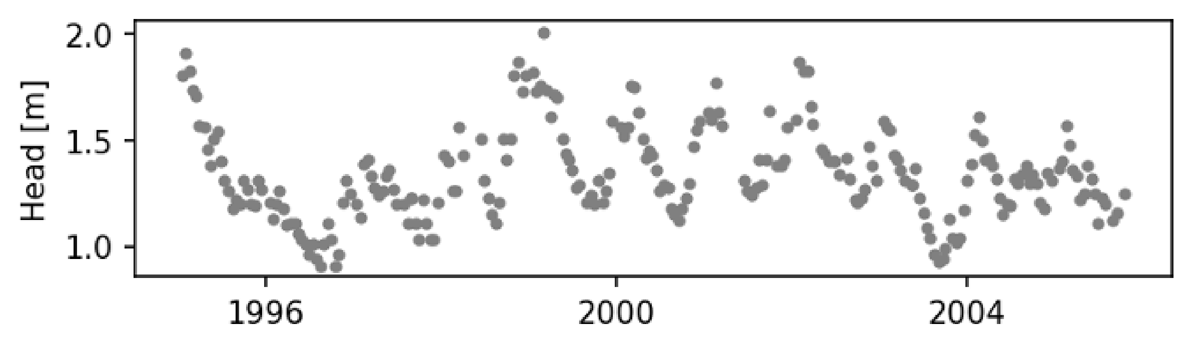
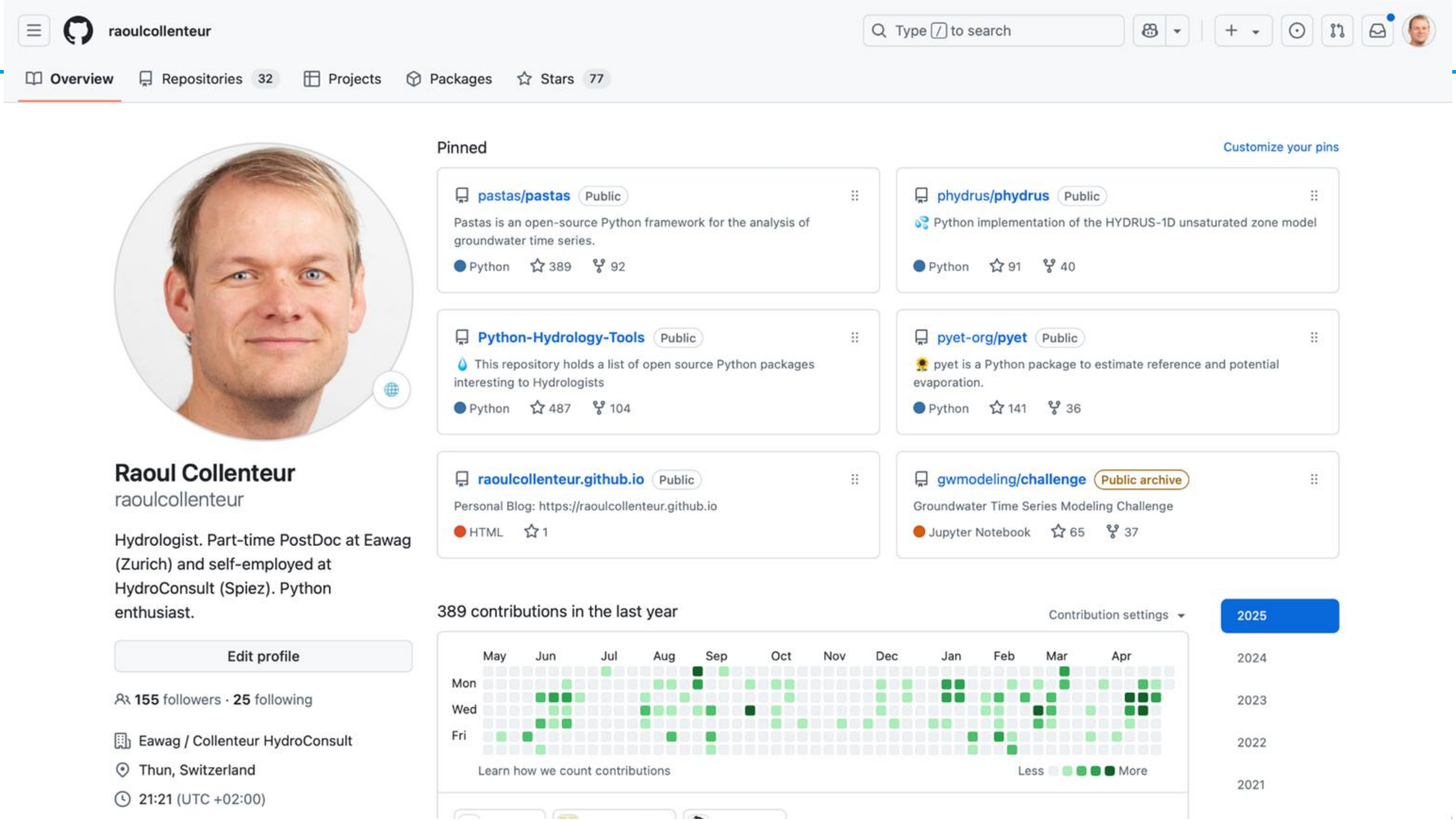
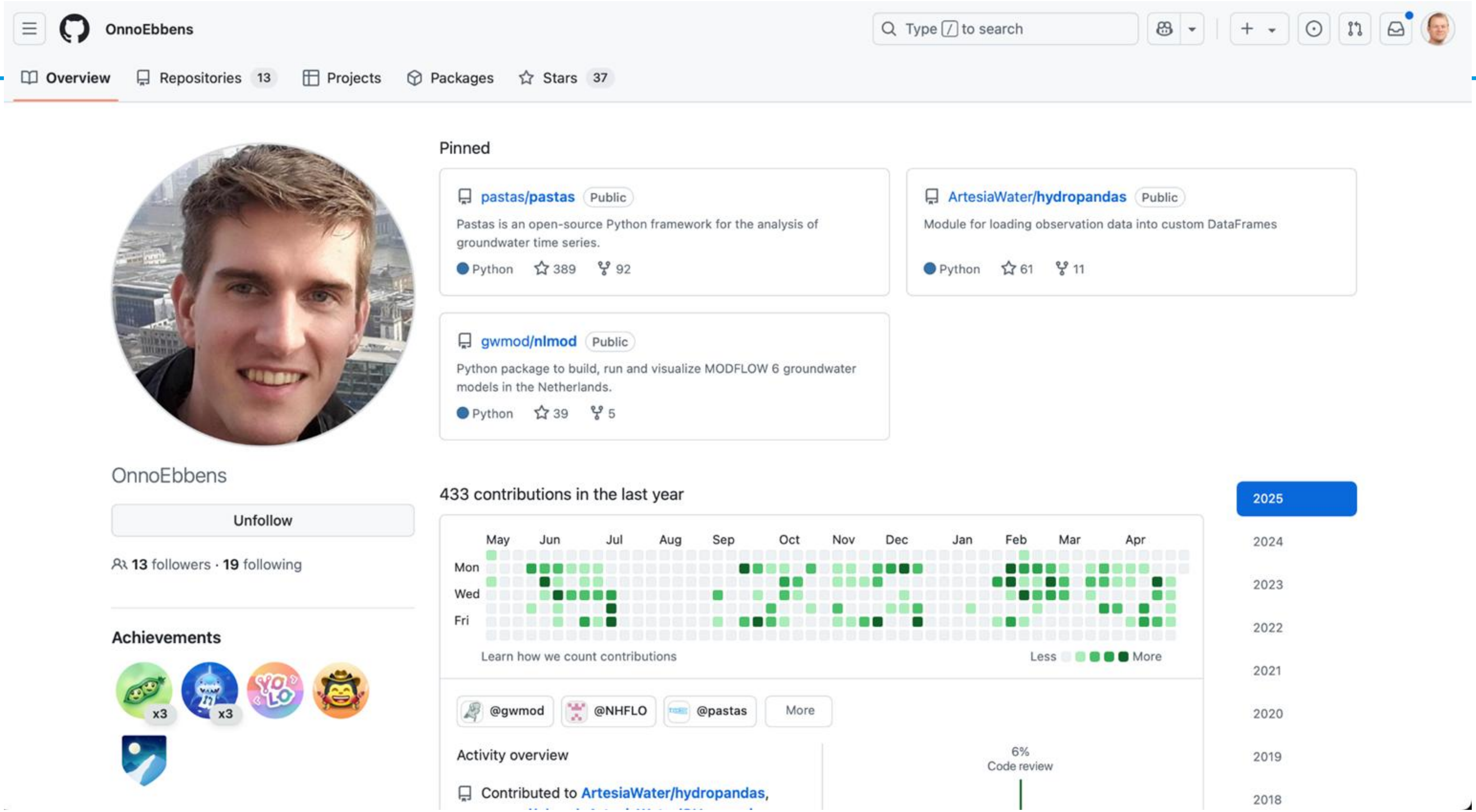
AWS Pastas Course Introduction Webinar
6th of May 2025, Online

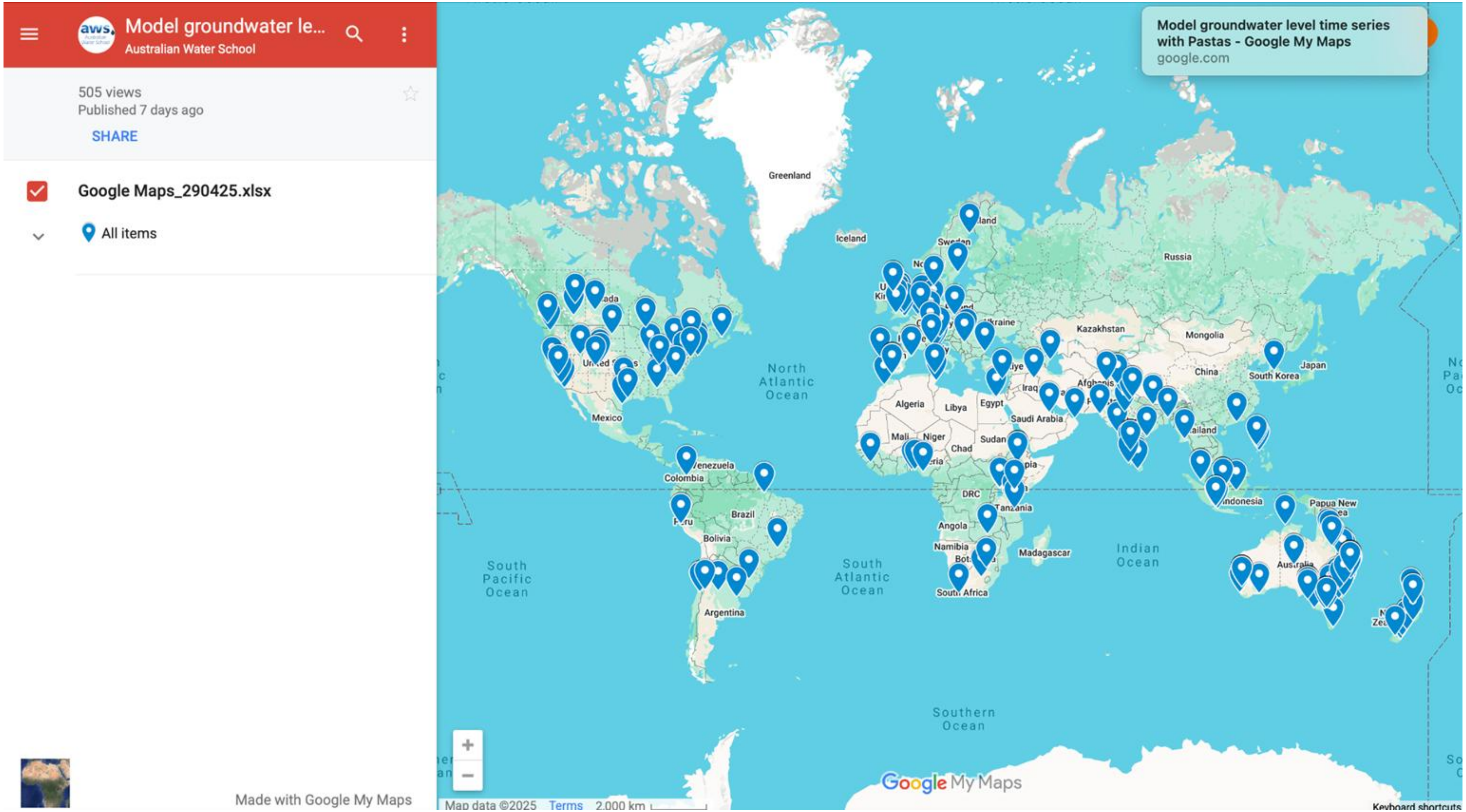
Raoul Collenteur, PhD (HydroConsult) & Onno Ebbens, MSc (Artesia)




raoulcollenteur
Type / to search
Overview
Repositories 32
Projects
Packages
Stars 77
Pinned
Customize your pins
pastas/pastas Public
Pastas is an open-source Python framework for the analysis of groundwater time series.
Python 389 92
phydrus/phydrus Public
Python implementation of the HYDRUS-1D unsaturated zone model
Python 91 40
Python-Hydrology-Tools Public
This repository holds a list of open source Python packages interesting to Hydrologists
Python 487 104
pyet-org/pyet Public
pyet is a Python package to estimate reference and potential evaporation.
Python 141 36
raoulcollenteur.github.io Public
Personal Blog: https://raoulcollenteur.github.io
HTML 1
gwmodeling/challenge Public archive
Groundwater Time Series Modeling Challenge
Jupyter Notebook 65 37
Raoul Collenteur
raoulcollenteur
Hydrologist. Part-time PostDoc at Eawag (Zurich) and self-employed at HydroConsult (Spiez). Python enthusiast.
Edit profile
155 followers · 25 following
Eawag / Collenteur HydroConsult
Thun, Switzerland
21:21 (UTC +02:00)
389 contributions in the last year
Contribution settings
May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr
Mon
Wed
Fri
Learn how we count contributions
Less More
2025
2024
2023
2022
2021


OnnoEbbens
Type / to search
Overview
Repositories 13
Projects
Packages
Stars 37
Pinned
pastas/pastas Public
Pastas is an open-source Python framework for the analysis of groundwater time series.
Python 389 92
ArtesiaWater/hydropandas Public
Module for loading observation data into custom DataFrames
Python 61 11
gwmod/nlmod Public
Python package to build, run and visualize MODFLOW 6 groundwater models in the Netherlands.
Python 39 5
OnnoEbbens
Unfollow
13 followers · 19 following
Achievements
x3
x3
433 contributions in the last year
May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr
Mon
Wed
Fri
Learn how we count contributions
Less More
2025
2024
2023
2022
2021
2020
2019
2018
@gwmod
@NHFLO
@pastas
More
Activity overview
6%
Code review
Contributed to ArtesiaWater/hydropandas,

