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High frequency sensors: do we even have the choice of ***not*** using them in drainage?

François Birgand
Associate Professor & University Faculty Scholar

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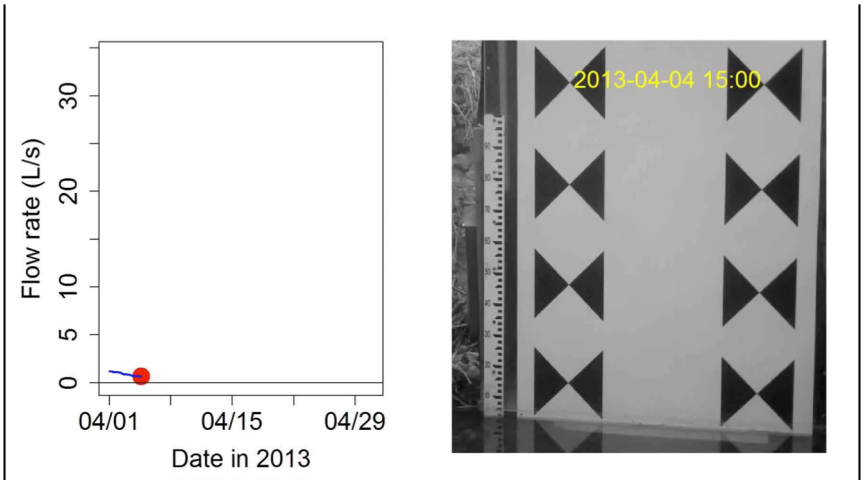
In Environmental Sciences we…

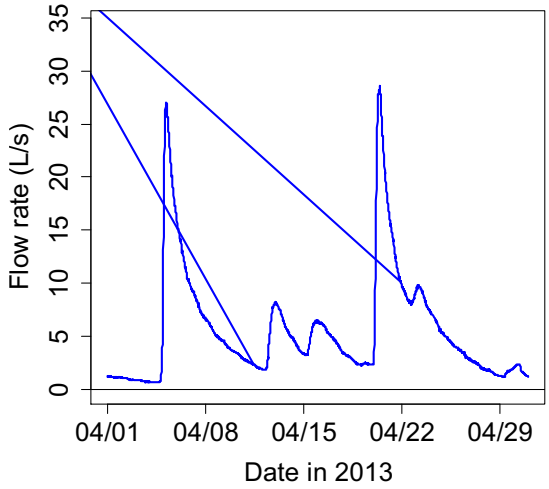
- … want to tell the story of how the world functions
- … make hypotheses
- … we collect data *partial in space and in time*
- … infer processes at play, quantify, extrapolate, model
- … make conclusions on how the world functions and what we should do about it

In hydrology, we have had access to 'the story'

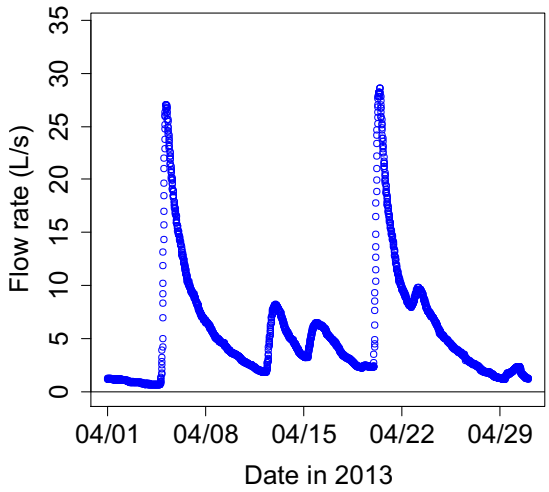
Images: GaugeCam.com



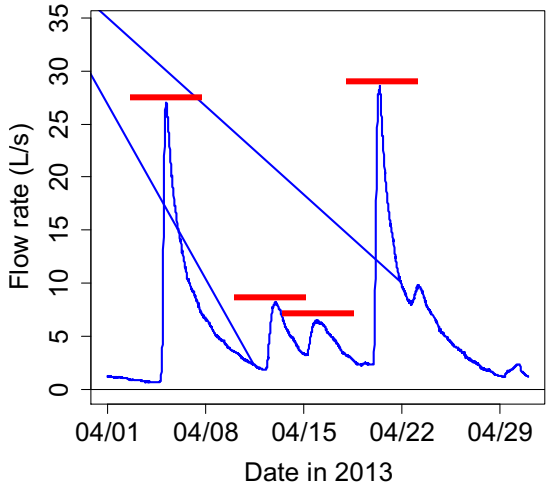
'Continuous' = high frequency



‘Continuous’ = high frequency

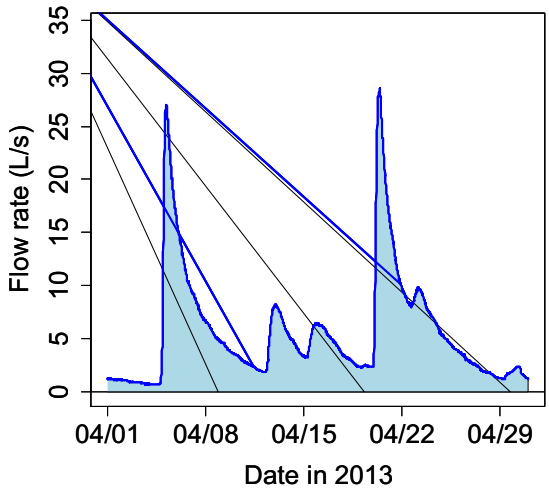


With the full story, we can…



With the full story, we can…

Calculate Cumulative flow volumes



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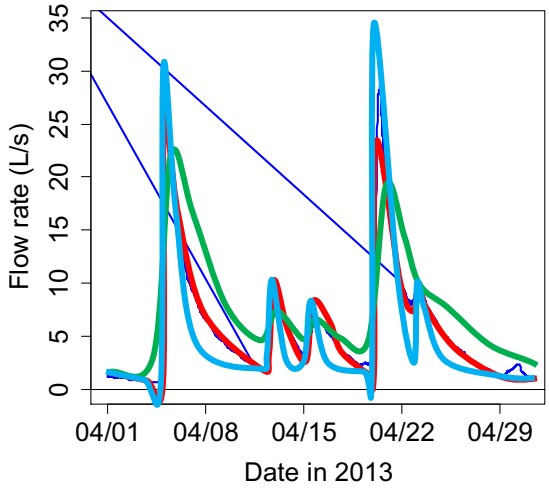
With the full story, we can…

Calibrate our models



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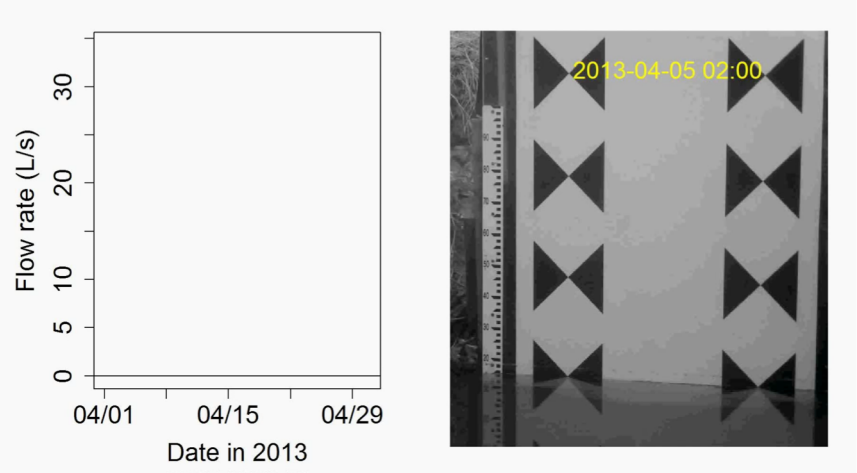
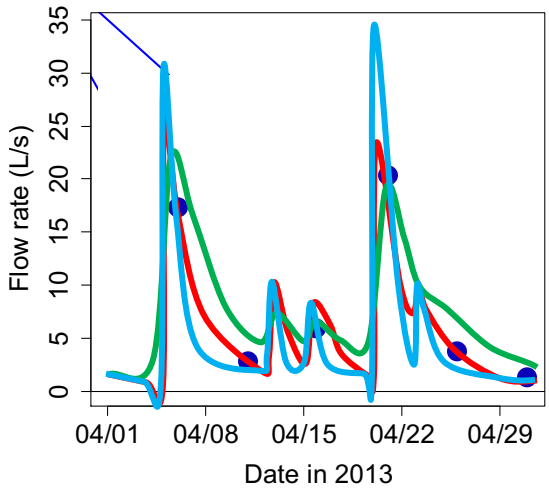
Just Imagine…



