National SCIENCE Challenges

OUR LAND AND WATER

Toitū te Whenua, Toiora te Wai

Benign de-nitrification in the subsurface environment

NSC Our Land and Water Annual Symposium, 11-12 April, Lincoln University, Christchurch

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*Presenting on behalf of our students, post-doc and colleagues Mr. Aldrin Rivas, Mr. Ahmed Elwan, Mr. Pete McGowan, Mr. Stephen Collins, Ms. Genevieve Smith, Ms. Heather Martindale, Dr. Uwe Morgenstern, Dr. Neha Jha, Dr. Andrew McMillian, Dr. Andrew Manderson, Dr. Lucy Burkitt , A/Professor David Horne, Professor Mike Hedley, Ms. Abby Matthews, and Dr. Jon Roygard

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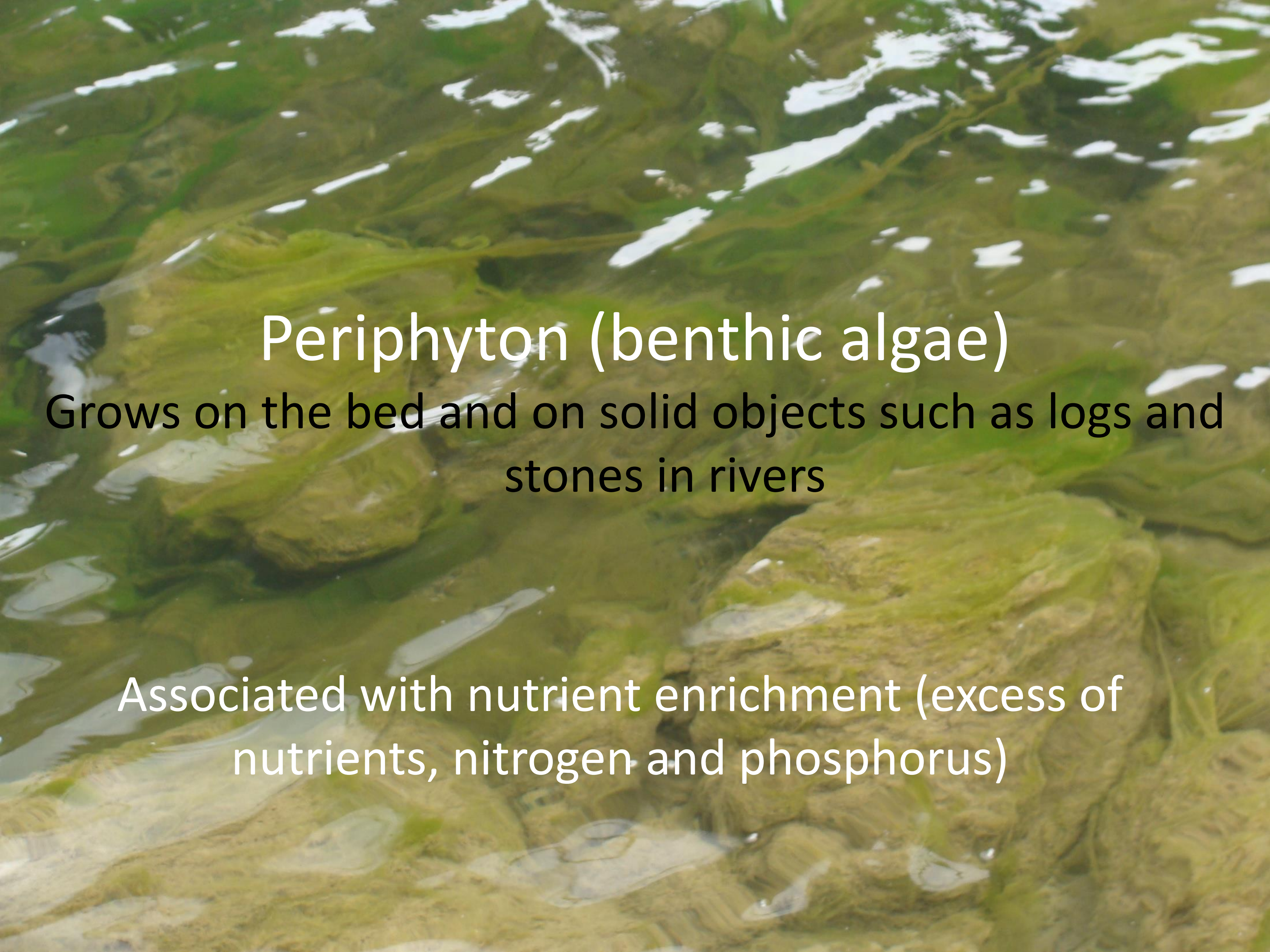
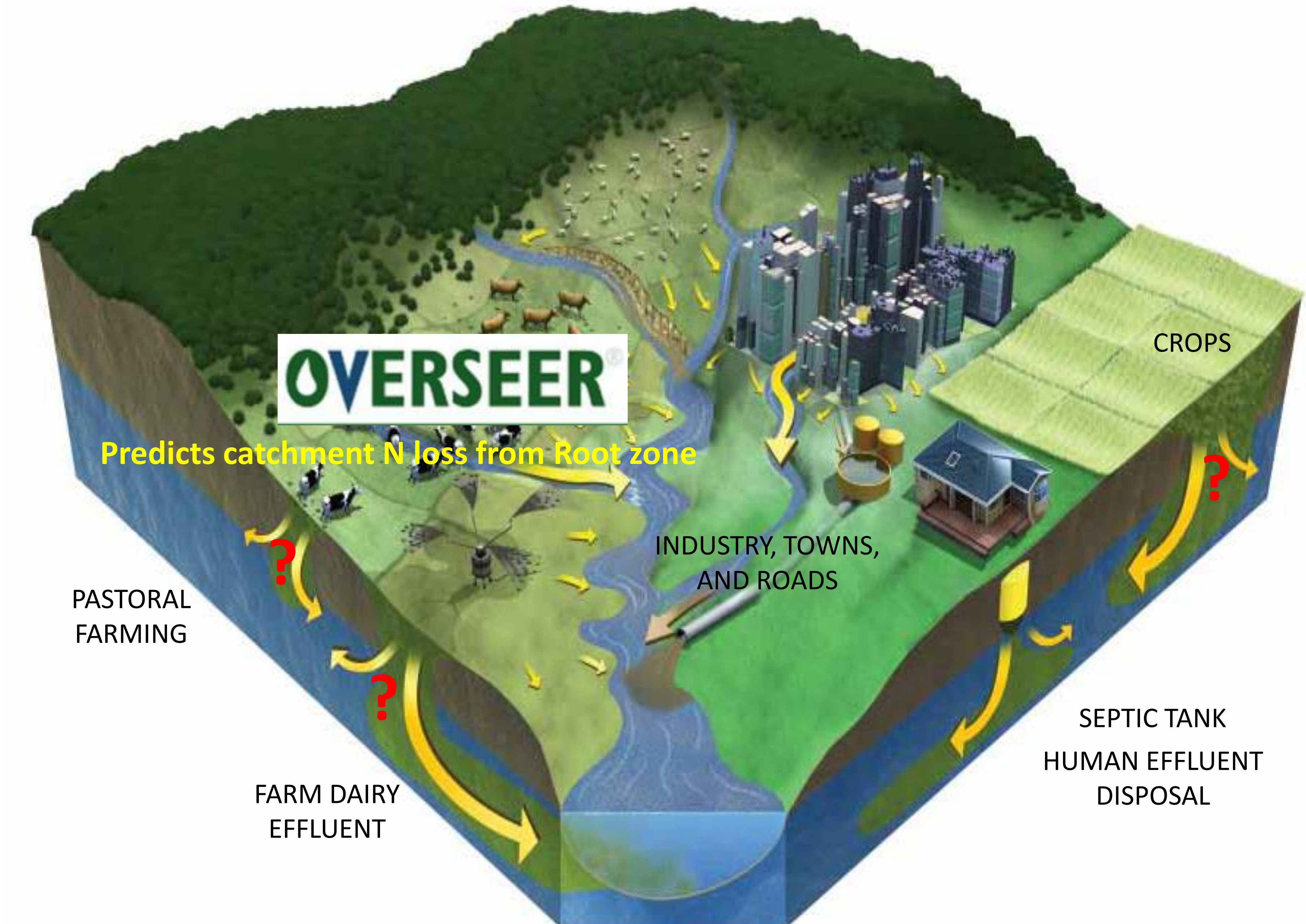