Participants from all over the world…

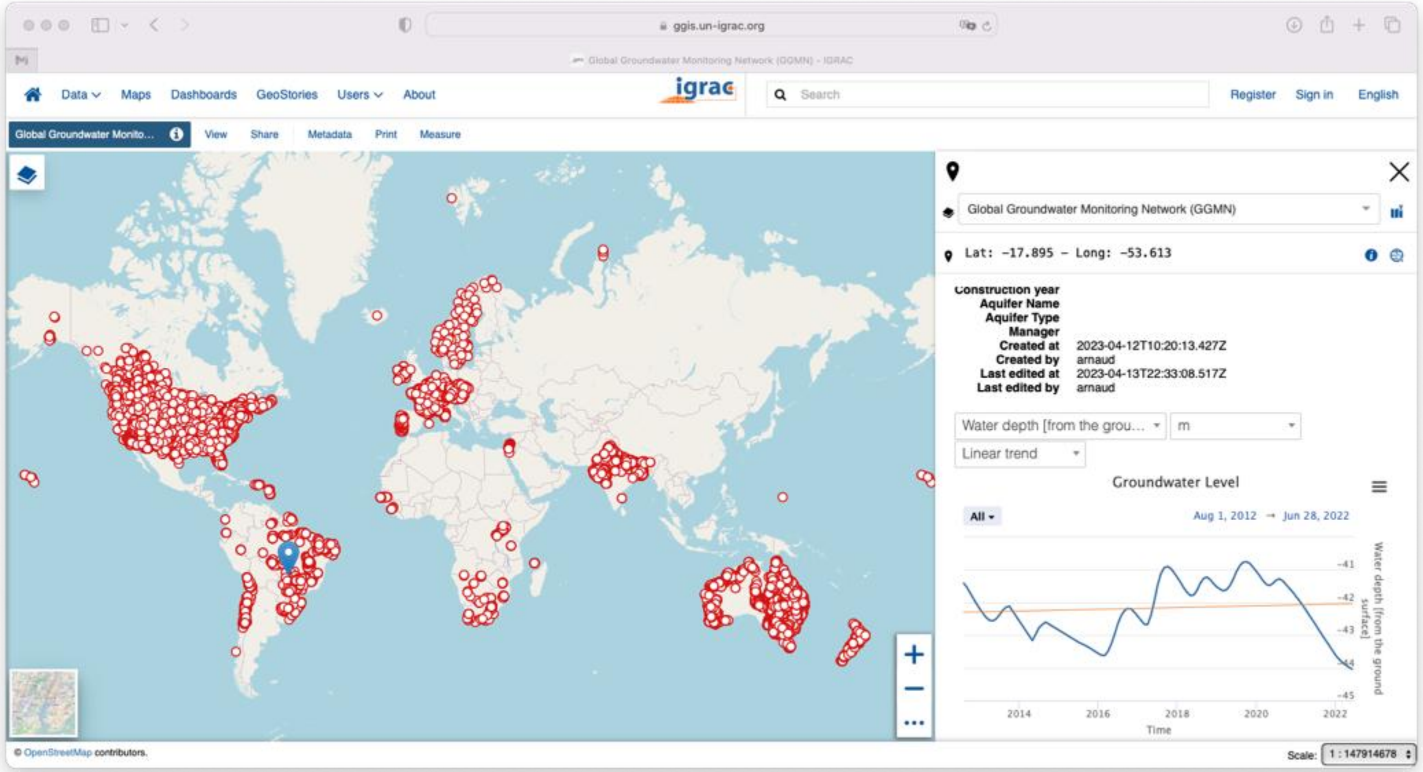


Groundwater monitoring around the world …

Monitoring is of key importance when trying to better understand and manage groundwater resources.

This is why extensive monitoring networks are operated in many countries worldwide*.

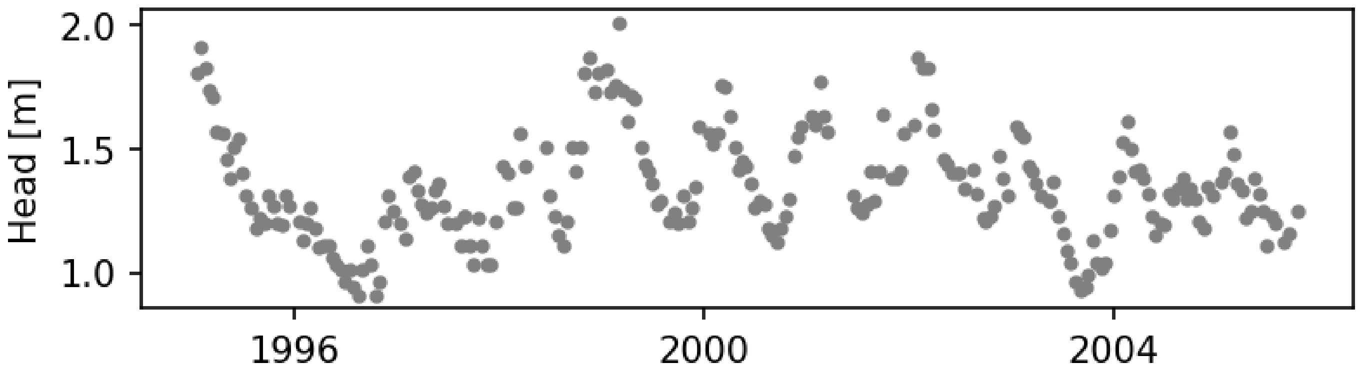
* more measurements always welcome

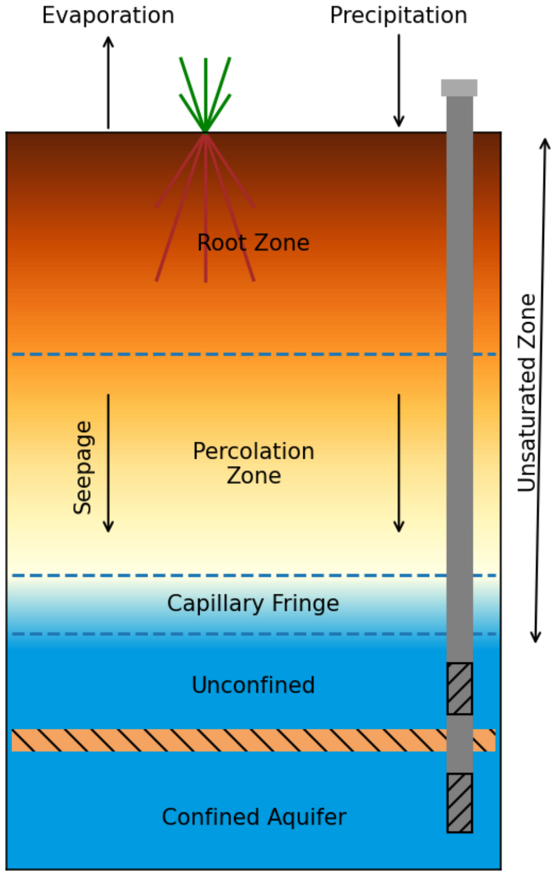


https://ggis.un-igrac.org/view/ggmn/

Monitoring wells

As the groundwater cannot be directly observed, we take measurements of the hydraulic head to obtain information on the (changing) state of the groundwater system over time.



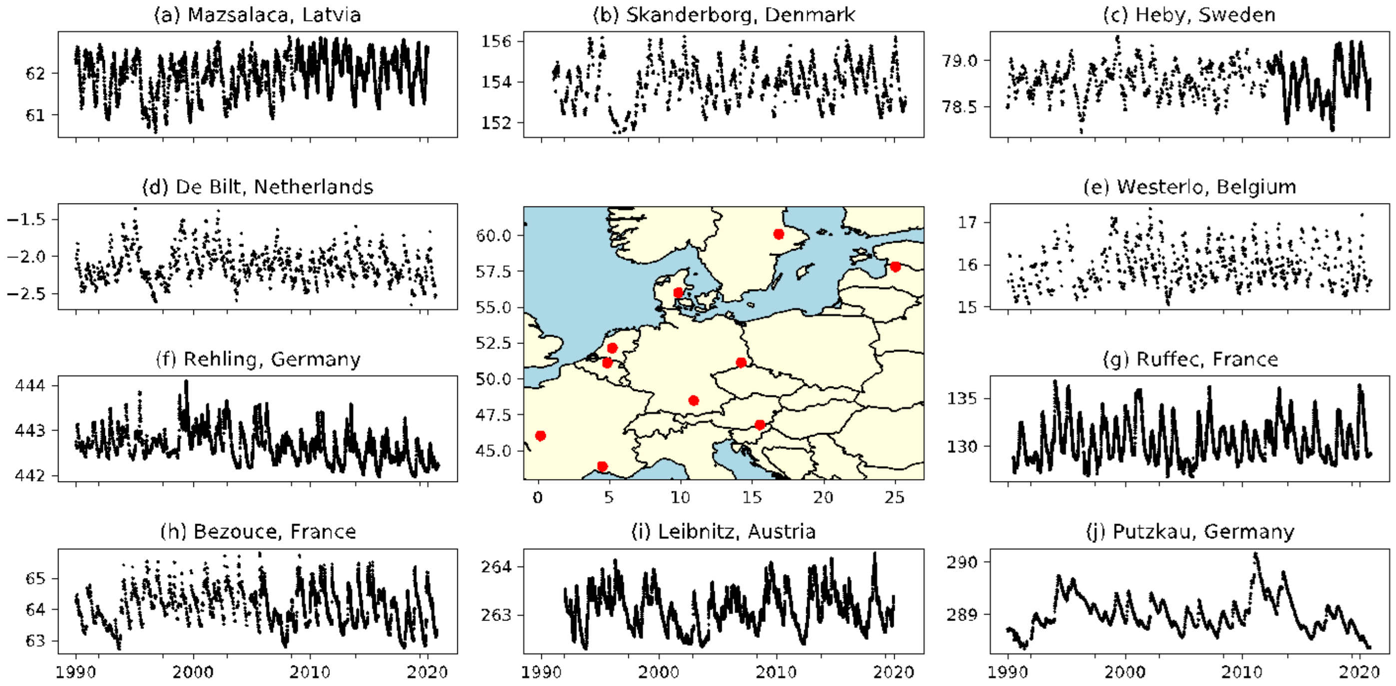


We will refer to hydraulic heads or groundwater levels as "heads"

Head time series characteristics

Head time series are often messy:

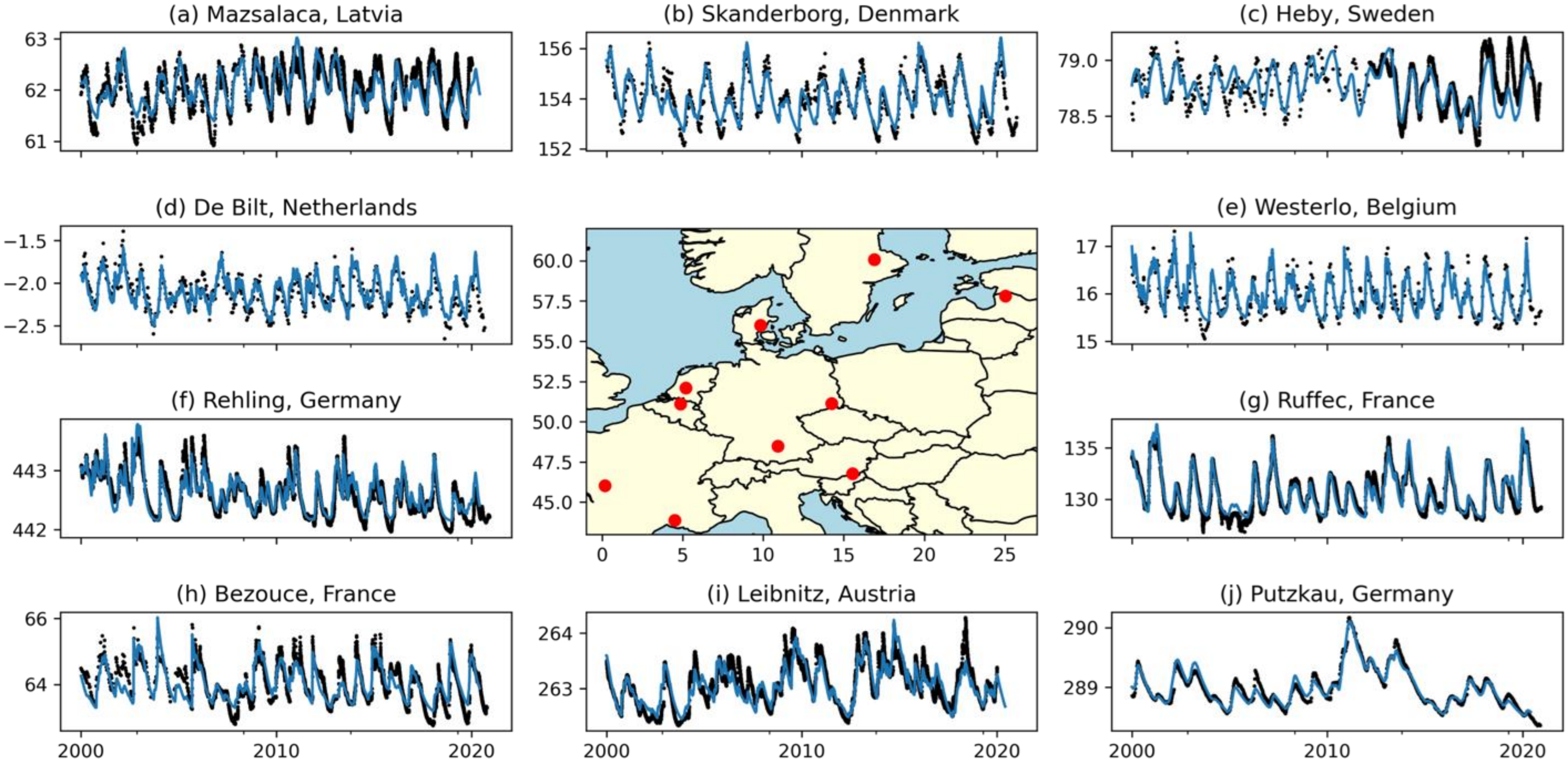
- Measurement errors
- Different measurement techniques
- Different observation periods
- Mixed observation frequencies
- …



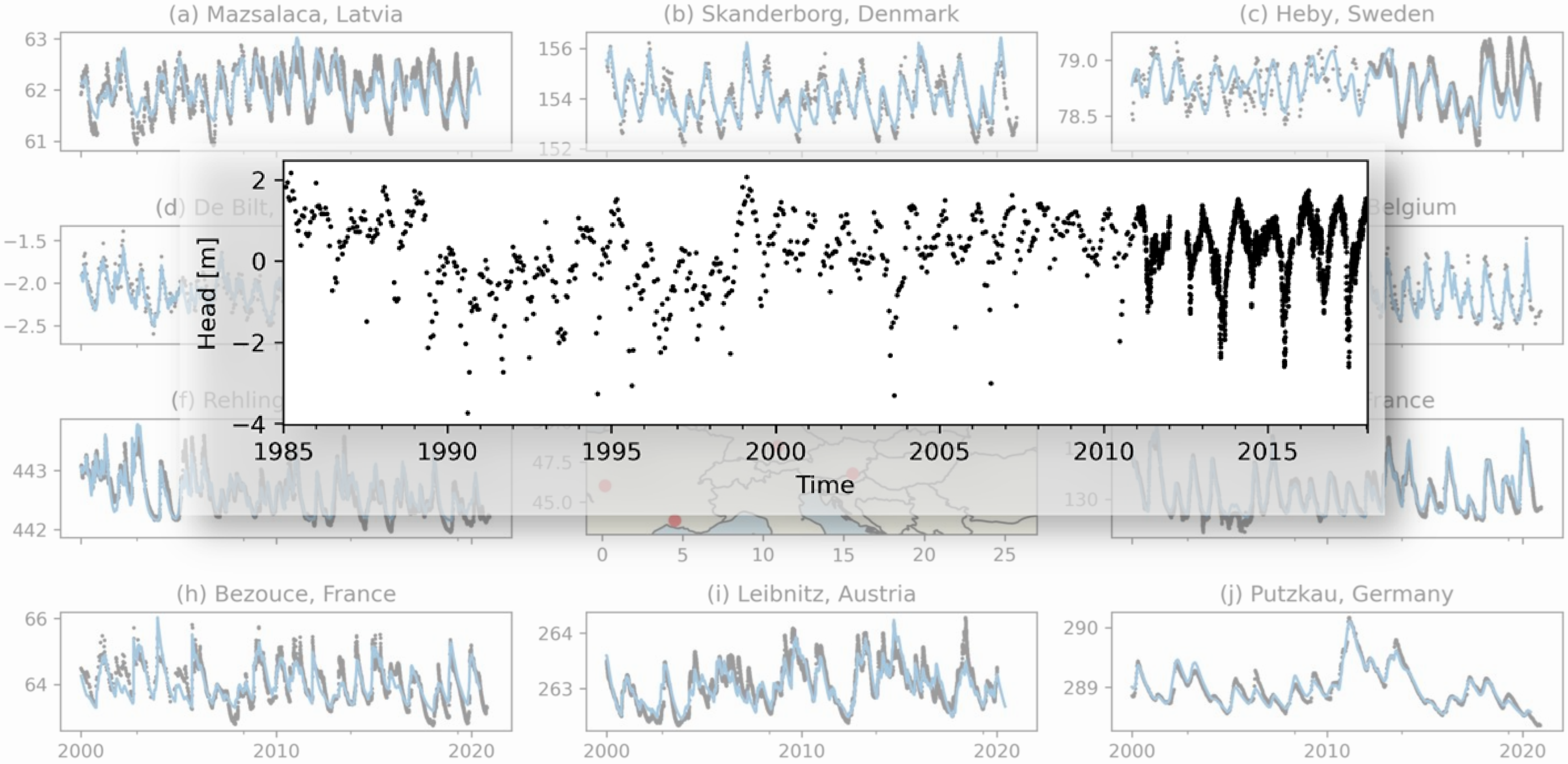
See also, for example:

- Post and von Asmuth (2013) Review: Hydraulic head measurements—new technologies, classic pitfalls. Hydrogeology Journal.
- Rau et al. (2019) Error in hydraulic head and gradient time-series measurements: a quantitative appraisal,. HESS

Measuring and modeling

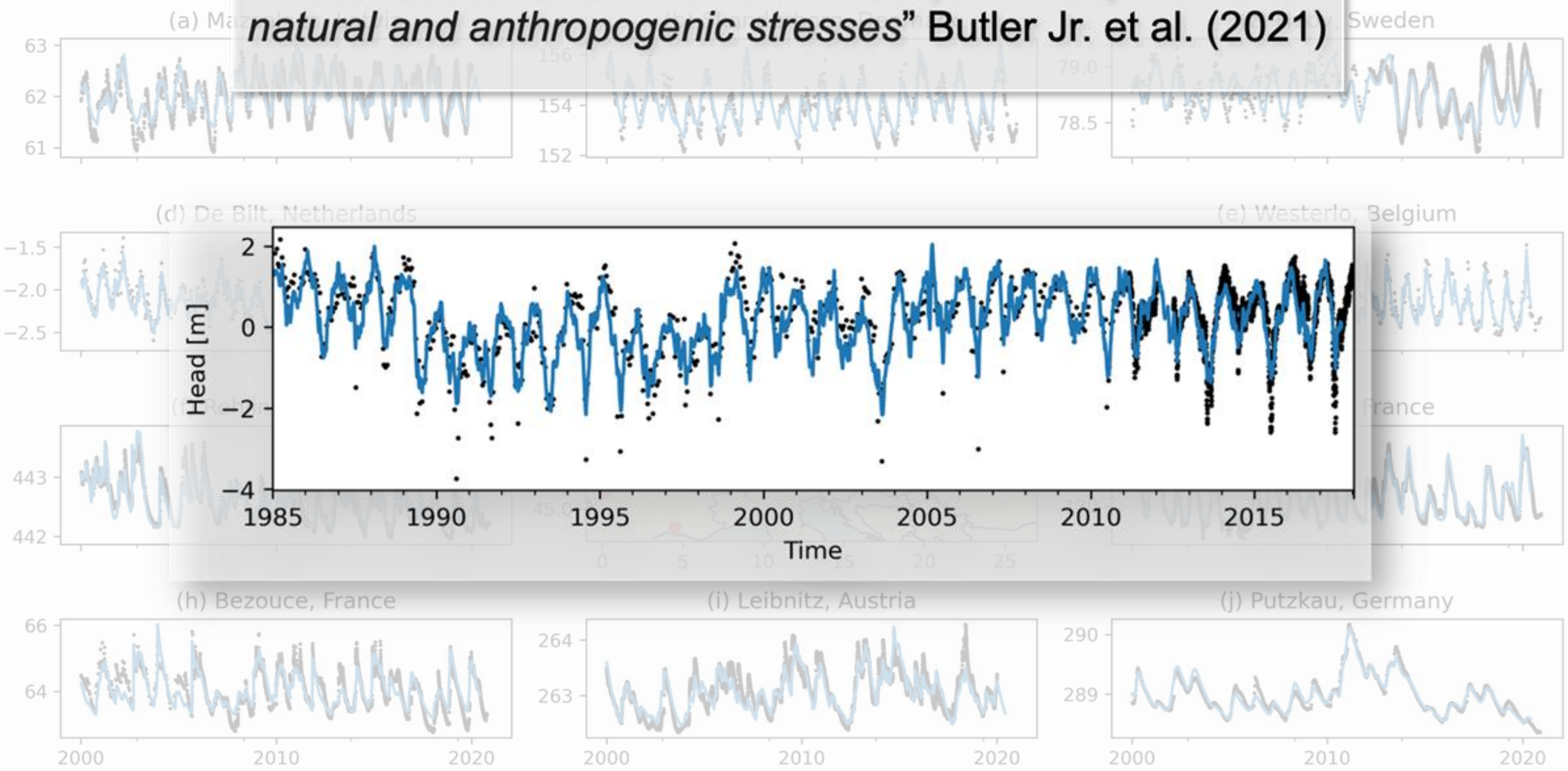


Measuring and modeling

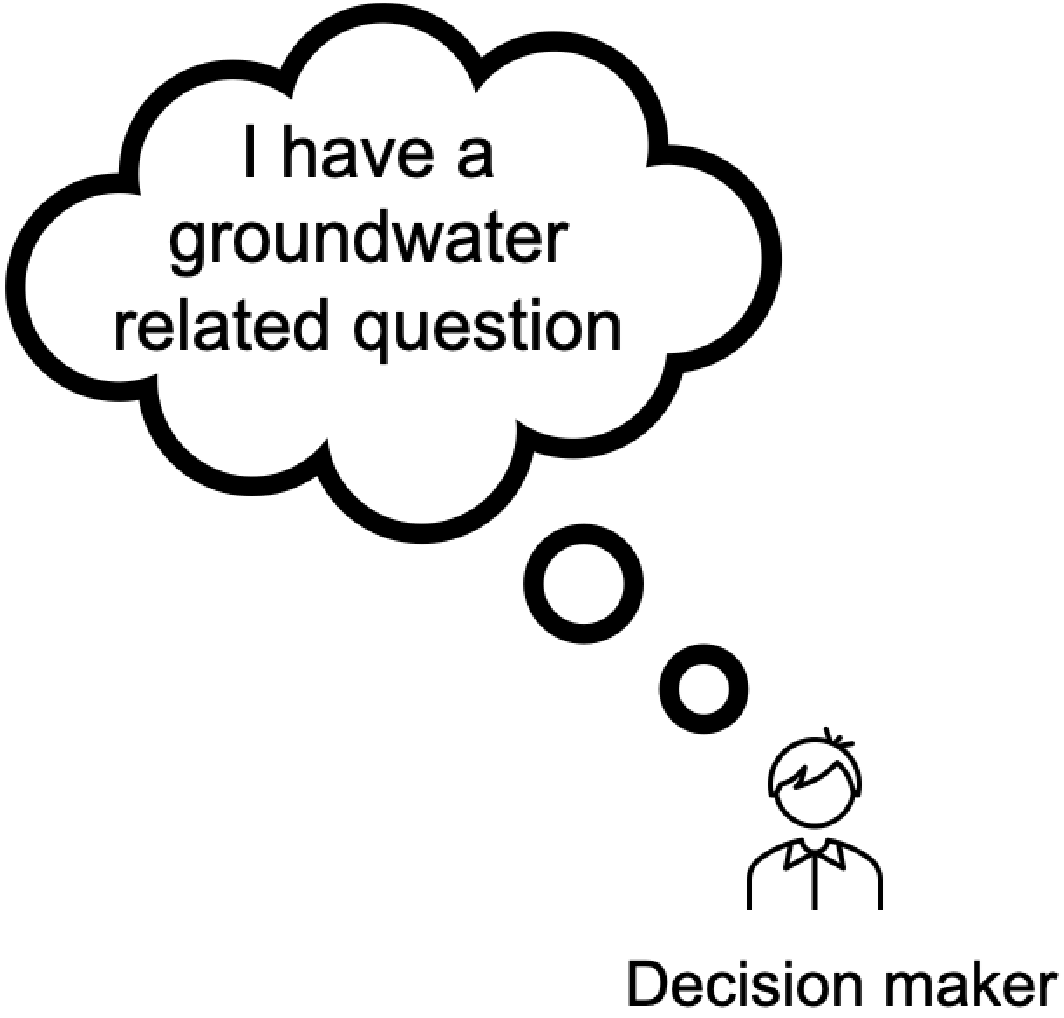


Measuring and modeling

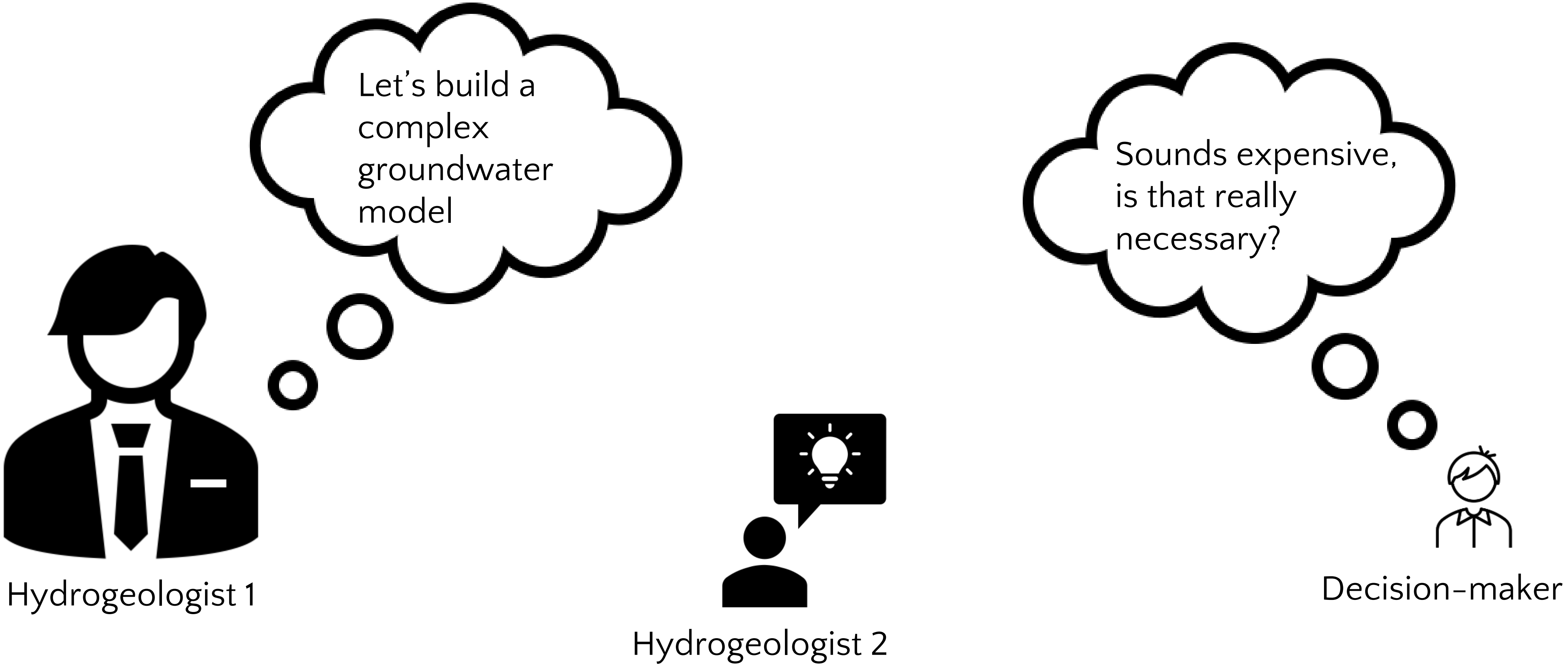
"*embedded in those hydrographs is **valuable information** about subsurface conditions and **aquifer responses** to natural and anthropogenic stresses*" Butler Jr. et al. (2021)



Solving groundwater problems

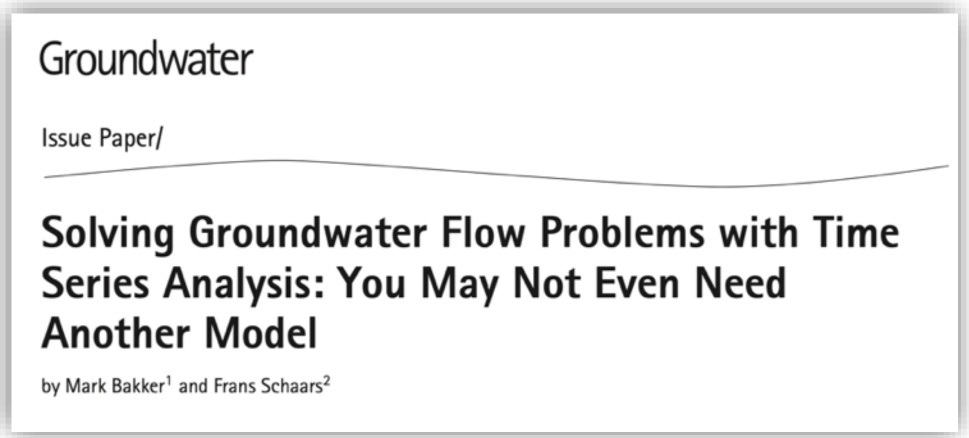


Groundwater modeling



Groundwater modeling

Instead of directly trying or having to understand the groundwater system in its entirety, can we answer the question* with a much simpler model that is much faster to develop?



