Detection Power & Lag Webinar (part 1)

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Toitū te Whenua, Toiora te Wai

Thanks to:
Zeb Etheridge, Olivier Ausseil, Rich McDowell
and the rest of the Our Land and Water crew

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Outline for this talk

1. Intro and background
2. Lag and its importance
3. Detection power as a concept and its levers
   a. Question
   b. Pathway
   c. Noise
   d. Sampling duration & frequency
4. Example Use cases → planning and consent conditions
5. Network design
6. Conclusions

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Who are we

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> “Everything should be made as simple as possible, *but no simpler*”

- **Current research**
  - ***Future Coasts Aotearoa*** (MBIE Endeavour): sea level rise propagation through aquifers, groundwater hazard assessment and adaptation
  - ***Climate Shock Resilience and Adaptation*** (MPI SLMACC): weather and climate + river flow + farm economic modelling to understand risk to primary sector + river health from increasing climate variability
- **Main consulting workstreams**
  - Regional plan change - flow and nutrient limit setting
  - Community and irrigation water supply
  - Mineral sand, gold mine and landfill AEE & compliance
  - Ground source heat pump feasibility and heat plume modelling

Zeb Etheridge

Matt Dumont

Evelyn Charlesworth

Jens Rekker

Patrick Durney

1. Why are we passionate about detection power & monitoring design?
   a. We've been heavily involved in limit setting for regional plan change processes. FFP plan effectiveness monitoring is key but largely absent in our experience
   b. Strong interest from stakeholders and communities in monitoring-based land and water management - status quo approach does not work
   c. We see water quality monitoring consent conditions with very little prospect of achieving their goals
   d. We want to empower RC practitioners to solve these issues

What's our angle?

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Monitoring Freshwater Improvements

https://www.monitoringfreshwater.co.nz/

Web App

These other outputs do not consider the impacts of lag.

→ Which can cause problems…

Here we focus on lag & bespoke detection power assessments.

Wider context

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*"Despite a strong body of scientific evidence and increasing awareness amongst stakeholders, **models and budgets used by policymakers in [best management practice] planning often do not adequately represent legacy N dynamics and associated time lags**…*

*… [Achieving] this would **support more realistic estimates of the trajectories of change following measures to reduce N loads, managing the expectations of stakeholders and supporting long term sustainable agriculture**. Incorporating N [lags] into improved models and budgets used in policy and regulatory frameworks for the sustainable management of agriculture can **better meet the needs of human health and the environment.**"*

- Ascott et al., 2021. The need to integrate legacy nitrogen storage dynamics and time lags into policy and practice

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Let's talk LAG

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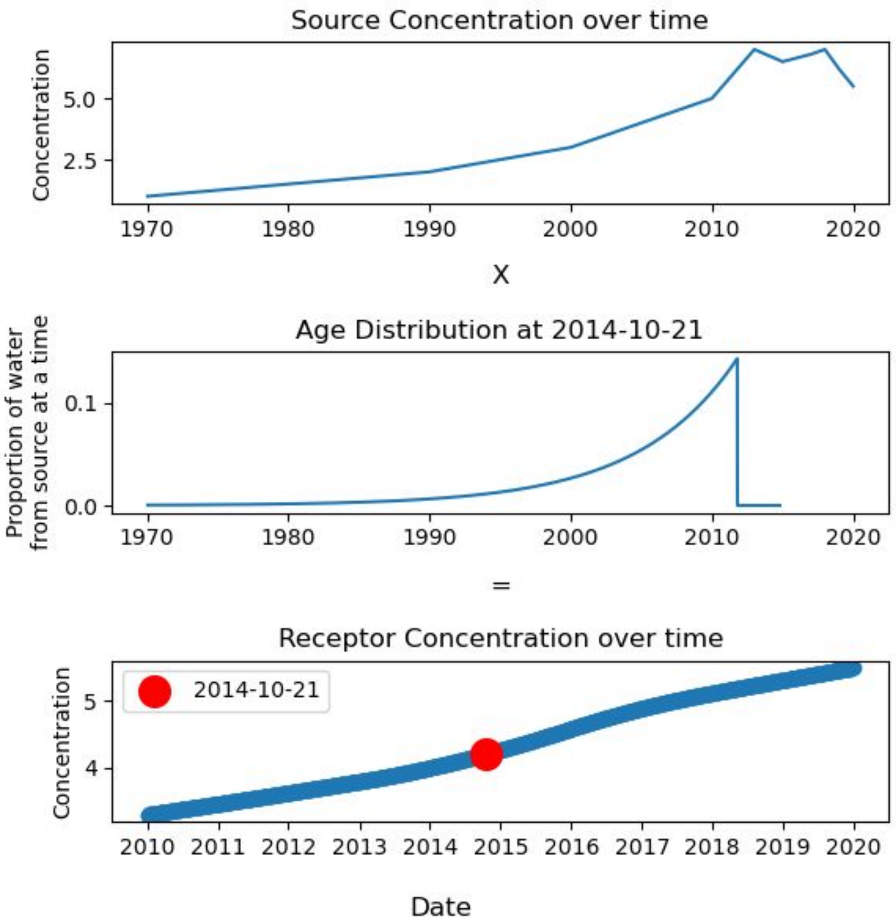
Water we're sampling is not one age

Here a EPFM:
- Mrt = 10y
- F_p1 = 0.7



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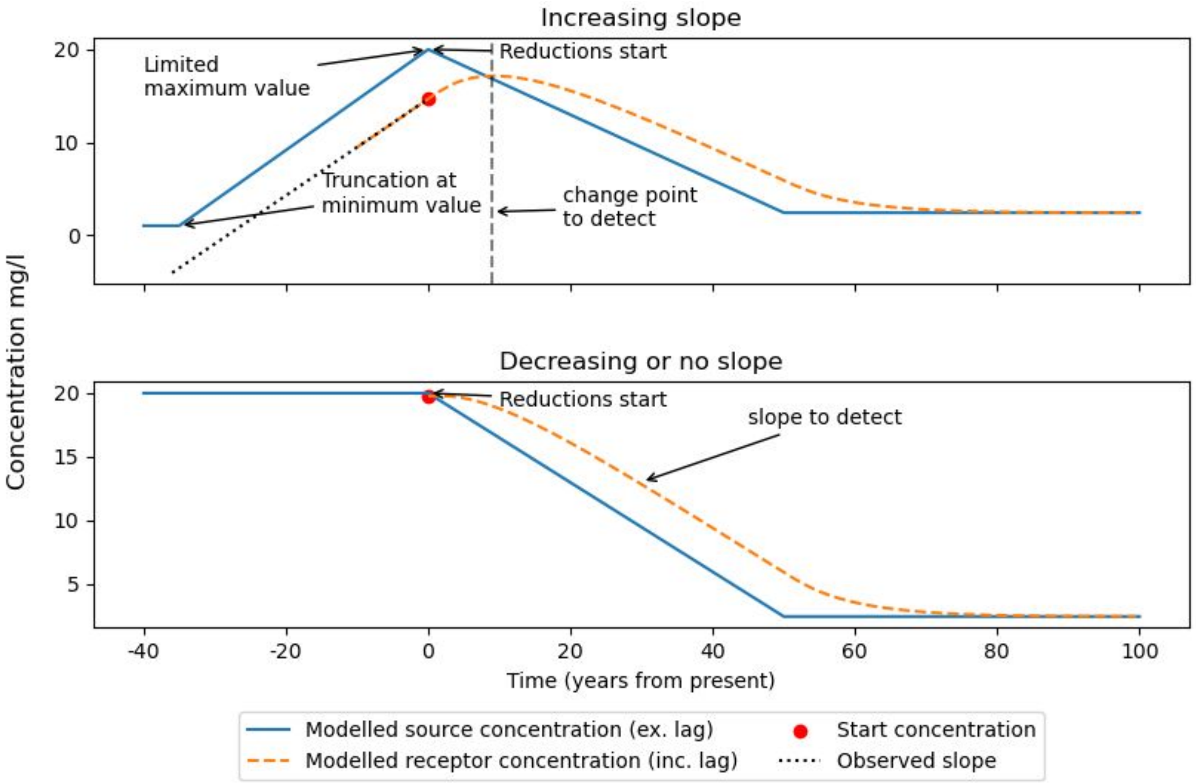
- **Lag**: The wait time between when action happens at the source and when something happens at the receptor

- **Temporal Dispersion**: Mixing of different aged waters which smooths applied changes

- **Hysteresis***: The historical actions at the source that are “in the post” and have yet to show up at the receptor

*I know it’s all hysteresis, but indulge my binning for the point of discussion.



Let's talk LAG

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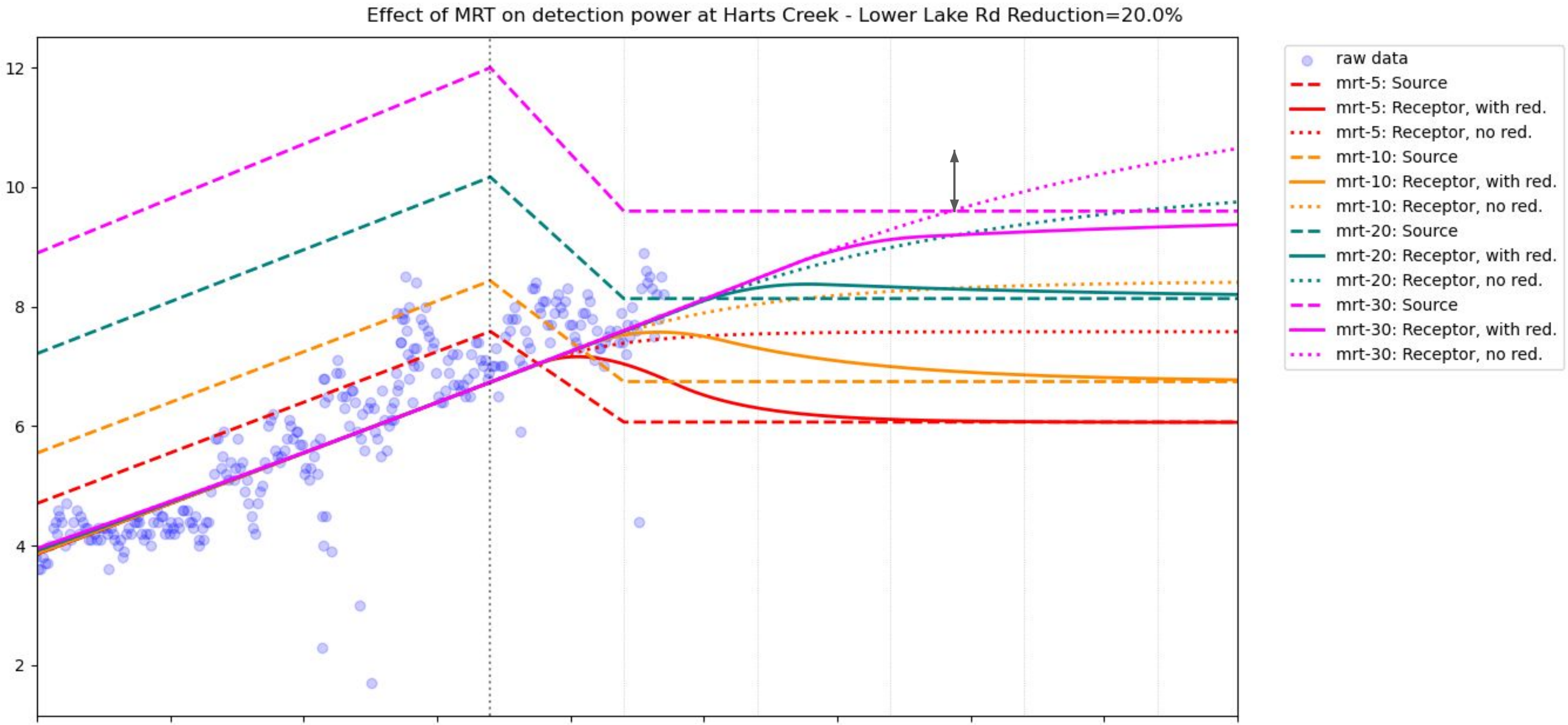

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Lag & surface water

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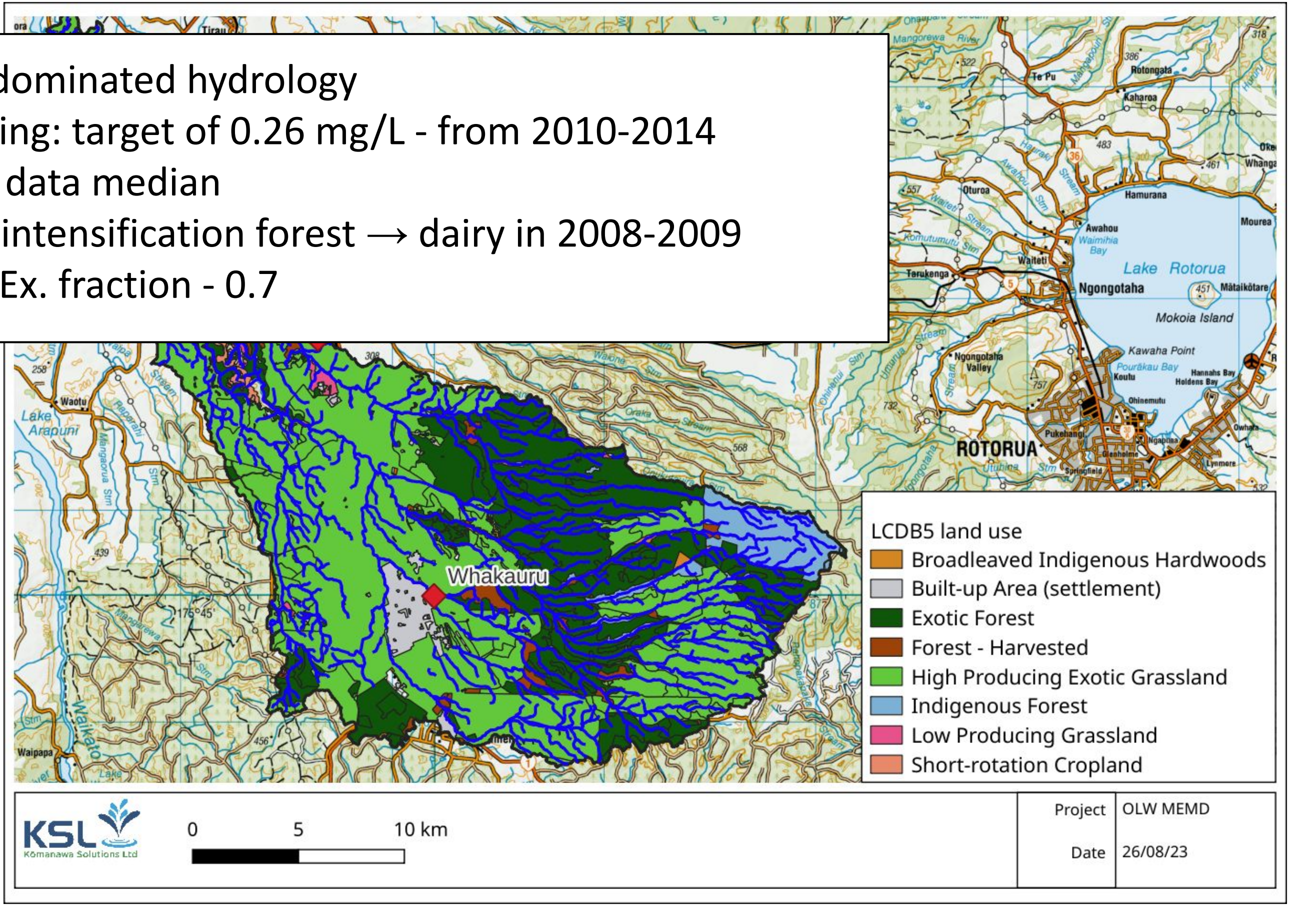
An example in the Whakauru Stream, Pokaiwhenua Catchment

- baseflow dominated hydrology
- Policy setting: target of 0.26 mg/L - from 2010-2014 measured data median
- History of intensification forest → dairy in 2008-2009
- MRT - 12, Ex. fraction - 0.7



