sludge + green waste

48 m^3 sludge +
189 m^3 green waste

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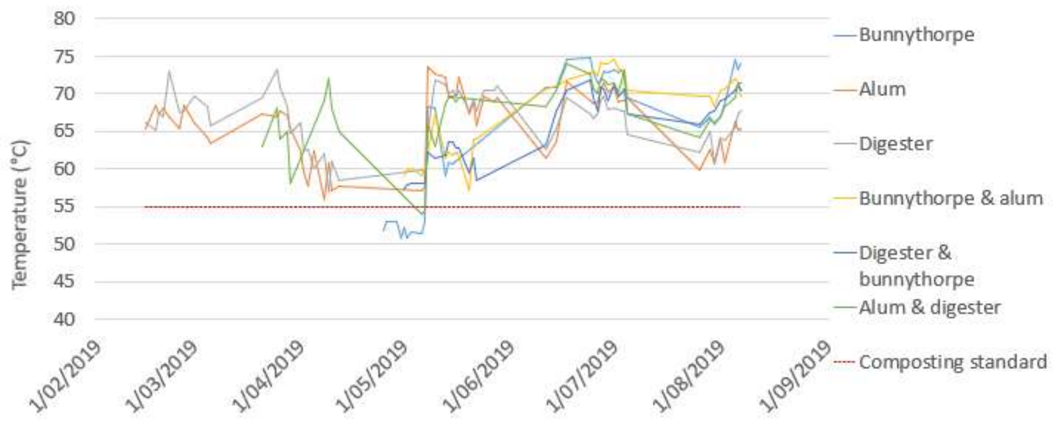
Baseline results for 12 windrows of Palmerston North sewage sludge mixed with green waste

		Treatment											
Parameter	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Nitrate-N	mg/kg	4.9	0.75	0.2	1.9	5.4	0.42	7.4	3.7	23	5.8	1.2	1
Nitrite-N	mg/kg	0.26	0.78	0.51	0.62	8	1.2	5.3	1.9	2	4.6	0.75	0.63
pH	pH unit	7.3	6.7	7	7.5	7.6	7.5	7.6	8.2	8	8	8.4	8.3
Ammonia -N	mg/kg	600	1100	2000	2000	1600	1200	3500	1500	5400	2000	2200	2000
Total C	% wt/wt	11	21	23	22	23	23	17	24	26	23	21	28
Total organic C	% wt/wt	9.9	18	23	21	22	22	15	24	26	22	17	20
Total oxidised N	mg/kg	5.2	1.5	0.71	2.5	13	1.6	13	5.6	35	10	2	1.7
Total P	%	0.24	0.22	0.49	0.59	0.53	0.33	1.1	0.47	0.73	0.37	0.65	1.2
Total solids	%	86	68.5	58.1	50.5	55.8	55.4	36.7	55.2	35.9	45.4	62.8	65.4
Voltile solids (OM)	%	54	40.7	59.8	62.4	47.4	46.5	49.4	22.8	54.8	44.3	52.1	52.8
As	mg/kg	7.2	8.5	10	12	12	12	7.9	54**	6.5	9.2	18	7.2
Cd	mg/kg	<0.45	0.46	<0.45	<0.45	<0.45	<0.46	<0.45	<0.44	0.48	<0.45	0.46	0.66
Cr	mg/kg	9.9	12	11	12	13	14	11	89	13	13	24	17
Cu	mg/kg	31	38	32	38	34	41	49	69	68	57	52	110*
Pb	mg/kg	48	48	84	72	56	46	42	35	44	47	54	50
Mg	mg/kg	2000	2300	2300	2500	2800	2800	2100	2000	2300	2300	3500	2600
Ni	mg/kg	6.5	5.3	4.5	4.8	8.8	6	4.5	5.1	6.2	5.5	14	9.7
Zn	mg/kg	200	250	190	210	210	210	220	180	370*	250	270	490*
E.coli	MPN/g	>190000*	740*	140*	>320000*	>290000*	>290000*	250000*	98000*	6200*	730*	11	630*
Salmonella	MPN/g	>1.3*	<0.023	<0.026	<0.03	<0.027	0.64	<0.041	<0.027	<0.041	<0.033	<0.024	0.34
Campylobacter	MPN/g	<0.015	<0.019	<0.022	<0.025	<0.022	<0.023	<0.037	<0.022	<0.034	<0.028	<0.02	<0.02
Helminth	/4g	<0.47	<1.0	0.89	0.8	<0.72	0.72	0.91	1	1.8	2	<0.64	<0.63
DHA	mg TPF kg^{-1} hr^{-1}	43.53	18.22	0.65	1	0.78	0.86	16.4	21.3	17.7	27.2	3.11	7.85
Adenovirus	/2.5g dw	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND



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LOWER NORTH ISLAND
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TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND
LOWE Environmental Impact
ESR Science for Communities