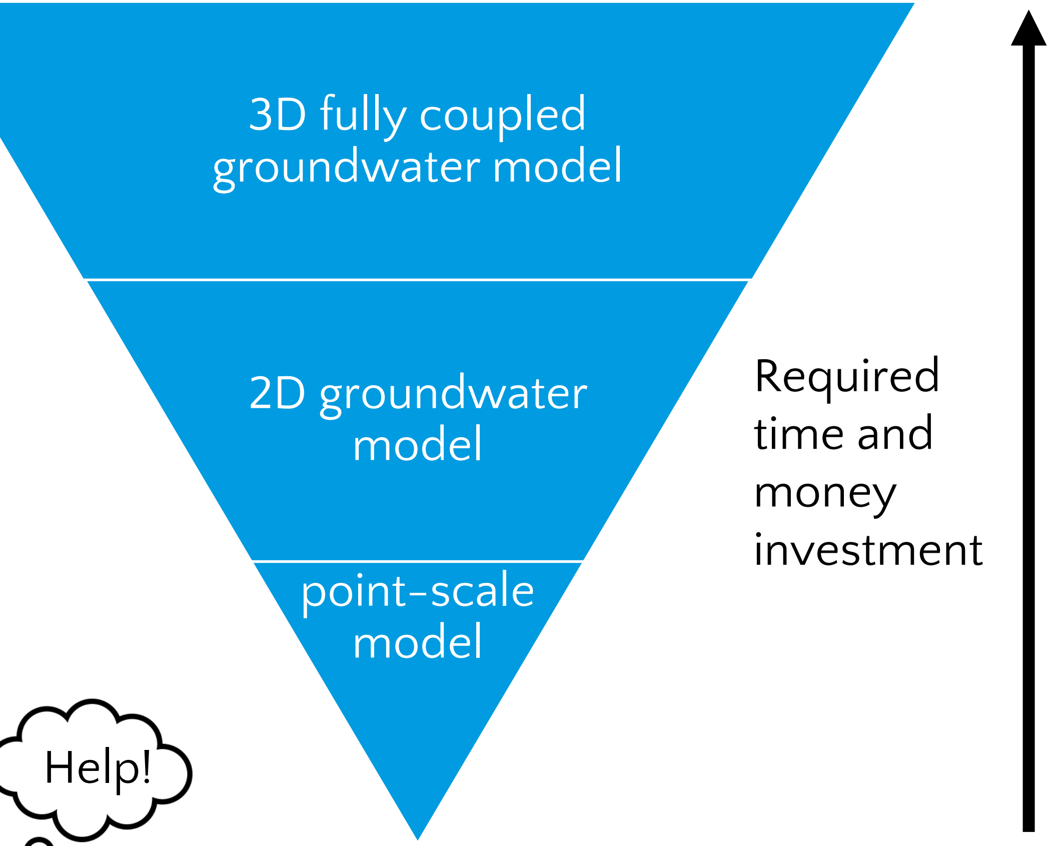
Groundwater

Issue Paper/

Solving Groundwater Flow Problems with Time Series Analysis: You May Not Even Need Another Model

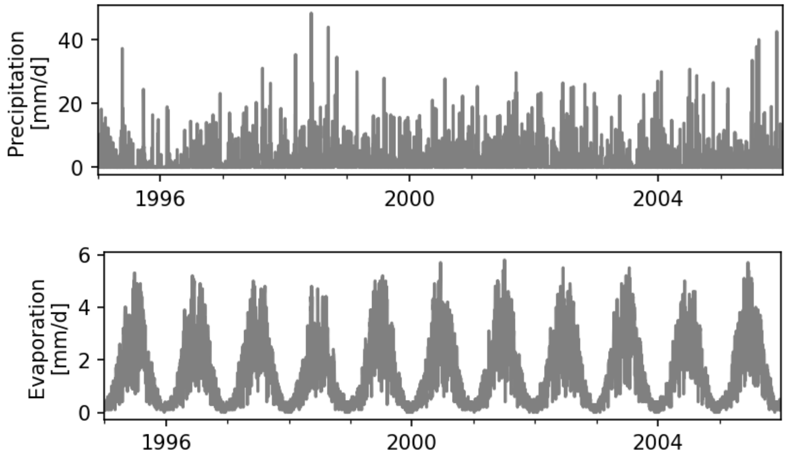
by Mark Bakker[1] and Frans Schaars[2]

*or help the decision-maker

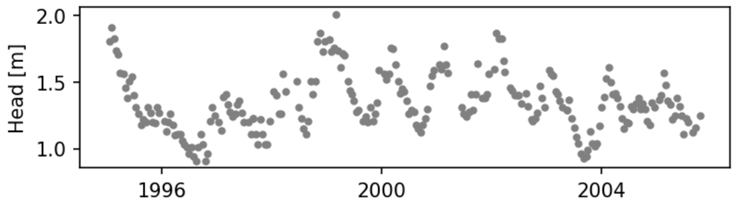


Groundwater modeling

A point-scale groundwater model translates some input time series (i.e., precipitation, evaporation, pumping) into a head time series.



Model



Independent variables, driving forces, or stresses

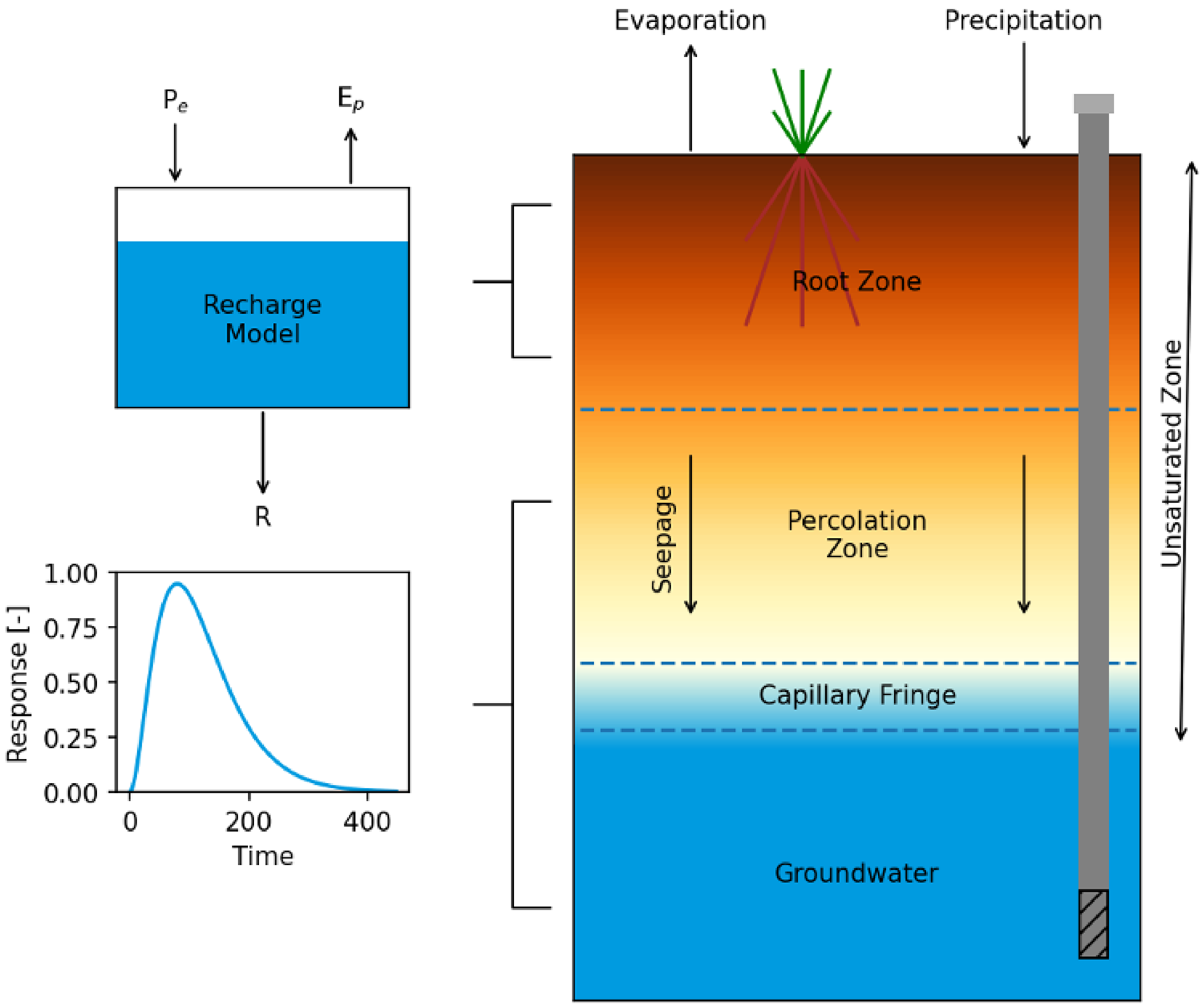
dependent variable

Lumped-parameter groundwater models

The groundwater levels are simulated using impulse response functions that describe the head response to impulses of stresses.

Common stresses include:

- precipitation
- pot. evaporation
- temperature
- pumping
- surface water levels
- tides
- ...

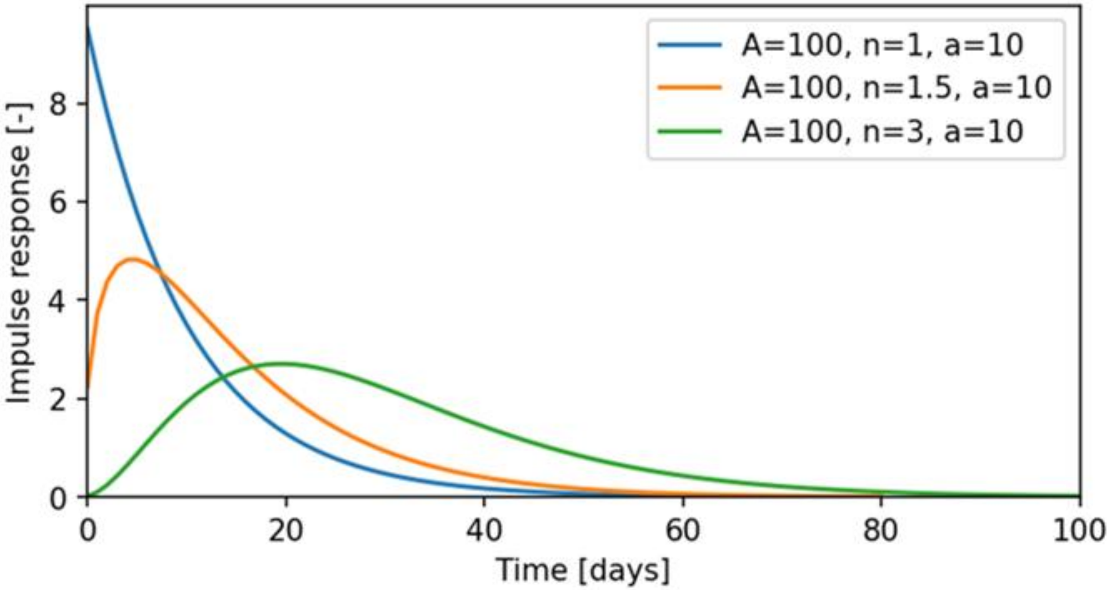


Predefined impulse response functions

As an impulse response functions, a scaled-gamma response function may be applied to quantify the head response to a stress:

$$\theta(t) = A\frac{t^{n-1}}{a^n\Gamma(n)}e^{-t/a}$$

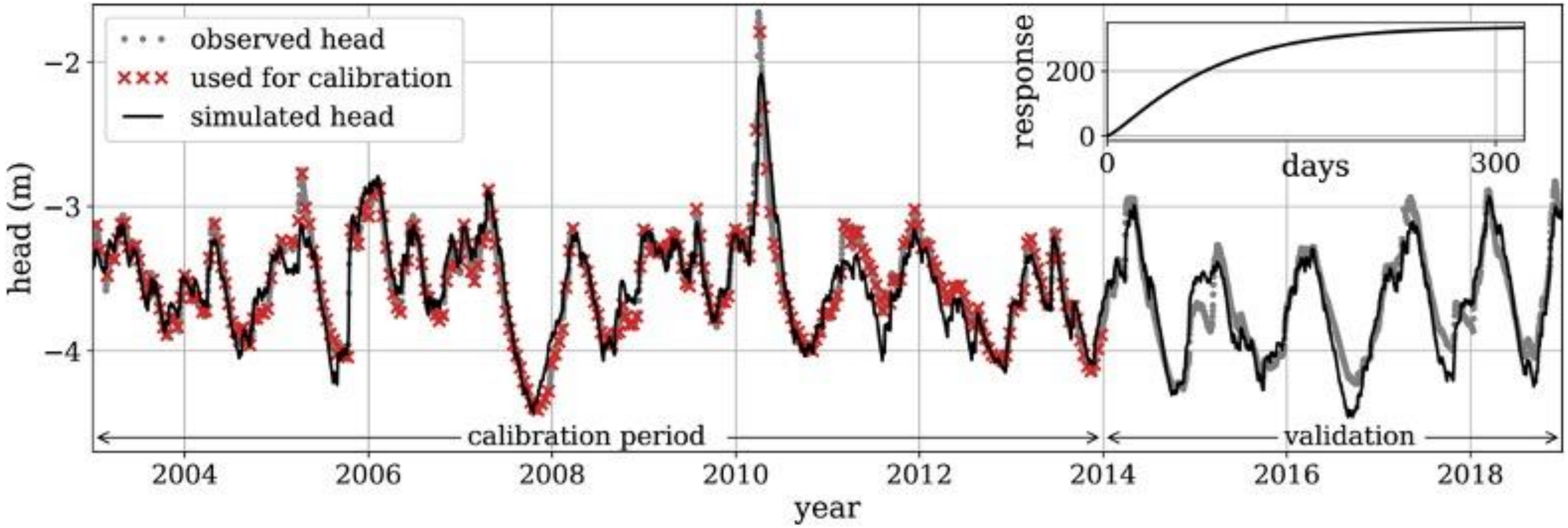
Where A, a, and n are shape parameters that determine the shape of the response function.



See also: von Asmuth et al. (2002) Transfer function-noise modeling in continuous time using predefined impulse response functions, *Water Resour. Res.*

Simple(r) models can work (really) well !

Lumped-parameter models have been successfully applied in countries worldwide in diverse settings: i.e., Australia, Austria, Switzerland, Netherlands, USA, Chile, Germany, Belgium, Norway, India, Brazil, and many more.



Pastas software

Pastas is an open-source Python package to perform time series analysis in groundwater studies.

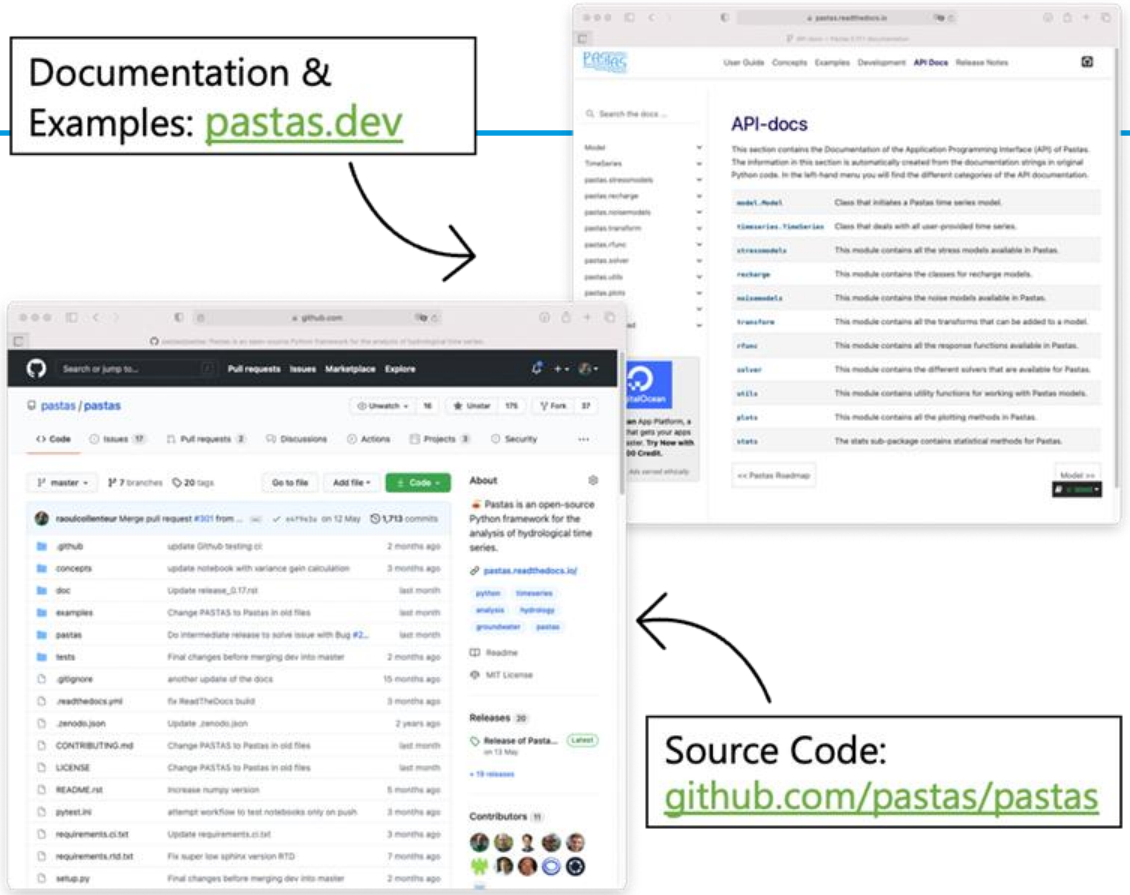
The goal of Pastas is:

"to provide a scientific framework to improve existing methods or develop and test new methods, while at the same time provide a reliable ready-to-use software tool for groundwater practitioners in the field"

Install:

```
>>> pip install pastas[full]
```

Documentation & Examples: pastas.dev



Source Code: github.com/pastas/pastas

Collenteur et al. (2019) Pastas: Open Source Software for the Analysis of Groundwater Time Series. Groundwater

Groundwater

Methods Note/

Pastas: Open Source Software for the Analysis of Groundwater Time Series

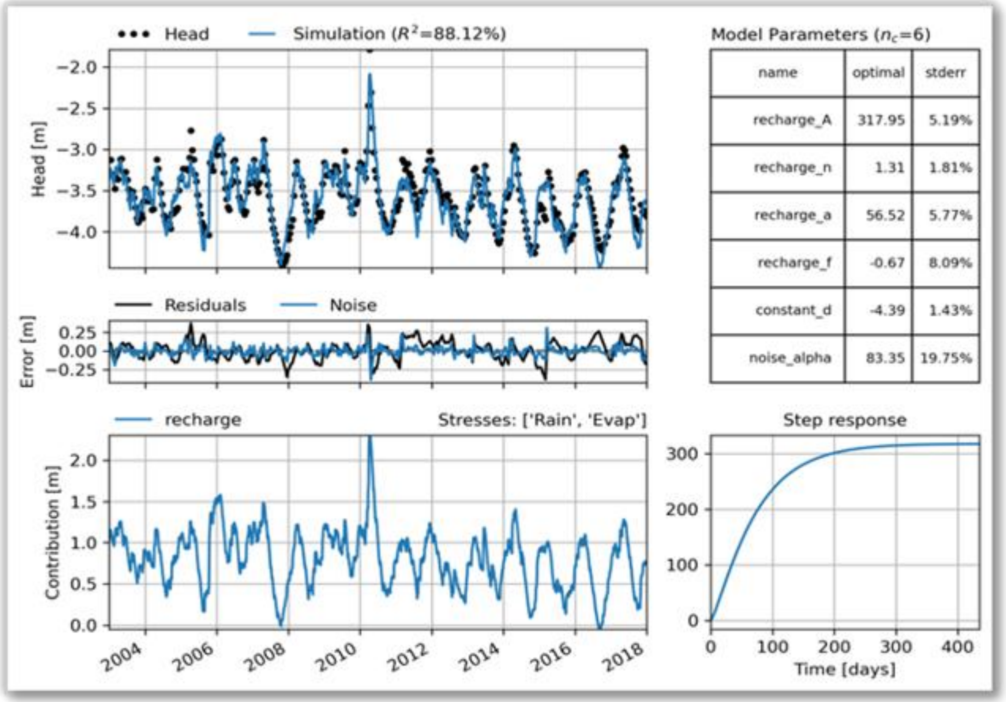
by Raoul A. Collenteur[1], Mark Bakker[2], Ruben Caljé[3], Stijn A. Klop[2,4], and Frans Schaars[3]

Abstract

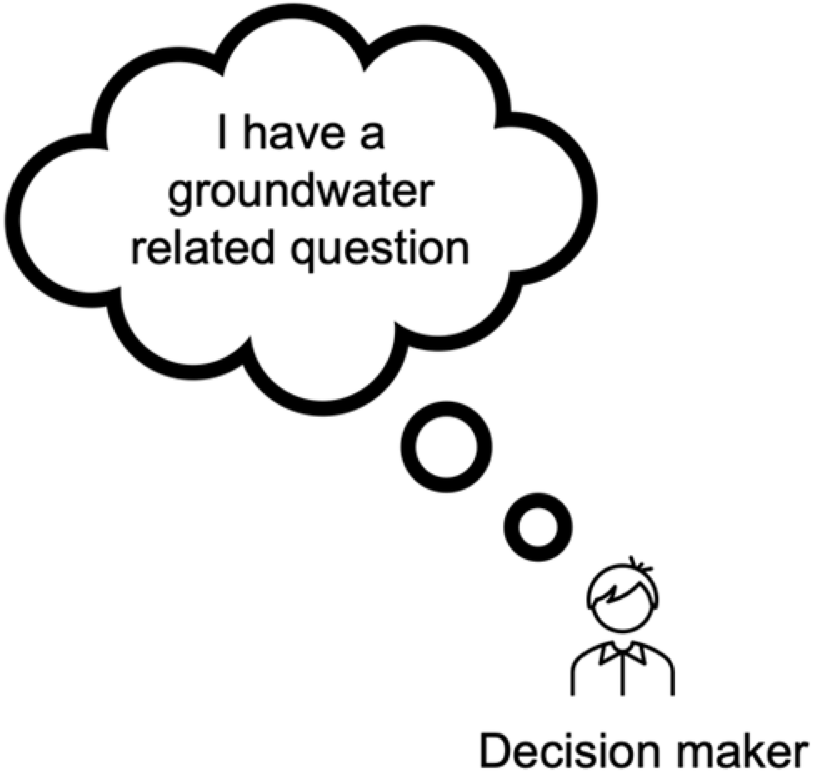
Time series analysis is an increasingly popular method to analyze heads measured in an observation well. Common applications include the quantification of the effect of different stresses (rainfall, pumping, etc.), and the detection of trends and outliers. Pastas is a new and open source Python package for the analysis of hydrogeological time series. The objective of Pastas is twofold: to provide a scientific framework to develop and test new methods, and to provide a reliable ready-to-use software tool for groundwater practitioners. Transfer function noise modeling is applied using predefined response functions. For example, the head response to rainfall is simulated through the convolution of measured rainfall with a Gamma response function. Pastas models are created and analyzed through scripts, ensuring reproducibility and providing a transparent report of the entire modeling process. A Pastas model can be constructed in seven simple steps: import Pastas, read the time series, create a model, specify the stresses and the types of response functions, estimate the model parameters, visualize output, and analyze the results. These seven steps, including the corresponding Python code, are applied to investigate how rainfall and reference evaporation can explain measured heads in an observation well in Kingstown, Rhode Island, USA. The second example demonstrates the use of scripts to analyze a large number of observation wells in batch to estimate the extent of the drawdown caused by a well field in the Netherlands. Pastas is free and open source software available under the MIT-license at http://github.com/pastas/pastas.

Modeling using Python scripts

```
In[1]: import pastas as ps
       import pandas as pd
In[2]: rain = pd.read_csv(”rain.csv”)
       evap = pd.read_csv(“evap.csv”)
       heads = pd.read_csv(“heads.csv”)
In[3]: ml = ps.Model(heads, name=“model”)
In[4]: rm = ps.RechargeModel(rain, evap,
              rfunc=ps.Gamma, name=“recharge”)
In[5]: ml.add_stressmodel([sm, rm])
In[6]: ml.solve()
In[7]: ml.plots.results()
```



Solving groundwater questions



6

Why model head time series?

System Characterization: Which driving forces and processes are impacting the aquifer under study?

Prediction and forecasting: Make a predictive model to predict and/or forecast the heads.

Quantification of input-response relations: Quantify the relationship between different stresses and the heads.

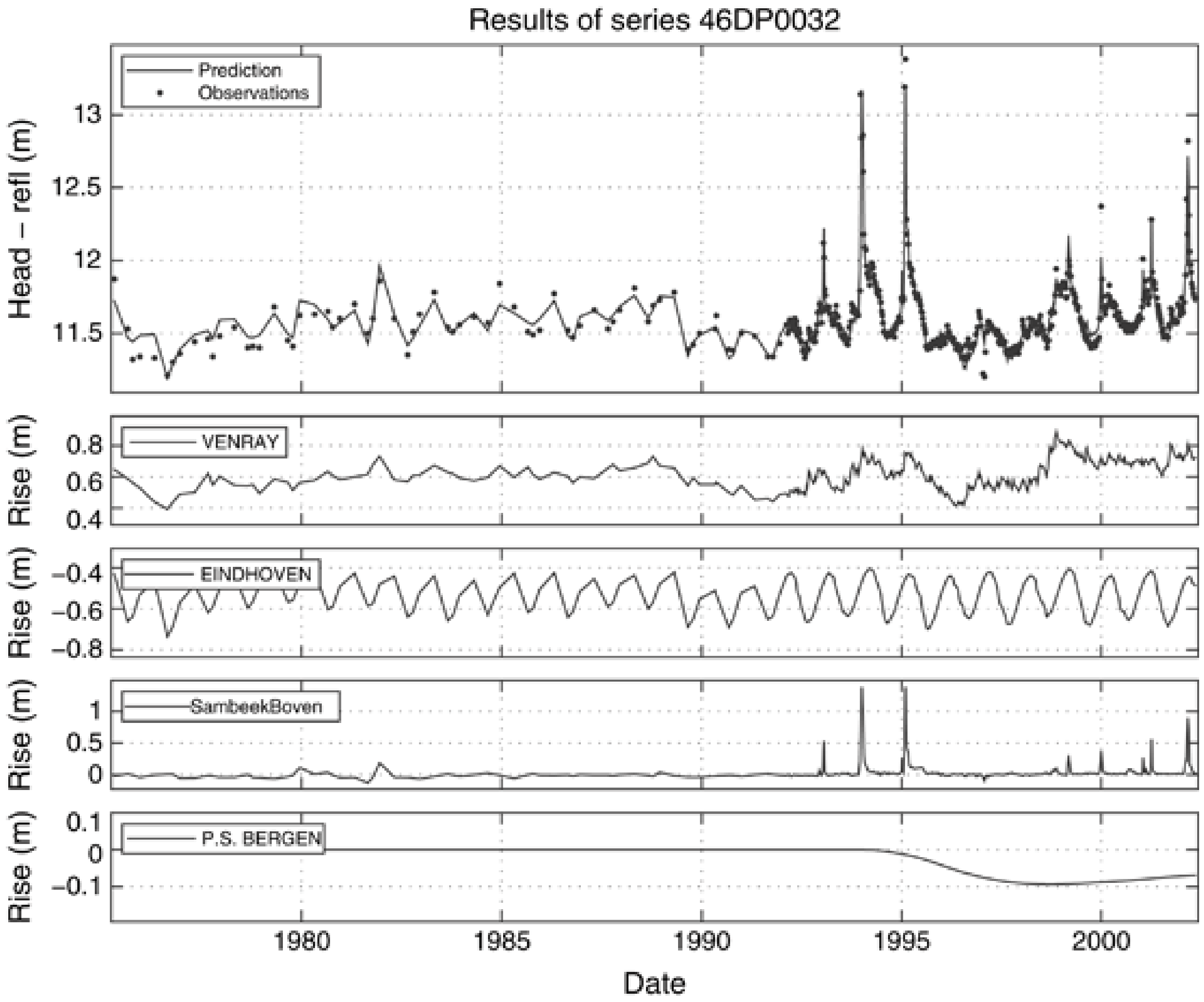
Support GW models: time series models can be used to support the development of numerical groundwater models.

Example: Identifying stresses on the groundwater system

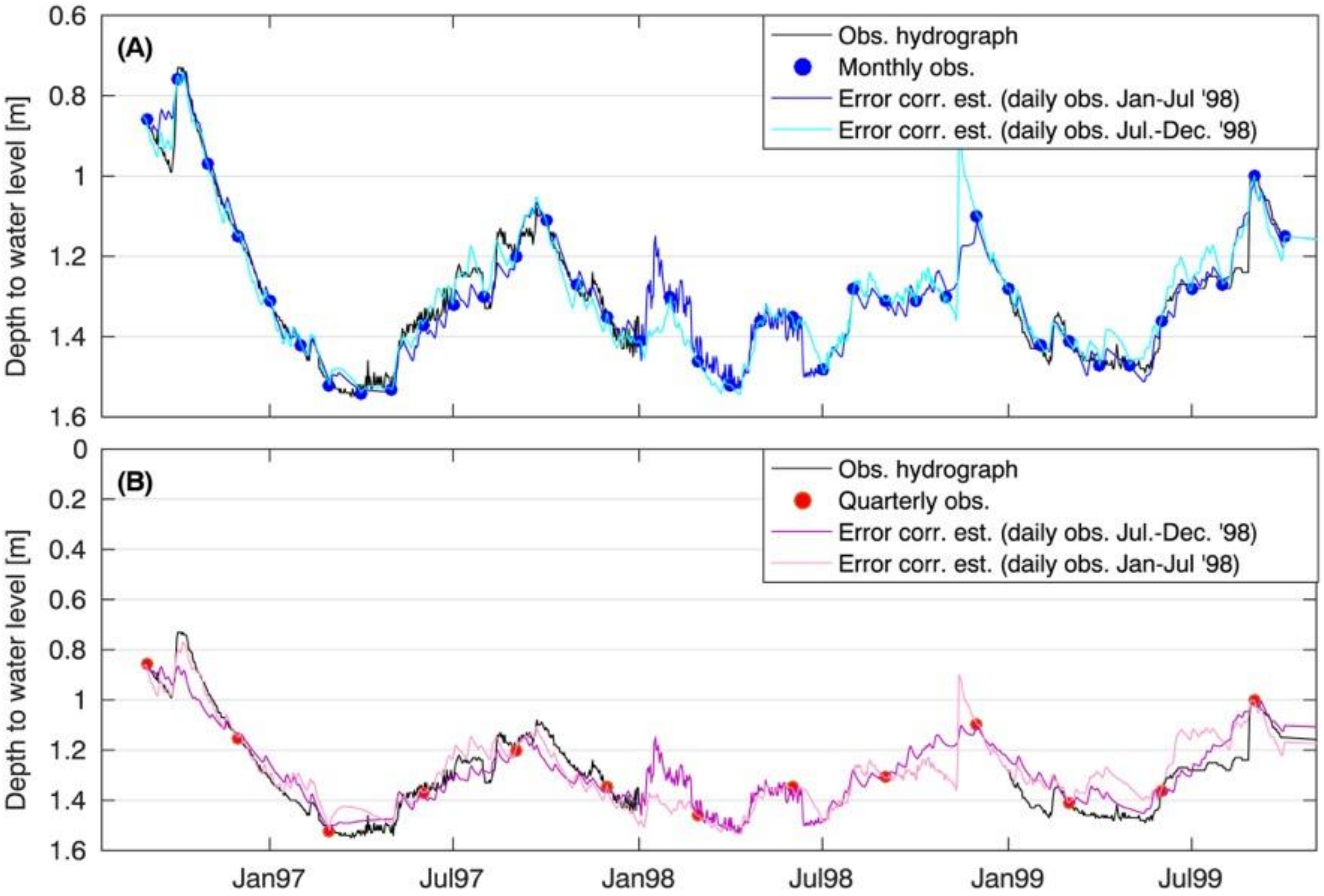
Understand what stresses might be causing the measured groundwater dynamics. Examples of stresses are:

- Precipitation
- Evaporation
- River stages
- Pumping
- …

Von Asmuth, Maas, Bakker, and Petersen (2008) Modeling Time Series of Ground Water Head Fluctuations Subjected to Multiple Stresses. Groundwater, 46: 30-40.



