# Linking soil quality, land use pressure and water quality

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# Overview

- Background, aims and ‘take-home messages’
- Data and statistical modelling
- Linking soil quality to land use pressure
- Overview of storymap
- Linking soil quality and land pressures to water quality
- Conclusions and implications

# Background

- Soil quality has been used to evaluate effect of land use intensification on water quality at a local scale, but not at catchment or national scales.

- Land use pressures (e.g. stock units, land value) have been related to land use intensity, and are now publicly available, nationally.

- Land value could be used as an indicator of land use pressure:
  - Publicly accessible, well defined, and routinely estimated
  - Has not been evaluated previously

- Soil quality and land value are measured at the farm scale, and may reflect changes in land management practices

- Could these factors with catchment characteristics help explain catchment water quality trends?

# Questions

- What relationship exists between land value, soil quality, and land pressure indicators (dominant land use, stock units, catchment characteristics)?
- Can linking land use pressure and soil quality help predict catchment water quality?

# Aims

- Link soil quality indicators to indicators of land use pressure
- Link soil quality, land pressures, and catchment characteristics to median water quality for the past 15 years

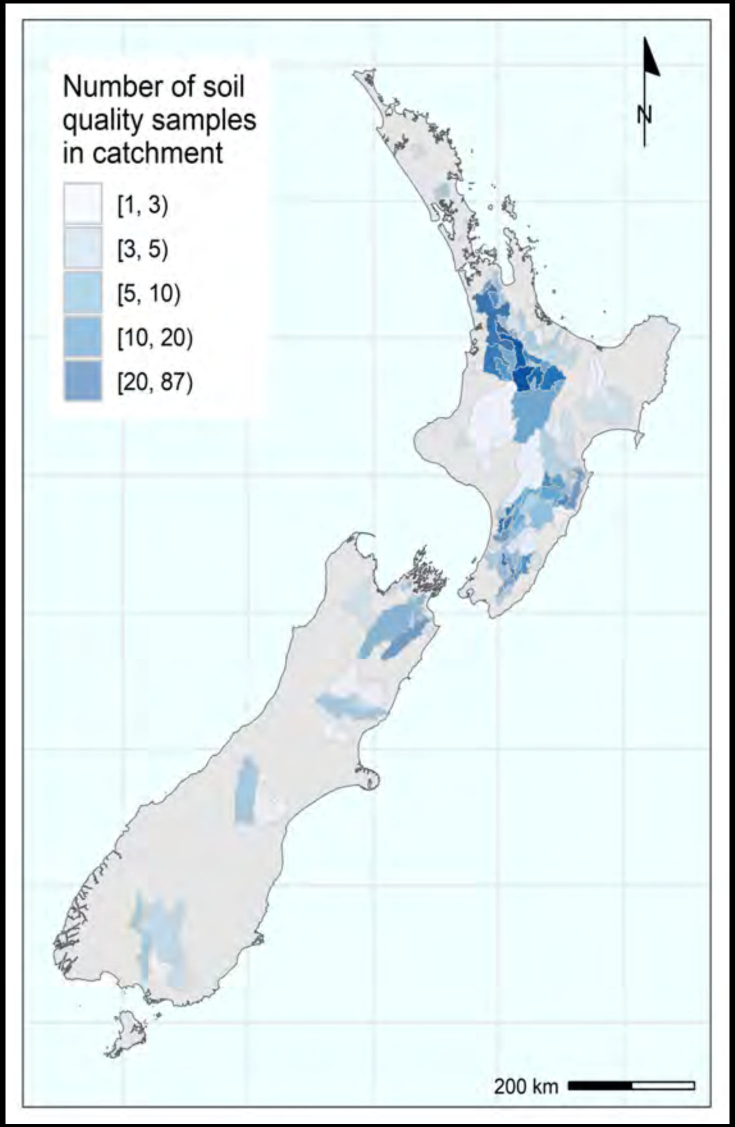
# Take-home messages

- **Soil quality and land pressure**
- Soil carbon, P, and bulk density had a highly significant effect in predicting land value.
- Other soil quality indicators, dominant land use, stock units, and catchment characteristics had little effect in predicting land value.

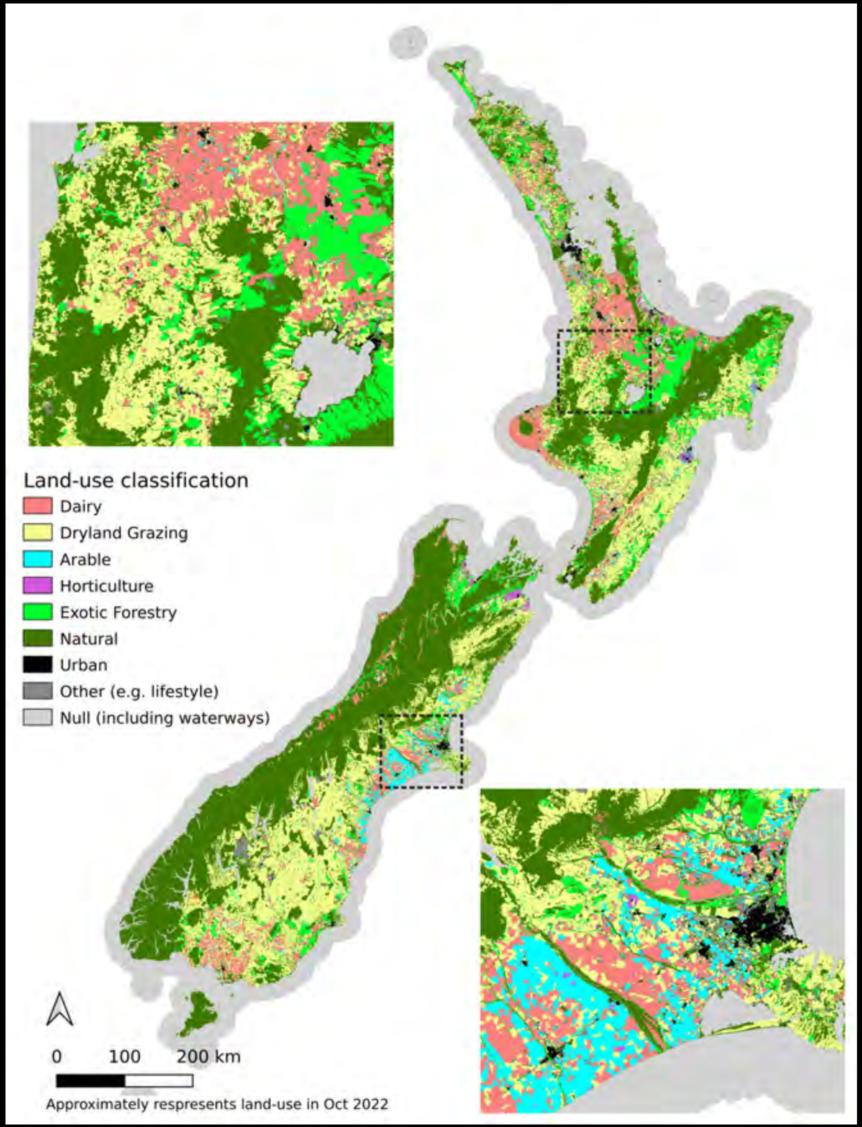
- **Water quality**
- The state and trend of water quality was strongly related to land use, catchment and climatic characteristics.
- Water quality relationships with soil quality and the land use pressures were weak.