		Treatment											
Parameter	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Nitrate-N	mg/kg	140	4.7	95	160	120	940	160	410	240	190	570	470
Nitrite-N	mg/kg	8.2	3.1	10	99	9.9	40	1.4	23	12	8.7	54	38
pH	pH unit	6.8	7.2	7.5	7.5	7.6	7.1	7.6	7.6	7.4	7.6	7.5	7.8
Ammonia -N	mg/kg	780	1200	860	1500	1600	580	920	1400	180	310	310	1300
Total C	% wt/wt	11	8.6	13	14	14	15	14	14	14	17	16	17
Total N	% wt/wt	0.9	1	1	1.1	1	1	0.9	1.1	1.2	0.6	1	1.2
Total organic C	% wt/wt	9.6	7.8	13	14	14	15	11	12	14	15	14	14
Total oxidised N	mg/kg	150	7.9	110	260	130	980	160	440	260	200	630	500
C:N	% wt/wt	11:1	9:1	13:1	14:1	14:1	15:1	14:1	14:1	14:1	17:1	16:1	17:1
Total P	%	0.26	0.24	1.1	1.1	0.59	0.63	0.52	0.49	0.5	0.44	1.2	1.1
Total solids	%	63.6	61.6	49.2	48.2	50.6	47.3	60.6	47.7	46.6	50.3	47.3	45.9
Voltile solids (OM)	%	30.4	37.4	33.3	34.5	37.1	31.8	30.7	39.2	39.3	38.4	38.9	40.1
As	mg/kg	10	10	14	16	16	16	10	13	9	14	12	9.8
Cd	mg/kg	0.55	0.47	<0.45	<0.45	0.52	0.52	0.41	0.4	0.53	0.51	0.49	0.51
Cr	mg/kg	13	13	14	16	19	21	14	15	14	18	18	17
Cu	mg/kg	56	44	53	50	60	65	38	34	52	52	61	69
Pb	mg/kg	63	52	110	88	110	65	55	34	59	67	58	56
Mg	mg/kg	2400	2400	2300	2600	2700	3000	2400	2500	2500	2800	3100	3200
Ni	mg/kg	7.1	6.5	5.2	5.9	6.5	8.4	6.3	4.9	6.5	7.3	7.8	9.2
Zn	mg/kg	290	260	260	280	350*	340*	240	210	330*	310*	340*	350*
E.coli	MPN/g	<0.028	<0.029	<0.37	<0.37	<0.36	1.6	<0.30	0.94	<0.39	<0.36	<0.38	0.98
Salmonella	MPN/g	<0.024	0.024	<0.031	<0.031	<0.03	<0.032	<0.0099	<0.013	<0.013	<0.012	<0.032	<0.033
Campylobacter	MPN/g	<0.02	<0.02	<0.025	<0.026	<0.025	<0.026	<0.021	<0.026	<0.027	<0.025	<0.026	<0.027

		Limit		Windrow met criteria after 6 months											
Parameter	Unit	NZS4454	Biosolids guidelines 'Grade Aa'	1	2	3	4	5	6	7	8	9	10	11	12
Biochemical															
pH	pH units	5.0 - 8.5	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Total Nitrogen	% DM	> 0.6	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Organic matter content	% DM	≥ 25	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pathogens															
E. coli	MPN/g	< 100	< 100	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Campylobacter	MPN/25g	n/a	< 1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Salmonella	MPN/25g	n/a	< 1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Trace Metals															
Cadmium (Cd)	mg/kg	3	1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Chromium (Cr)	mg/kg	600	600	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Arsenic (As)	mg/kg	20	20	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Lead (Pb)	mg/kg	250	300	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nickel (Ni)	mg/kg	60	60	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mercury (Hg)	mg/kg	2	1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Zinc (Zn)	mg/kg	600	300	✓	✓	✓	✓	✗	✗	✓	✓	✗	✗	✗	✗
Copper (cu)	mg/kg	300	100	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Temperature	°C	> 55°C for 15d	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Meets criteria for use for NZS4454				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Meets criteria for Grade Aa Biosolids				✓	✓	✓	✓	✗	✗	✓	✓	✗	✗	✗	✗

✓	Criteria met
✗	Criteria not met

SUBSURFACE EFFLUENT IRRIGATION DOES NOT INCREASE SOIL HEAVY METAL LOAD AT OMAHA WWTP TREATMENT FIELDS

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ABSTRACT

The Omaha wastewater treatment plant is located near Matakana approximately 70 km north of Auckland CBD. The plant treats wastewater from local townships and has been in operation since 1982; undergoing expansions in 2000 and 2004, due to increased residential development. Treated effluent is applied by underground dripper to the Omaha golf course and nearby peatland. To fulfil their obligations for continued operation of the treatment site, Watercare requested Manaaki Whenua–Landcare Research to prepare a report detailing any soil or vegetation differences between effluent irrigated and non-irrigated areas of golf fairways, dunes and peatland. From 24 by 0–200 mm deep soil samples we did not detect any significant differences in heavy metals except for cadmium in the peaty soils where the cadmium concentration was greater in the non-irrigated site than the irrigated site. There were significant differences in some exchangeable cations and Olsen P, with levels increasing under irrigation especially in sandy soils which likely have low CEC. Visual observation of soil physical properties in the sandy soils and near-saturated hydraulic conductivity in the peaty soils did not reveal any difference in soil physical properties. No adverse effects on vegetation were detected.