Predicting source concentration

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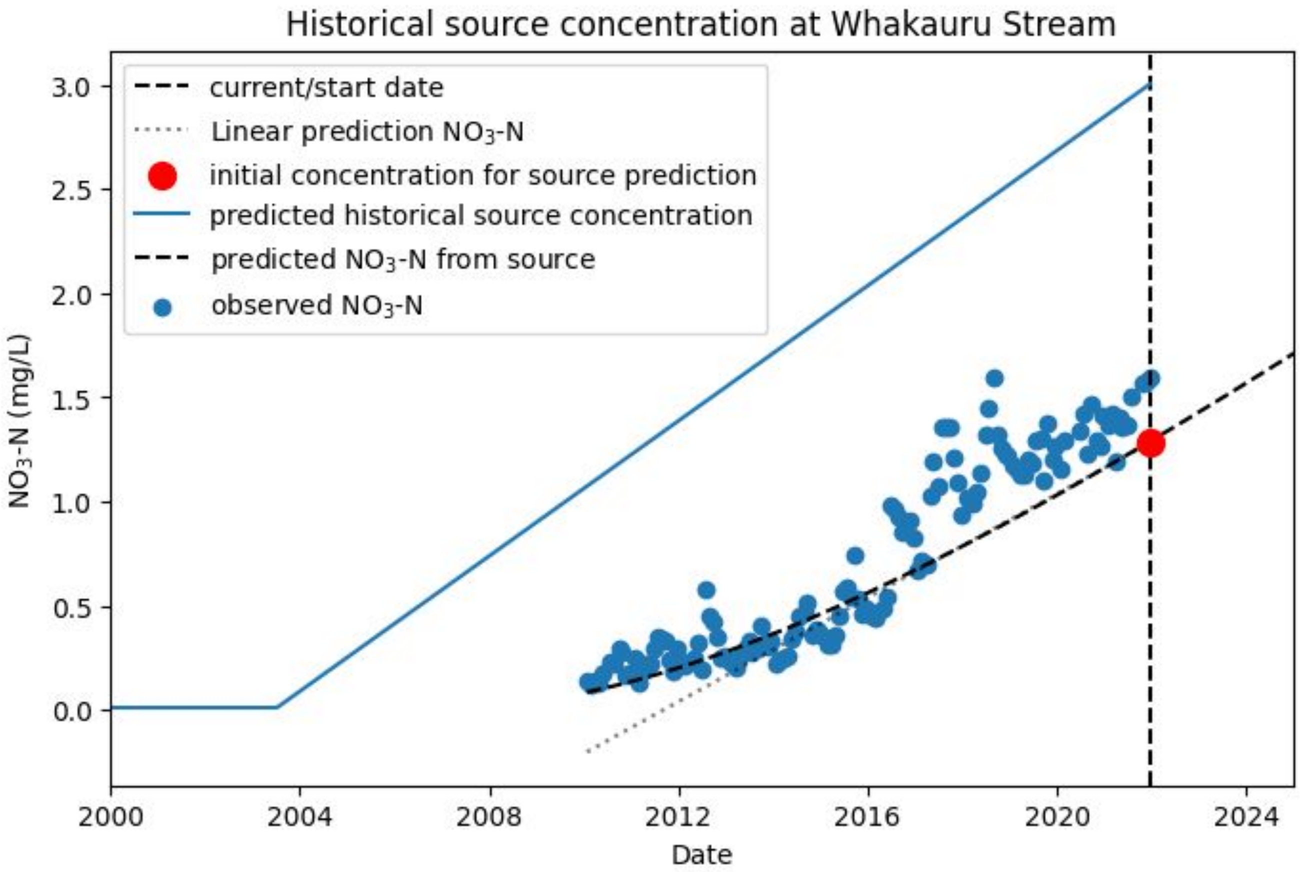
Predicting source concentration from historical slope, current concentration, and age distribution. (method implemented in python package)



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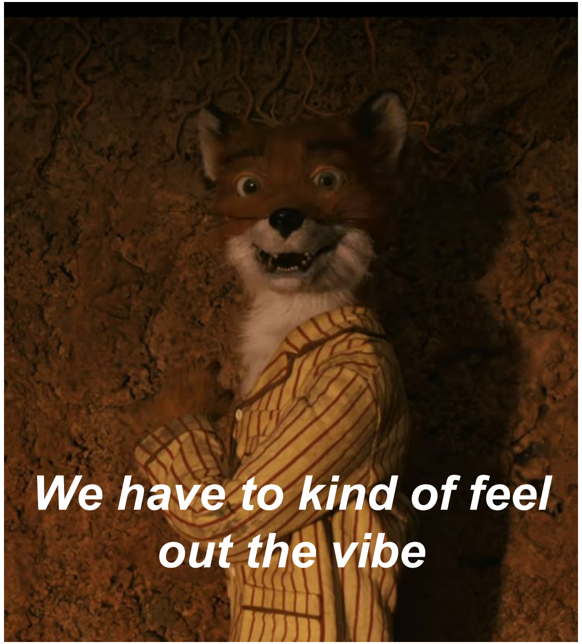
Pathway ISH

When establishing the pathway for **detection power**. It doesn't have to be perfect, just **in the ballpark.**

For **limit setting and planning reductions…** it needs to be much more **precise**



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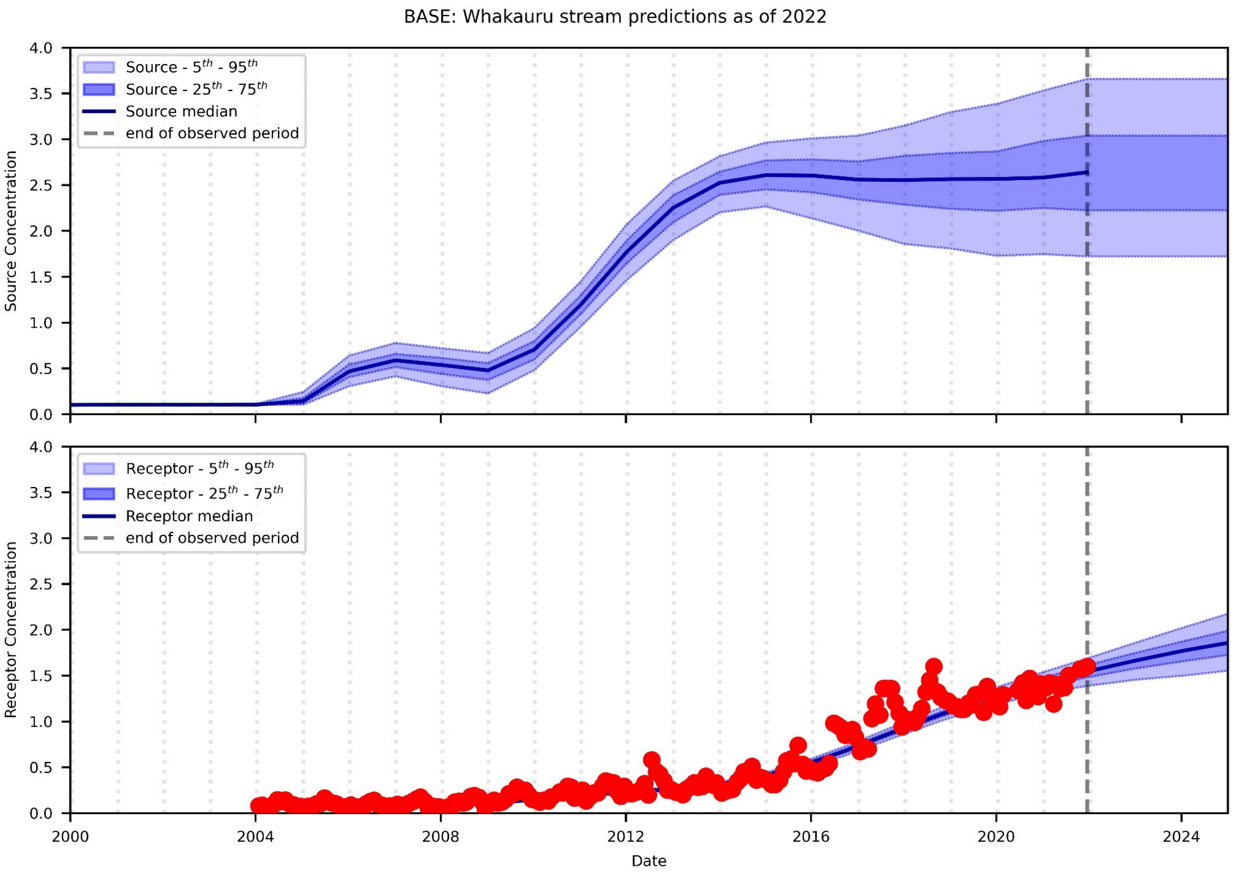
Bayesian Approach to Source Estimation (BASE) method (talk to us)



Predicting source concentration

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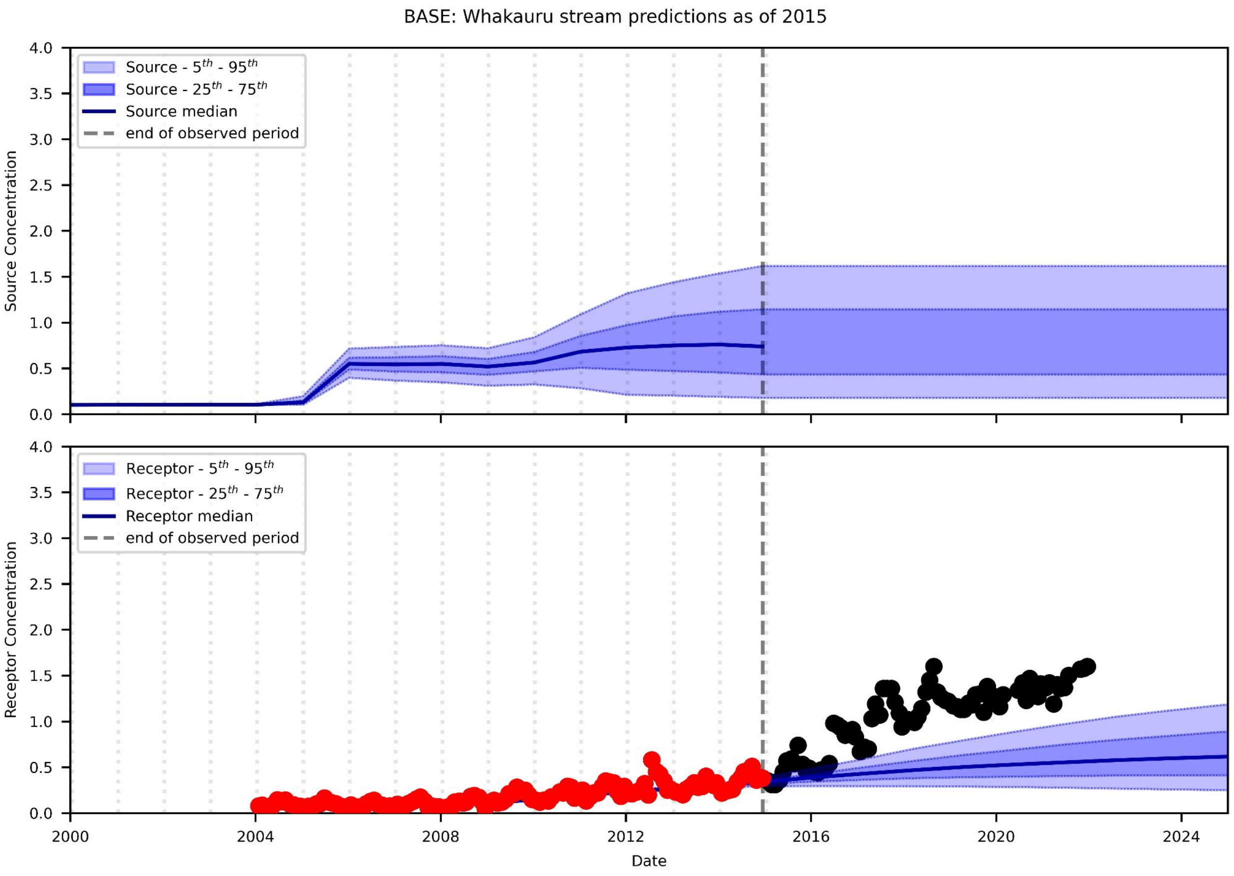

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Predicting source concentration

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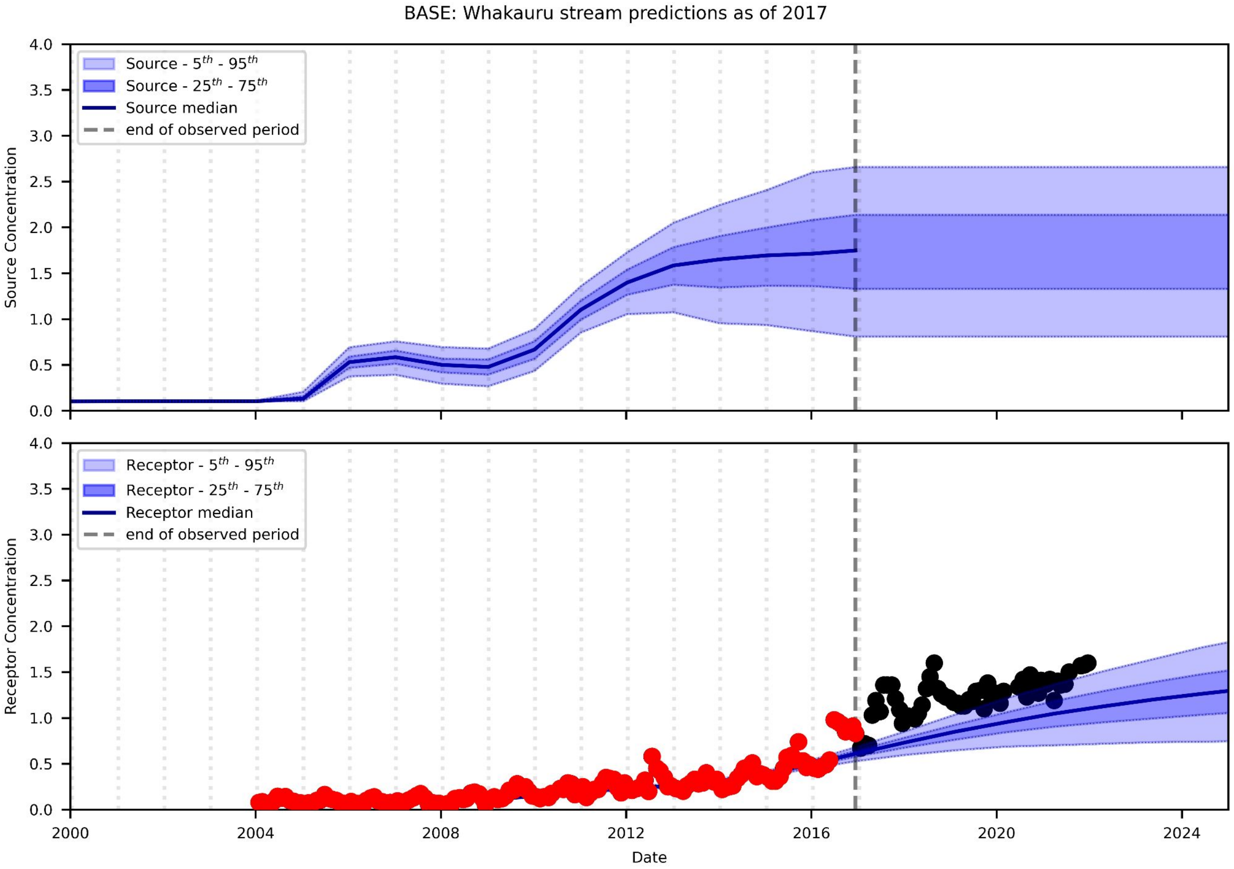

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Predicting source concentration