Periphyton (benthic algae)

Grows on the bed and on solid objects such as logs and stones in rivers

Associated with nutrient enrichment (excess of nutrients, nitrogen and phosphorus)

Sources and contributions to nutrient loadings?



Source: Environment New Zealand 2007, MfE.

Manawatu Catchment @ Upper George

Nitrogen attenuation factor (AF_n)

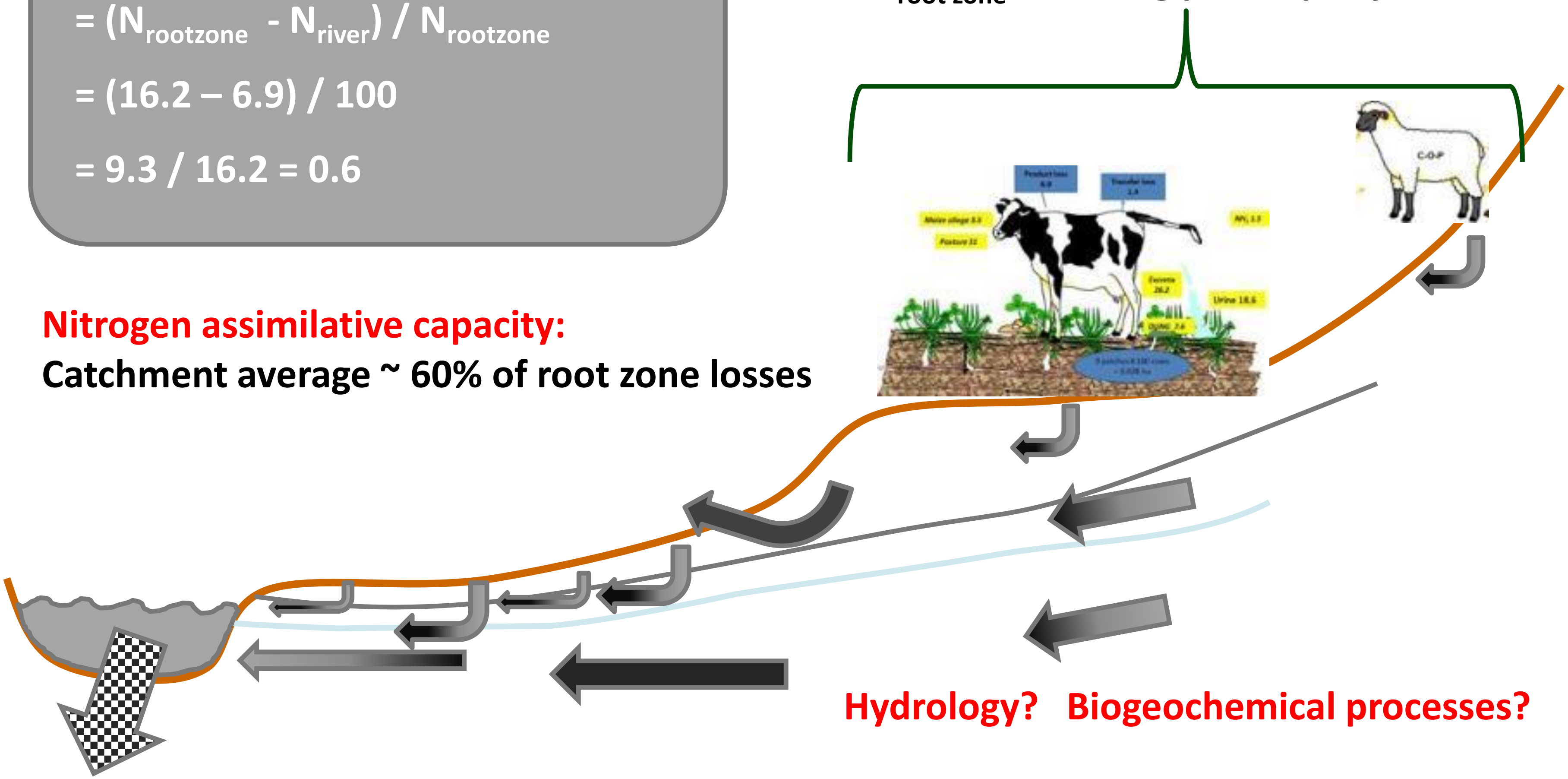
$= (N_{rootzone} - N_{river}) / N_{rootzone}$

$= (16.2 – 6.9) / 100$

$= 9.3 / 16.2 = 0.6$

Root zone N losses (catchment average):

$N_{root\ zone}$ = 16.2 kg per ha per year



Nitrogen assimilative capacity:

Catchment average ~ 60% of root zone losses

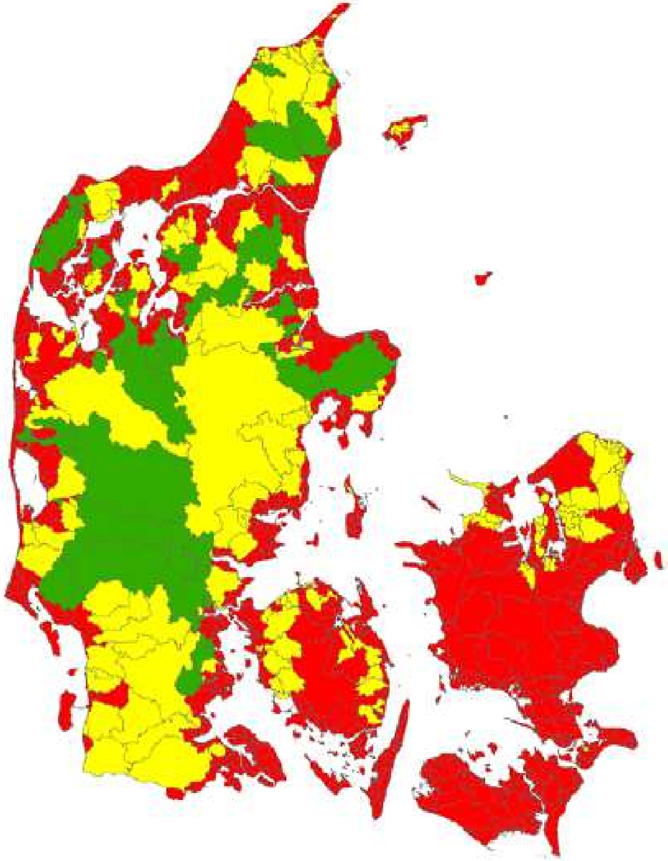
Hydrology? Biogeochemical processes?

River N load (catchment average):

N_{river} = 6.9 kg per ha per year

Source: Elwan et al. (2015), Massey University

Sustainable primary production



Example: The Danish national map of nitrate reduction classes.
(Source: Ernstsen et al., 2008)

	Nitrogen Attenuation Capacity	Targeted investment in solutions, e.g.
Green	> 80 % N reduction	**High Capacity Areas:** Sustainable Land Use Intensification
Yellow	50 – 80 % N reduction	**Medium Capacity Areas:** Reduce Nitrogen Leaching via Best Effluent and Nutrient Management Practices
Red	< 50 % N reduction	**Low Capacity Areas:** Duration controlled grazing Sheep/Goat milking Cut and Carry Systems

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A collaborative, co-developed and co-funded research programme