# Study data sources

- Water quality
  - Up to 15 years of 8 analytes (e.g. visual clarity, total nitrogen), generally sampled every 28 days
  - Sampling locations from:
    - Land, Air, Water, Aotearoa website (www.lawa.org.nz) (873 sites)
    - NIWA's National River Water Quality Network (NRWQN) (35 sites)
    - 192 catchments that also hold soil quality data (about 20% of catchments, 31% of land area)
- Soil quality
  - Range of soil properties sampled 1995-2020 by Regional Authorities
  - Up to 85 properties measured; we chose 6 key properties for this study
- Land value
  - Property valuation data including a ratings unit and an improvement value
- Land use
  - Land Cover Data Base, AsureQuality's AgriBase, QEII National Trust boundaries
  - 8 land use classes as proportions of each catchment as of October 2022
- Livestock type and stocking rate
  - Combined AgriBase farm locations, 2015–2020 Agricultural Production Survey, to give stock equivalent units within a catchment




Soil quality



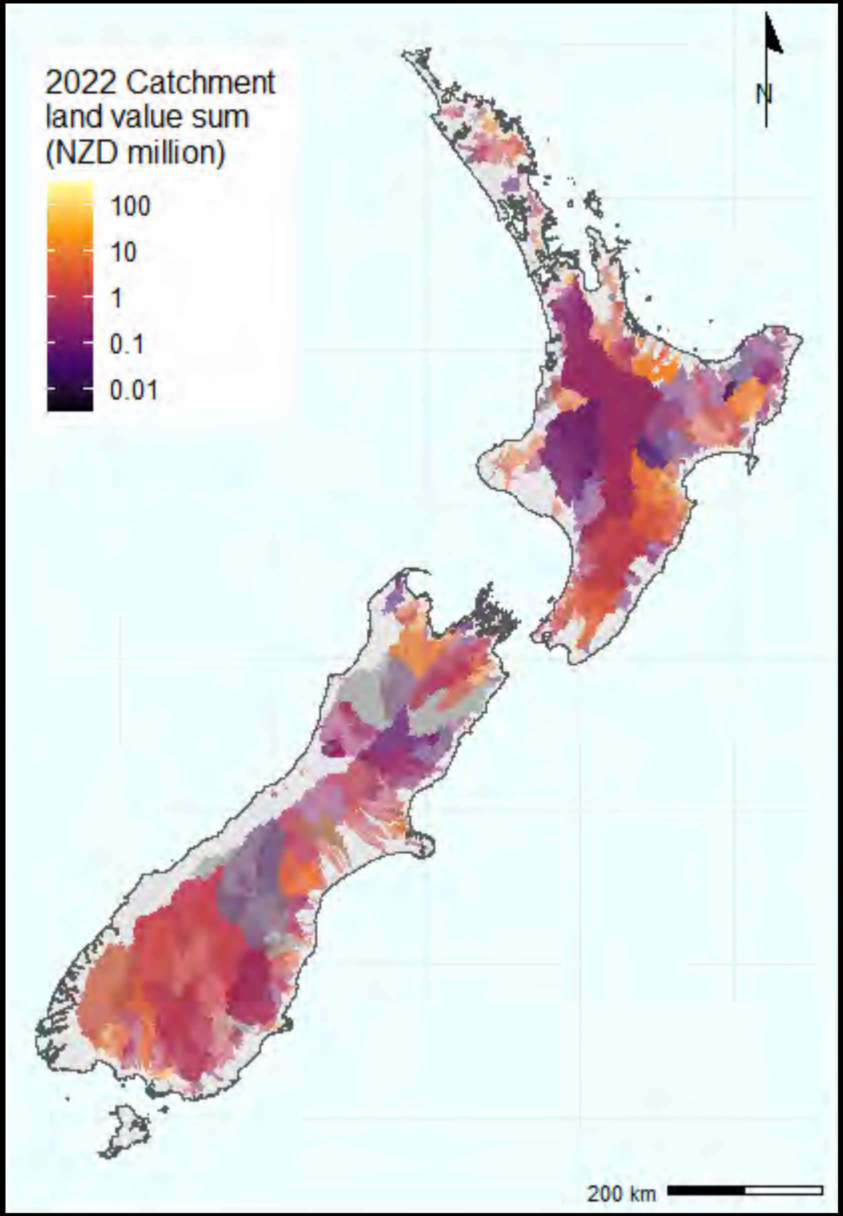

Land use

# Land value

- There are practical difficulties defining land value:
  - Some areas have no defined value (e.g. national parks, protected areas), so we assign a very small value
  - Some areas have no data available at all
  - Constituent data is imperfect, so cleaning is required