Just Imagine…

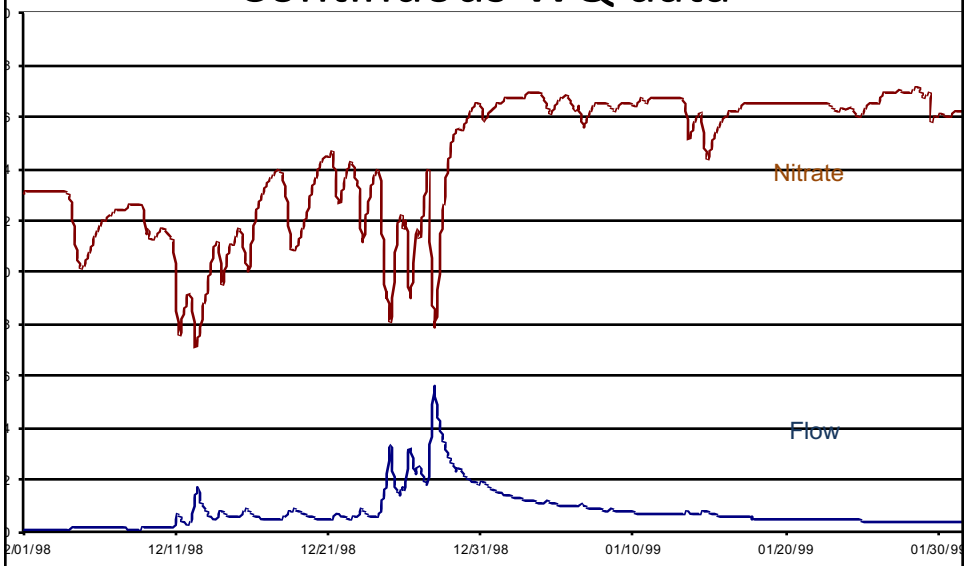


1 ?

2 ?

3 ?

Continuous WQ data



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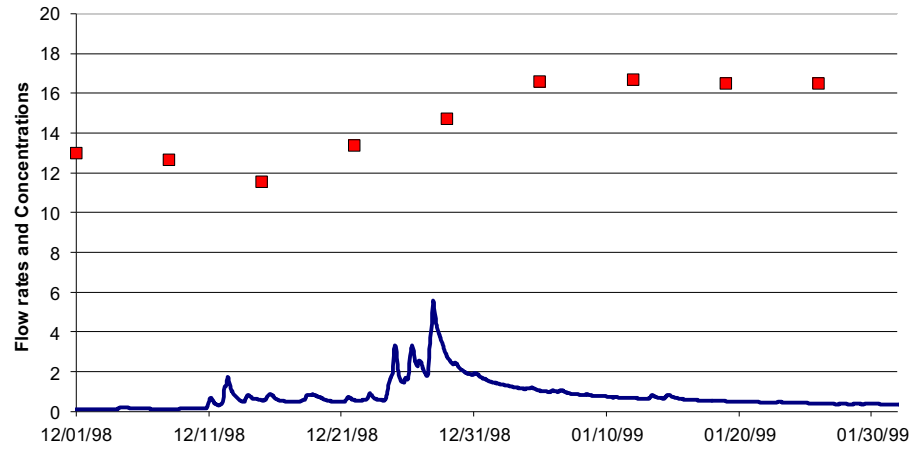
Weekly samples…



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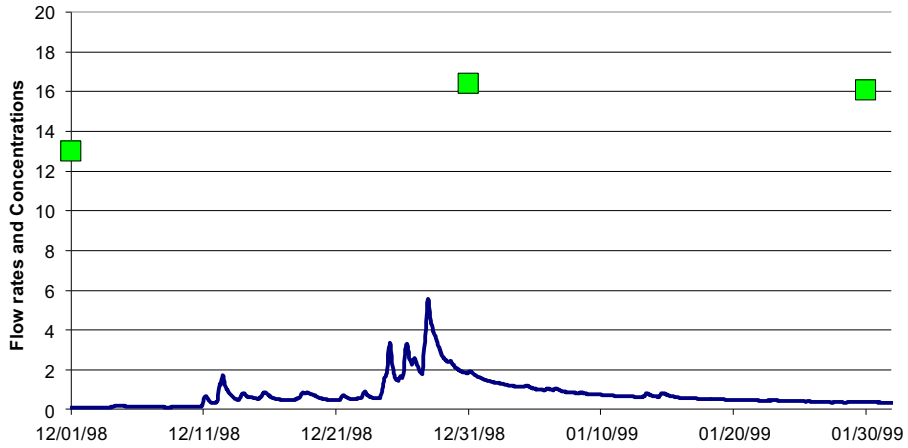
Monthly samples…



A little story

" … …Troy … … … . … … … … hard; … … … … … … … … … … … … unconscious … … …, … … … … … face … … … … … … … … … … … … bad … … … …"

A little story

" … …Troy … … … . Marc … … … hard; … … … … … … … … … forehead. … … … … unconscious … … floor, … … … … … face … … Marc … … … all … … … … bad … … … feared."

A little story

"Marc … … … … …. … … … … … … ; … missed … … … … … … …. Troy … … … … … … … … … … smile … … … … … … … … … … … … … … … … not … … … … … …."

A little story

"Marc … … … … catch. … … … ball… ; … missed … … … landed … … …. Troy … … … unconscious … … … … … … smile … … … … reassured … … … was … … … not … … … … … … feared."

A little story

"Marc and Troy were playing catch. Marc threw the ball hard; Troy missed it and it landed on his forehead. Troy was laying seemingly unconscious on the floor, but the smile on his face quickly reassured Marc that everything was all right and not as bad as he had feared."

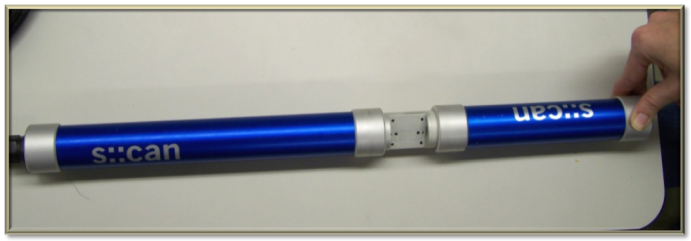
We need the full drainage story otherwise…

- … our load calculations may be erroneous and we might not detect water quality improvements
- … drainage fields are going to remain a big black box: are we are stuck in the 1990s…?!
  - Little chance to propose new management solutions
- … all our water quality models are wrong, but we have no idea by how much…!