Programme Co-ordination


Dr. Ranvir Singh


Assoc. Prof. Dave Horne


Dr. Uwe Morgenstern


Ms. Abby Matthews


Dr. Jon Roygard


Prof. Mike Hedley

Programme Partners

Massey University – Te Kunenga ki Pūrehuroa – University of New Zealand

horizons regional council

Landcare Research – Manaaki Whenua

Fertilizer & Lime Research Centre

DairyNZ

GNS Science – Te Pū Ao

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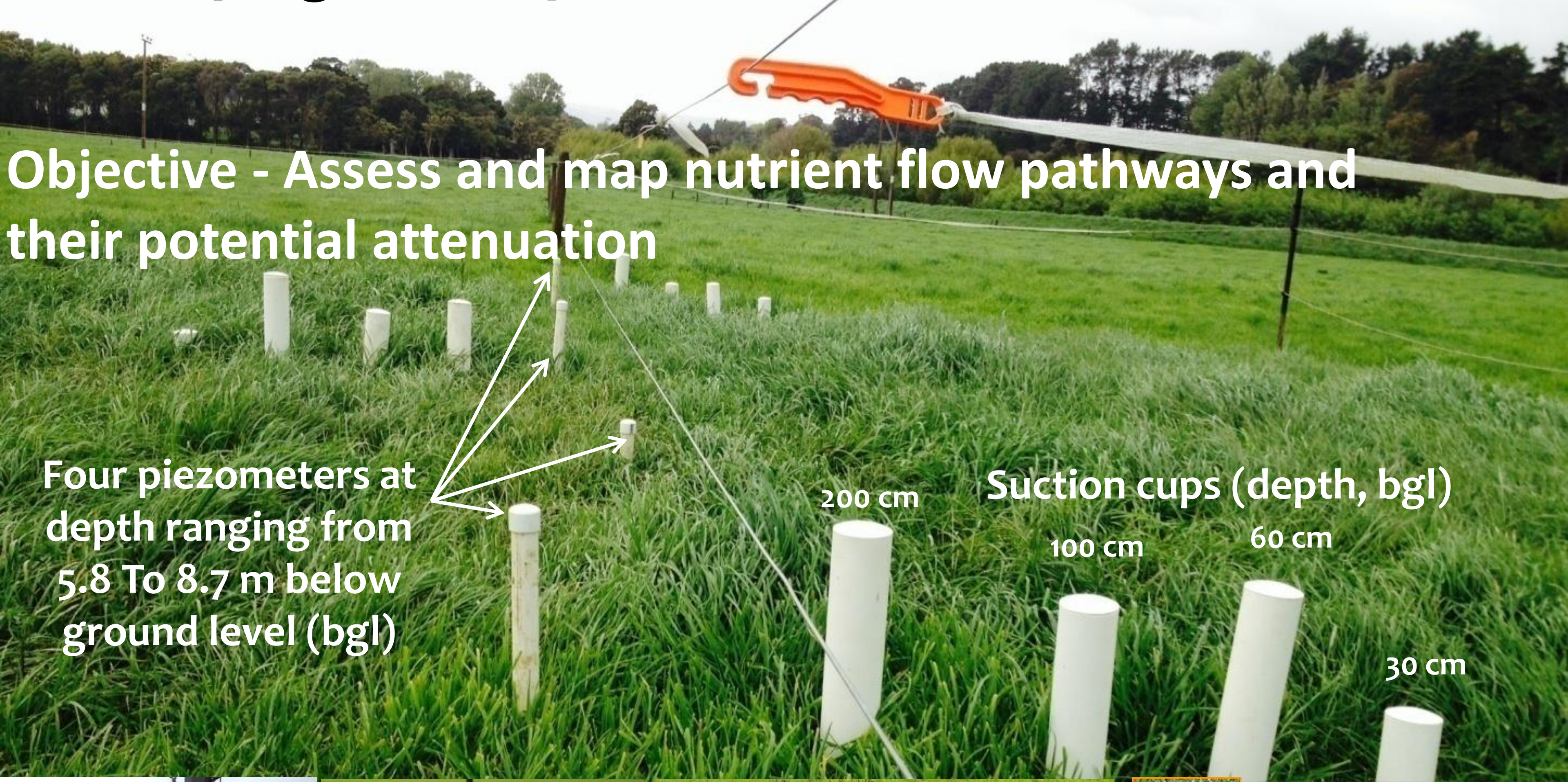
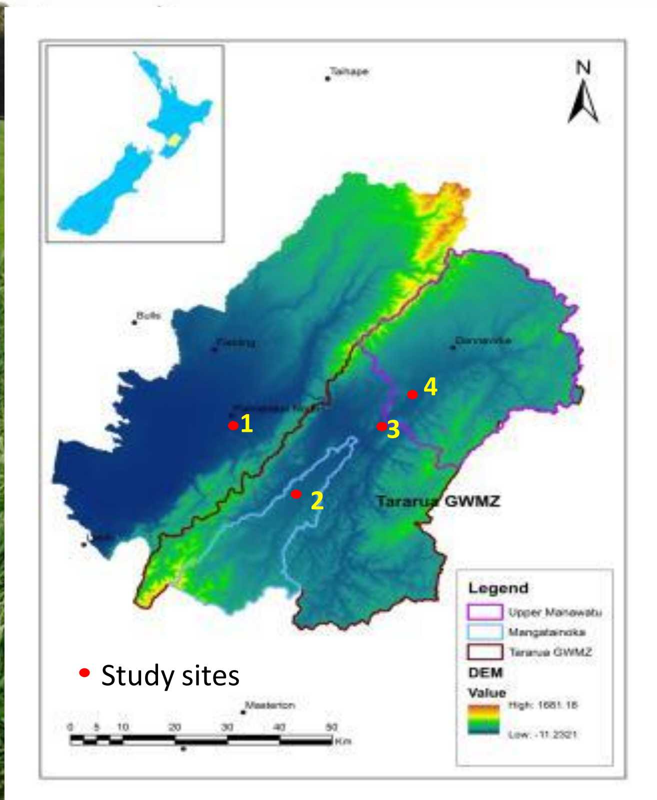
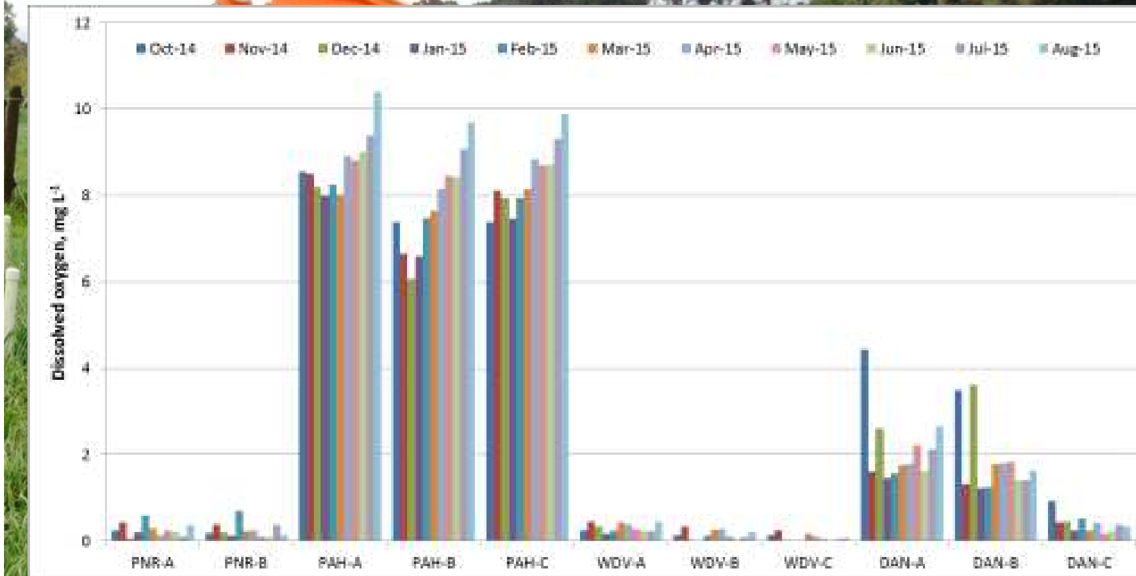
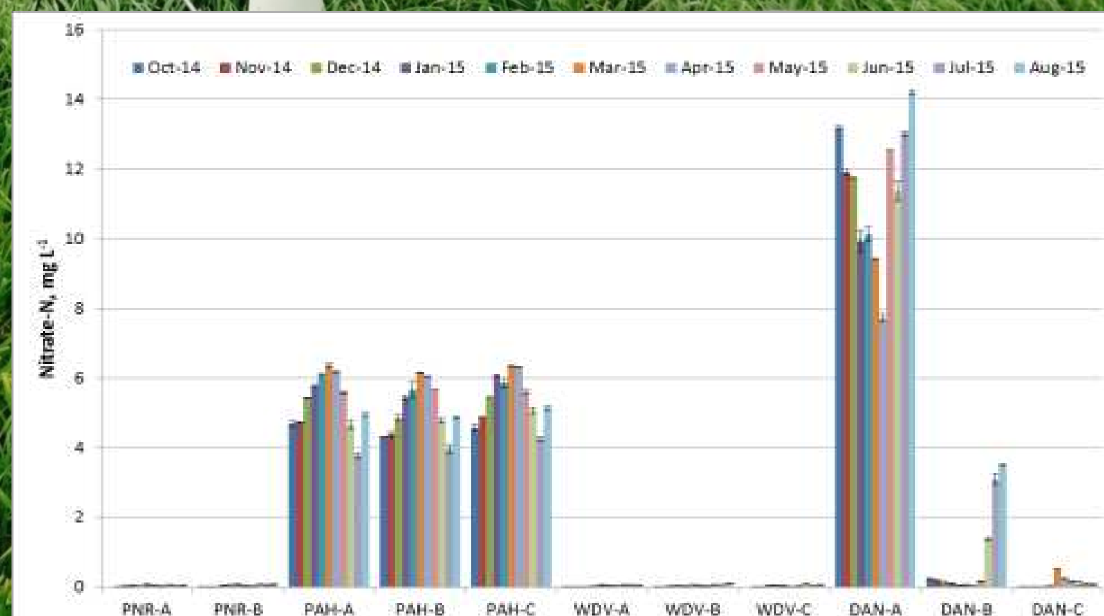
Developing techniques, methods and models