- Since a catchment can cover a large land area, the association between total land value and intensification is diffuse

- Key question here is whether land value is a viable surrogate for intensification



# Statistical modelling

## Characteristics of the water quality data analysis

- An irregularly-sampled time series exhibiting within- and between-year trends
- Behaviour is catchment-specific, moderated by the overall effect of land use, soil, etc
- Unknown effect of land value and soil quality data with all other covariates

## Time series analysis

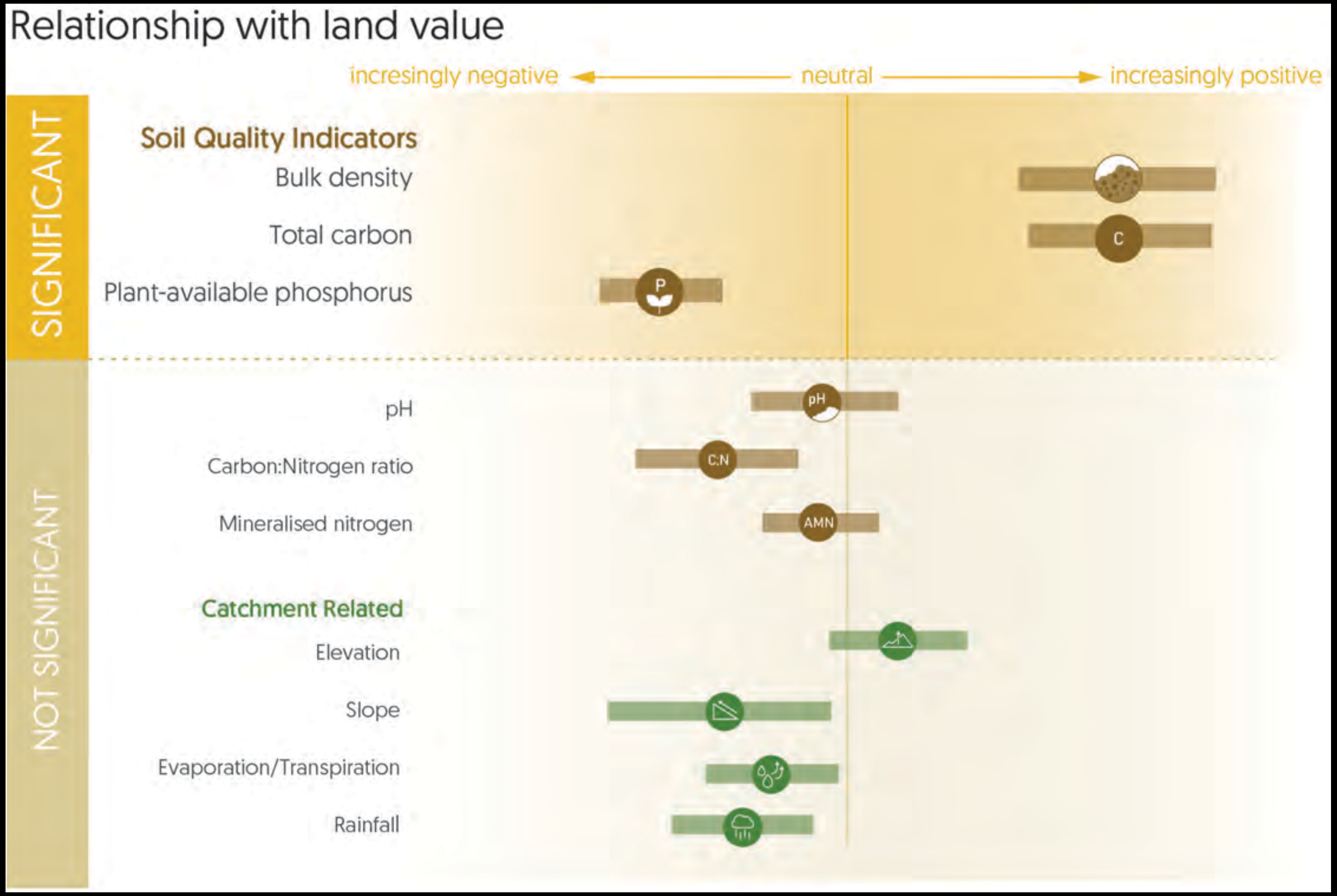
- Semi-parametric model to adapt to the characteristics of each catchment, while incorporating the effect of covariates
- Use a generalised additive model (GAM)
- Makes extensive use of the New Zealand eScience Infrastructure (NeSI) high performance computing facilities

## Soil quality and land pressure

- Analysis designed to understand the relationship between covariates
- A relatively straightforward linear model

# Soil quality and land pressure - key results

- Carbon concentration, Olsen P, and bulk density have a highly significant effect in predicting land value
- Other variables including dominant land use have no significant effect in predicting land value



# .....more detail

- Carbon concentration had a positive relationship with land value (plausible)
- Bulk density had the greatest positive association with land value (plausible)
- An increase in Olsen P is associated with a reduction in land value (unexpected)
- The interaction terms for bulk density and exotic forestry were significant, or highly significant (carbon and exotic forestry)
- The interaction terms (Olsen P and dairy; carbon and dairy) were marginally significant
- Modelling of high land value was adequate, but was poor for low land values