Example: Gap-filling



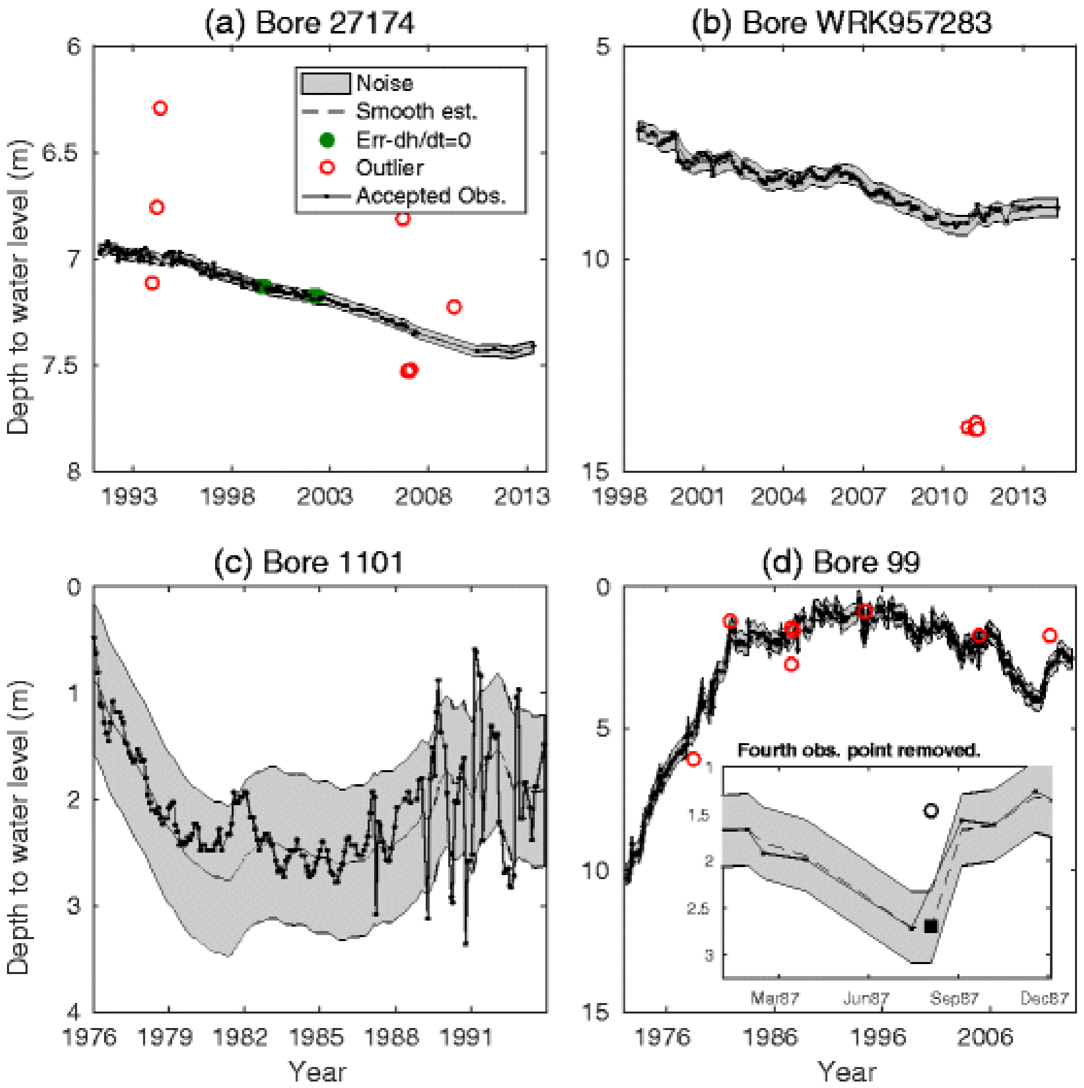
Peterson & Western (2018). Statistical interpolation of groundwater hydrographs. Water Resources Research, 54, 4663-4680.

Example: Outlier detection

Help* the detection of possible outliers, logger drift, and similar measurement errors

* Human oversight will remain necessary!

Peterson, Western & Cheng (2018) The good, the bad and the outliers: automated detection of errors and outliers from groundwater hydrographs. *Hydrogeol J* **26**, 371–380.



Example: Input–output relationships

What is the impact of groundwater pumping on the heads?

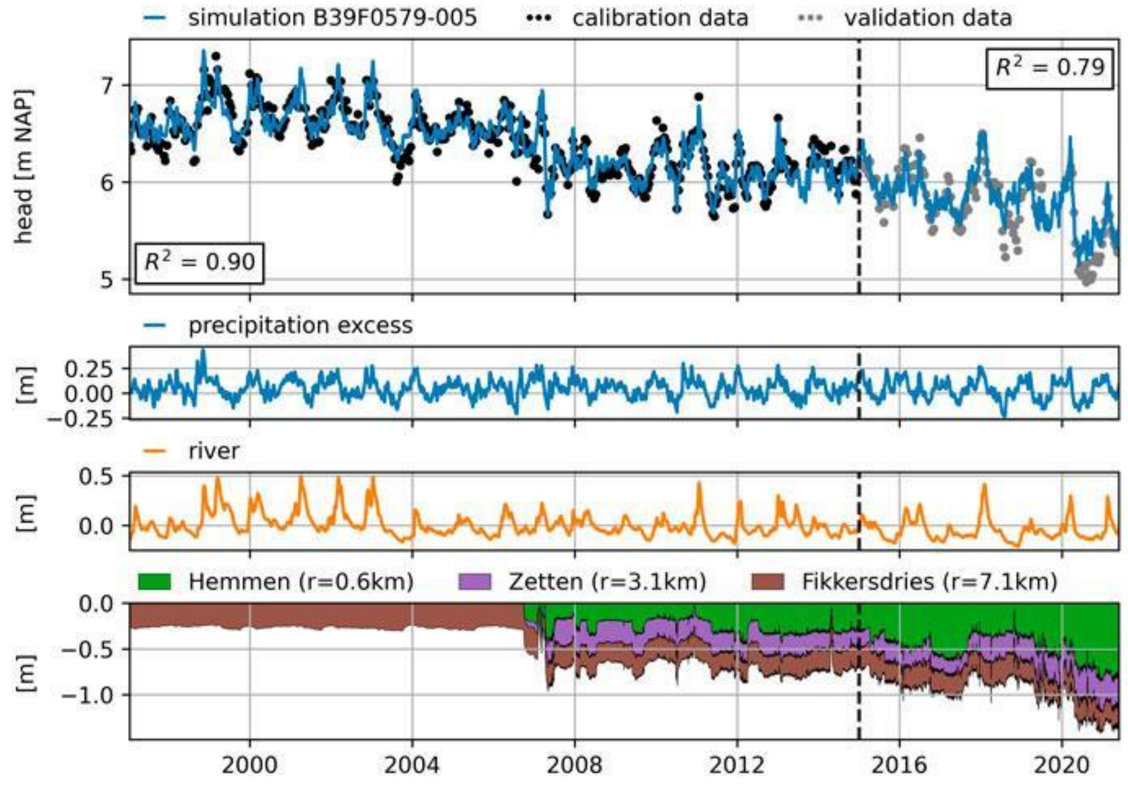
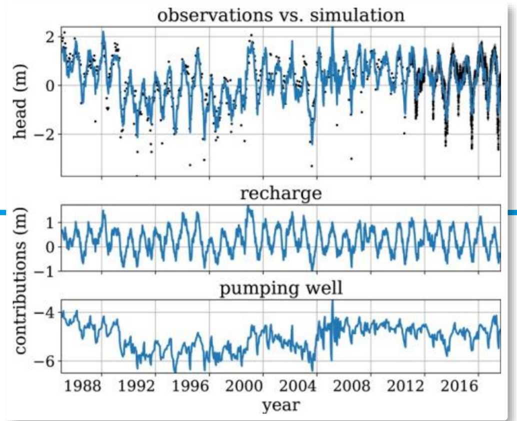


Figure: Effect of pumping on the head. **Source:** Brakenhoff et al. (2022)

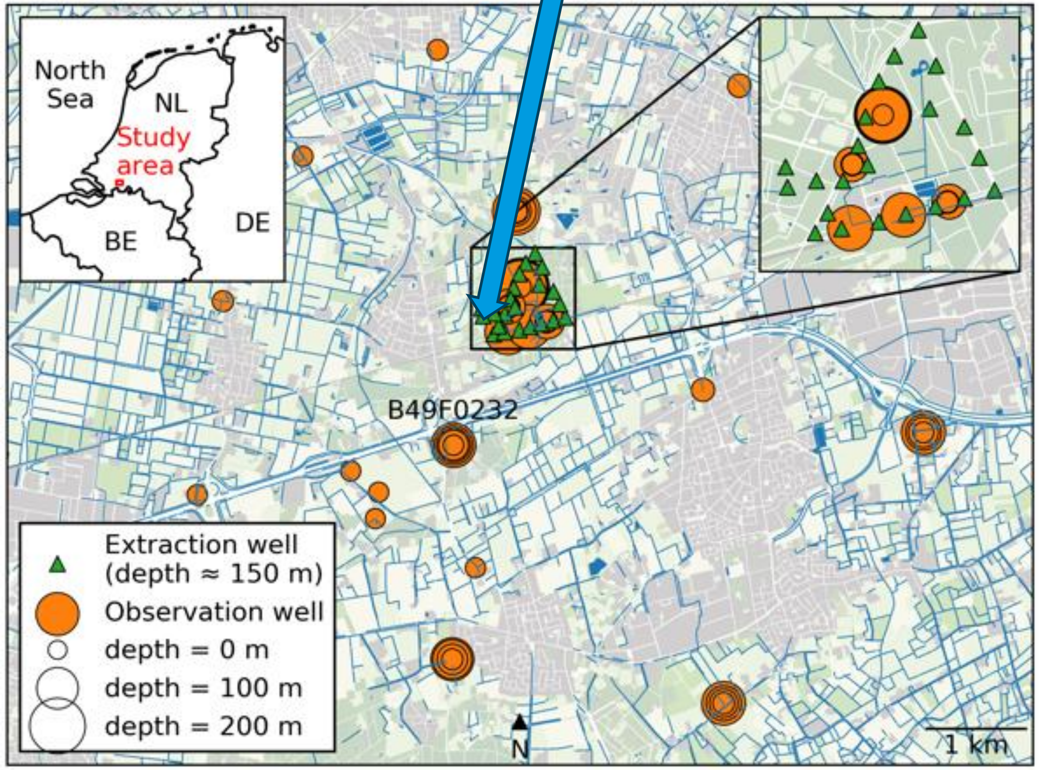
See also:

- Collenteur et al. (2019), Pastas: Open Source Software for the Analysis of Groundwater Time Series. Groundwater.
- Brakenhoff et al. (2022) Application of Time Series Analysis to Estimate Drawdown From Multiple Well Fields. *Frontiers in Earth Science*.c

Example: Spatial analysis



Often many monitoring wells in the same groundwater system are modelled simultaneously, providing a spatial view.



See also:

- Collenteur et al. (2019), Pastas: Open Source Software for the Analysis of Groundwater Time Series. Groundwater.
- Brakenhoff et al. (2022) Application of Time Series Analysis to Estimate Drawdown From Multiple Well Fields. *Frontiers in Earth Science*.c

Example: Forecasting groundwater levels

Where might the water table be in one month?

We can drive a Pastas model with ensemble forecasts of meteorology to obtain probabilistic groundwater level forecasts.

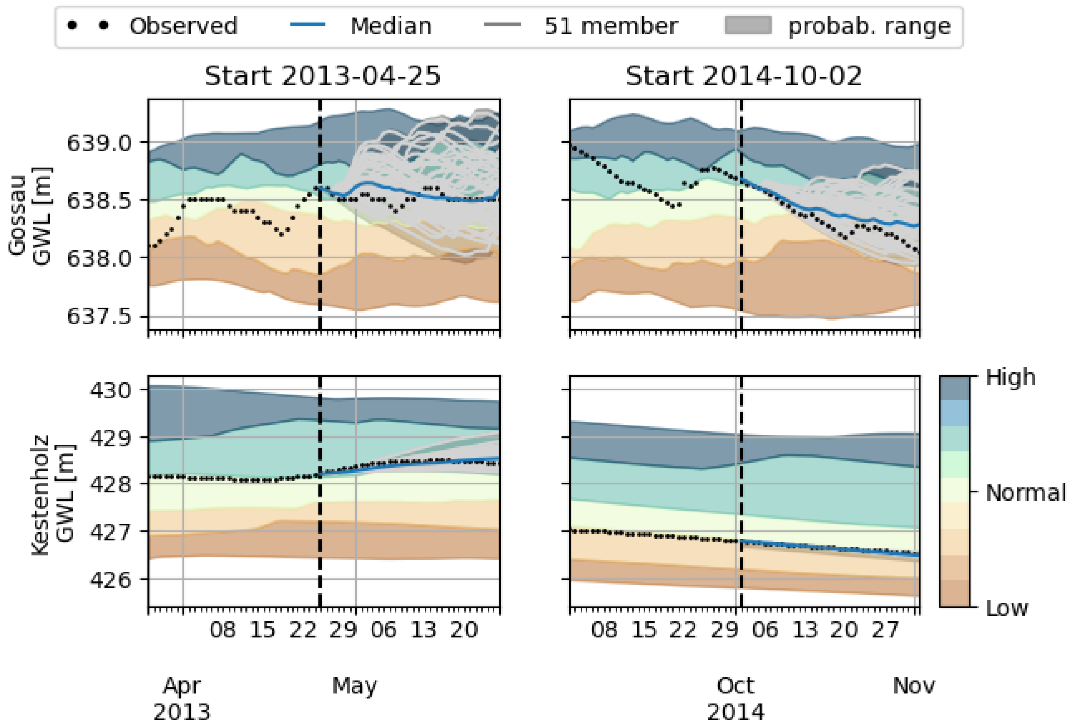


Figure: Ensemble groundwater forecasts for Switzerland for two locations and two start dates. **Source:** Collenteur et al. (In preparation) Ensemble groundwater prediction (EGP) in alluvial aquifers in Switzerland

Example: Supporting Numerical Model development

How may time series analysis help?