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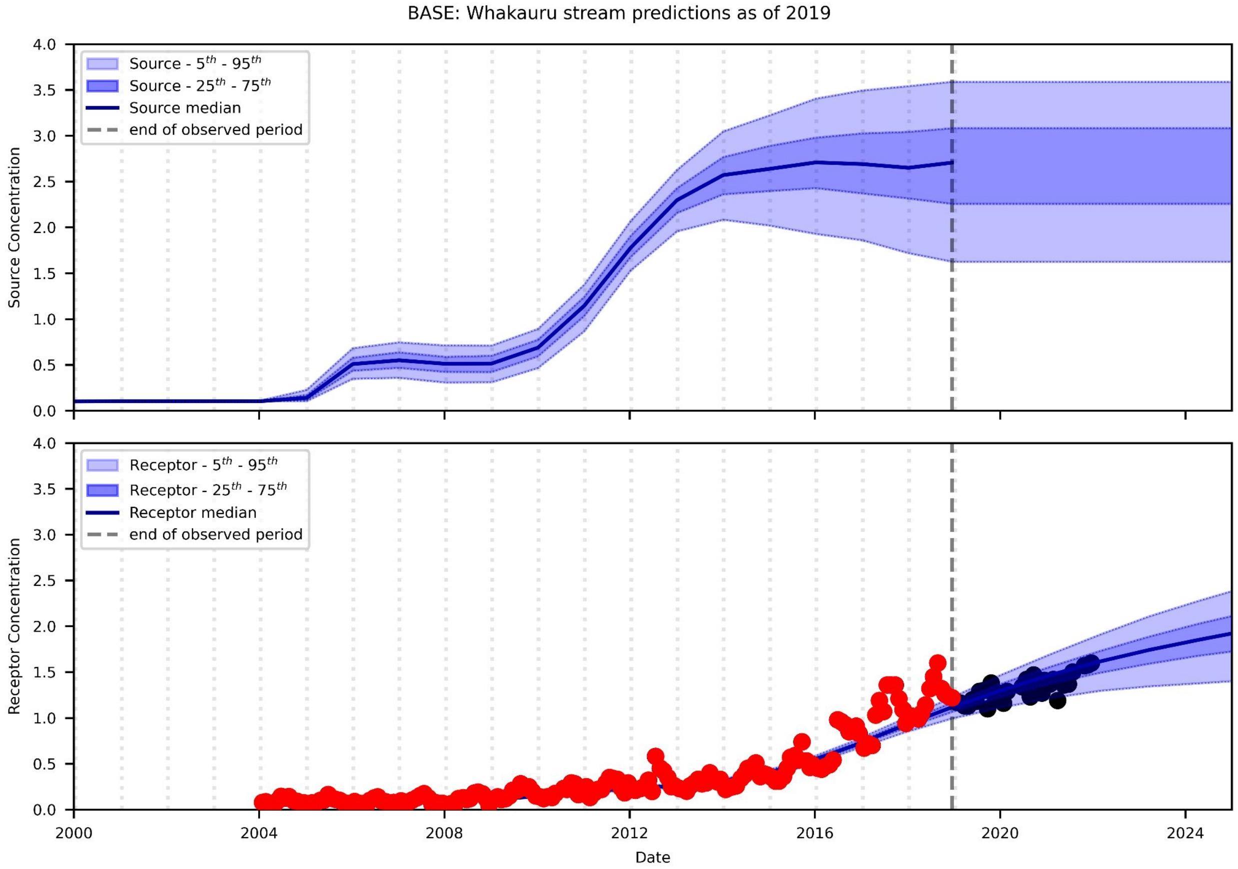

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Predicting source concentration

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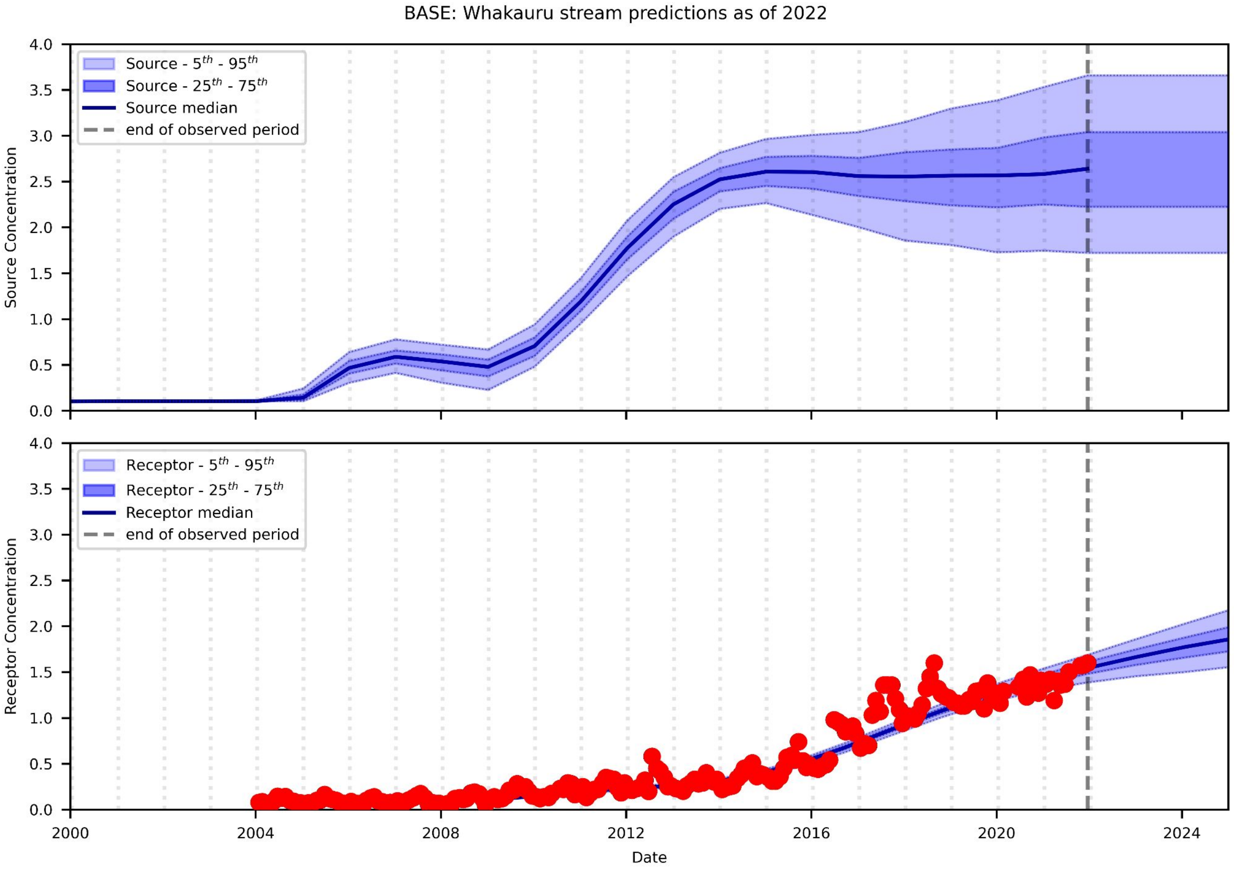
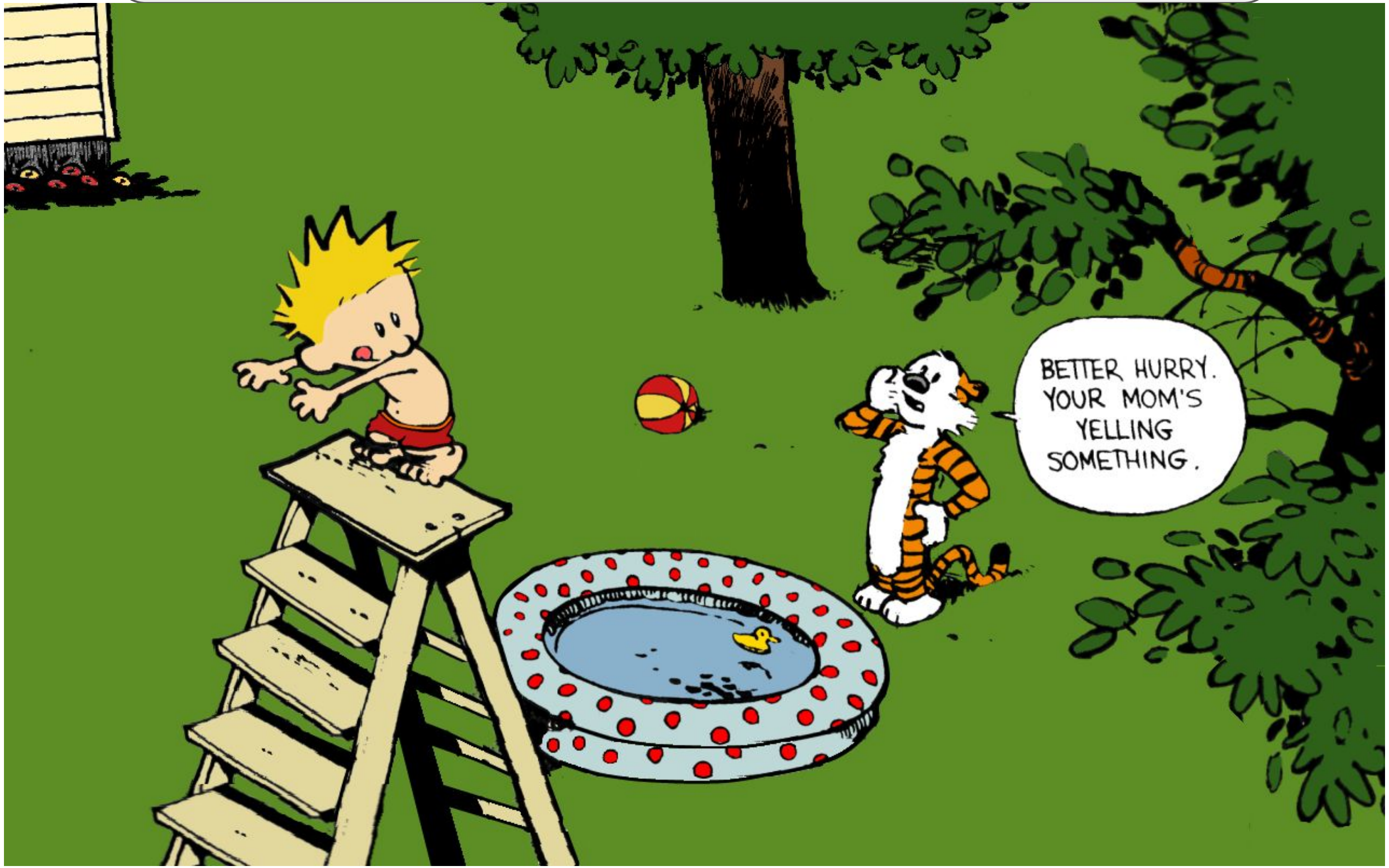


Predicting source concentration

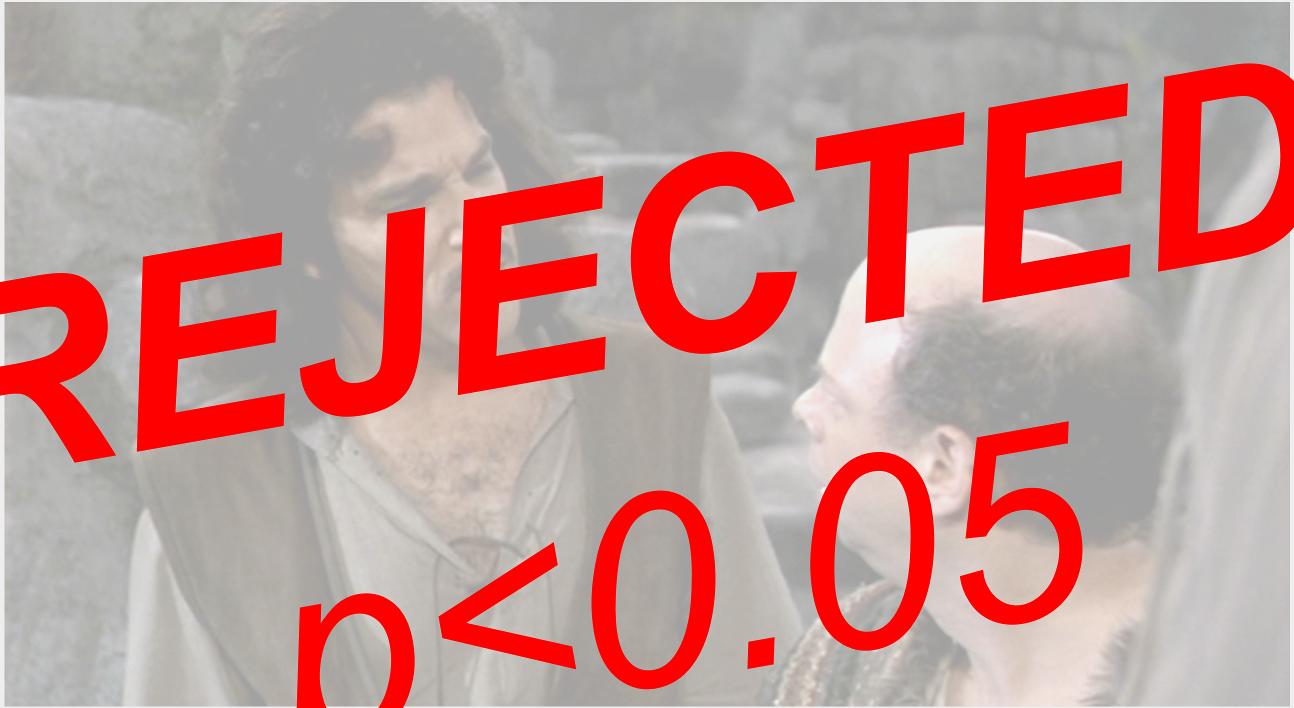
Alright without further ado, let's jump into detection power as a concept



You keep using those data

I do not think they mean what you think they mean

You keep using those data



REJECTED

$p<0.05$

I do not think they mean what you think they mean

The Solution

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Statistical Errors

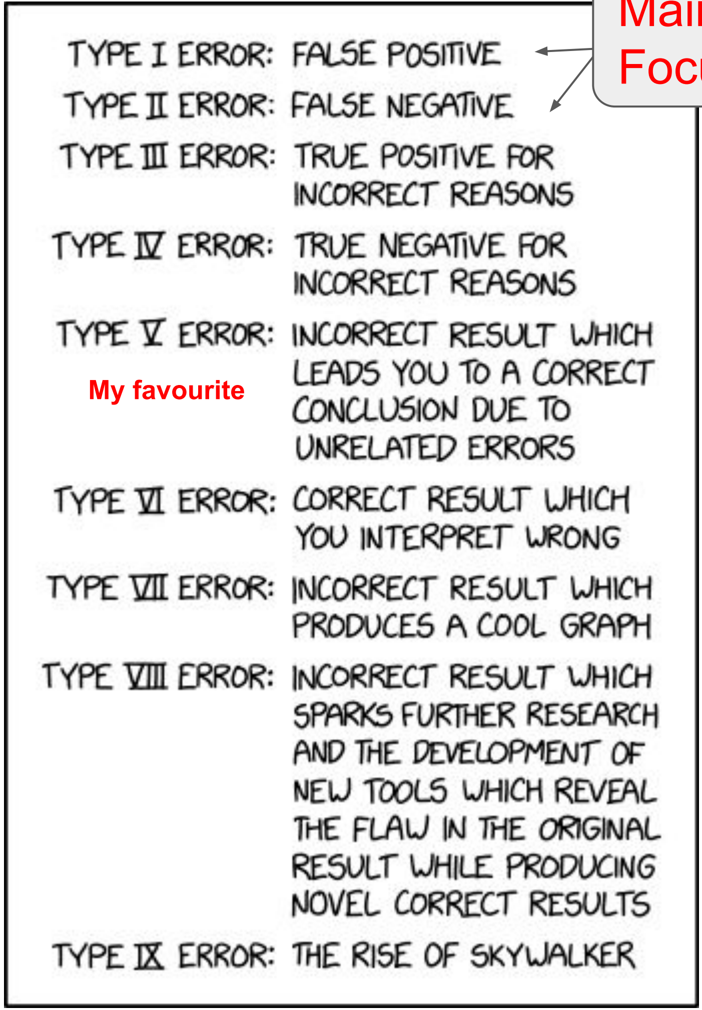
Null Hypothesis
What we assume in the absence of information. *Ex., there is no trend in the data.*

Alternative Hypothesis
What we would like to prove. *Ex., There is a trend in the data.*

P-values and statistical tests
P is the probability that you reject null hypothesis just by chance

P<0.05 means there is, in theory, a <5% chance of a Type I error

Main Focus



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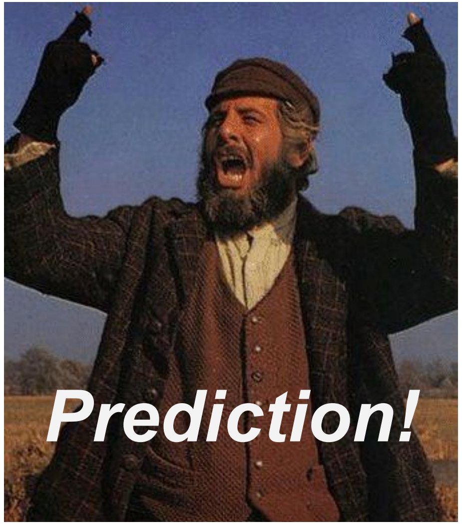
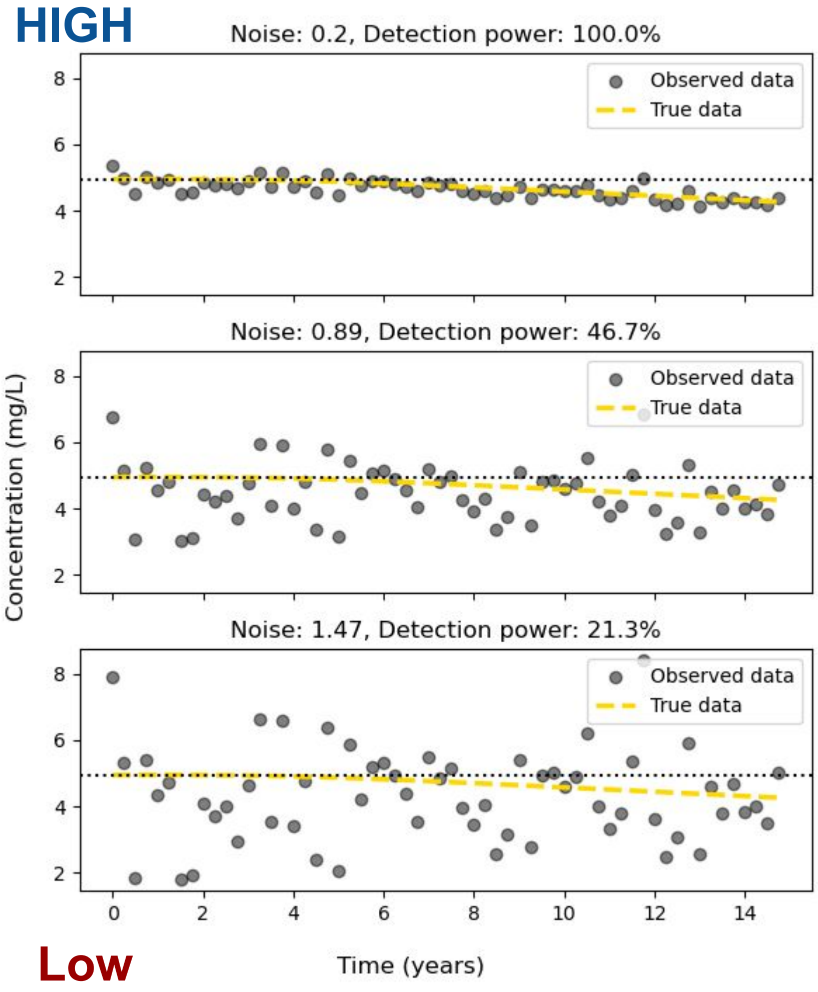
It's easy to understand the ***Statistical Power*** *(e.g., p)* of an existing record.