# Revealing research through a storymap

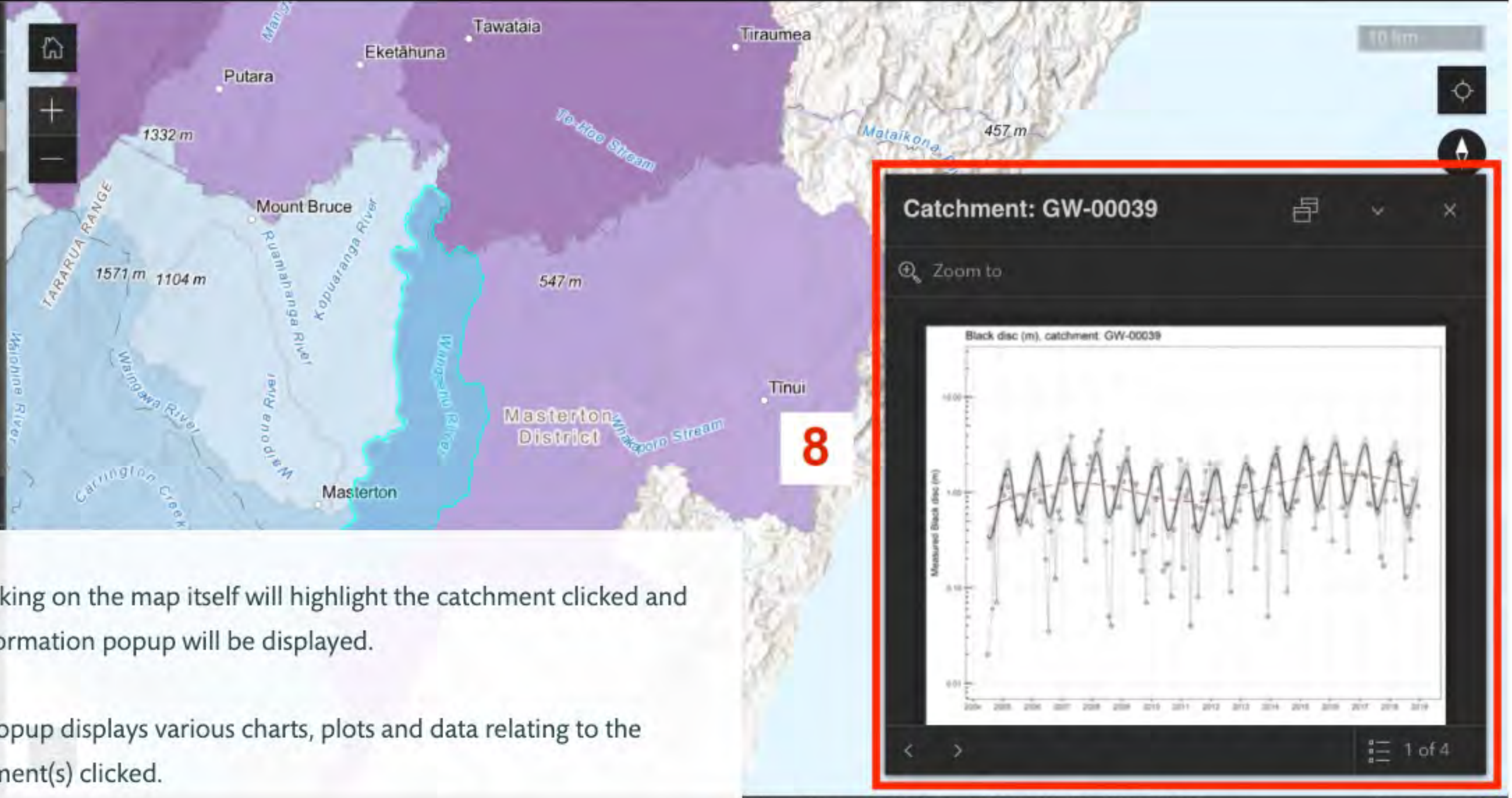
## Catchment trends link land use to soil and water quality

- pH
- E. coli
- Clarity

Black disc is a type of water clarity observation. How far away can a black target ("black disc") be seen horizontally through the water. The further away the disc can be seen, the clearer the water.

More info

- Turbidity
- Nitrate
- Ammonium
- Total Nitrogen
- Phosphorus
- Total Phosphorus
- Monitoring




**8.** Clicking on the map itself will highlight the catchment clicked and an information popup will be displayed.

This popup displays various charts, plots and data relating to the catchment(s) clicked.