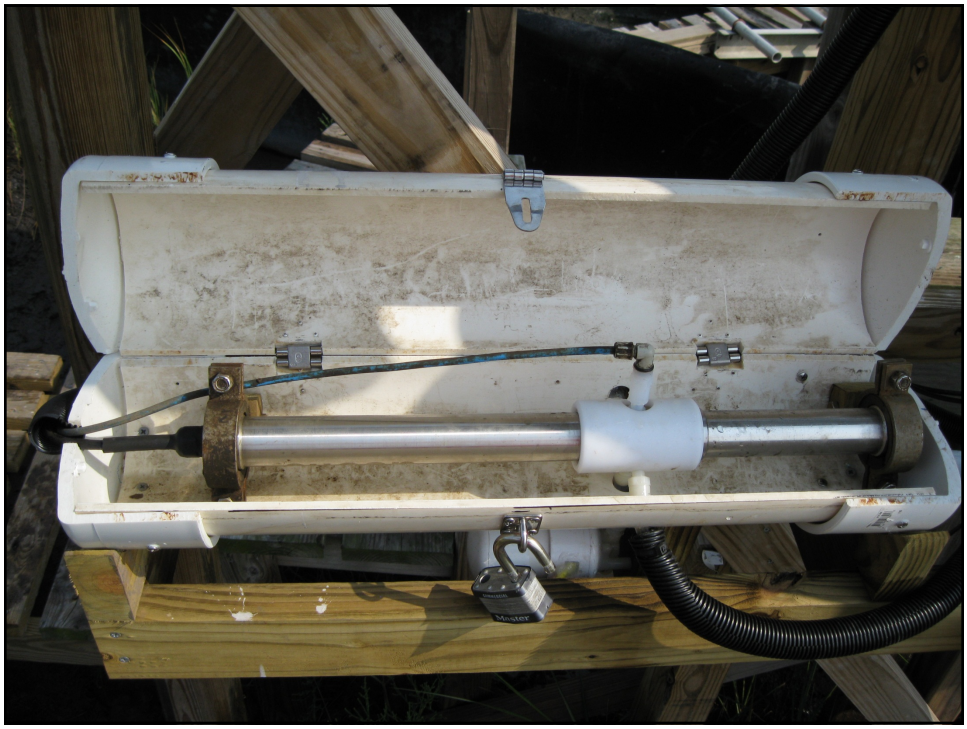
Are there solutions ?

Continuous sensors

- Field UV-vis spectrophotometers

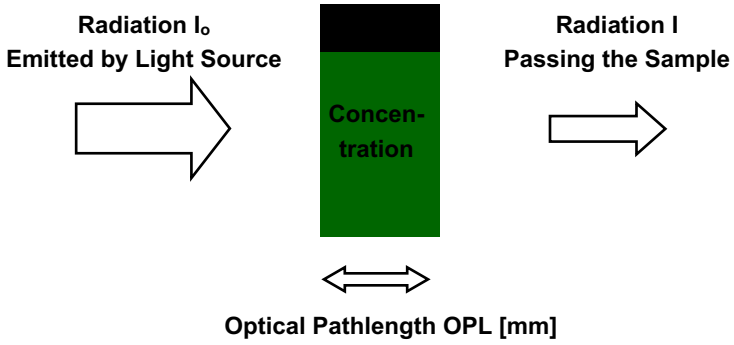


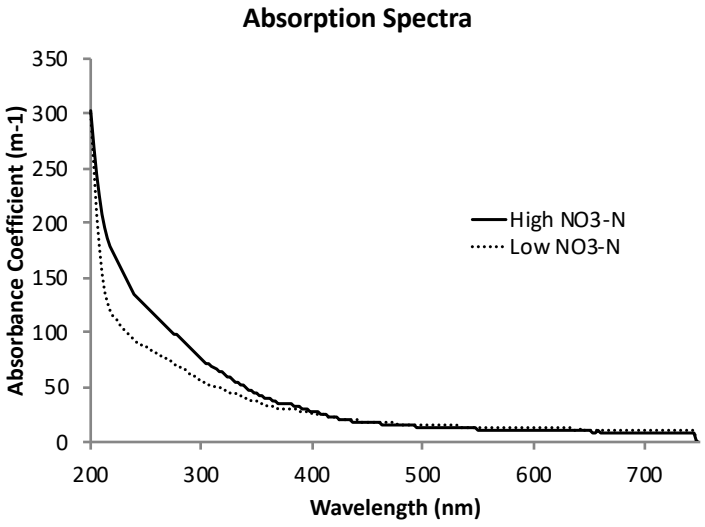
- Spectro::lyser from S::CAN, Austria



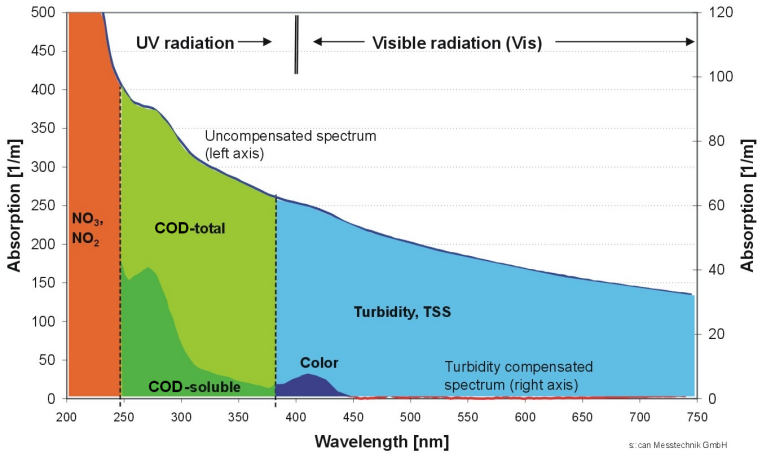
The spectrometric process analyser

The measuring principle – Lambert Beer





Absorption Spectra



What parameter can we measure?

- Most manufacturers advertise for Nitrate
- Some add DOC and Turbidity

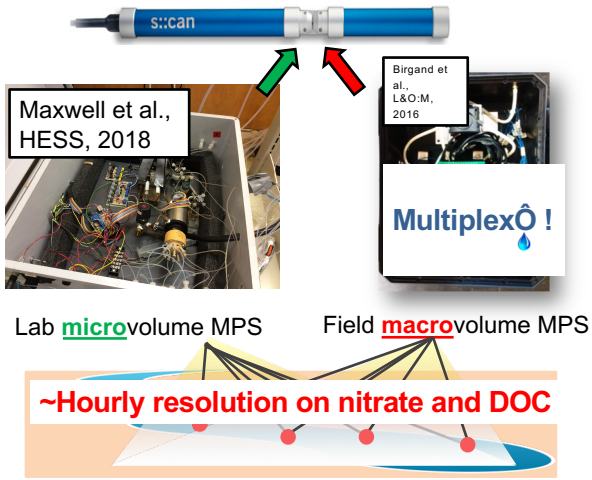
- Other parameters may be linked to turbidity (e.g. TP, PON) or to DOC (e.g. DON)
- Possibly covariability between light absorbance and other parameters?

Can these sensors fit into drainage pipes?

- No…
- Installation possible in drainage collectors but we miss characterizing dynamics at the field scale…
- They are not cheap, yet…

1- possible solutions

- Space limitations:
  - Pump water from drainage lines to the sensor
- Cost limitations:
  - Pump from several sources to one sensor
  - Obtain high resolution data in space and in time