Detection Power (DP) *is the likelihood that the statistical power of your test will be significant (p<0.05) in the future*

How do we do this:





Detection Power

Inputs for DP

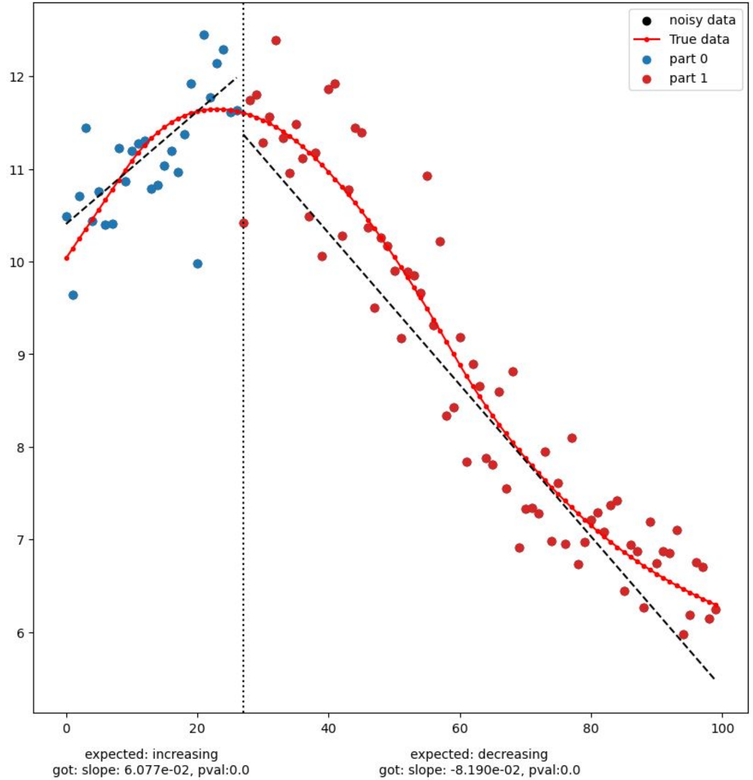
Factor	Impact to detection power as the factor increases
Your **question** / statistical test	IT DEPENDS
Noise at the site	↓
The future **pathway** at your site's concentration will take	IT DEPENDS
- The size of change	↑
- The difference between scenarios	↑
Sampling **frequency**	↑ IT DEPENDS
Sampling **duration**	↑

Slope Detection

Do the observations show a trend, increasing/decreasing?

Tests:

- Linear regression
  (monotonic, parametric)
- Mann Kendall
  (monotonic, non-parametric)
- Multipart Mann Kendall
  (non-monotonic, non-parametric)



Question Options

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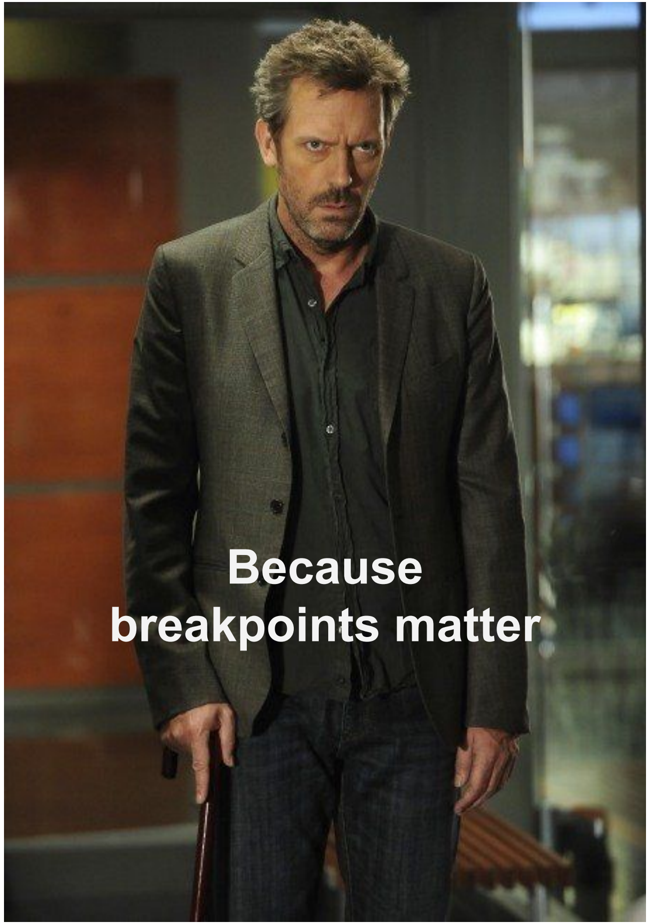
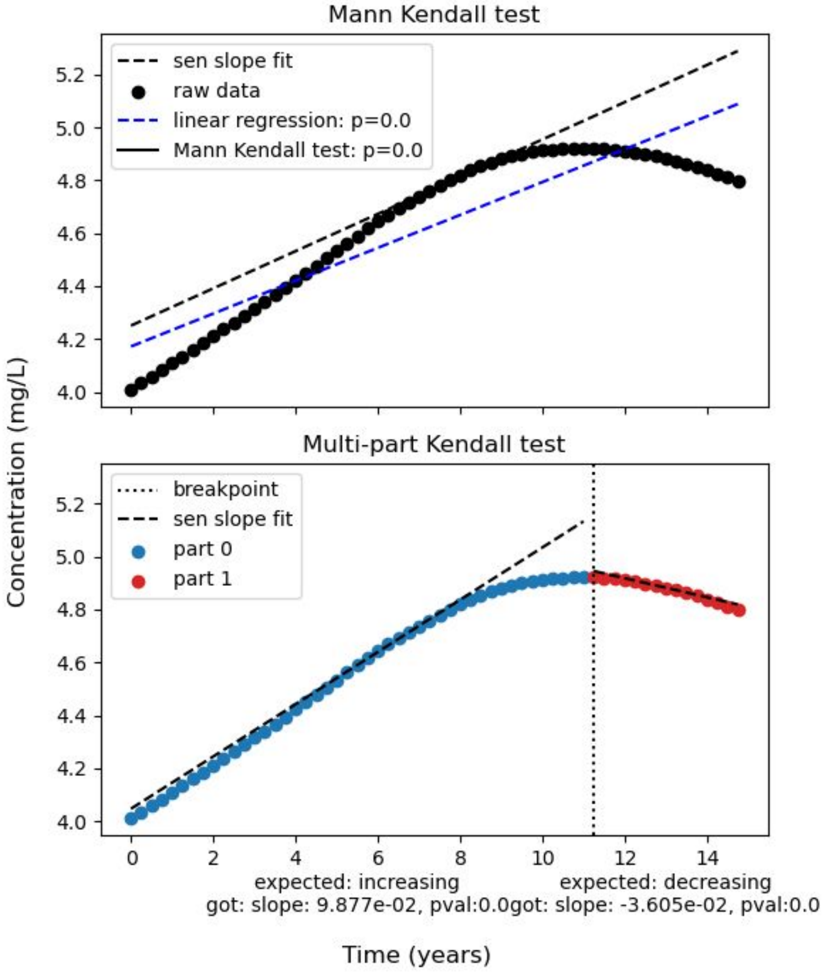
Multipart Mann Kendall





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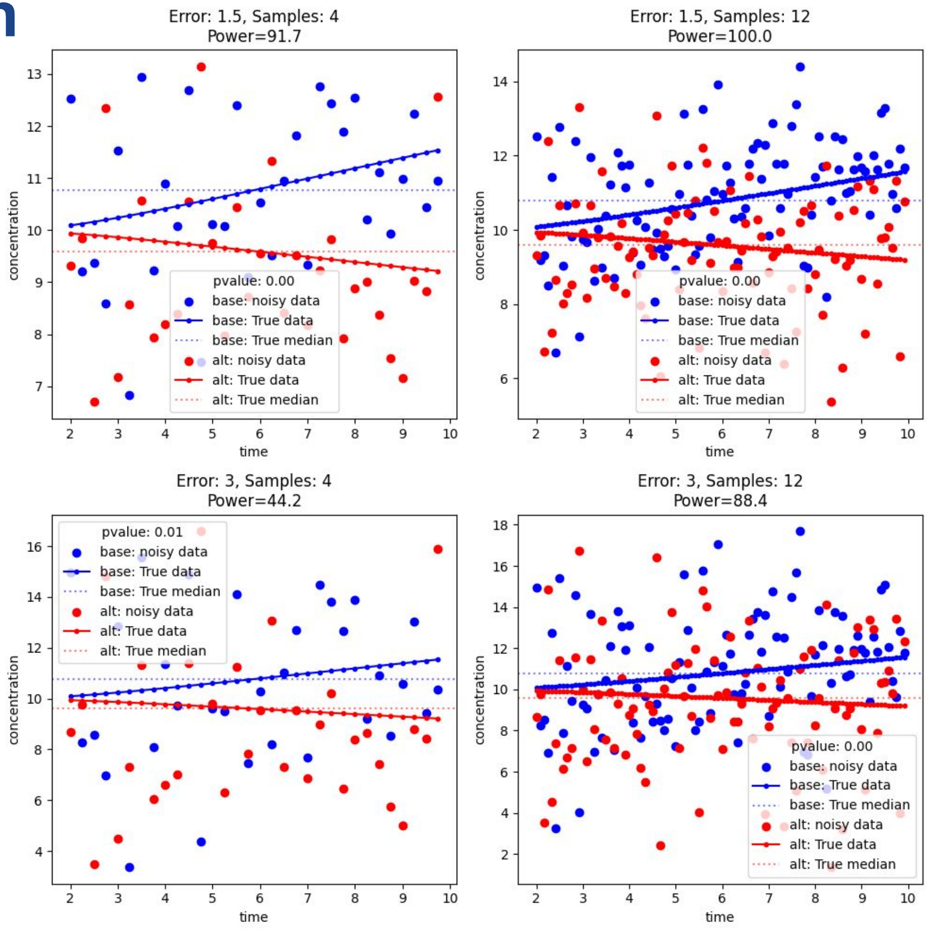
Counterfactual detection

Is pathway 1 significantly different than pathway 2?

- Is it **less** or **more**?

Tests:

- Paired T-test (paired, parametric)
- Wilcoxon signed-rank test (paired, non-parametric)



Question Options

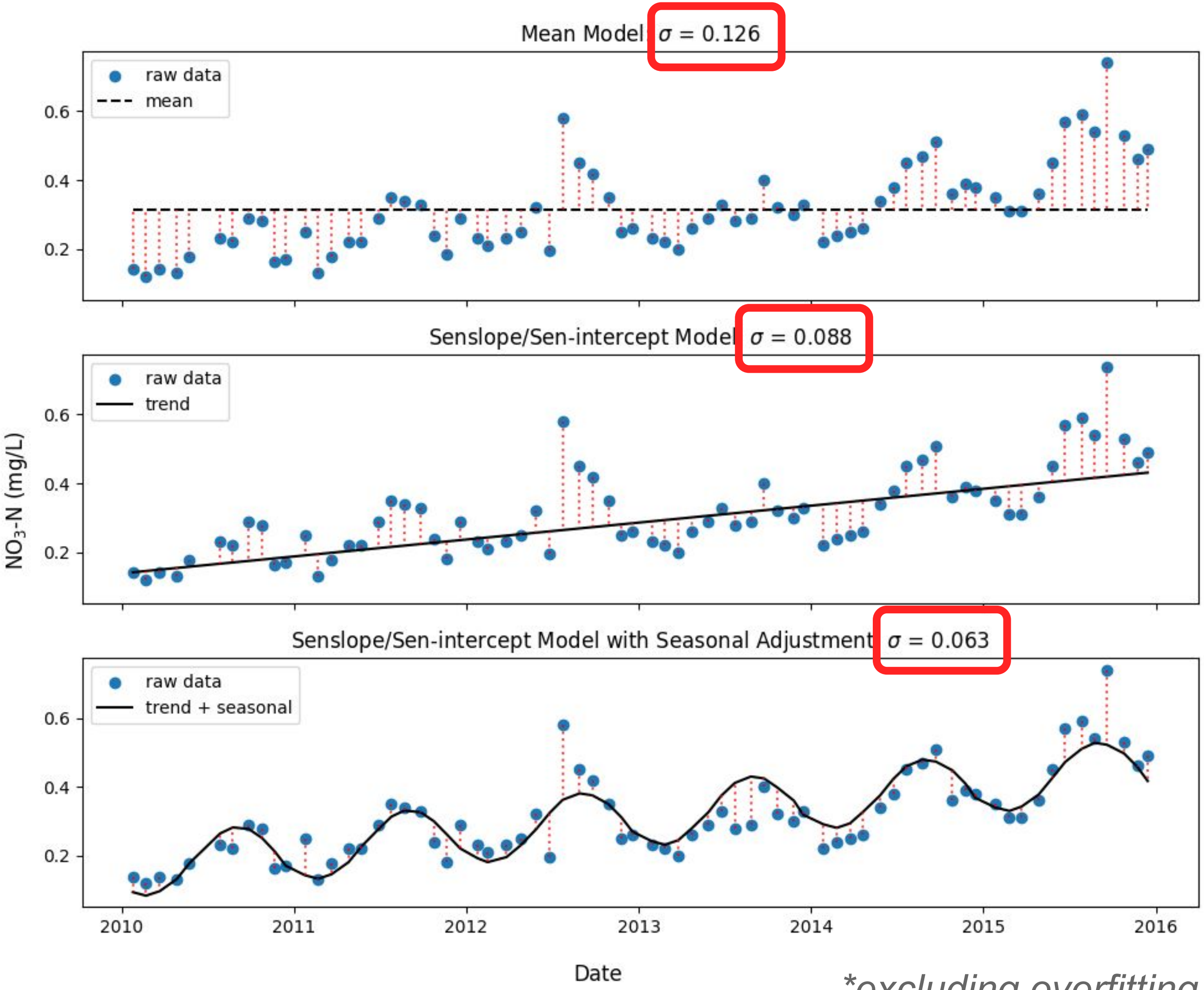
Let's talk noise

Noise here means the unexplained variance of the data.