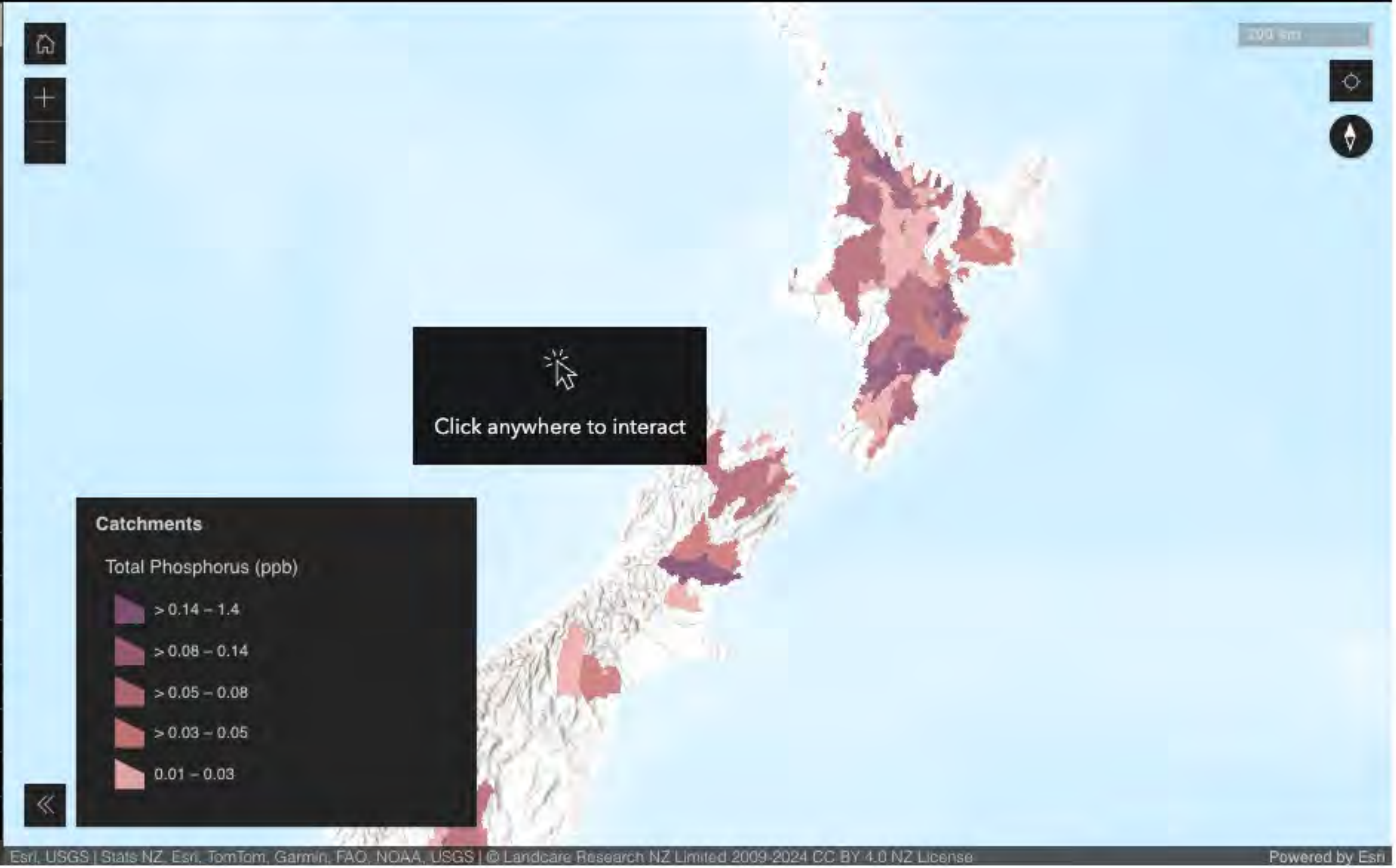
# Catchment trends link land use to soil and water quality

**Total Phosphorus**

Total phosphorus, displayed here in parts per billion (ppb), encompasses all forms of phosphorus in the water, including both dissolved and particulate forms, as well as organic and inorganic types. High levels of total phosphorus in water can originate from wastewater or run-off from agricultural land.

More info

- Phosphorus (DRP)
- Total Nitrogen
- Ammonium
- Nitrate
- Turbidity
- Clarity
- E. coli
- pH
- Monitoring
- Soil quality



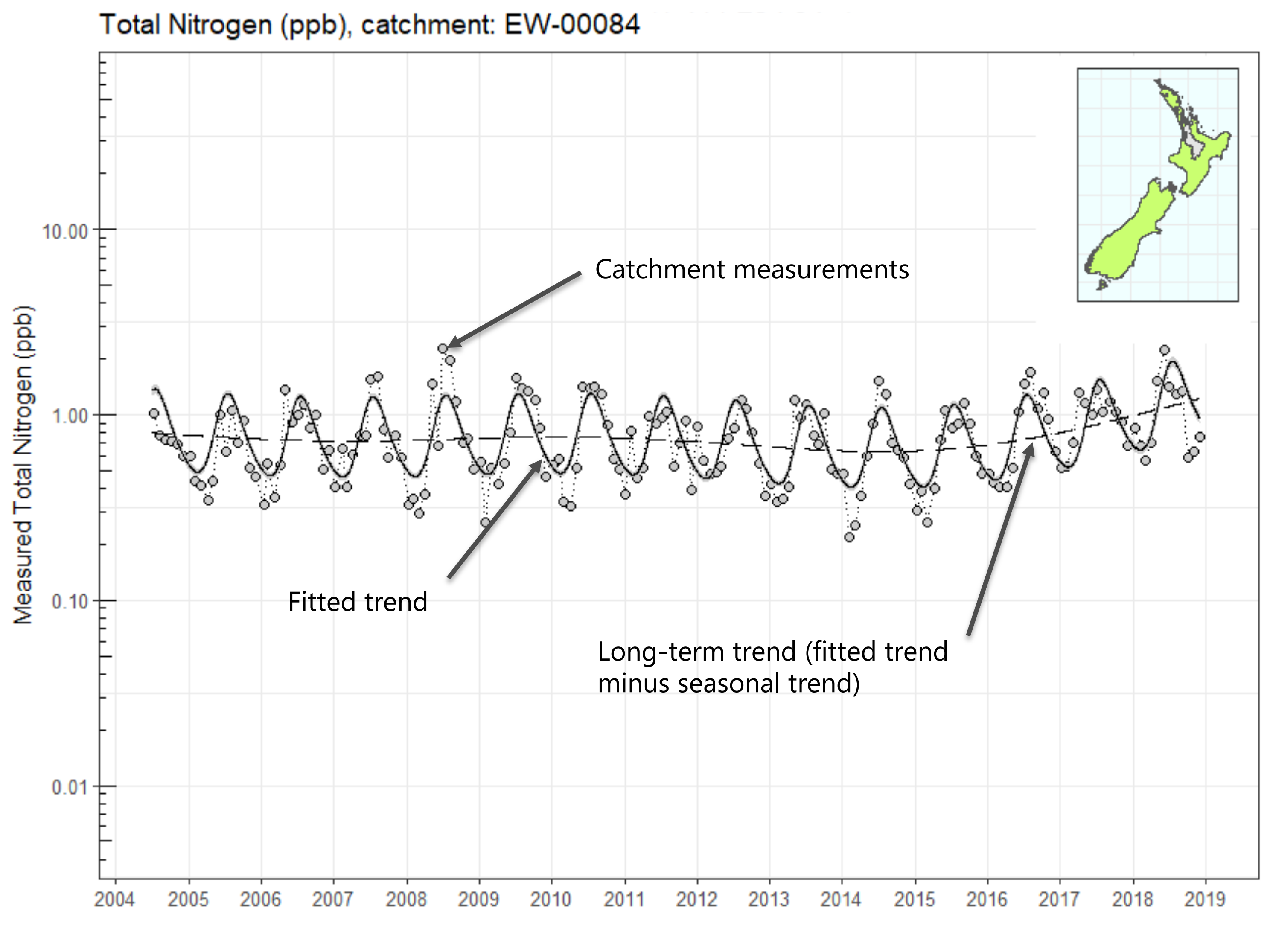
***How were the catchments chosen?*** Catchments were based on the availability of data.