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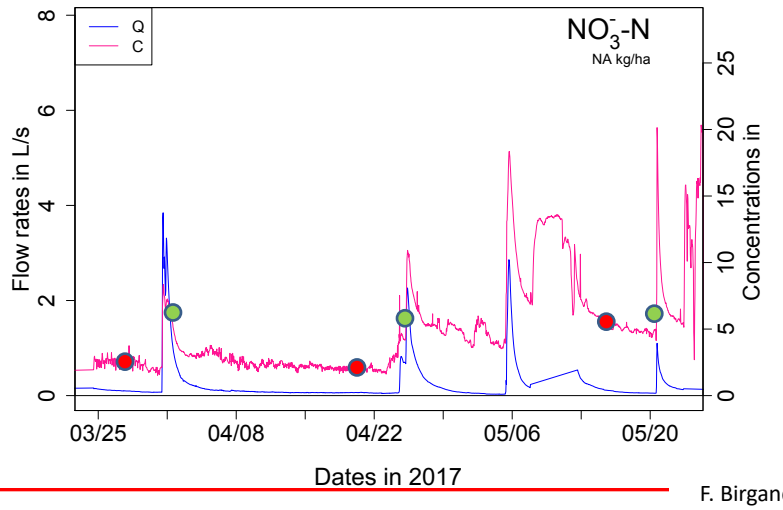
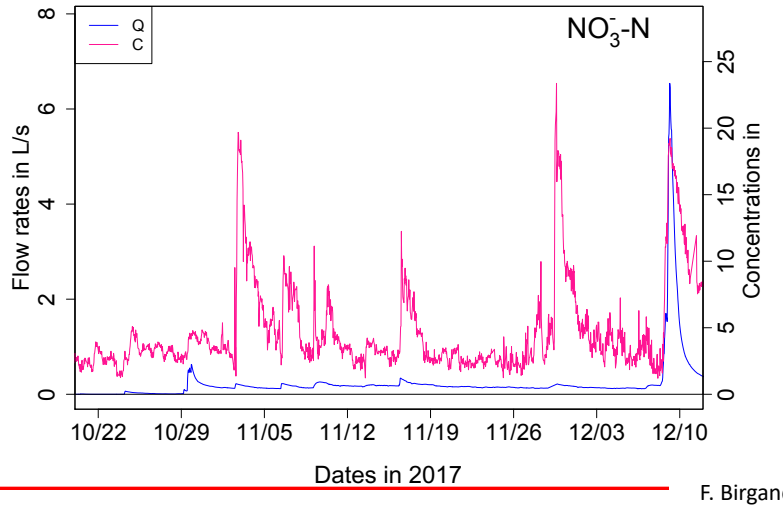
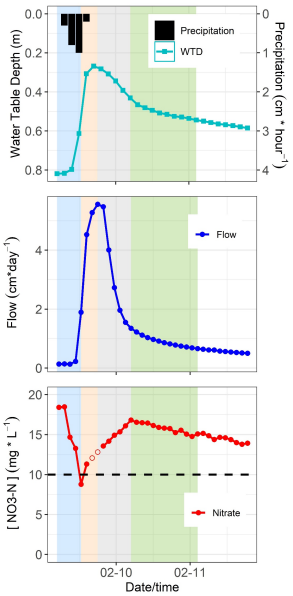
What do we get?

2- Some of the story in NC drainage

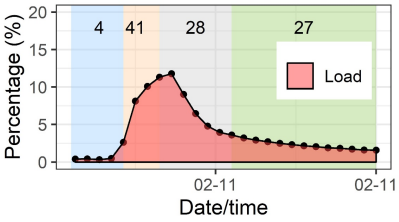


Some of the story in NC drainage



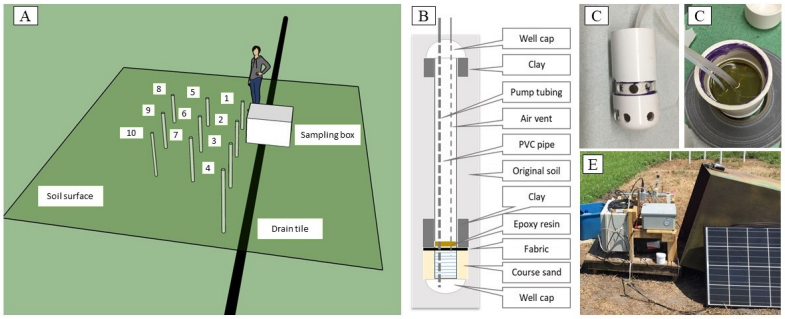


Evolution of nitrate leaching from the field.



Liu et al., submitted

Well nest along an array of depths and distance from the drain



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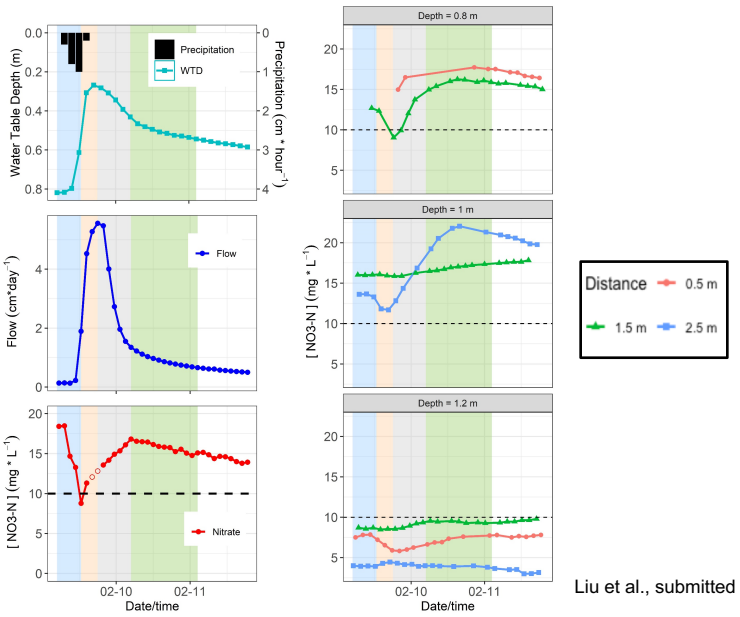

Liu et al., submitted

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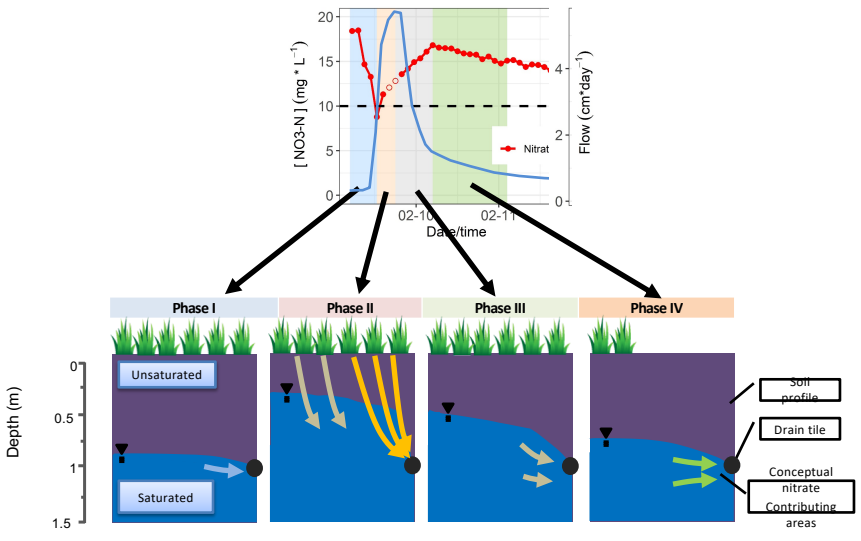

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Management considerations

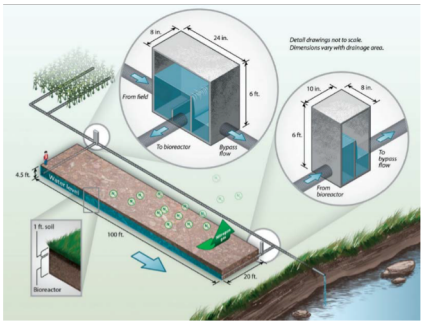
- Quick flow near the drain contributes to most of flow and nitrate load
- Adjust fertilization accordingly?

3. Unveiling the inside of another black box:

- Woodchip bioreactors

What are woodchip bioreactors?