The more you model, the better you can account for noise*

3 fixes to noise:

- Sampling freq.
- Sampling dur.
- Δ - size



*excluding overfitting

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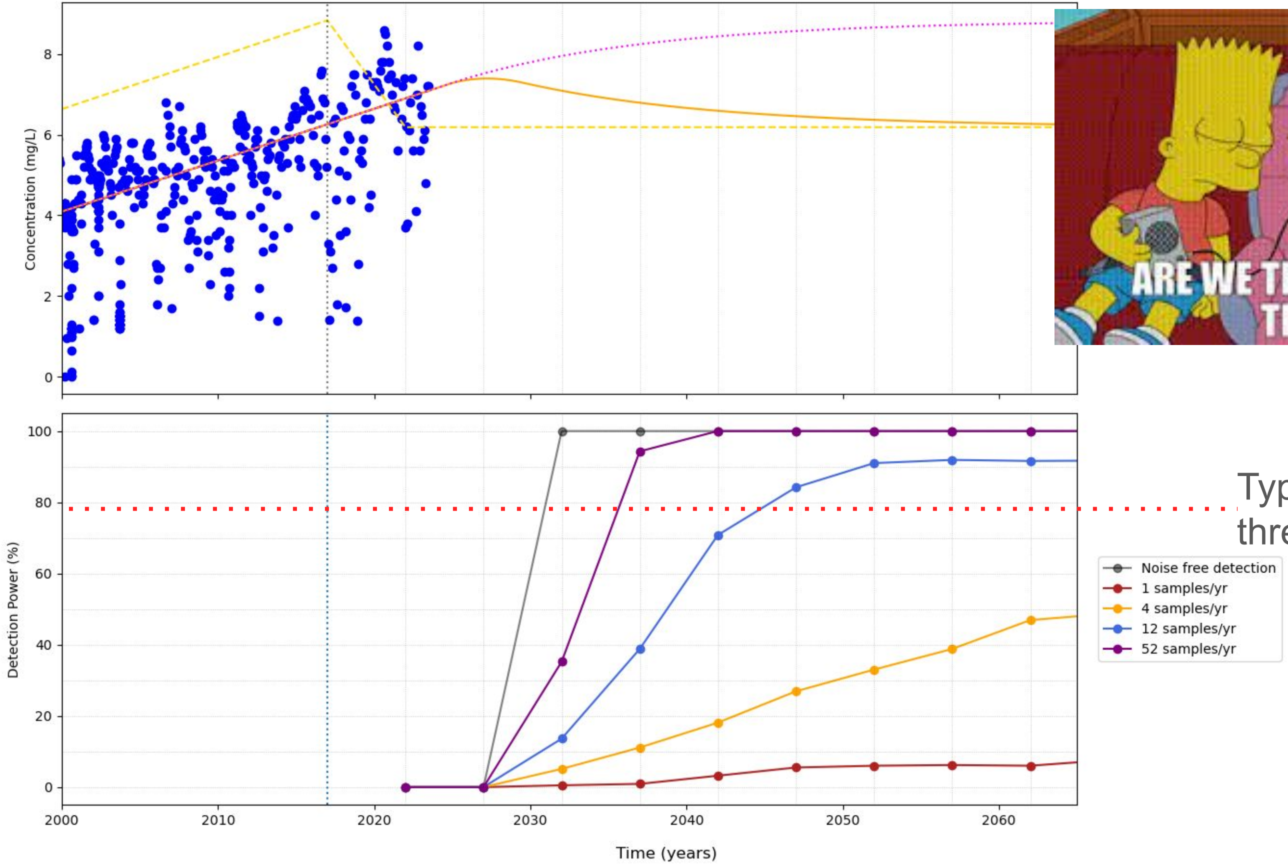
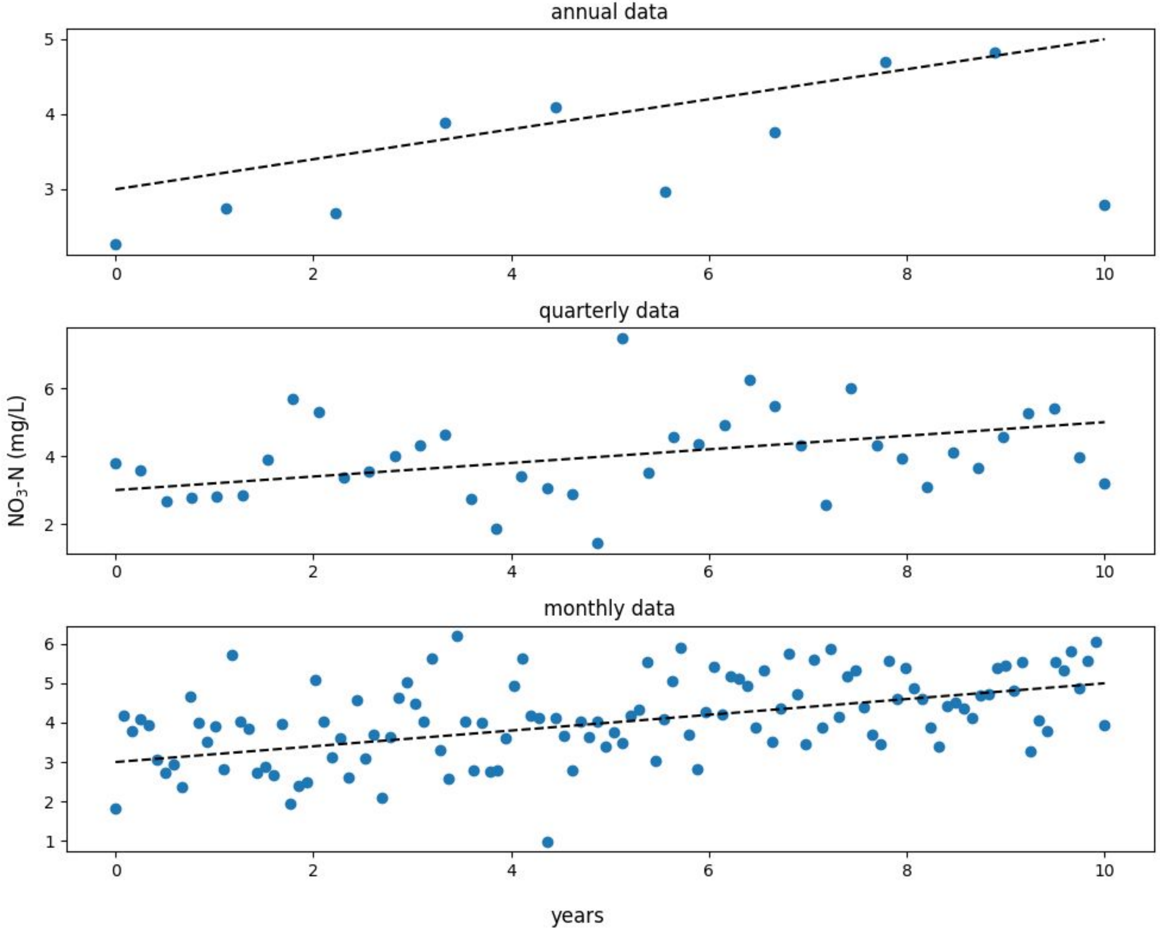
Sampling Duration: *The unhelpful silver bullet to detecting a change*



Typical threshold

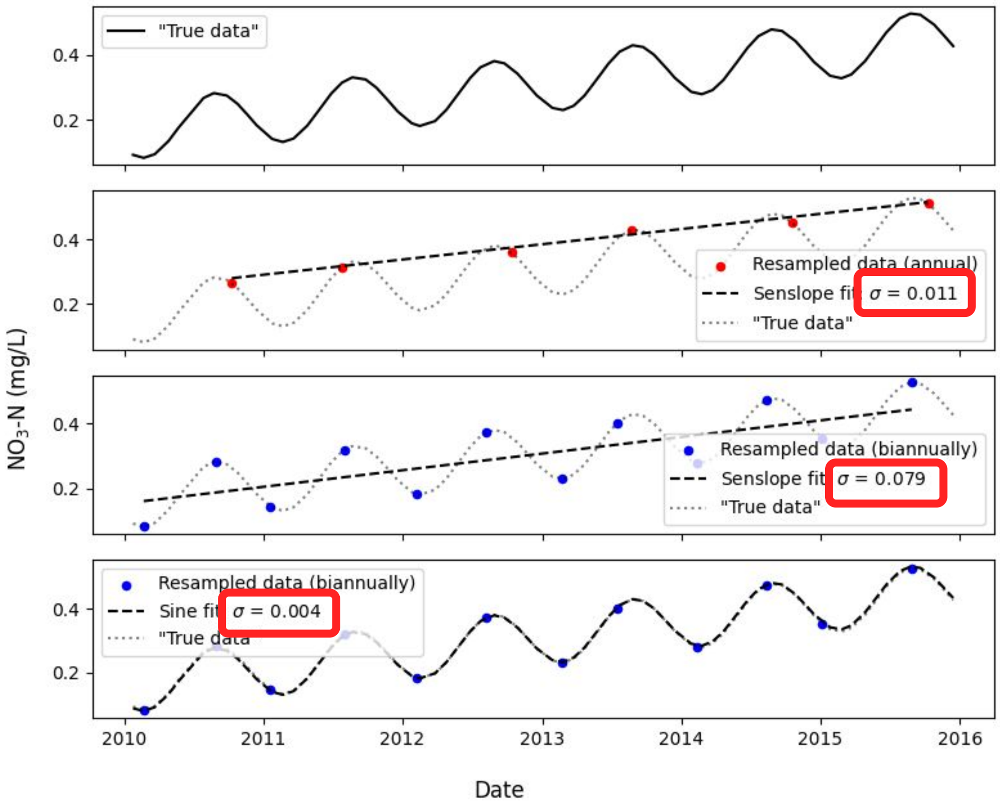
Sampling Duration

***Sampling Frequency:** The expensive silver bullet to detecting a change**



**once lag effects have been overcome.*

- *“A higher frequency sampling may introduce more noise whereas the proposed analysis seems to make **the assumption that noise is independent of sample frequency**. If higher sample frequency increases the proportion of noise, then it may not provide the conclusive evidence that is being suggested here.”*



Frequency - Noise

Frequency - Noise

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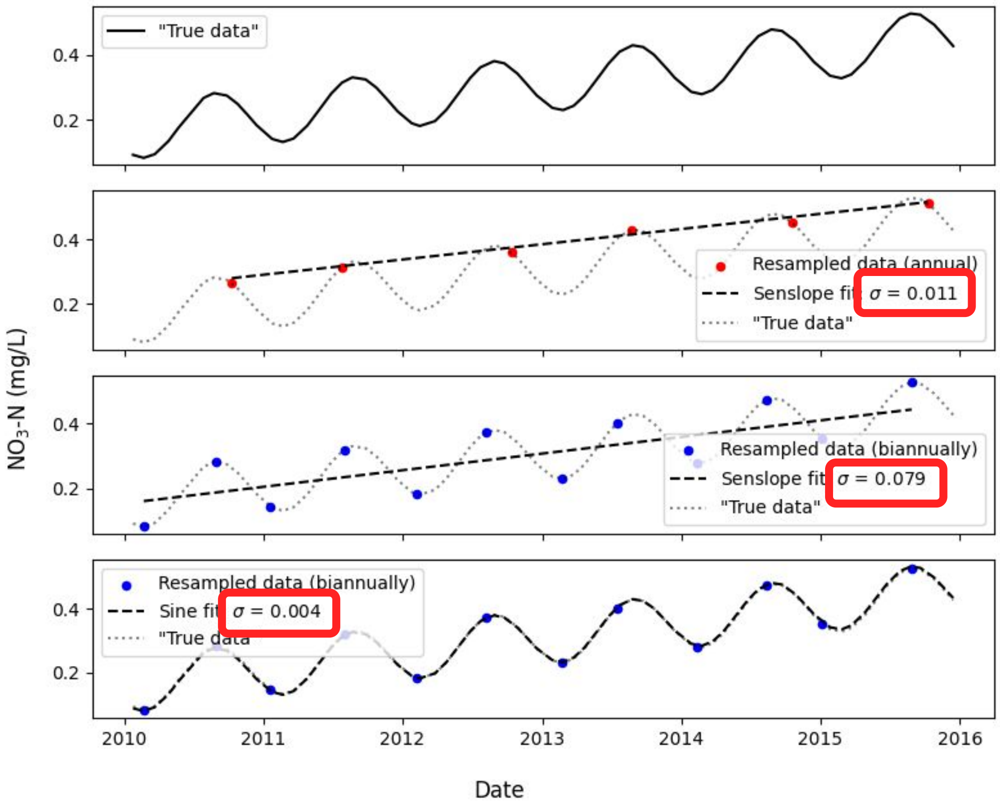
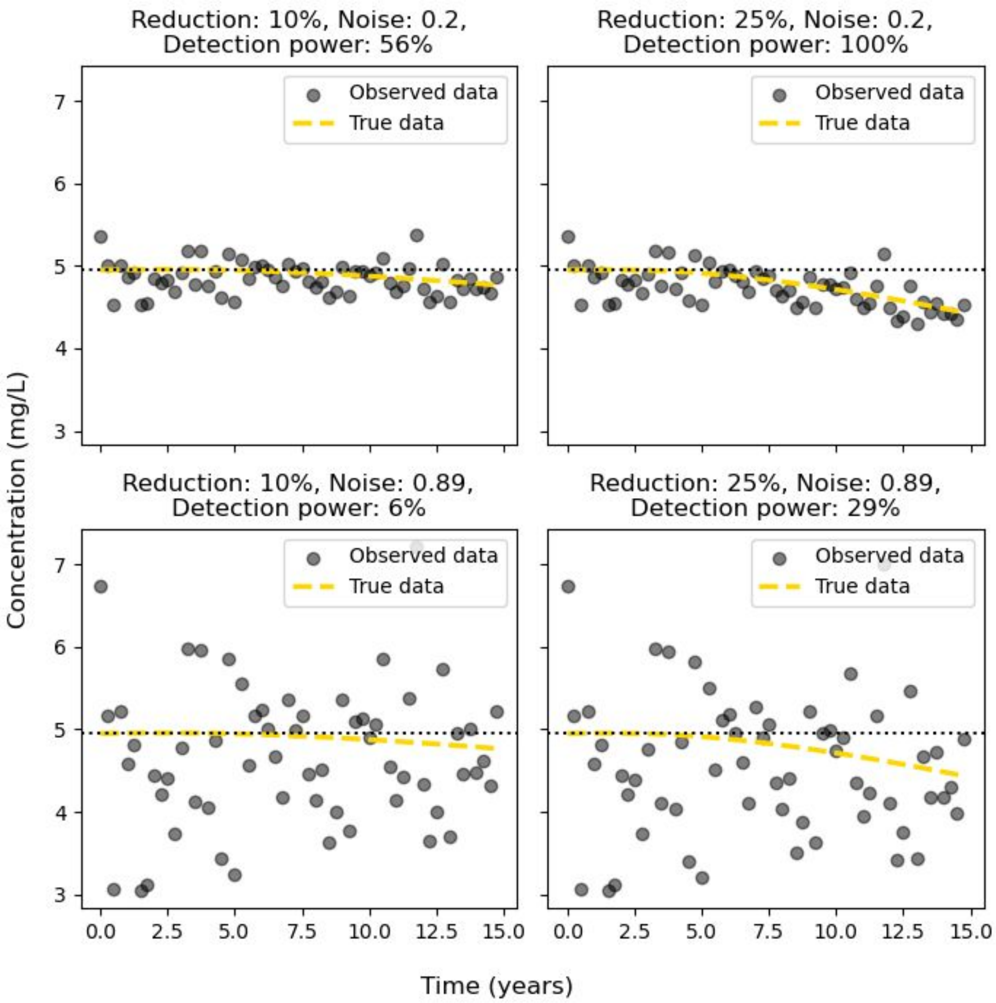


- ***More data always yields more information*, but you may need to work harder to extract it***

**autocorrelation*

*The ratio of **noise : change** is more important than the absolute noise or absolute change in concentration*



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Pathways (Δ size)