In-field monitoring and observations







1. Massey No. 1, Dairy
2. Pahiatua site, Dairy
3. Woodville site, Sheep & beef
4. Dannevirke site, Dairy

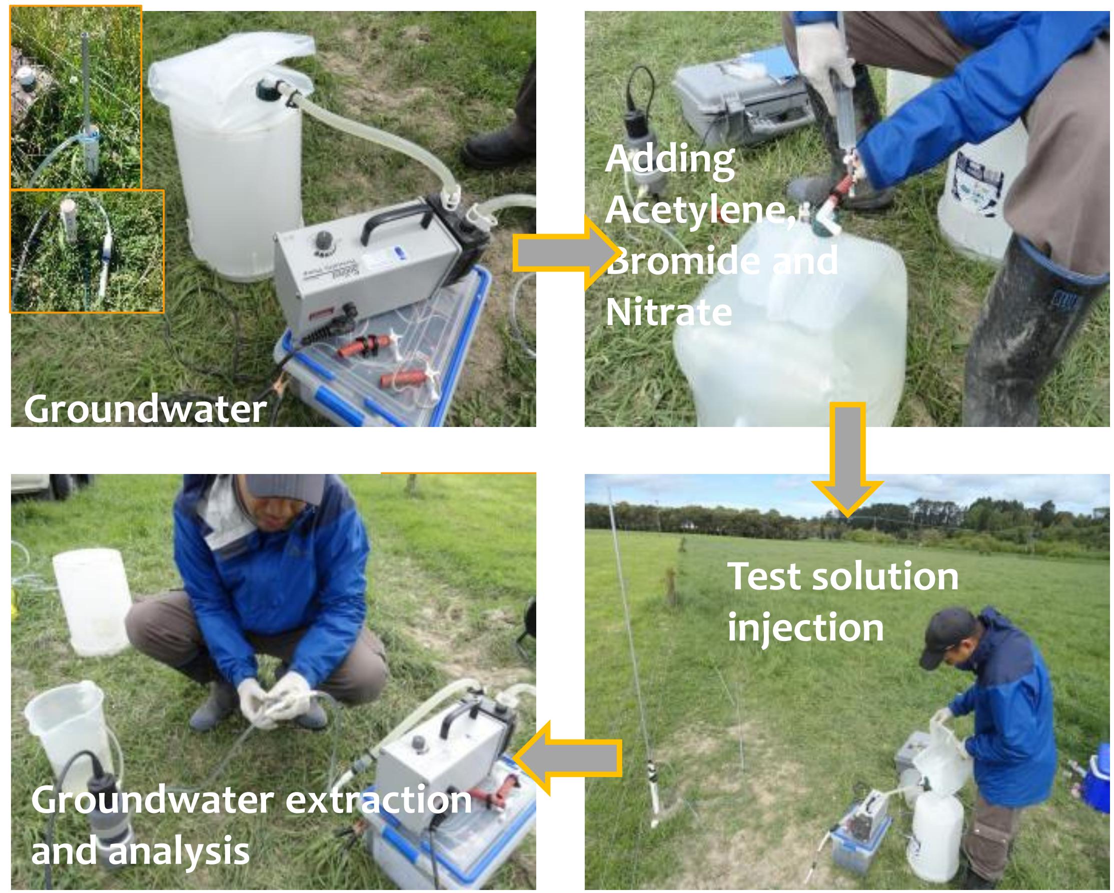
Source: Aldrin Rivas,
PhD Student, Massey University

De-nitrification: the key nitrogen attenuation process

Methods:

- Lab incubations and in-field ‘push-pull’ tests
- Isotope tracer techniques
- **Excess N_2** (being developed by GNS Sciences)
- **Molecular techniques** (being developed by Massey FLRC and Landcare Research)

Single Well ‘Push-Pull’ Test



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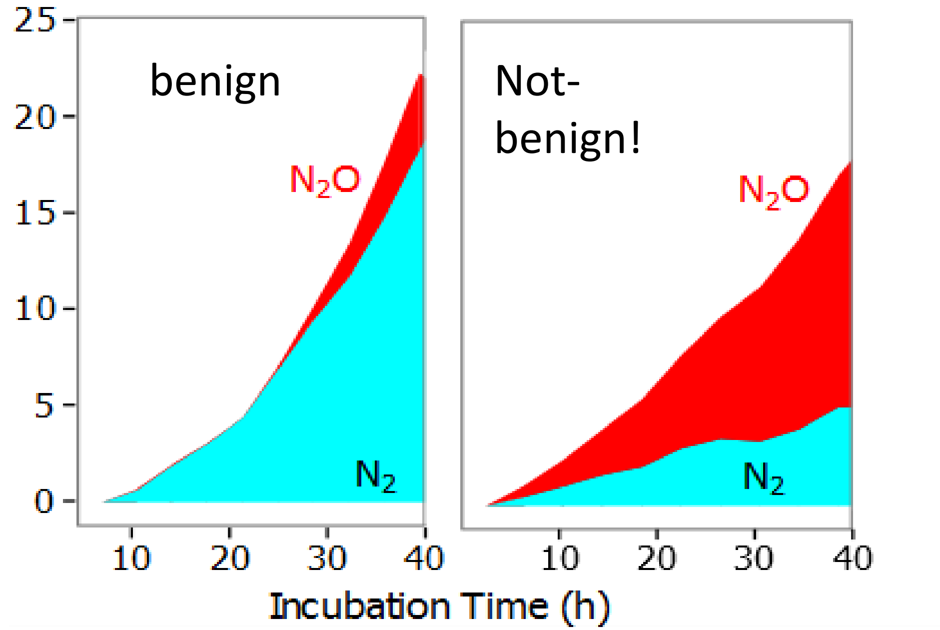
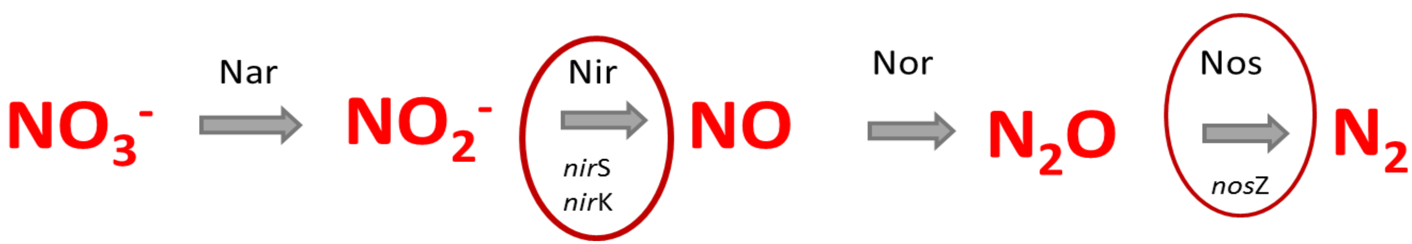
De-nitrification: the key nitrogen attenuation process

Groundwater de-nitrification? benign or not-benign?

- Direct measurement of the terminal products of denitrification, N_2O and N_2

- Direct measurement of the de-nitrifiers, *nir*S, *nir*K and *nos*Z genes





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Relationships between nitrogen attenuation and catchment characteristics

Nitrogen attenuation factor (AF_n) = ($N_{rootzone}$ - N_{river}) / $N_{rootzone}$