- Agricultural BMP
- Intercept tile drainage
- Targets nitrate removal
- ~20 year lifespan
- NRCS approved
- 2-22 g N m^{-3} d^{-1} in field
- Mainly seen in Midwest



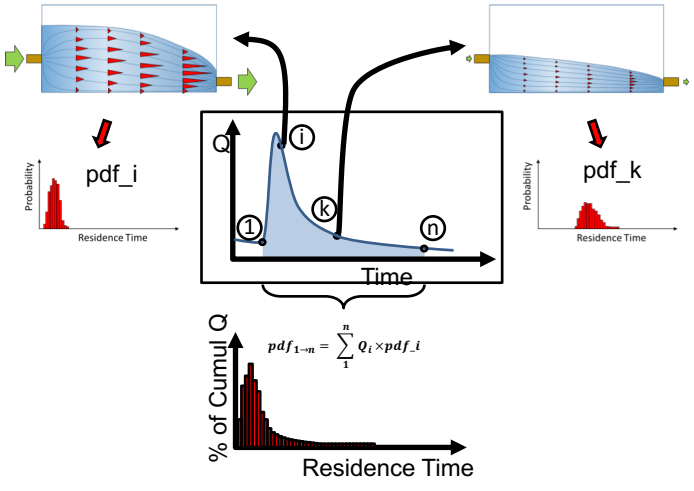
Christianson and Helmers, 2011

From the literature

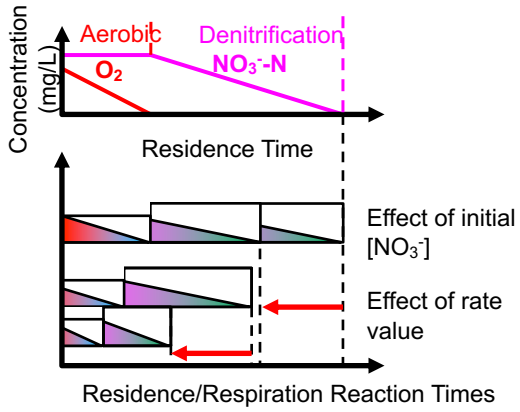
- Reported nitrate removal efficiencies varying from less than 10% to more than 90%
- Decrease of removal efficiency within one to several years from >60% to <20%

Research questions

- Why are there so much discrepancies in the reported removal rates?
- What are the factors driving the nitrate removal efficiencies, and its decrease over time?
- What can we do to 'rejuvenate' bioreactor and maintain removal efficiency?
- Can we provide guidelines for maintaining and increasing nitrate removal efficiencies?



Respiration rates and residence time



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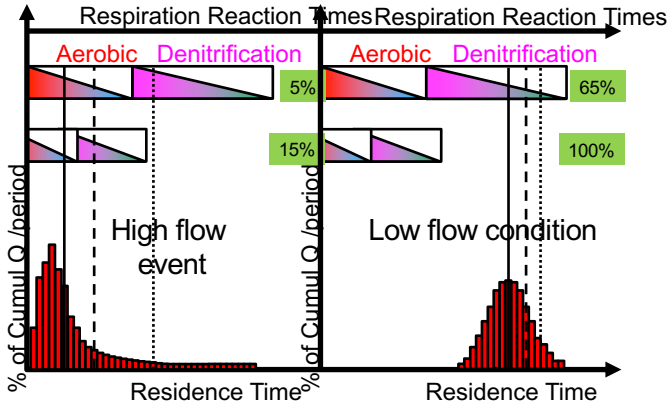
Apparent removal rates



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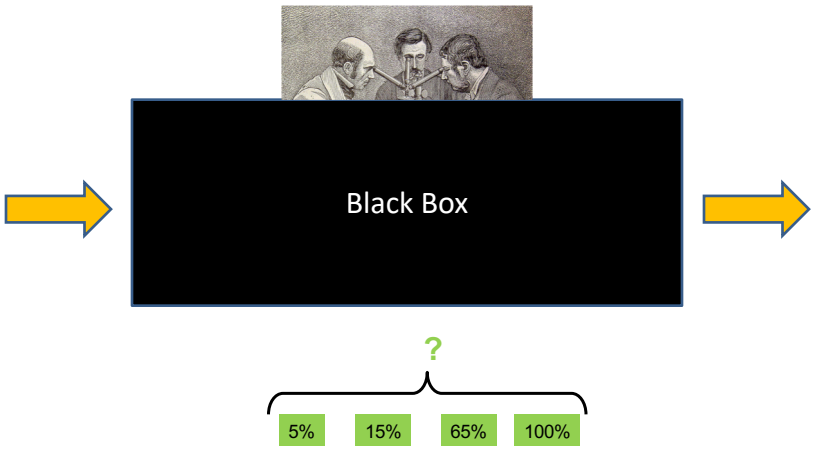

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Objectives

- Track and quantify the fate of water, nitrate, and DOC to reconstruct the apparent functioning
- Measure in the lab and in the field the aqueous and gaseous removals and emissions associated with the use of bioreactors
- Find solutions to 'rejuvenate' woodchip bioreactor
- Integrate this new knowledge into 2D biogeochemical computer models
- Use the models to explore and define novel and optimized design and management guidelines

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Method

- Use high resolution instruments to measure gaseous and aqueous concentrations
- Lab column experiments
- 2-5 week long experiments in field bioreactors in North Carolina, Iowa, New Zealand
- Process-based modeling

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4. Effect of wetting and drying cycles to rejuvenate bioreactors: replicated column experiment in the lab

What are drying-rewetting cycles?

- Cycle between dry/wet conditions
- Gradient of conditions

- Based on literature:
  - Stimulates respiration
  - Increases mineralization of C & N
  - Changes in microbial community

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Experimental Hypothesis

Do drying-rewetting cycles in woodchip bioreactors significantly improve treatment performance by increasing nitrate removal rates?

denitrification… Aerobic breakdown increases available carbon DENITRIFICATION!!!

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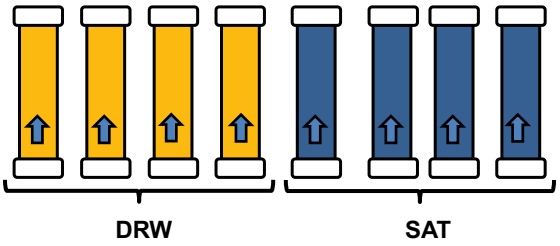
Methods

- Lab experiment with 8 woodchip-filled columns

- Continuous upflow (~8 hr HRT) for 10 months, ~20 mg NO3-N/L
- Two treatment groups
  - **DRW** – Drained once a week, unsaturated for 8 hr
  - **SAT** – Continuously saturated
  - Both columns received SAT treatment for first 3 weeks



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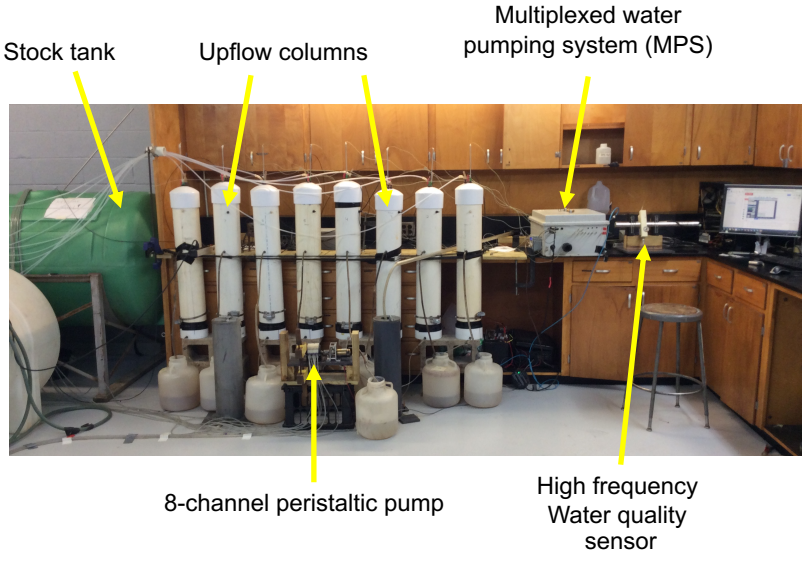

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Results : High frequency data

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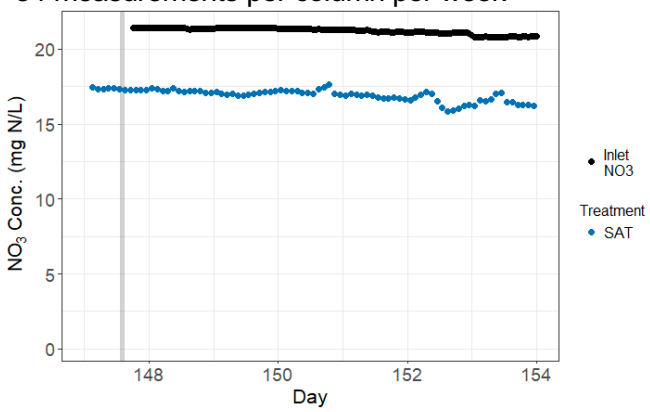
84 measurements per column per week