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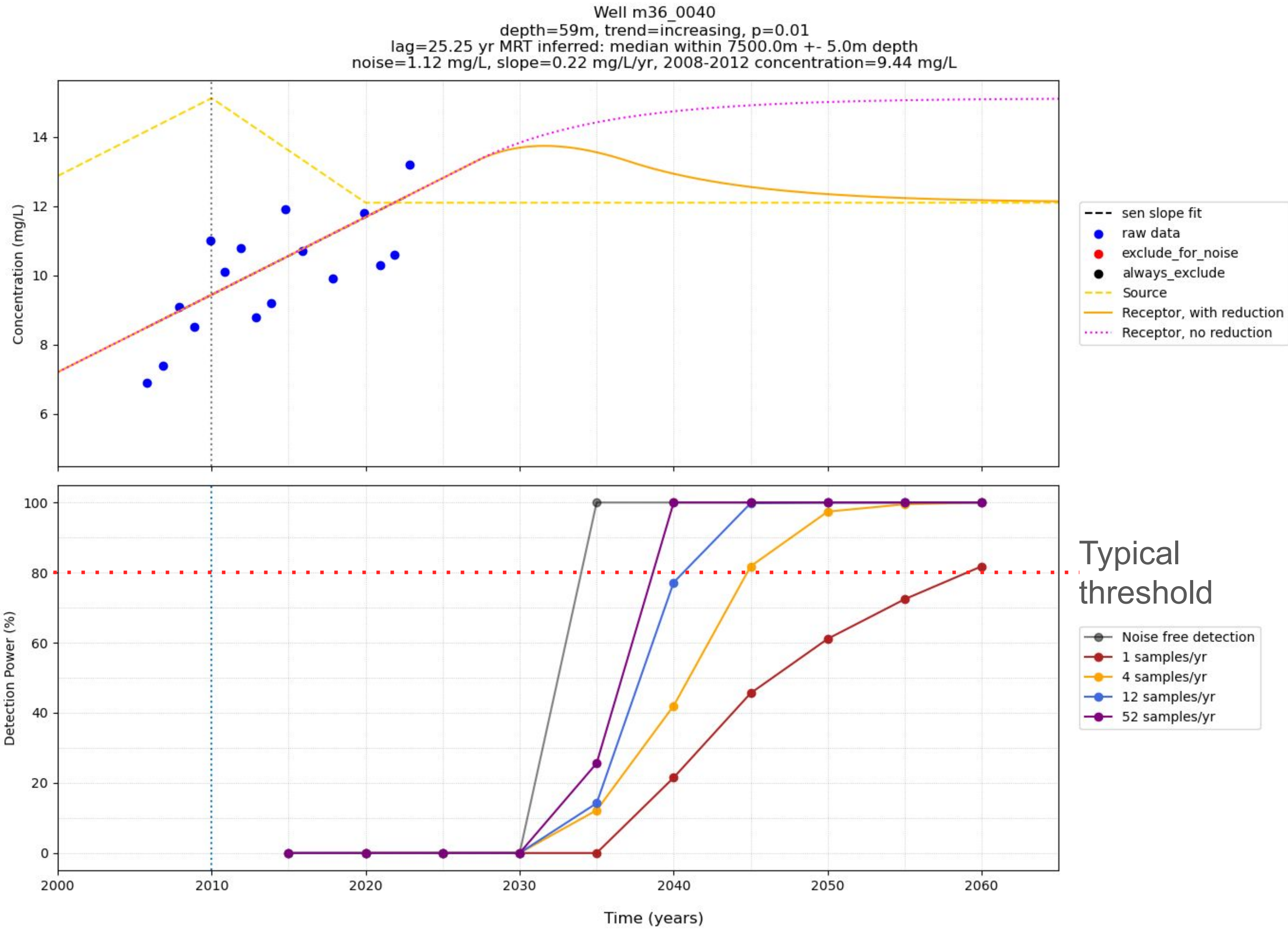
Putting it all togeather

Question + Pathway + Noise + Frequency + Duration = Detection Power



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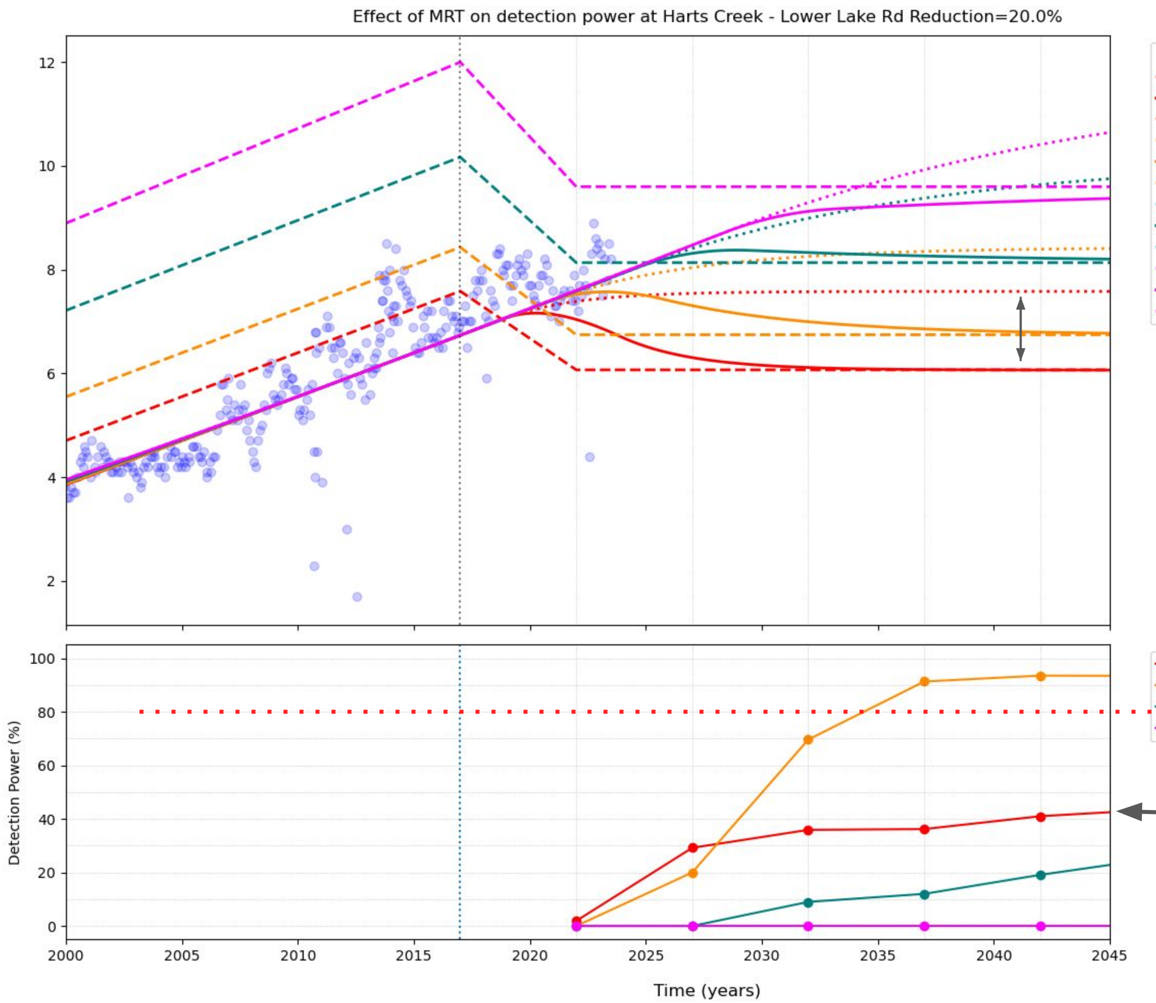
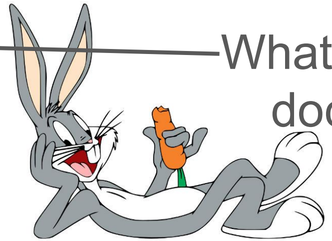
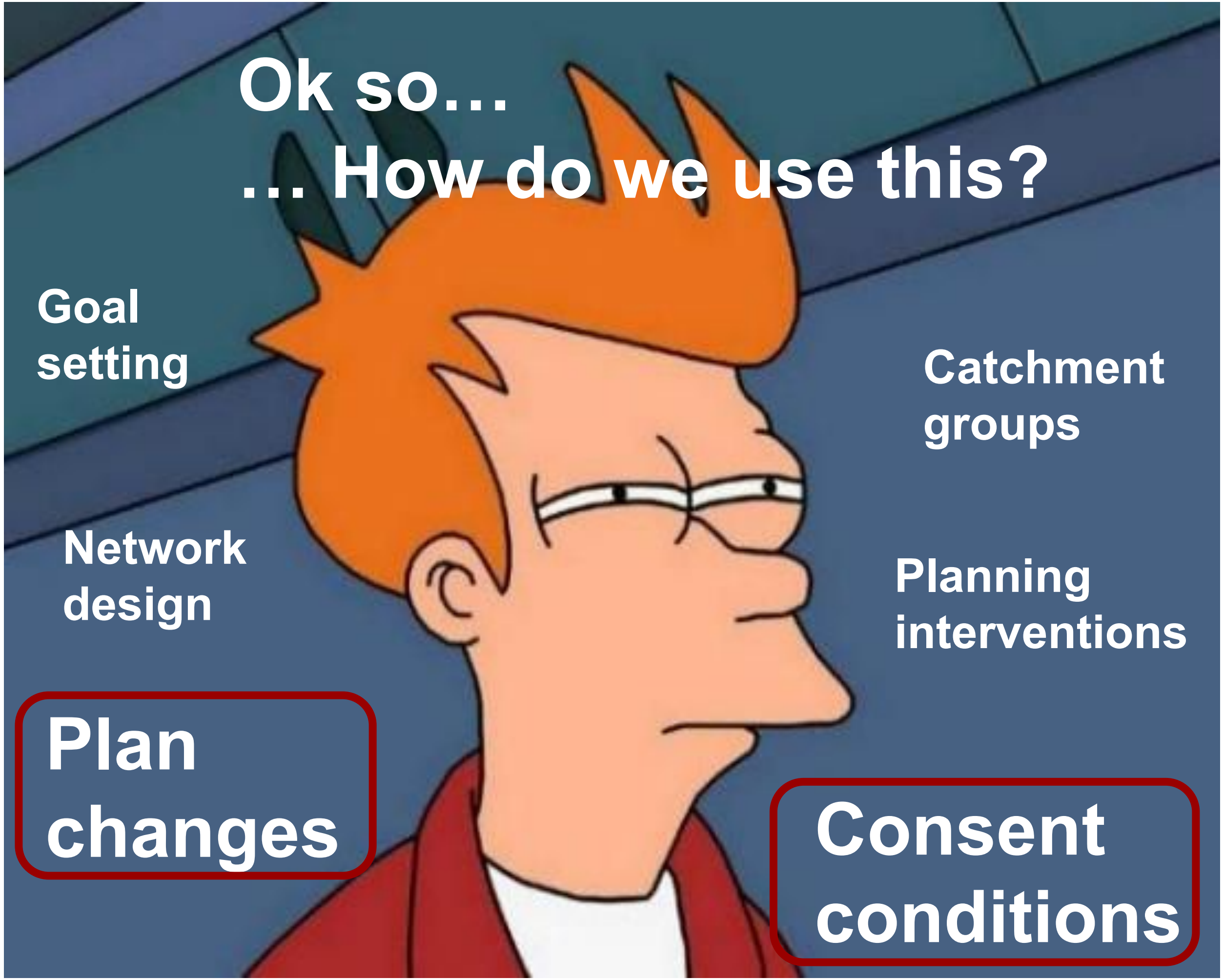


Typical threshold



What's up, doc…

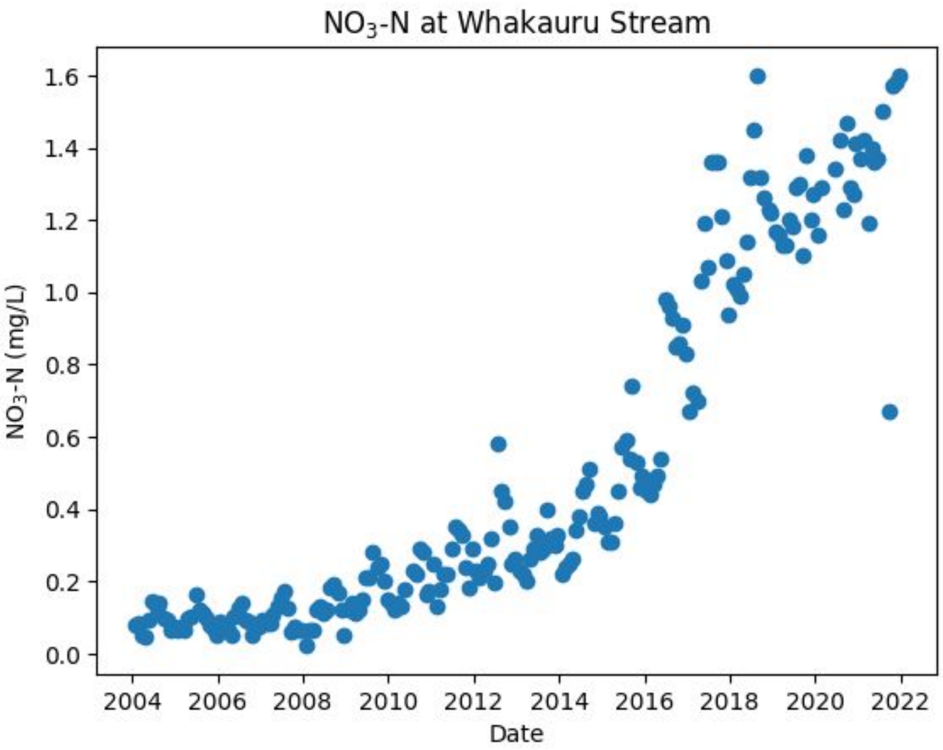
Lag & surface water


Ok so…
… How do we use this?
Goal setting
Catchment groups
Network design
Planning interventions
Plan changes
Consent conditions

Use Cases (UC)

Plan changes

Theoretical plan reduce the source concentration of Whakauru stream to 1.5 mg/l by 2040



¿ When will we see a reducing slope in the Whakauru stream?

Use Cases (UC)

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Plan changes

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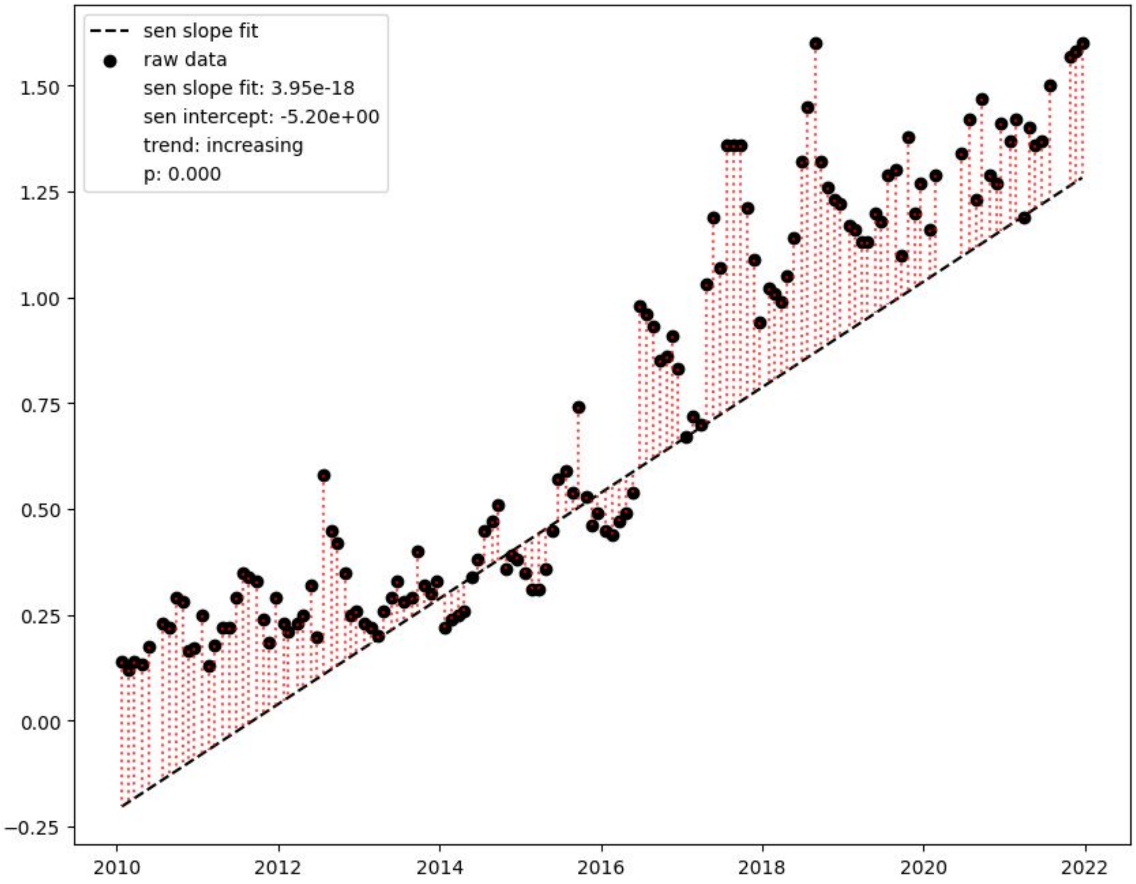

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Use Cases (UC)