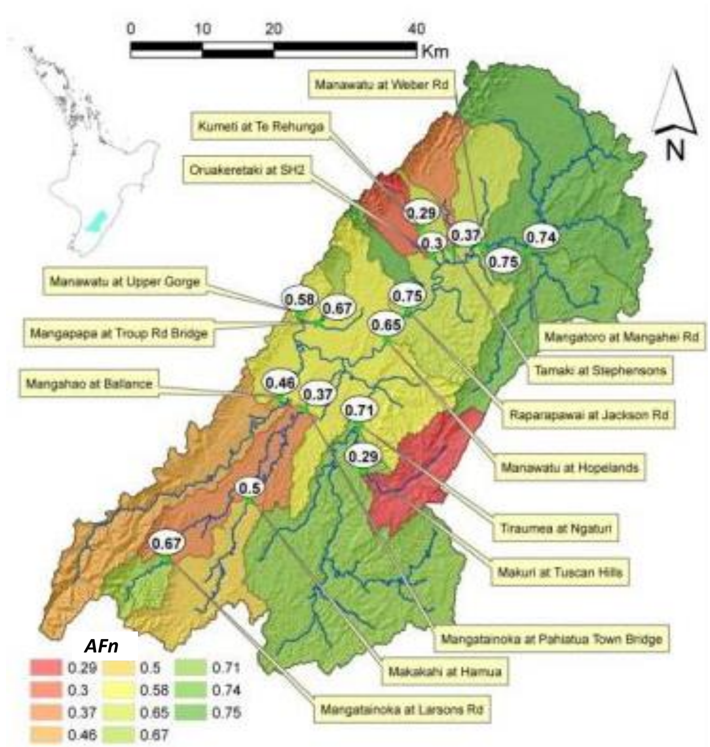
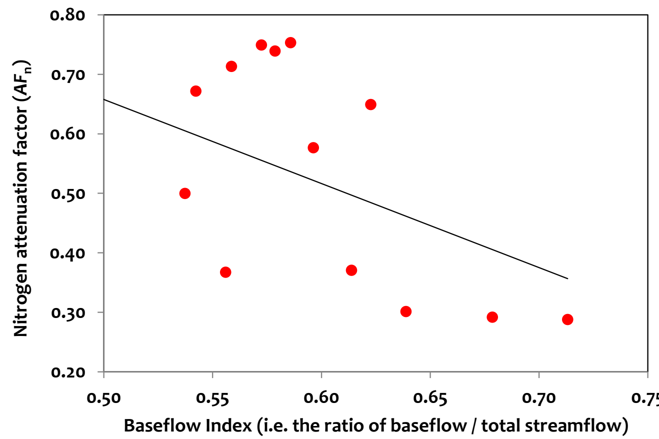


Table 1: Results of linear regression analysis between the AF_N values and catchments characteristics

Catchment Characteristics	AF_N	
	R^2	p
Well-drained (e.g. soils with drainage class 5) soils*	-0.35	<0.05
Fine textured (e.g. clay loam) soils	0.37	<0.05
Base Flow Index (*BFI*)	-0.31	<0.05

*Soils with drainage class 5, in the Fundamental Soil Layer "FSL", are well-drained soils.



Spatial distribution of the nitrogen attenuation factor for 15 sub-catchments in the Tararua Groundwater Management Zone (TGWMZ) (Elwan et al, 2015).

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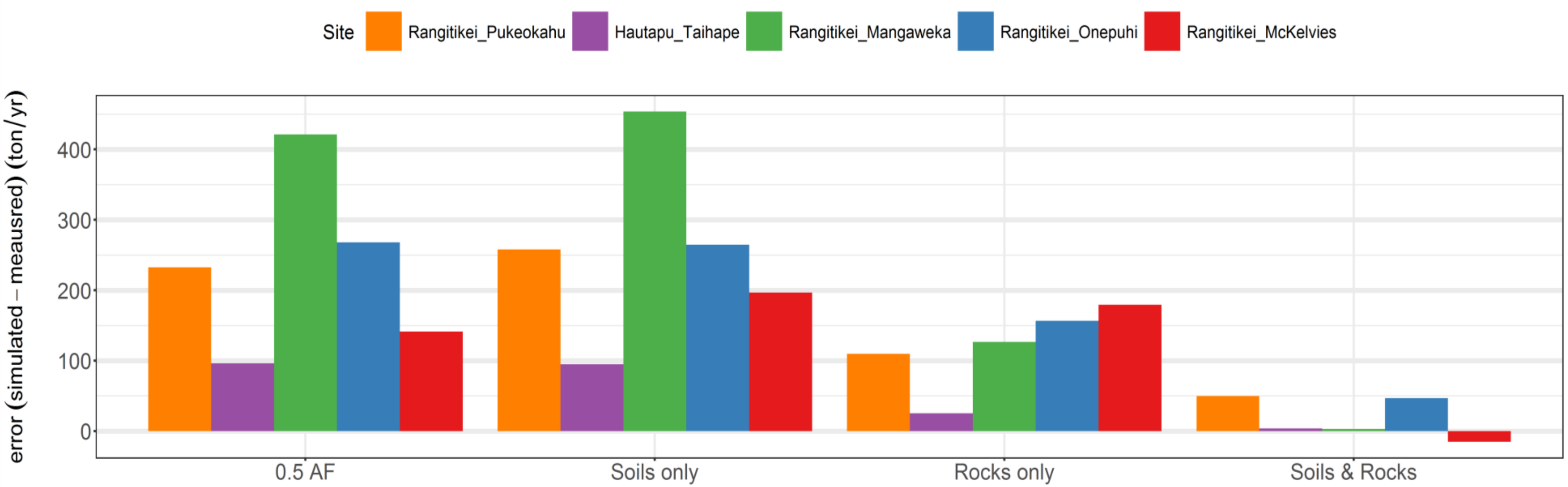
Prediction of nitrogen loads in the Rangitikei River

Model - Variable nitrogen attenuation factor (based on soil and rock types – *FSL* and *QMAP* layers)

$$River\ N\ load\ (ton\ \mathrm{yr}^{-1}) = m \sum_{i=1}^{n} A_i * N_i * (1 - AF_{N_{RT}})(1 - AF_{N_{ST}})$$

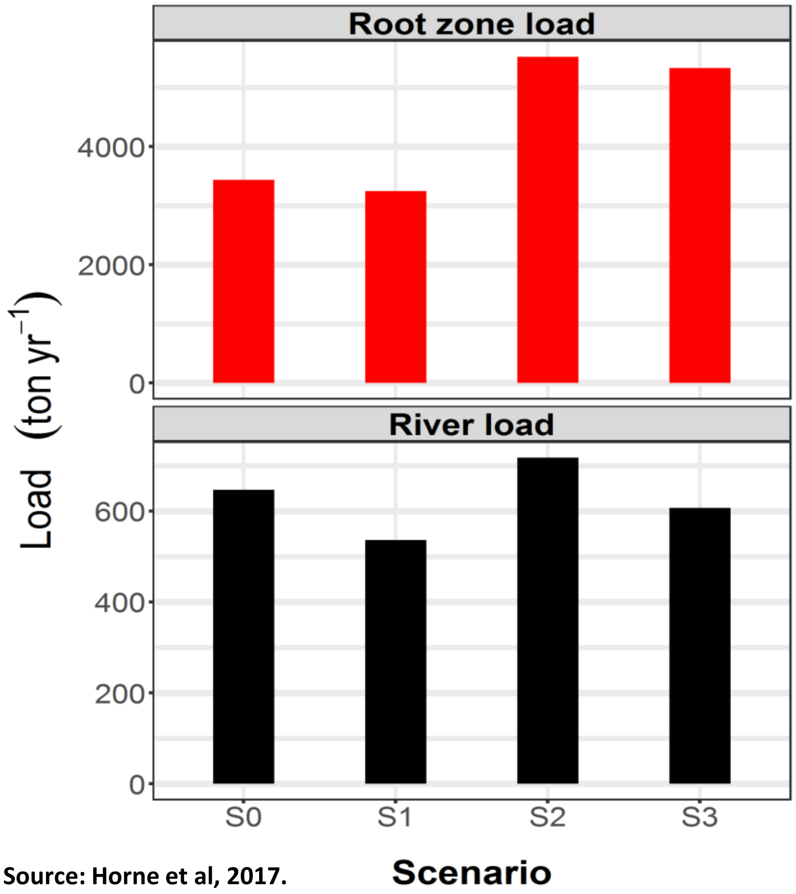
Comparison of predicted vs. measured average annual soluble inorganic nitrogen (SIN) loads in different sub-catchments of the river



Source: Singh et al, 2017.