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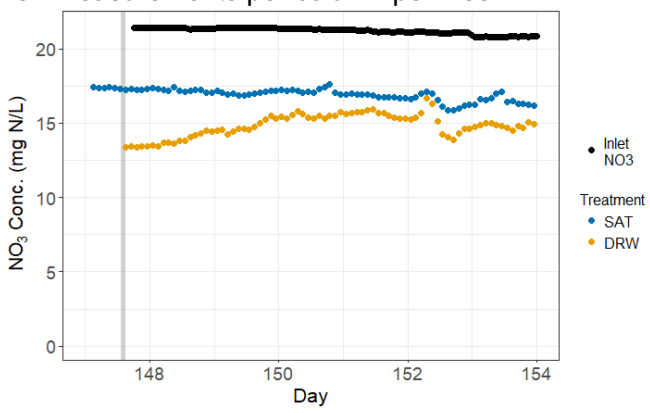

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Results : High frequency data

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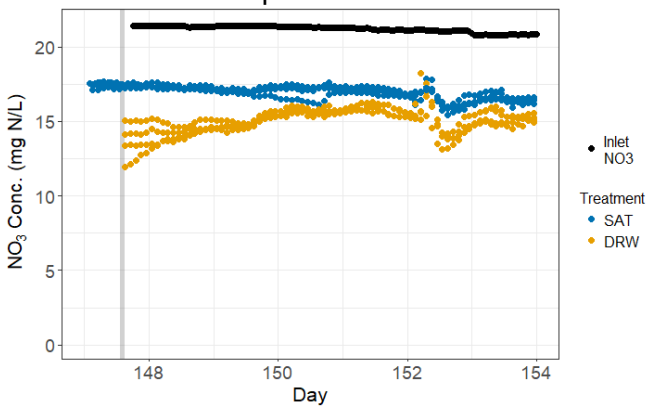
640 measurements per week for all columns



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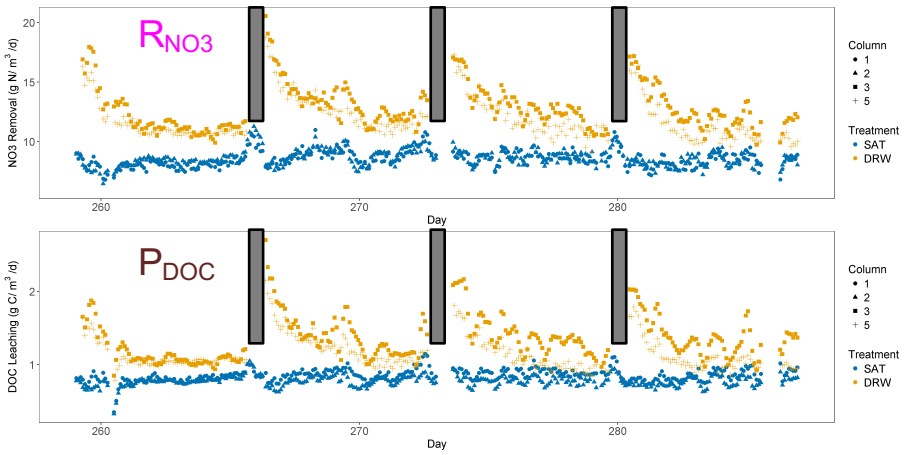
Rapid and Large response to DRW cycles



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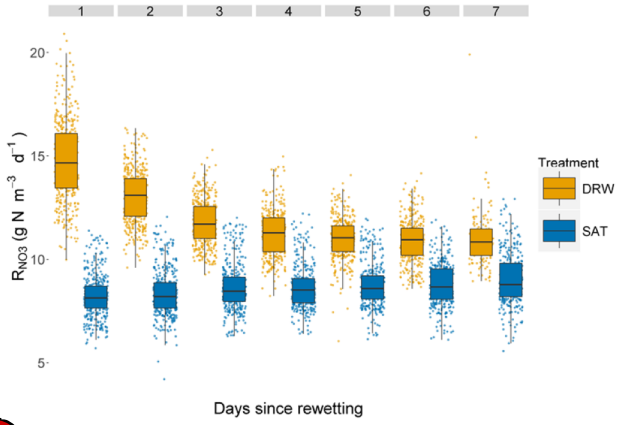
Nitrate response to DRW cycles



Removal rates in DRW columns decreased quickly within 3 days of rewetting, and were still significantly higher 7 days later

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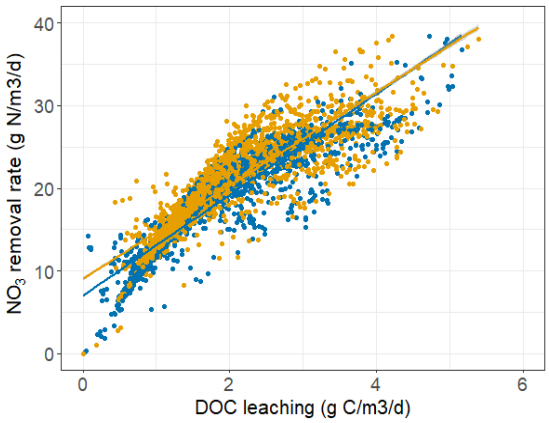
Does DOC production explain NO3 removal?



DOC production (leaching) rates explained most of variance in removal (R^2 : 0.90 – 0.97)

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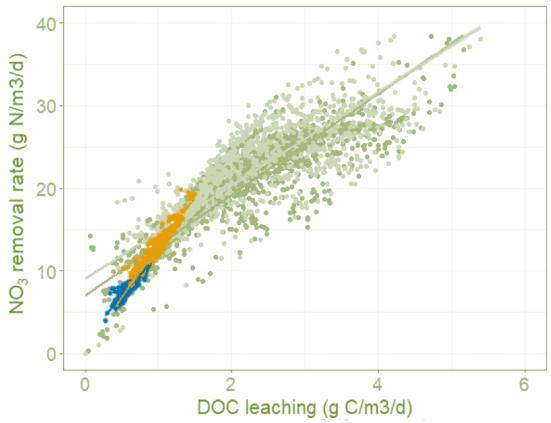
Does DOC production explain NO3 removal?



Days 140 - 180

Treatment
SAT
DRW

DOC production (leaching) rates explained most of variance in removal (R^2 : 0.90 – 0.97)

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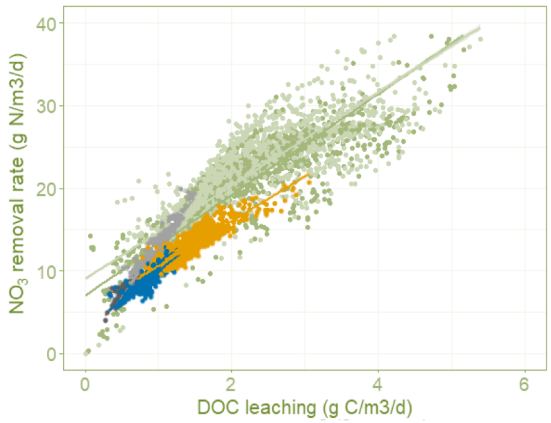
Does DOC production explain NO3 removal?