***Why are some water quality indicator trends not showing for the full 2004 to 2019 period in the graphs?*** The trend lines are shown for the available water quality sampling dates. Not all indicators are available across all of 2004 to 2019. Sampling may have commenced or finished during that period.

***Was the statistical significance of the long-term trend determined for each water quality indicator in every catchment?*** No. The trend could be ascending, descending, ascending-then-descending, etc. If we were only interested in the change from the start time to the end time of sampling, then we could estimate the significance of the difference between the response at those two points in time.

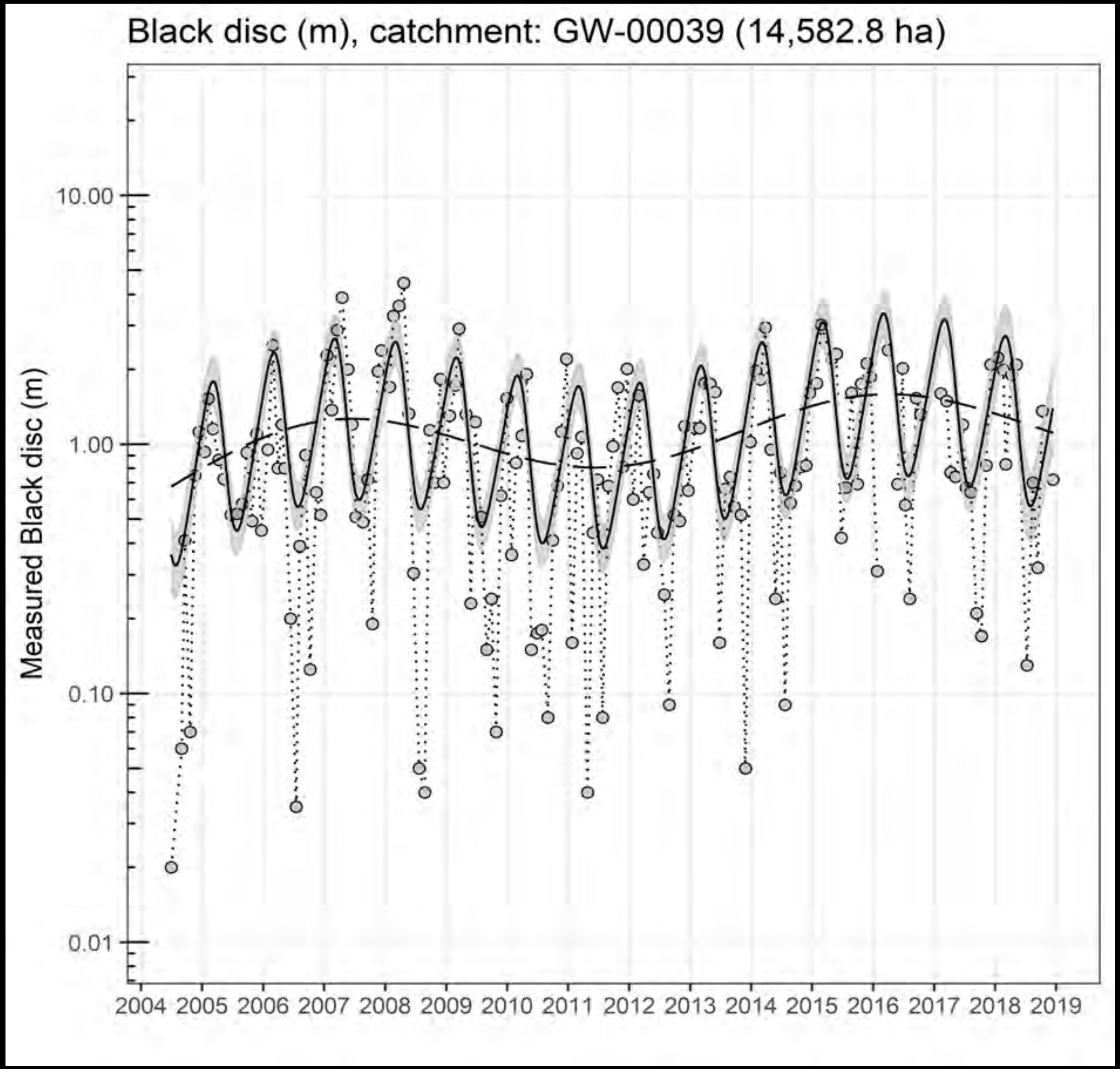
But that wasn't a requirement of the modelling undertaken in this research, and the more complex long-term trends are at least as important as the absolute changes from the start to the end. The factors that influence change (e.g. land use