1. Test conceptual model hypotheses
2. Engage stakeholders
3. Support model design
4. Provide calibration targets

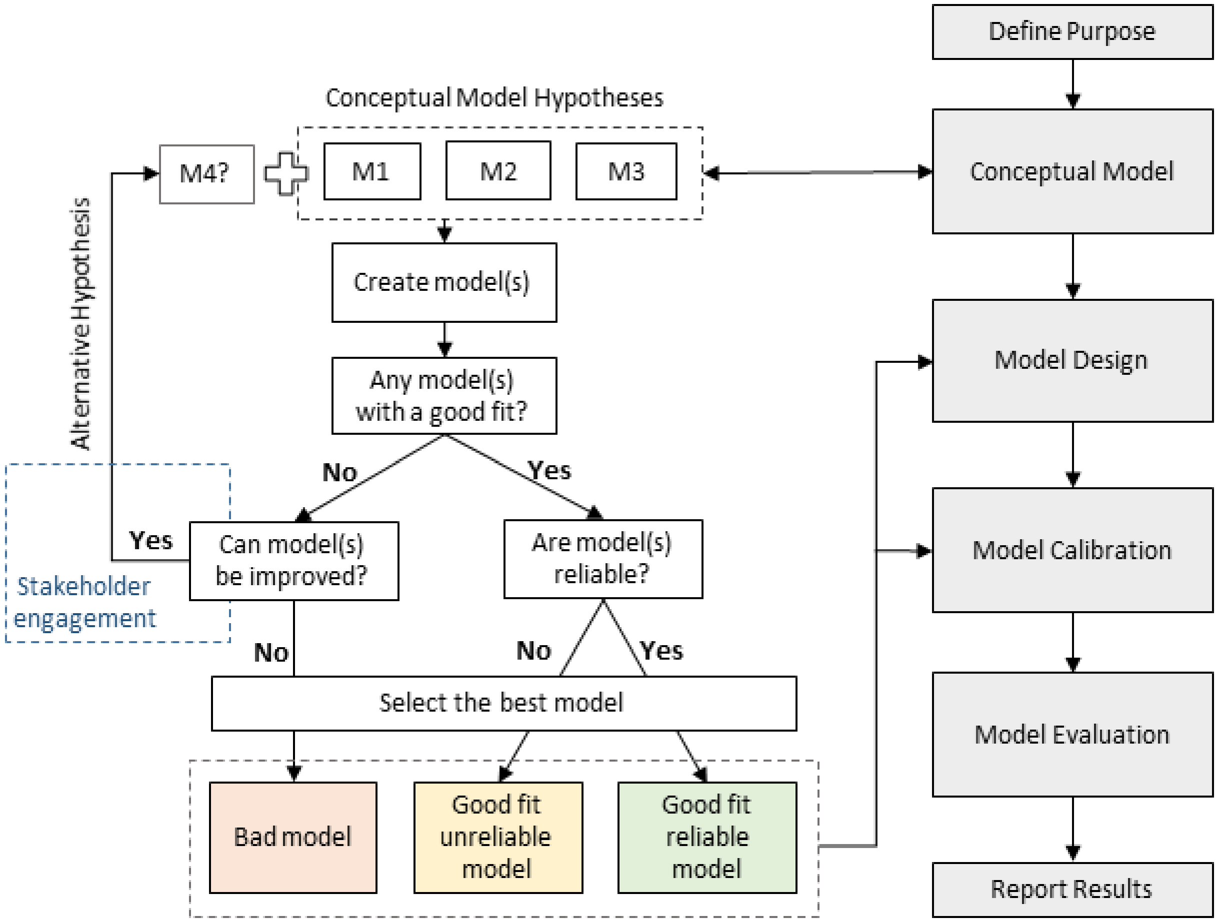
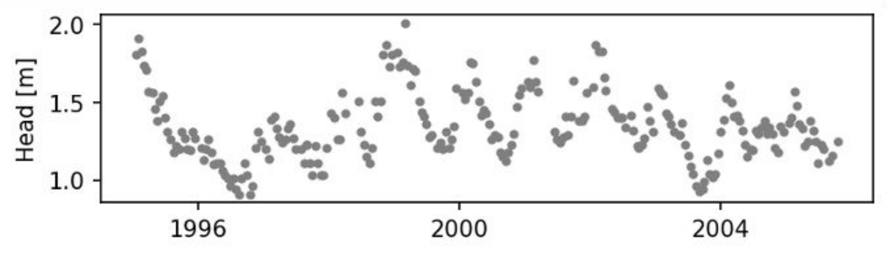


Figure source: Collenteur et al. (2022) Presentation at MODFLOW and More 2022, Princeton, USA

Model groundwater level time series with Pastas

Onno Ebbens, MSc (Artesia) & Raoul Collenteur, PhD (HydroConsult)



Case study: Time series analysis with Pastas

Kinderdijk
Netherlands

Continent: Europe

Coordinates: 51.886, 4.632

Antipodal point
South Pacific Ocean

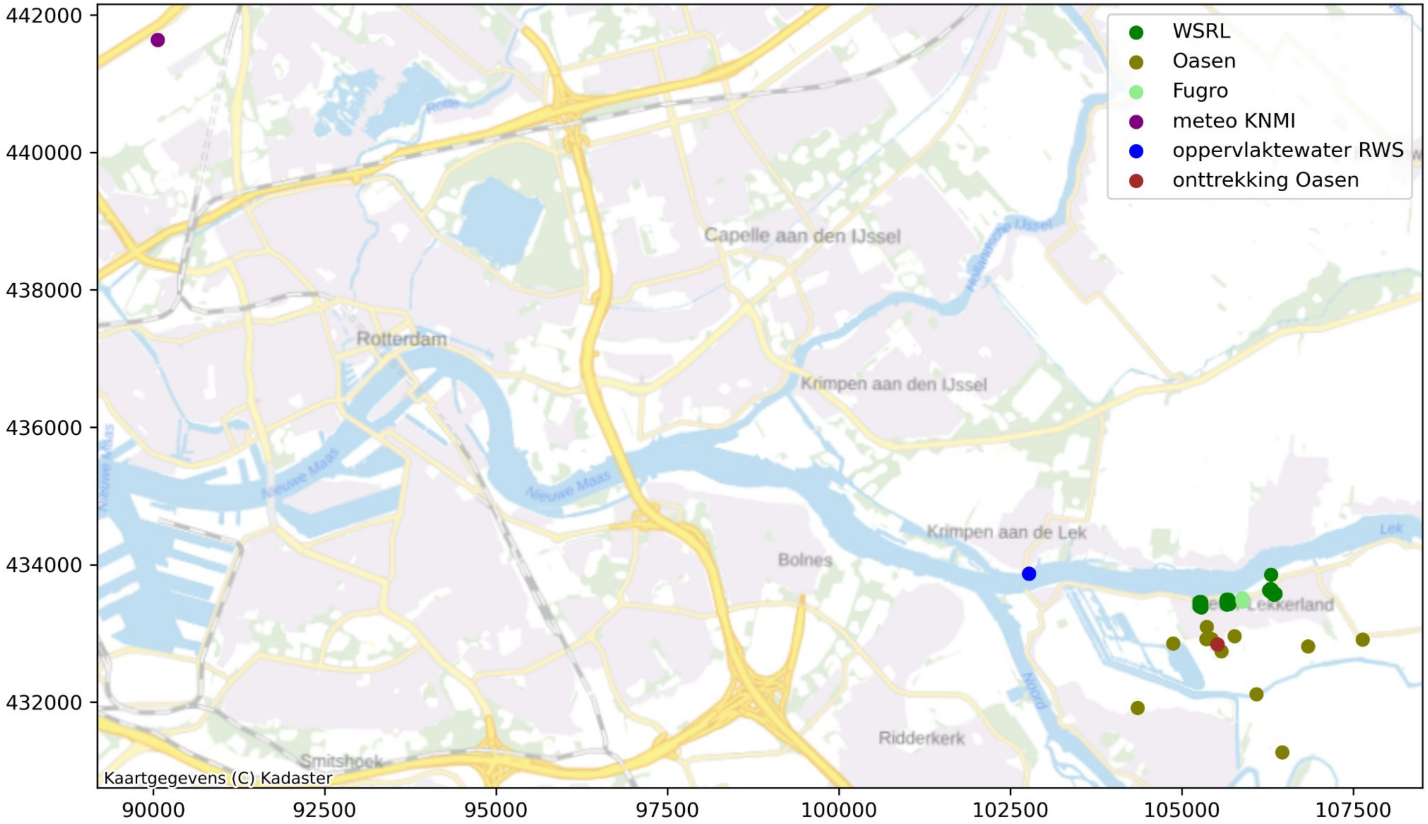
Exact location on the other side of the world

Coordinates: -51.886, -175.368

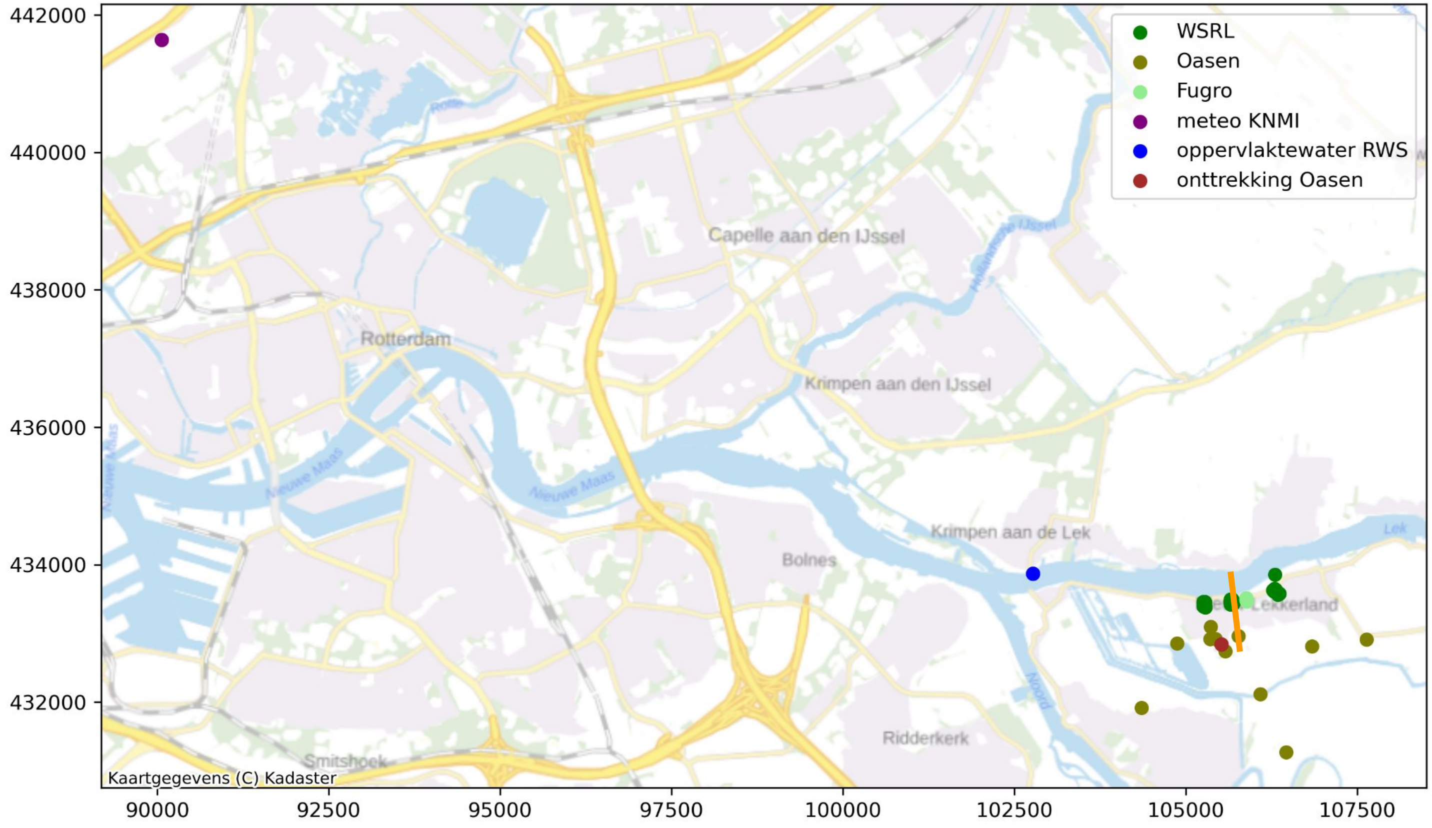
Waitangi
New Zealand

Waitangi is the closest city to Kinderdijk's antipodal point (886 km).

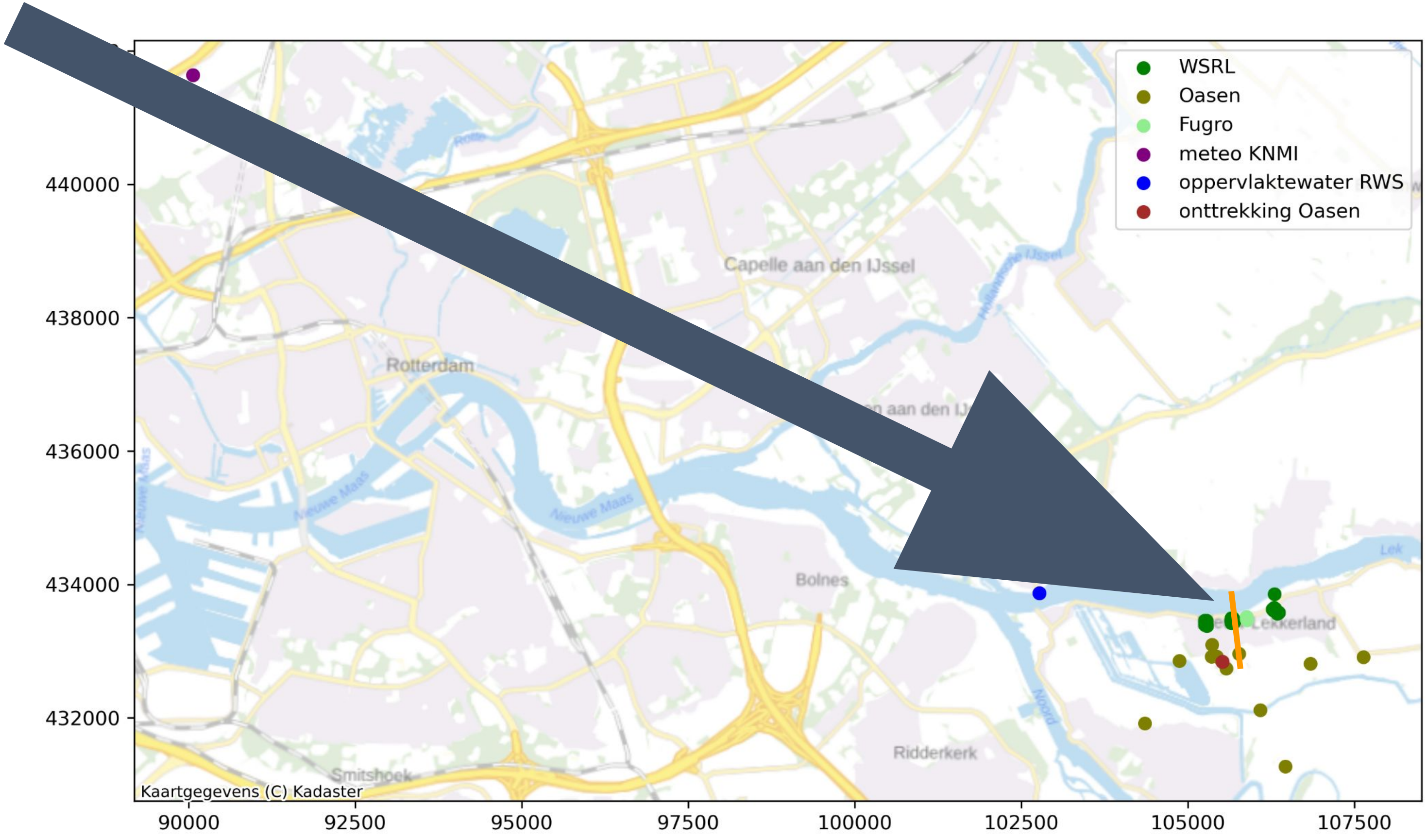
Case study: Time series analysis with Pastas



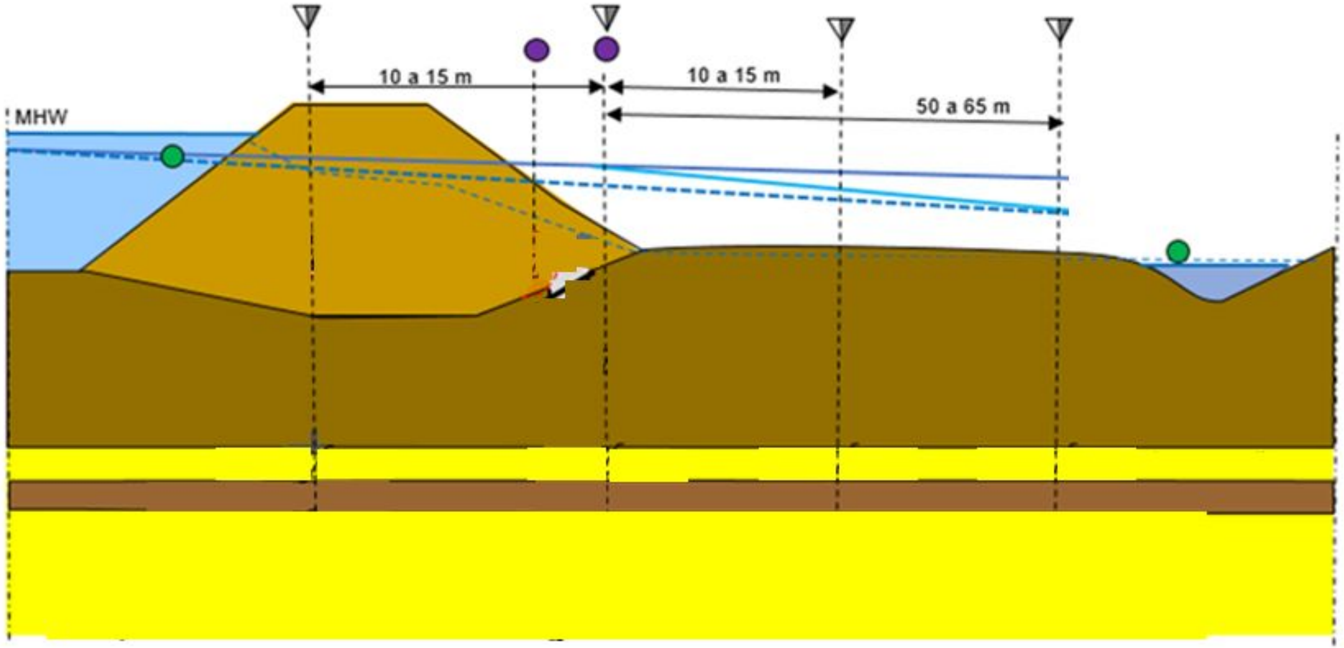
Case study: Time series analysis with Pastas



Case study: Time series analysis with Pastas



Cross section



Case study: goals

What are the most important influences (recharge, pumping, river) on the groundwater?