Prediction of nitrogen loads in the Rangitikei River

De-intensify (~9,800 ha) and Intensify (~83,000 ha) landuse (S3)



Source: Horne et al, 2017.

Root zone N losses increase by 55%

River N load decreases by 6%

Concluding Remarks

- Opportunity to spatially align intensive high-value primary production with naturally high contaminant attenuation capacity areas

- Reduce water quality impacts, hence sustain and/or enhance cultural resources, mahinga kai, taonga species.

- Collaborative, co-developed, co-funded research programme

- Developing cost-effective practical techniques, methods and models

- Aligned with the OLW Challenge 'Sources and Flows' & 'Land Suitability' programmes for wider applications

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Thank you – Questions
and suggestions please!

Supporting Slides

De-nitrification: the key nitrogen attenuation process

De-nitrification is a biogeochemical process, which converts nitrate-nitrogen to gaseous forms of nitrogen; predominantly to dinitrogen in groundwater systems.

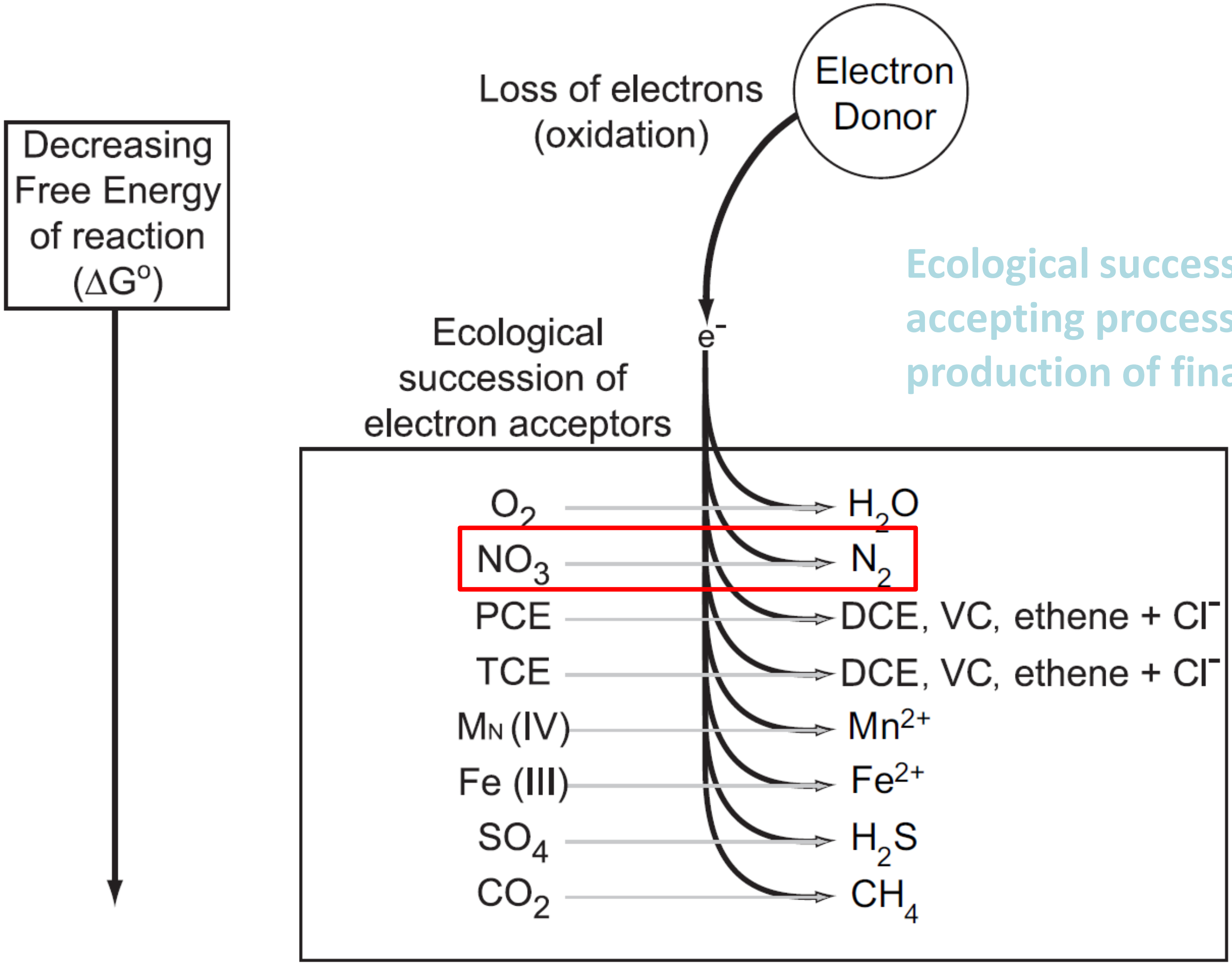
benign de-nitrification

Nitrate (NO_3^-) → **Nitrite (NO_2^-)** → **Nitric Oxide (NO)** → **Nitrous Oxide (N_2O)** → **Dinitrogen (N_2)**

This capacity is mainly governed by the physical, chemical and biological characteristics, and importantly by nutrient and oxidisable carbon in flow pathways. It requires

- Low oxygen environment (influenced by hydrogeological settings);
- Carbon source (dissolved organic carbon); and
- Denitrify bacteria

De-nitrification: the key nitrogen attenuation process



Ecological succession of electron-accepting processes and sequential production of final products

Source: McMahon & Chapelle (2008)

De-nitrification: the key nitrogen attenuation process

Table 1
Threshold Concentrations for Identifying Redox Processes in Regional Aquifer Systems

	Water Quality Criteria (mg/L)					
Redox Process	**O_2**	**NO_3^--N**	**Mn^{2+}**	**Fe^{2+}**	**SO_4^{2-}**	**Comments**
Oxic						
O_2 reduction	≥0.5	—	<0.05	<0.1	—	—
Suboxic						
—	<0.5	<0.5	<0.05	<0.1	—	Further definition of redox processes not possible
Anoxic						
NO_3^- reduction	<0.5	≥0.5	<0.05	<0.1	—	—
Mn(IV) reduction	<0.5	<0.5	≥0.05	<0.1	—	—
Fe(III)/SO_4^{2-} reduction	<0.5	<0.5	—	≥0.1	≥0.5	—
Methanogenesis	<0.5	<0.5	—	≥0.1	<0.5	—
Mixed						
—	—	—	—	—	—	Criteria for more than one redox process are met

de-nitrification? benign or not-benign?