Days 250 - 290

Treatment
SAT
DRW

DOC production (leaching) rates explained most of variance in removal (R^2 : 0.90 – 0.97)

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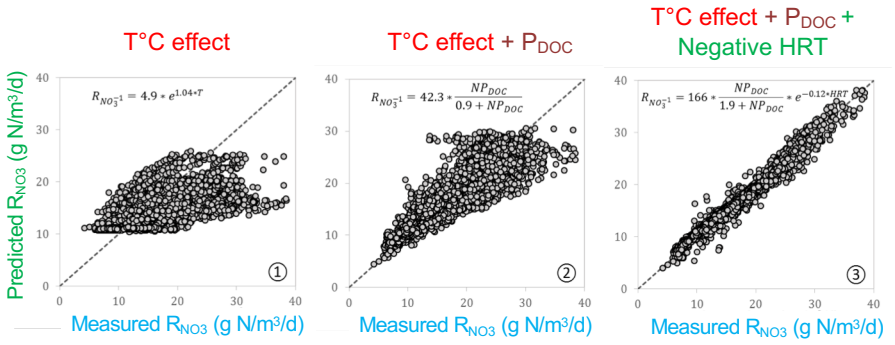
Column modeling insights



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Column Experiment Highlights

- Drying-rewetting cycles increased nitrate removal rates in woodchip bioreactors by 30-80%
- Aerobically-produced DOC is a main driver
- Long HRT result in building of inhibitory substances
- DRW have ~10x less N_2O emissions
- Microbial community shift
- Continuous saturation may not be best design for treatment systems relying on anaerobic processes!

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5- Results from the field

Plymouth, NC

Nashua, IA

Tatanui, NZ

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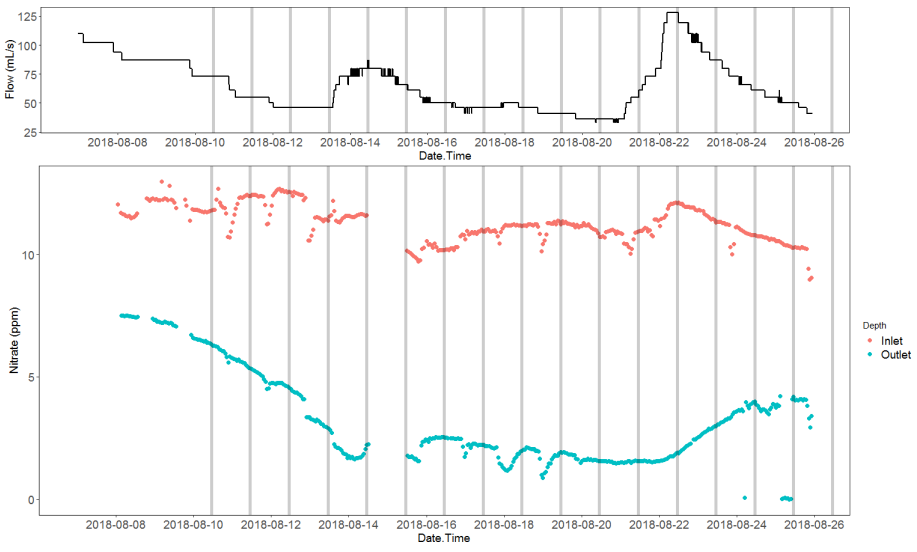

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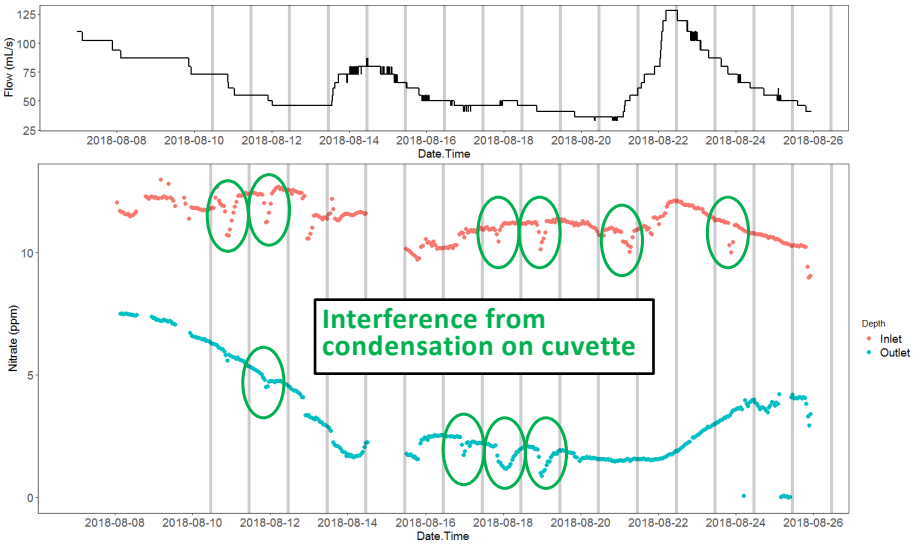

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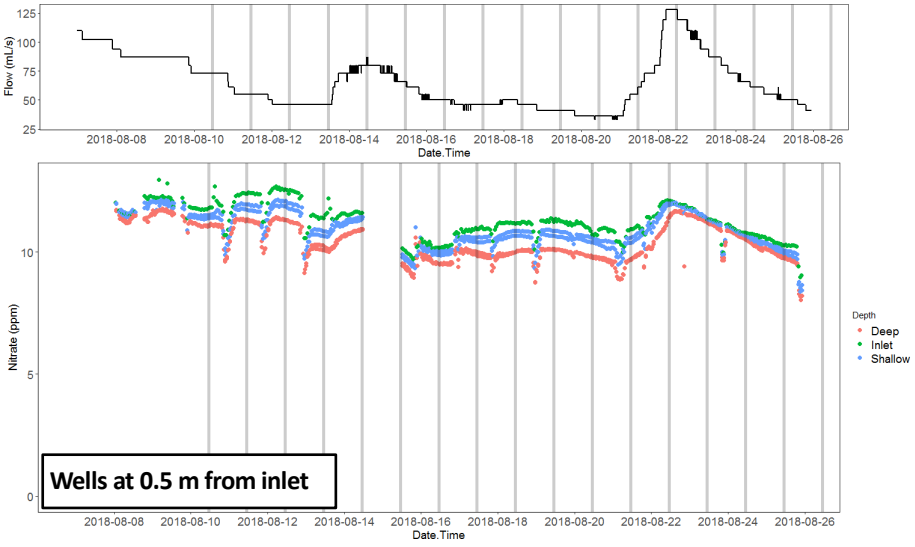

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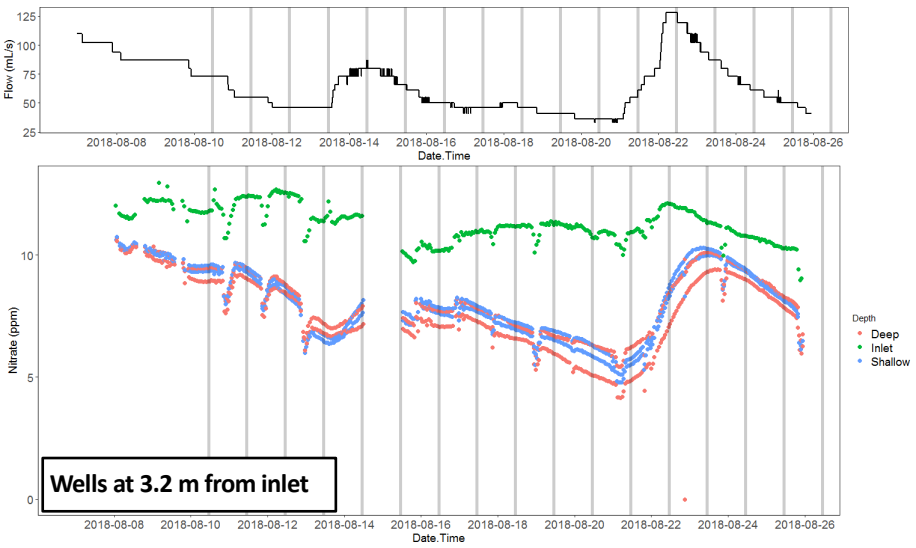