Manaaki Whenua
Landcare Research

MANAAKI WHENUA – LANDCARE RESEARCH

WWTP IRRIGATION AT OMAHA

Malcolm McLeod

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Whangateau
Ti Point
Big Omaha
Point Wells
Omaha
Sir John Key sold his place here
Little Omaha Bay
Matakana


Golf course sandy soils
Eucalyptus peaty soils
WWTP

Fairway	Dune	Eucalyptus
		
Sandy	Sandy	Peaty

Subsurface irrigation at sandy fairways and dunes (15-50 cm), below litter in peaty eucalypt forest

Judging from this found in the rough

- An expensive house by the sea and expensive overseas holidays does not guarantee good golf

Omaha WWTP 300,000 m^3/year 1500 connections

- 4 mm inlet screen
- Aerated lagoon
- Oxidation pond
- Storage dam
- Tertiary filters
- UV disinfection
- 200 micron filtration

Typical wastewater discharge quality

Parameter	Range of mean
pH	7.3-7.9
DO (mg/L)	7.3-9.1
F. coliforms (cfu/100 mL)	2.5-7.2
TSS (mg/L)	8.1-8.4
NH_4-N (mg/L)	8.4-19.3
NO_3-N (mg/L)	3.9-6.5

For consenting purposes

- 0-20 cm soil samples fairways, dunes, eucalypt forest
- Chemical and physical properties incl. changes indicative salt damage
- Vegetation survey
  - Type
  - Weeds
  - Soil cover
  - Vegetation health
- Concentration of metals

Methods – physical, chemical

- Irrig & non-irrig sites sandy fairways, sandy dunes, peaty eucalypt forest 4 reps each
- Tube sampler to get soil samples for chemistry
- Visual inspection soil pit to 20 cm on sandy soils to check for effect of salts
- Near saturated hydraulic conductivity cores in peaty soils (10 reps both irrig & non-irrig)

Methods - vegetation

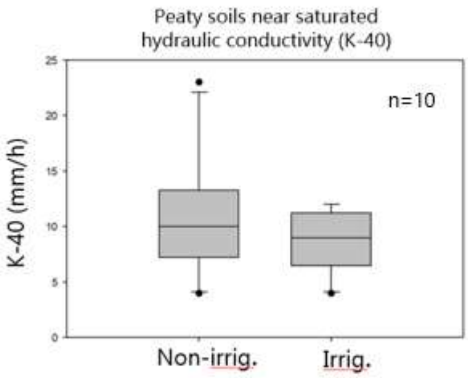
- 1 m^2 quadrat for veg assessment (4 reps)

Chemical properties

- For the sandy sites
  - Olsen-P and K^+ greater in irrigated soils
  - Mg^+ and Na^+ greater in non irrigated soils
- For the peaty sites
  - pH, Ca^{2+} and Na^+ greater in irrigated soils

Physical properties

- No visible differences soil profile sandy soils



Vegetation

- Minor differences between irrigated and non-irrigated sites
- No differences that could be attributable to "salt damage"

Irrigated | Non-irrigated | Irrigated | Non-irrigated

Metals

- This was quite hard for me but luckily our expert Jo Cavanagh was to hand
- And what to do with left censored data? A whole career talking about it.
- Analysed for "totals" of
  - As, Cd, Cu, Pb, Ni, Zn

- All values lower than or within median background range for NZ soils.

Metals

- In the sandy soils = fairways and dunes

- No significant difference between non-irrigated and irrigated sites

Metals

- Values for metals at one peaty non-irrigated site were greater than other peaty sites
- No explanation
- But no significant difference between non-irrigated and irrigated sites

Metals – Ecological Soil Guideline Values Eco-SGVs

- Jo Cavanagh is the expert, I only dig holes and paraphrase
- Standardise the toxicity data
  - Use EC30 toxicological endpoint (WTF is this?)
  - Effective concentration at which there is a 30% reduction in the endpoint (e.g., root growth, root elongation) being measured

Metals – Ecological Soil Guideline Values Eco-SGVs

- Ageing/leaching factor
  - Decreases toxicity for contaminants added to soil
- Normalise to minimise effect of NZ soils on toxicity data
  - Based on typical, sensitive, tolerant soils
    Brown, Recent, Allophanic

Metals – Ecological Soil Guideline Values Eco-SGVs

- Account for secondary poisoning
  - Food, recreational, ecologically sensitive areas
- There is a report on Envirolink site on Eco-SGVs
- Talk to Jo Cavanagh in the MWLR Lincoln office

Thanks

- Watercare
- Jo Cavanagh