Source: McMahon & Chapelle (2008)

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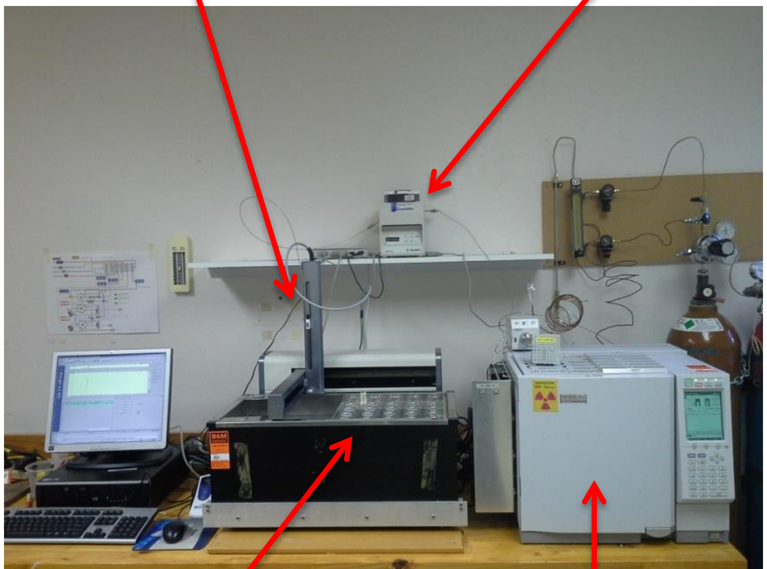
Direct measurement of the terminal products of denitrification, N_2O and N_2

Automatic sampler

Peristaltic pump



25 sealed vials

Gas Chromatograph
With 3 detectors:
ECD, FID and TCD

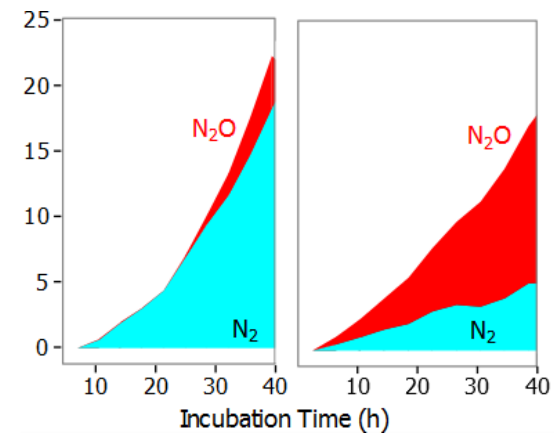
The Dynamics of Denitrification
Gas Chromatograph (DDGC)

Helium
Headspace

20 g dwt soil

125 mL Serum Vial

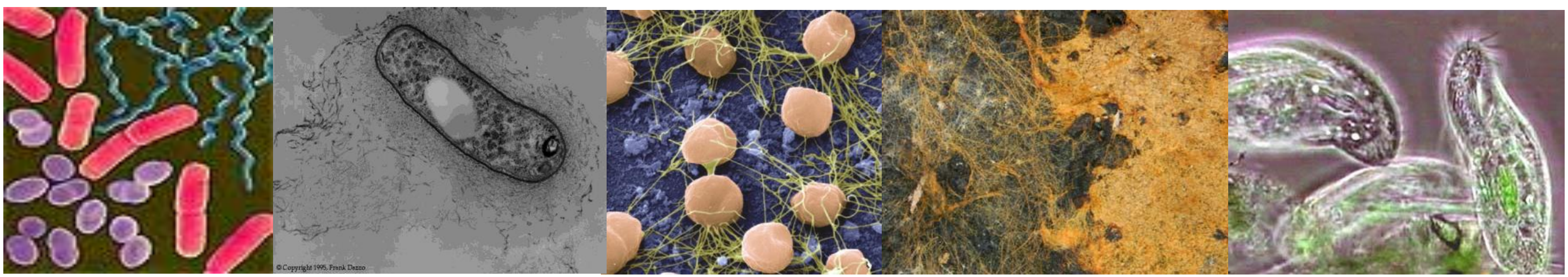
how “benign” the de-nitrification, i.e. calculate the N_2O:N_2 ratio



Direct measurement of the de-nitrifiers, *nir*S, *nir*K and *nos*Z genes

$$NO_3^- \xrightarrow{\text{Nar}} NO_2^- \xrightarrow[\text{nirS, nirK}]{\text{Nir}} NO \xrightarrow{\text{Nor}} N_2O \xrightarrow[\text{nosZ}]{\text{Nos}} N_2$$

- Anaerobic respiration
- Phylogenetically diverse: Bacteria, Archaea, Fungi, Protozoa



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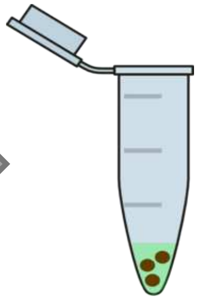
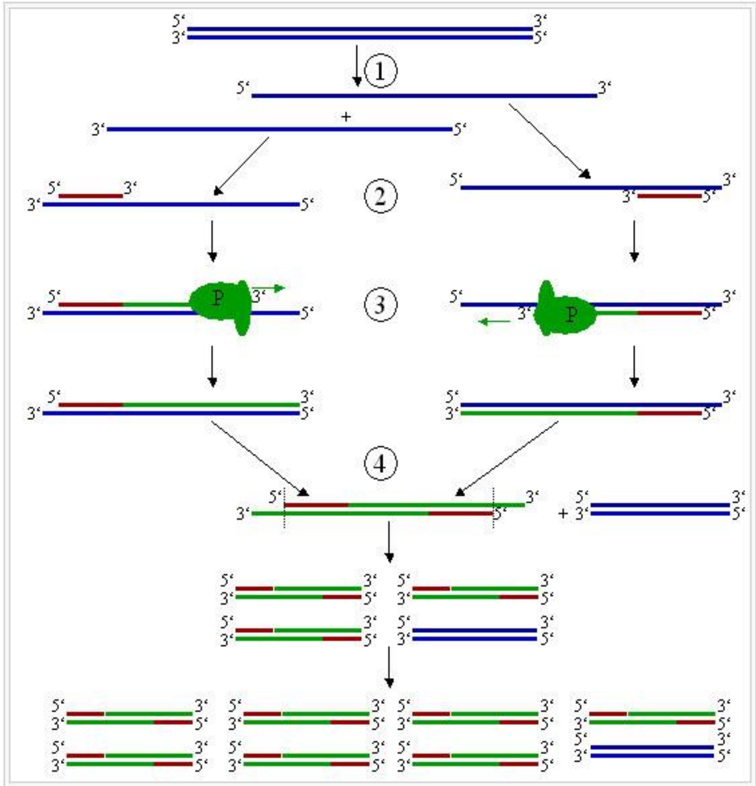
Direct measurement of the de-nitrifiers, *nir*S, *nir*K and *nos*Z genes

Polymerase Chain Reaction (PCR) technique

Soil Sample



Extracted DNA



Amplified gene of interest

Amplified product visible on gel