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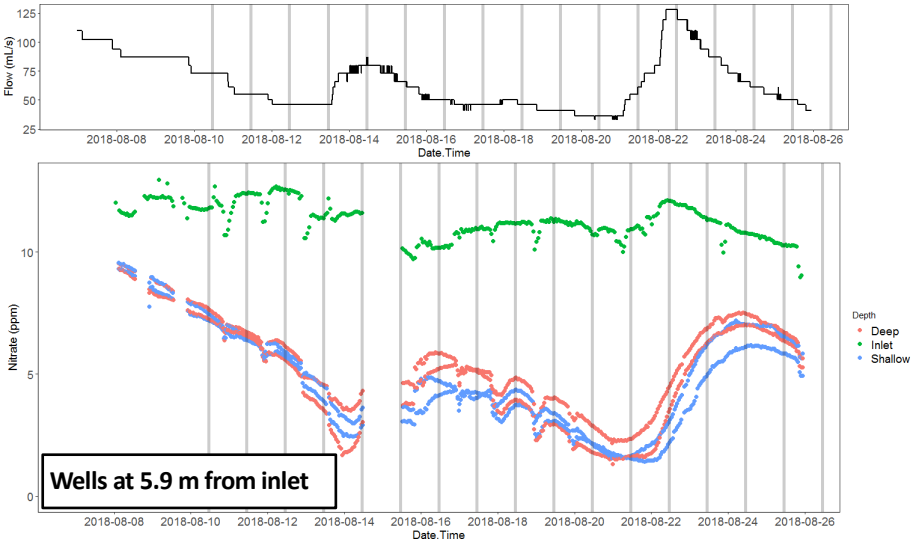

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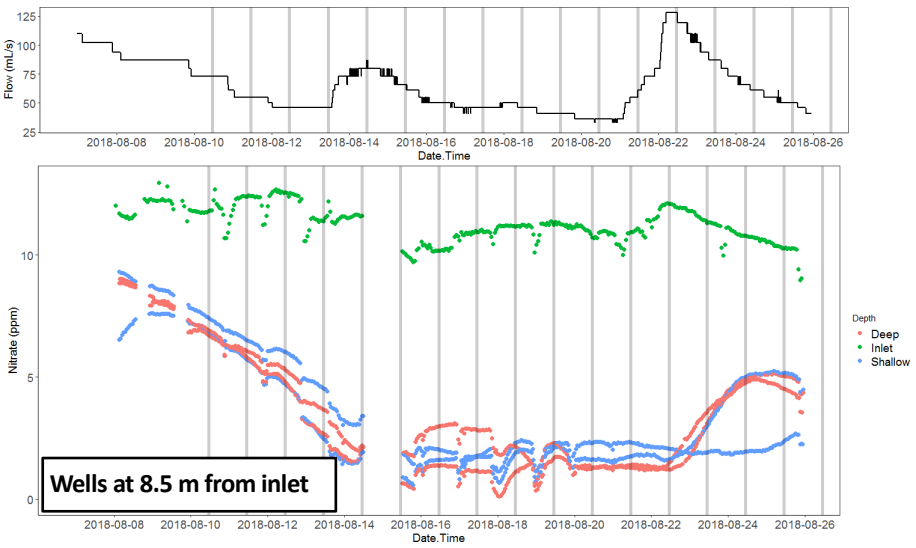

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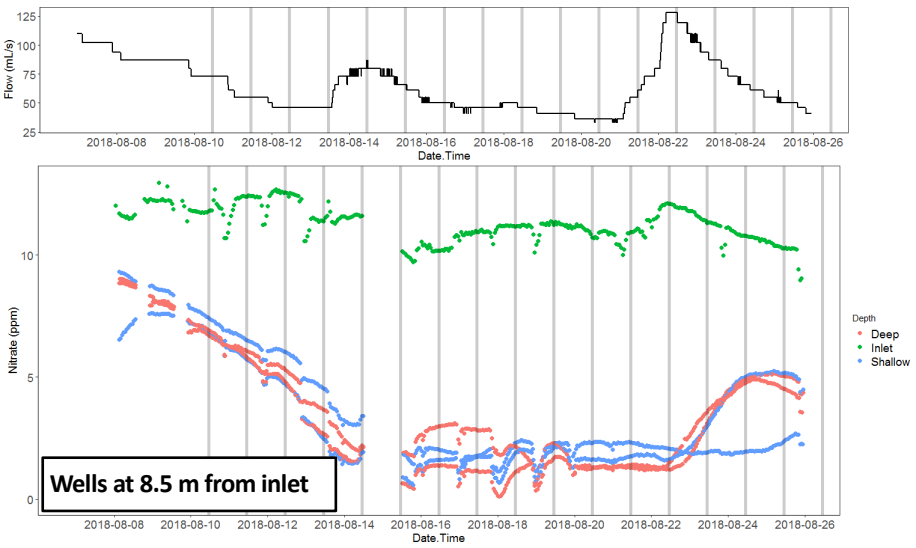

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5- Field results highlights

- Able to capture the concentration and flow variability
- High resolution measurements have to be accompanied with particle tracking modeling
- MultiplexÔ: available for reseachers

High resolution water quality in drainage?

- Only mean to capture stochastic events intrinsically linked with hydrological processes
- Has the potential to reveal new nutrient dynamics
- Largely improves uncertainty on loads
- Gives data all modelers need
- Can yield new management solutions
- However, the power of these new data heavily relies on strong 2D hydraulic modeling

Team effort


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David Williams


Laura Christianson


Mohamed Youssef

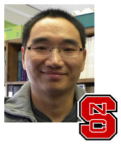

Matt Helmers


Louis Schipper


Bryan Maxwell


Wenlong Liu


Sam Garvey


Shying Tian

Sensors for drainage?

→**My opinion: They are absolutely necessary!!**

The challenges…

- A lot more information that comes with…
  - … A lot more work
  - … A lot more money
- There are some 'dirty' little secrets: optics foul…
  - There are ways around that

Etheridge et al., 2013 JEQ

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Acknowledgements

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STROUD WATER RESEARCH CENTER → Microbial Analysis

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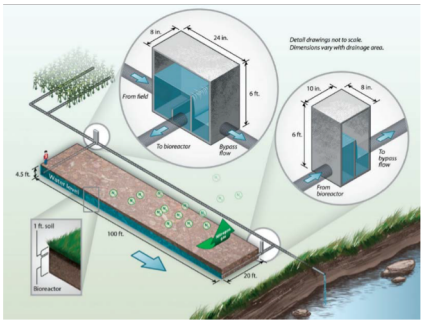
What are woodchip bioreactors?

- Agricultural BMP
- Intercept tile drainage
- Targets nitrate removal
- ~20 year lifespan
- NRCS approved
- 2-22 g N m^{-3} d^{-1} in field
- Mainly seen in Midwest



Christianson and Helmers, 201

Breaking the manufacturers code

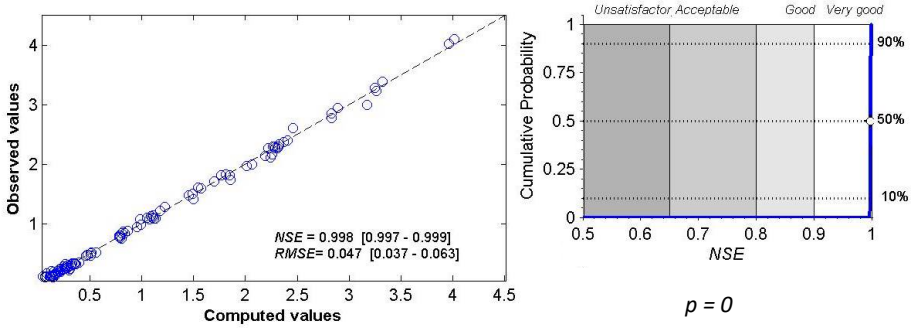
- Manufacturers have created algorithms able to calculate reliable concentrations
- Relatively simple to require affordable computational capabilities

- Use chemometrics to create regressions between absorbance and concentrations
- Main tool: Partial Least Square Regression (PLSR)

plsr

- Partial least squares regression correlates spectral data with chemical concentrations
- Reduces dimensions of system
- Allows selection of the number of dimensions to use in modeling the relationship between uv/vis spectral fingerprint and concentrations

Results for NO3 in our marsh



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(Graphs from Fiteval, Ritter and Muñoz-Carpena, 2013, JH)