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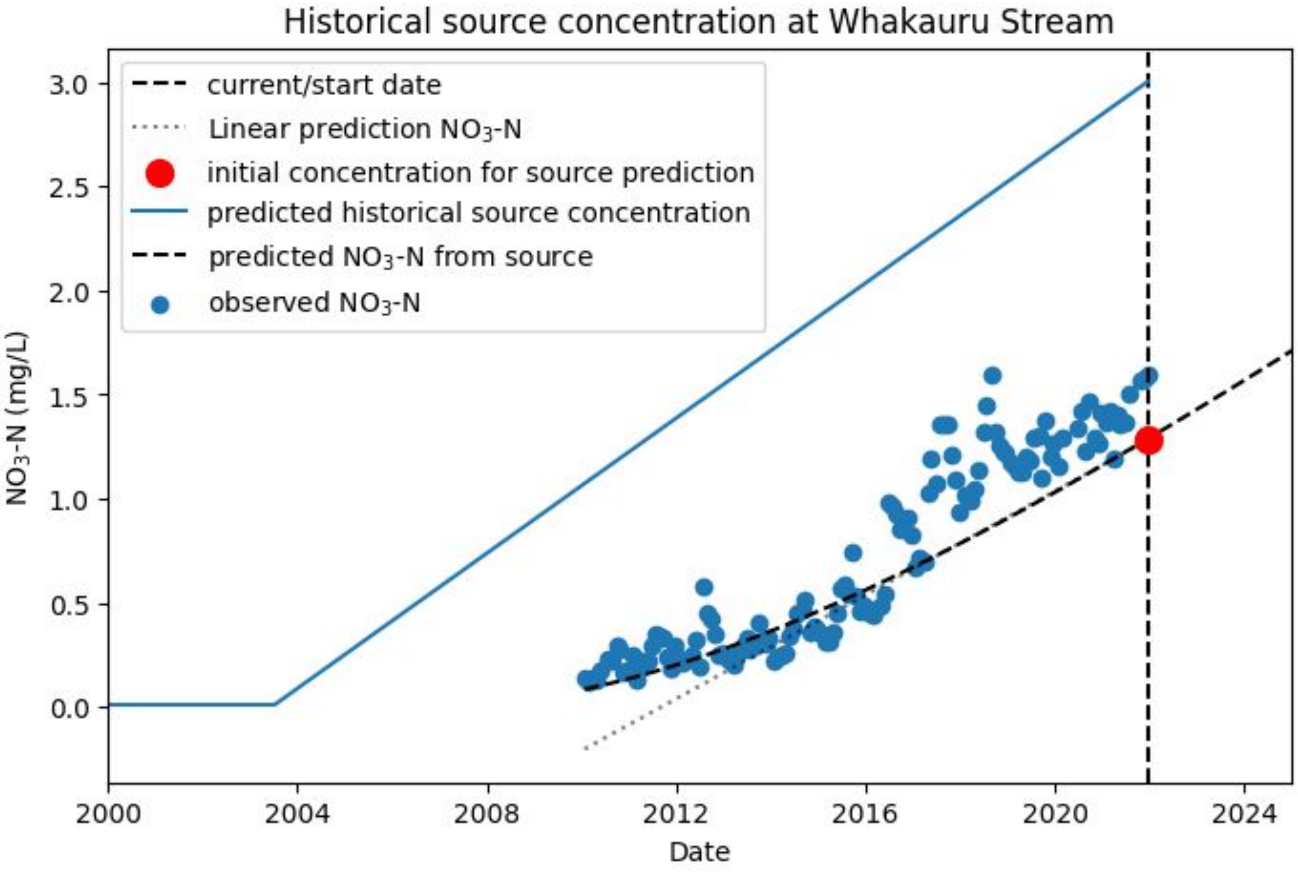

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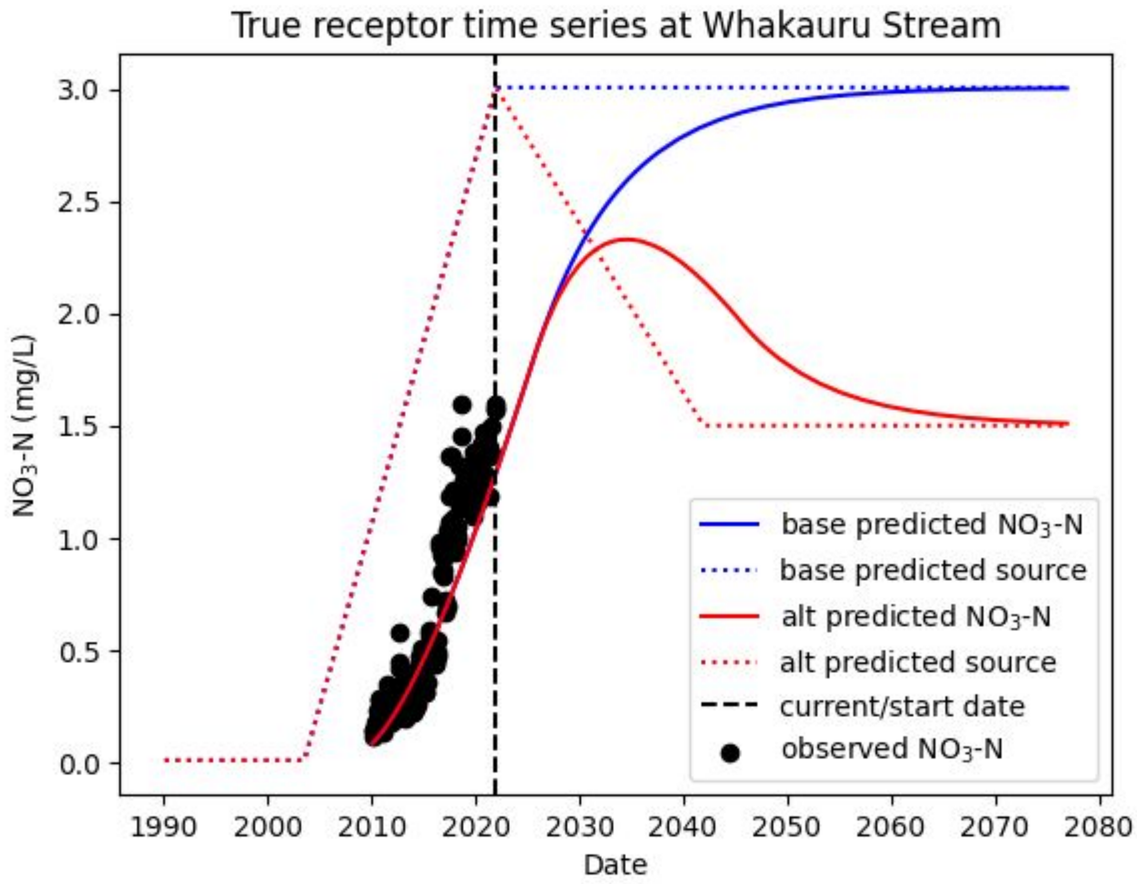

¿ When will we see a reducing slope in the Whakauru stream?

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Use Cases (UC)

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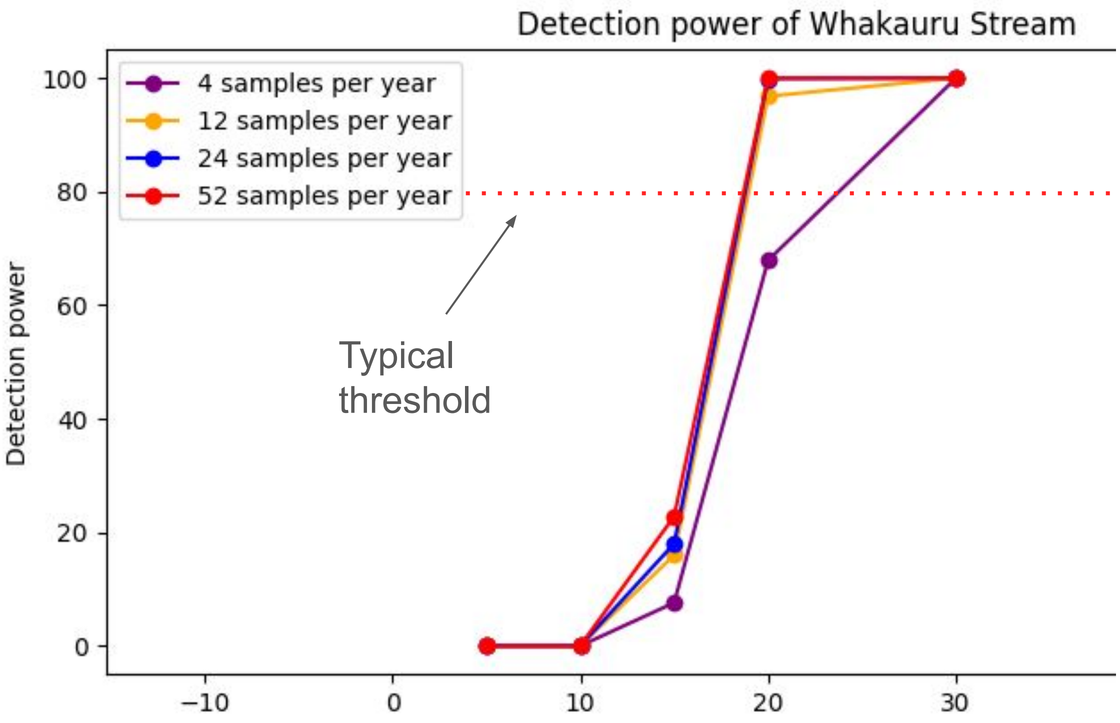
Plan changes

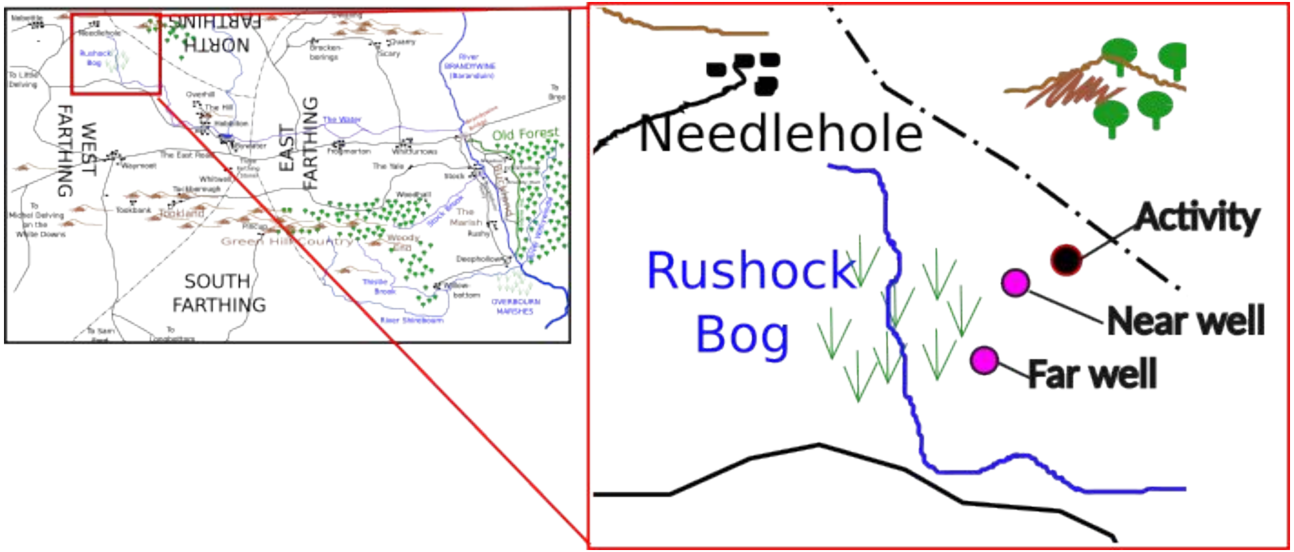
Detection power allows us to:

- **Set expectations**
  - Might start to see reductions after 15 years but it's unlikely
  - We should see reductions after 20 years
- **Set sampling frequency:**
  - Need at least monthly samples



Consent conditions

New consent, which could increase groundwater concentrations

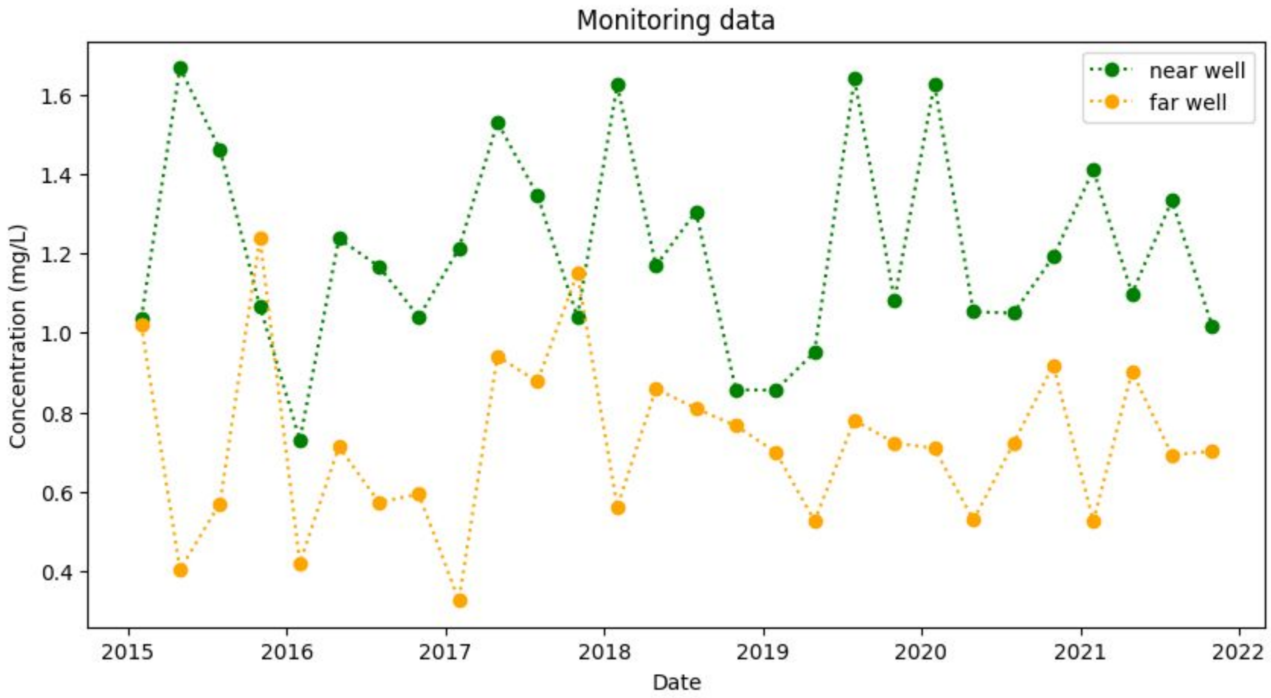


Thanks: Chiswick Chap - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=89087488; also J.R.R Tolkien

Consent conditions

New consent, which could increase groundwater concentrations

Existing data (quarterly)



Noise near well: 0.26 mg/L

Noise far well: 0.22 mg/L

Use Cases (UC)

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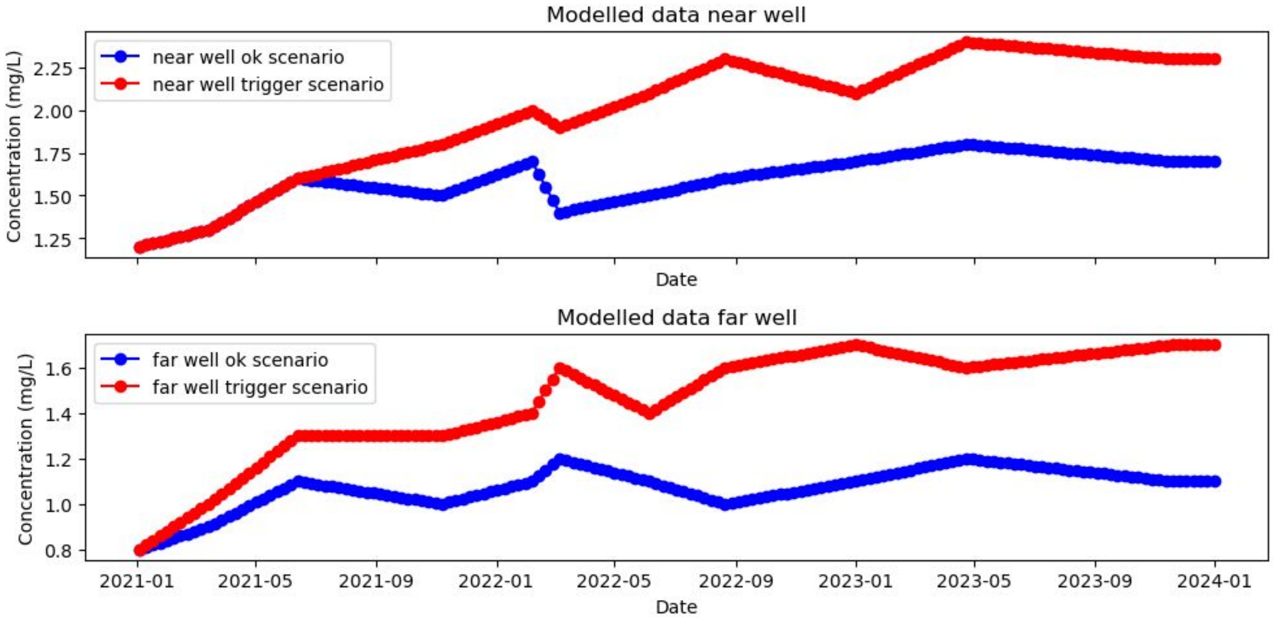
Consent conditions

Modelled acceptable
and trigger scenario



¿How frequently do we need to sample to tell the expected (ok) scenario from the trigger scenario?