# Back to water quality: e.g. Total Nitrogen



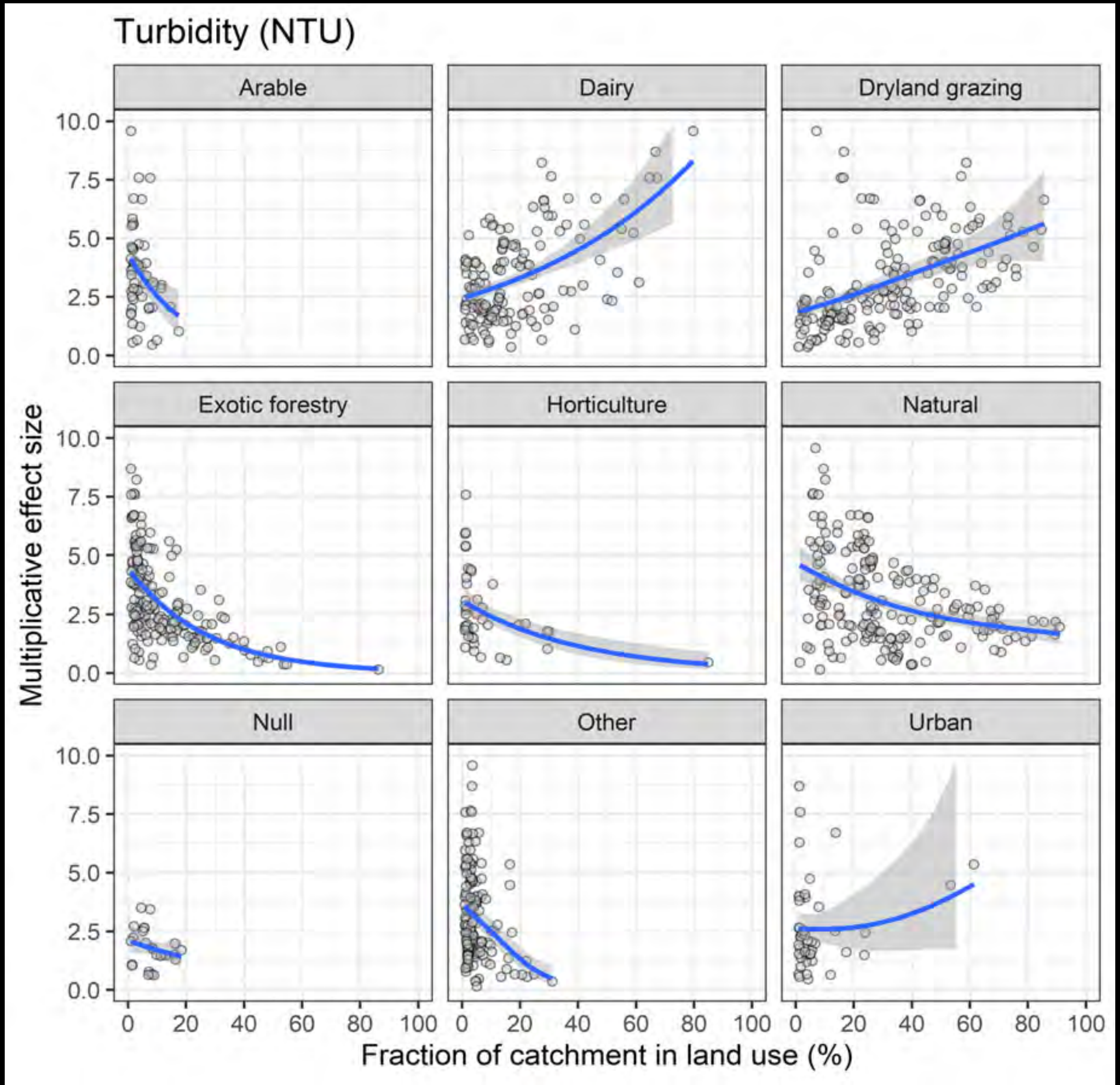

- Modelling approach can extract the seasonal and long-term trends
- Measurements can be unevenly-spaced, and modelling adapts to the overall trend
- Generally, we are interested in the overall change – the long-term trend
- Method depends on adequate sampling over time and an unchanging seasonal trend