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Use Cases (UC)

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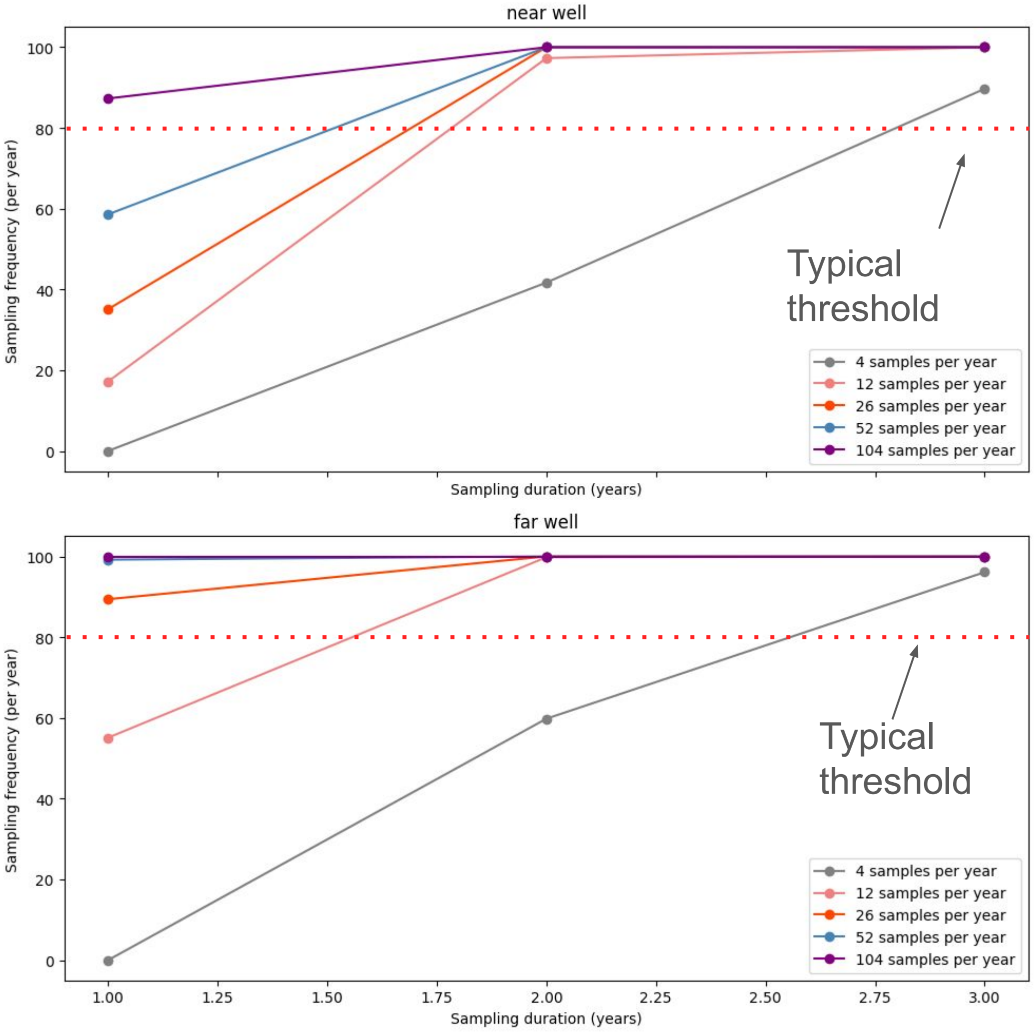
Consent conditions

Applicant proposes to use the **current quarterly sampling** to assess the impacts of the activity

Detection power analysis suggests that **quarterly monitoring would not be sufficient** to distinguish the two scenarios. At a minimum monthly sampling is needed, but **fortnightly sampling at the far well would likely allow characterisation within 1 year**



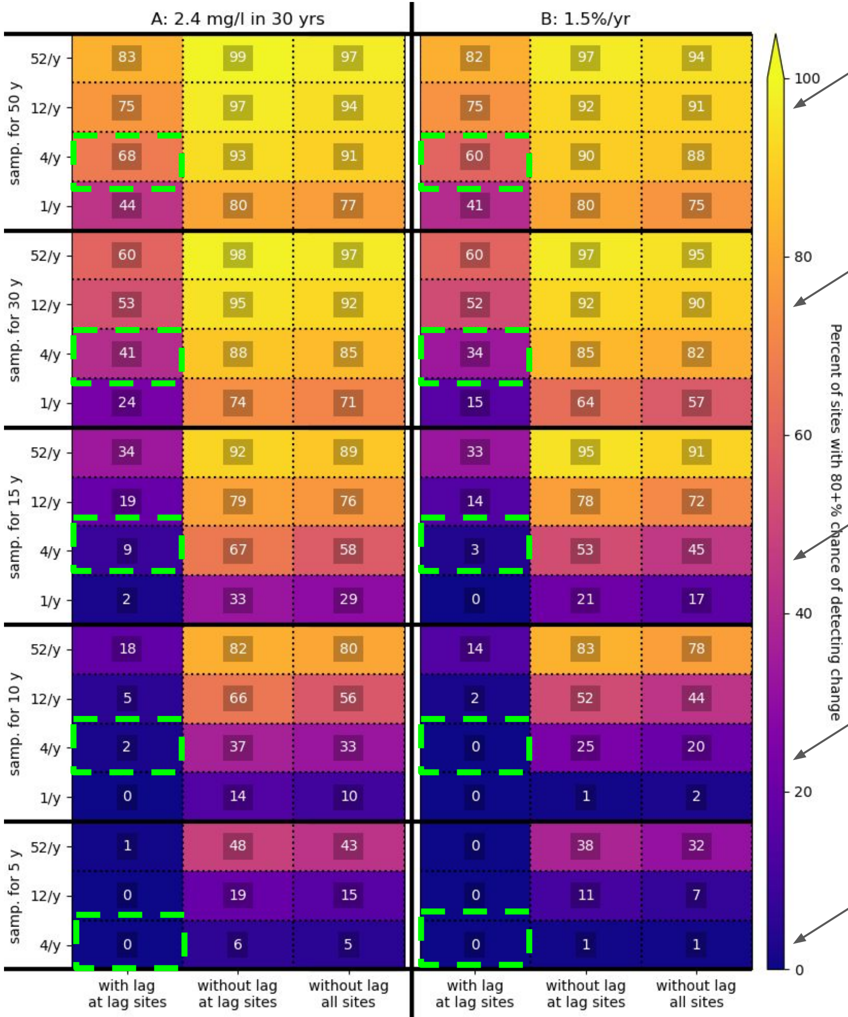
Use Cases (UC)

What to expect

Our national monitoring networks are not well suited to detecting change

Fixing this is expensive

- *Dumont et al., (in submission)*



75% reduction

45% reduction

22.5% reduction

15% reduction

7.5% reduction

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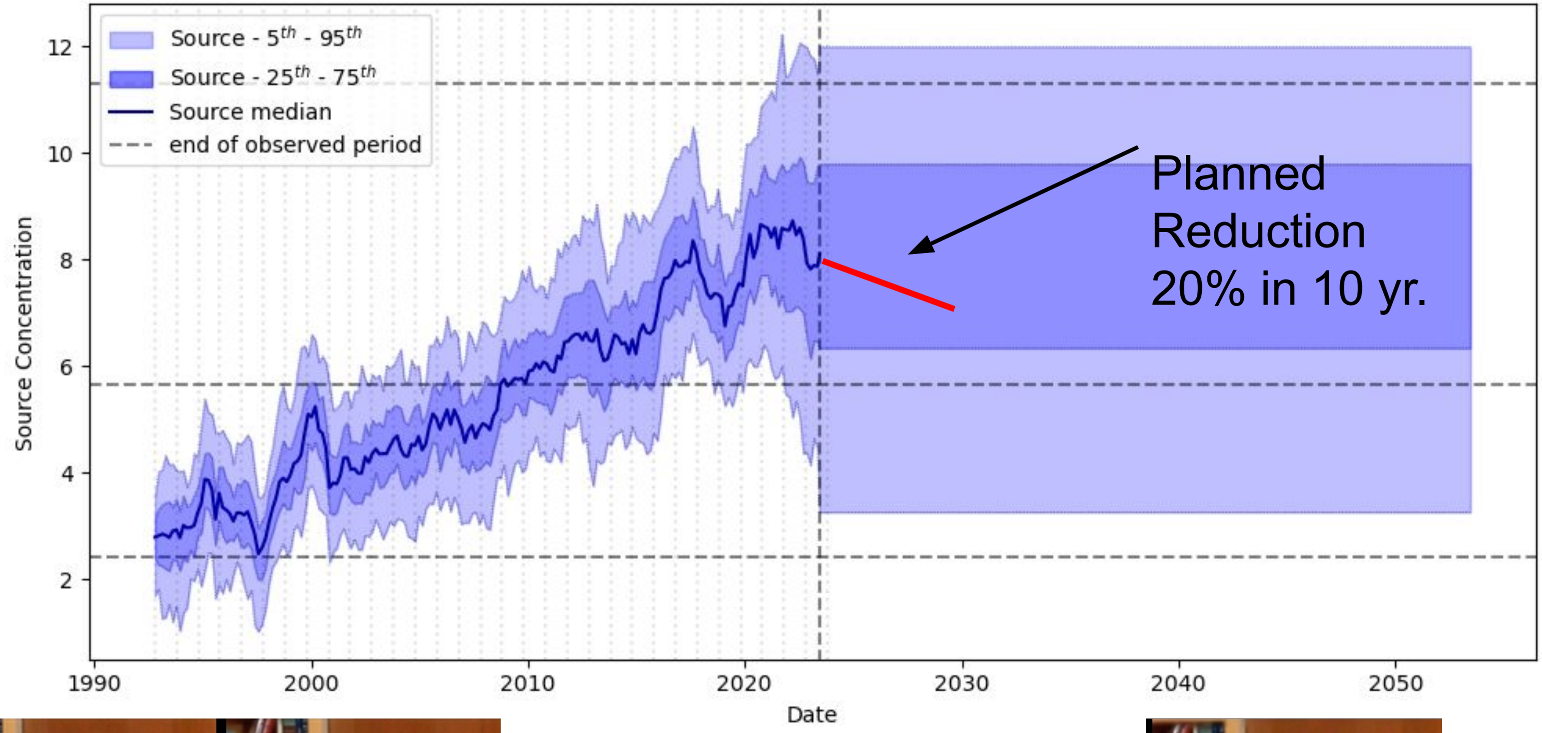
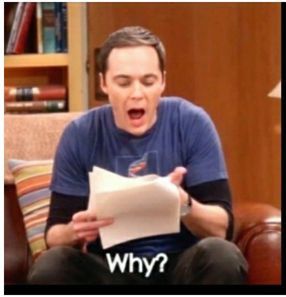
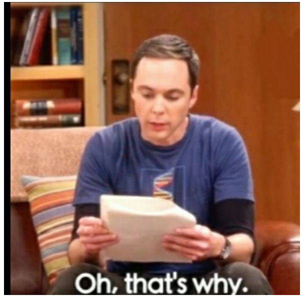
But… we've seen change



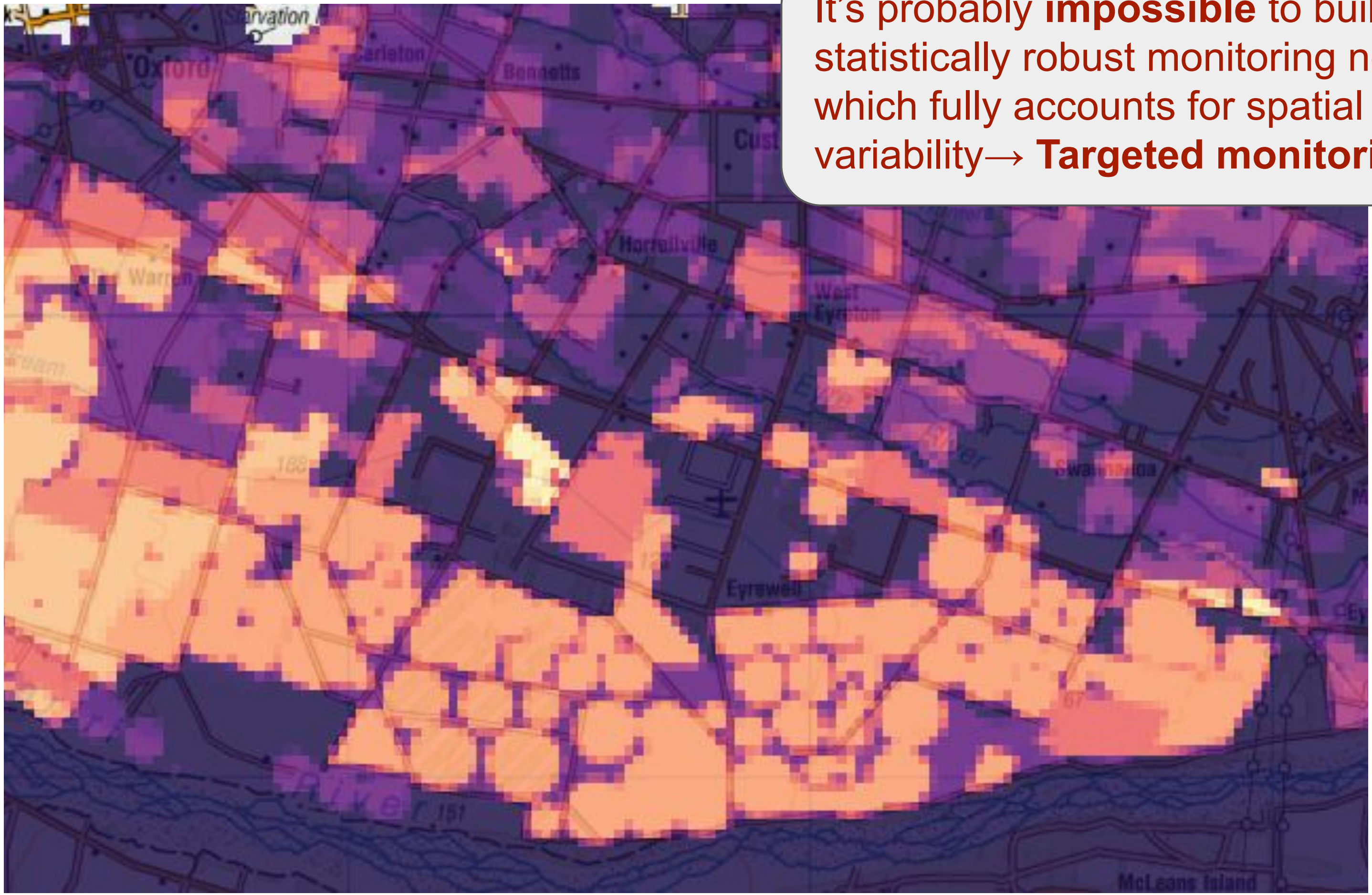


We break things fast, and fix things slow



Spatial variability

It’s probably **impossible** to build a statistically robust monitoring network which fully accounts for spatial variability→ **Targeted monitoring**



Bespoke network design and review process:

1. Initial network design:
    a. Define mitigation plans/scenarios and monitoring goals
    b. Develop a conceptual model of the monitoring area: (nitrate load distribution, reduction rates, travel paths, attenuation and transit times)
    c. Identify key knowledge gaps
    d. Integrated analysis of groundwater and surface water detection power for existing sites
    e. Evaluate representativeness of priority monitoring sites
    f. Identify new monitoring sites (if needed)
    g. Undertake a sampling frequency cost-benefit analysis
2. Review network frequently (e.g., after 1, 3, 5 years)
    a. Have detection power and timeframe requirements have changed in light of new information.