# Water quality



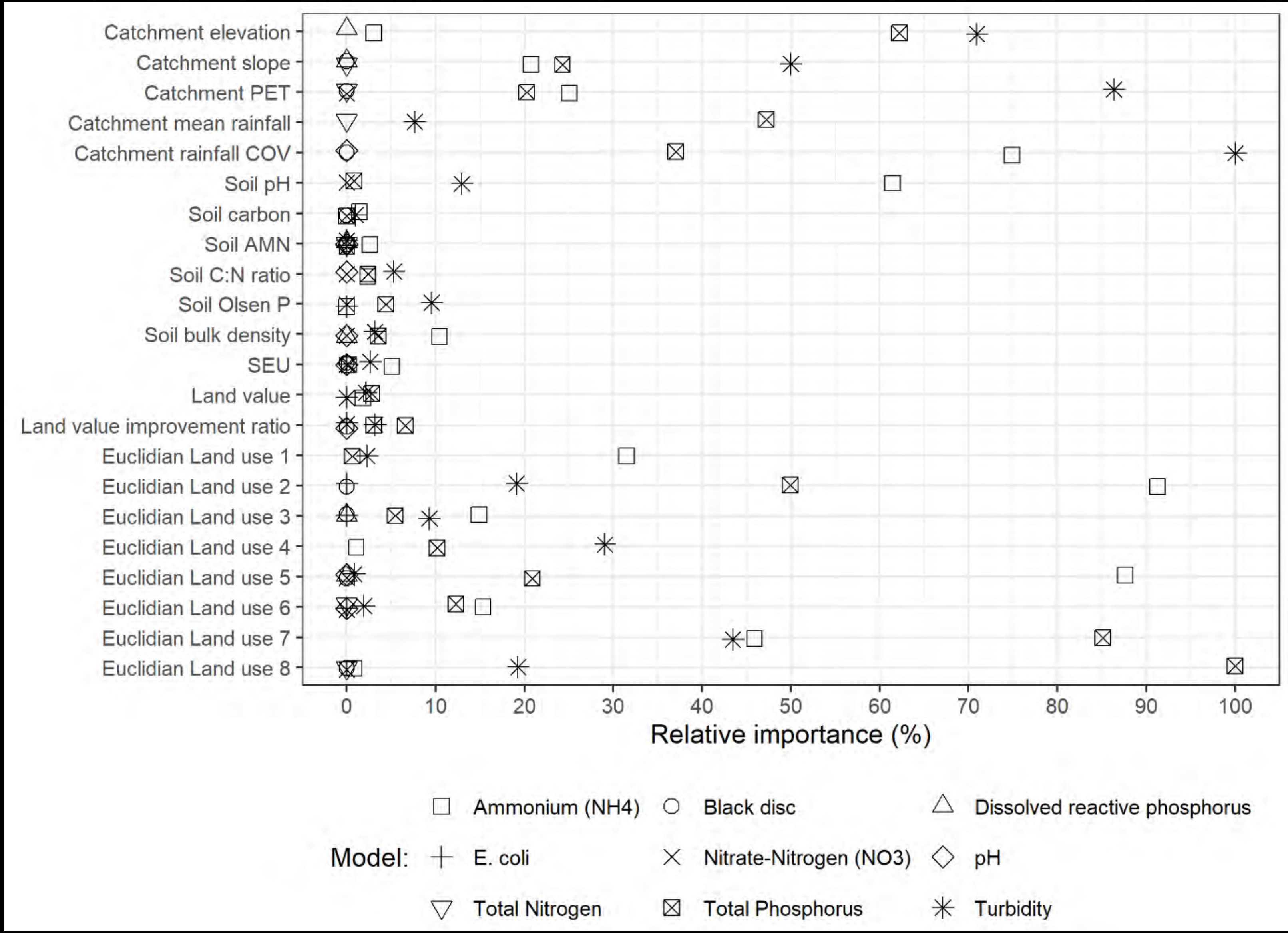

- Some catchment analytes (e.g. Black disc, turbidity) are difficult to model, resulting in over-smoothing:
  - Very small values can be poorly modelled
  - Early very irregular sampling can lead to outliers
- But, long-term trends are stable – these long-term trends indicate how catchment properties are improving or degrading

# Land use effects for turbidity




- This effect is the proportional change in turbidity as the fraction of land use increases (plus 95% confidence interval)
- The sum of land use is 100%, so increasing one land use affects others, and their effects
- For turbidity:
  - Increasing dairy or dryland grazing is associated with an <u>overall</u> increasing effect (but each catchment is different!)
  - Increasing fractional cover for arable, exotic forestry, and natural is associated with an overall reduction in turbidity

# Relative importance of covariates on water quality




- Further to right side implies a more influential effect
- Depending on WQ response, high relative importance of catchment characteristics and land use
- Relatively small importance of soil quality, stock units, land value

# Results – significance of soil quality variables

Soil quality variable

| | ph | Carbon | C:N ratio | AMN | Olsen P | Bulk density |
|---|---|---|---|---|---|---|
| Black disc (m) | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| Turbidity (NTU) | ✗ | ✓ | ✓ | ✓ | ✗ | ✓ |
| Ammonium ($NH_4$) (ppb) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Nitrate-Nitrogen ($NO_3$) (ppb) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Total Nitrogen (ppb) | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ |
| Dissolved reactive phosphorus (ppb) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Total Phosphorus (ppb) | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ |
| pH | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ |
| E. coli (N/100ml) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

✗ The explanatory variable is not significant

✓ The explanatory variable is highly significant

- Although soil quality variables have a relatively small effect in predicting the response, most of them are significant
- Olsen P and bulk density most likely to be non-significant

# Summary results

| Response | # catchments | % variability explained |
|---|---|---|
| Black disc (m) | 173 | 42.1 |
| Turbidity (NTU) | 192 | 45.5 |
| Ammonium (NH4) (ppb) | 191 | 66.9 |
| Nitrate-Nitrogen (NO3) (ppb) | 192 | 65.2 |
| Total Nitrogen (ppb) | 192 | 70.5 |
| Dissolved reactive phosphorus (ppb) | 192 | 70.3 |
| Total Phosphorus (ppb)" | 192 | 50.6 |
| pH | 192 | 52.6 |
| E. coli (N/100ml) | 192 | 34.8 |

Most WQ responses had ~130,000 data points

- GAM modelling approach explains a moderate to high proportion of variation
  - DRP, TN, NH4, and nitrate-N are well explained by the model
  - *E. coli* and black disc only moderately
- Soil quality variables have an effect, but there are few obvious patterns
  - Olsen P and bulk density are more likely to have a non-significant association
- GAM model significance for land pressure:
  - Log land value, log land value ratio, and stock units have a highly significant effect
  - catchment characteristic and land use have a highly significant effect

# Conclusions

- Soil carbon concentration, Olsen P, and bulk density have a highly significant effect in predicting land value, but the other variables do not.
- The state and trend of water quality was strongly related to land use, catchment and climatic characteristics.
- Although significant, water quality relationships with soil quality and the land use pressures were weak.
- While national soil quality might be useful for evaluating environmental risk at the field or farm scale, without a large increase in sampling, they were not relevant at the catchment scale.

# So what? Overall implications

- Land value is a unique indicator associated with land use pressure (agricultural intensification). We used a snapshot in time - examining land value over many years may be useful in future.

- Increasing the frequency of land pressure indicators, and soil quality data points, may improve catchment water quality predictions (was a snapshot).

- Soil quality may be unrepresentative of land use or hydrologic flow paths to rivers.

- To inform water quality management via environmentally focused soil tests, additional analyses to detect change are needed in future.

# Further information

- Linking soil quality indicators to land use pressure and water quality. Pūtaiao #17, 2024. https://www.landcareresearch.co.nz/publications/putaiao/

- Science of the Total Environment:

  Drewry JJ, McNeill SJ, McDowell RW, Law R, Stevenson BA. 2024. Linking soil quality indicators to land use pressure.

  McDowell RW, McNeill SJ, Drewry JJ, Law R, Stevenson BA 2024. Can linking land use pressure and soil quality indicators help predict water quality?

- Storymap link in follow-up email

# Acknowledgements


- We thank regional councils and Land Monitoring Forum for soil quality data (national environmental reporting dataset), Headway Systems Ltd for district valuation roll data, regional councils, LAWA, NIWA for water quality data, and StatsNZ for stock data.
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