How will a flood wave affect groundwater levels?

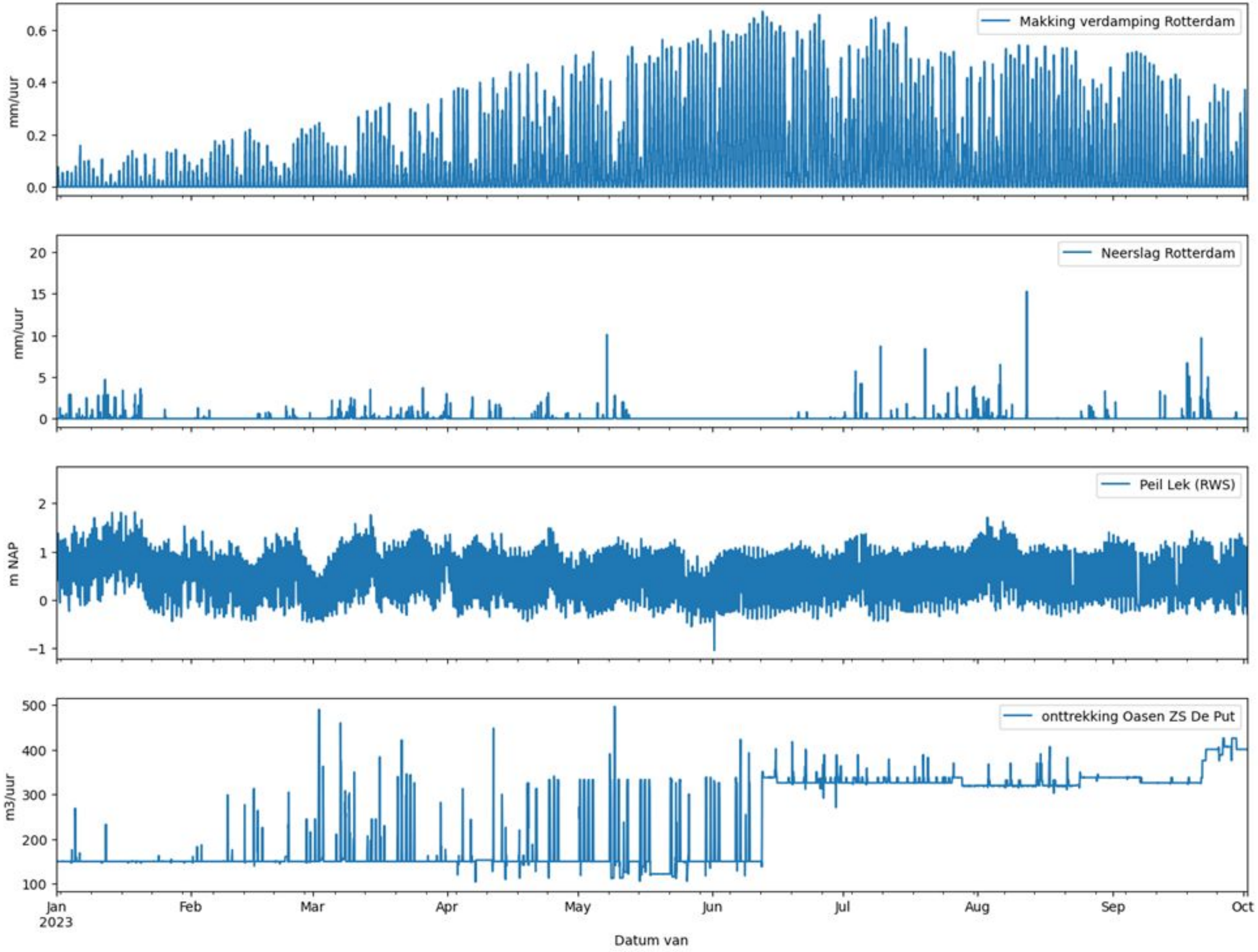
How will a reduction of pump rates affect groundwater levels?

Evaporation

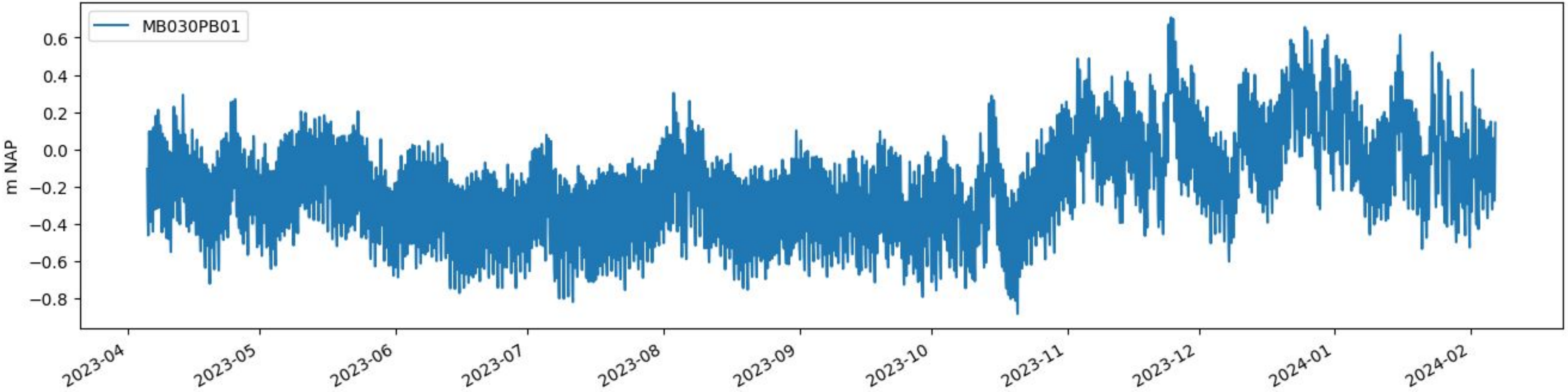
Precipitation

Water levels river

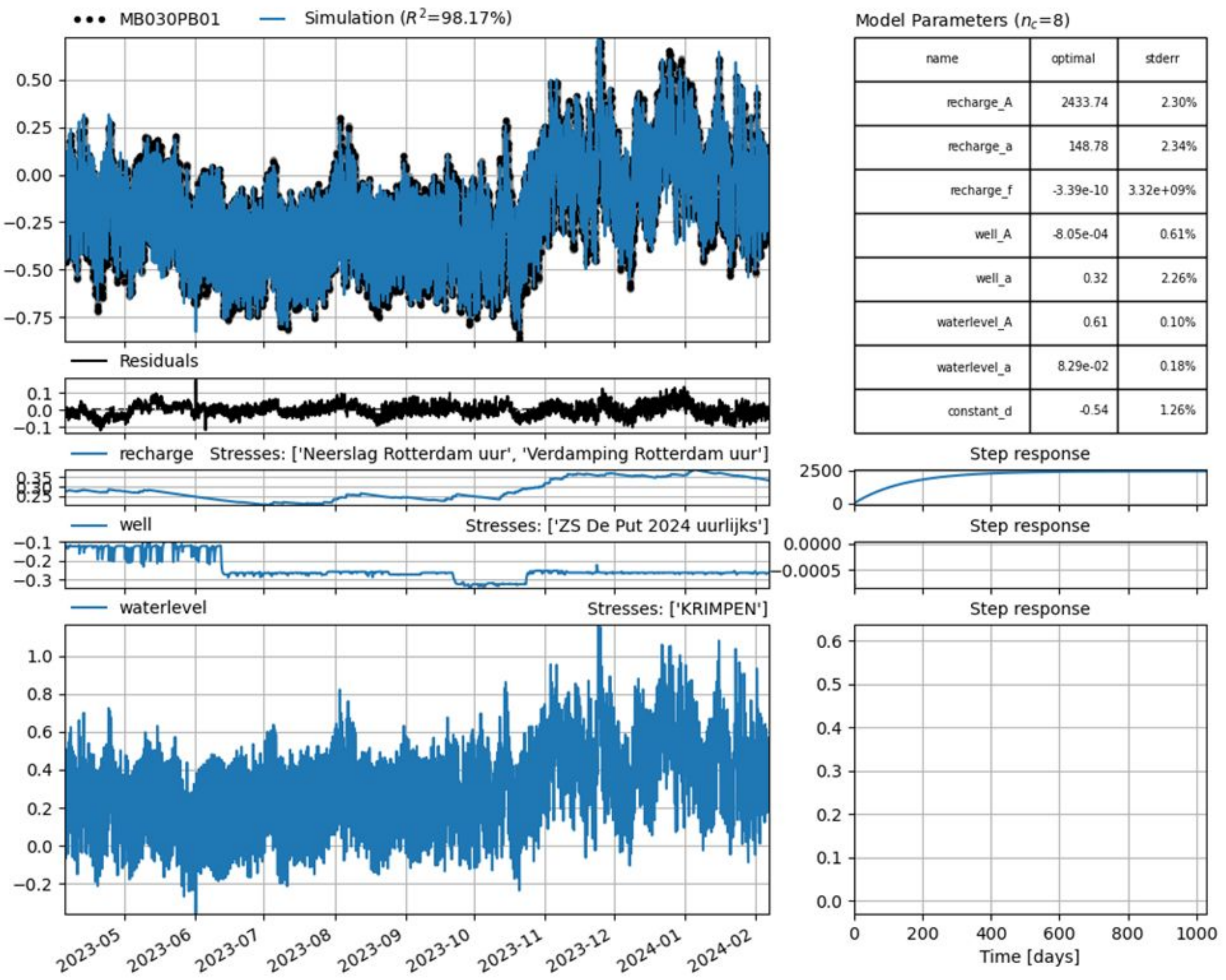
Extraction well rates



Groundwater head measurements



Time series model



name	optimal	stderr
recharge_A	2433.74	2.30%
recharge_a	148.78	2.34%
recharge_f	-3.39e-10	3.32e+09%
well_A	-8.05e-04	0.61%
well_a	0.32	2.26%
waterlevel_A	0.61	0.10%
waterlevel_a	8.29e-02	0.18%
constant_d	-0.54	1.26%

Model groundwater level time series with Pastas

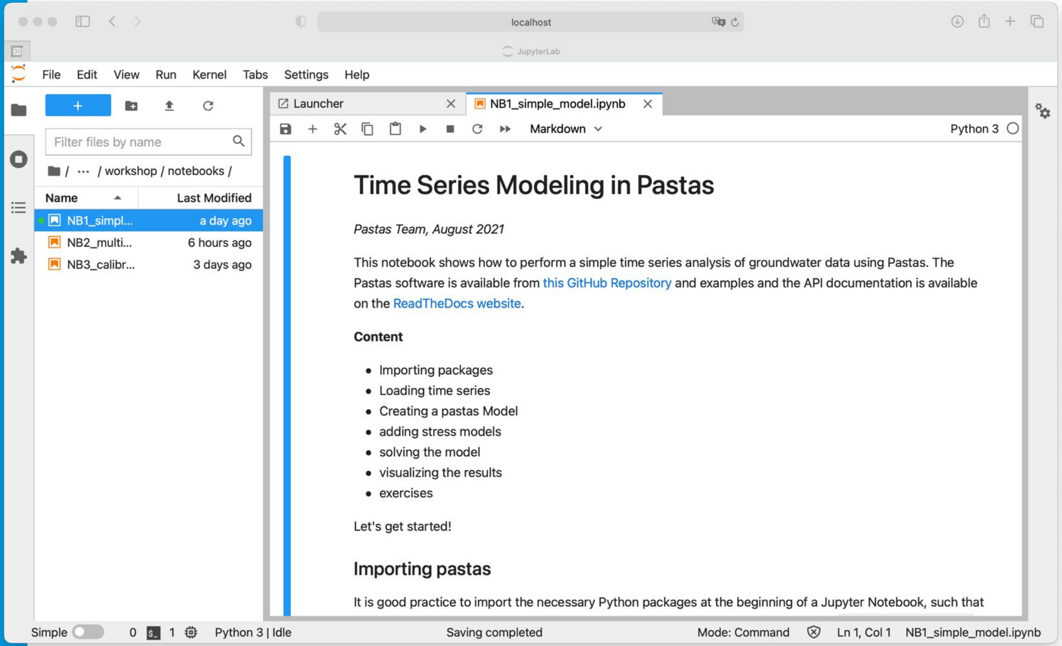
- 4 sessions, 2 hours per session
- Presentations: theory, examples
- Demonstrations: live coding in Jupyter Notebooks
- Exercises: make your own models

Model groundwater level time series with Pastas

Session	Title	Topics Covered
1	Analysing time series with Pandas	• Load and analyse time series data • Plot time series • Correct missing values • Prepare data for Pastas models
2	Setting up your first Pastas Model	• Understand impulse response functions • Build a basic Pastas model • Perform calibration • Analyse results and model parameters
3	Different model structures for Pastas	• Add stresses (e.g., pumping) • Account for precipitation and evaporation • Build and compare complex models
4	Model calibration and analysis	• Improve calibration settings • Model residuals using noise models • Statistical analysis of residuals • Intro to model uncertainty

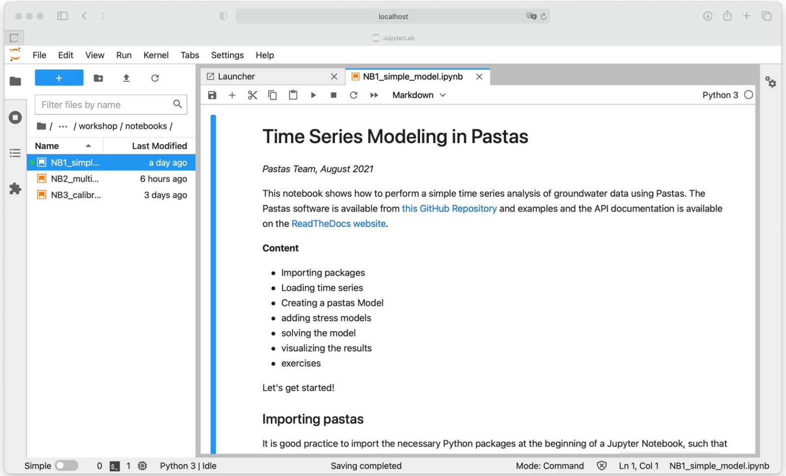
Over to Python

KEEP
CALM
AND
PYTHON
ON



Summary

- Pastas is open-source Python software to analyze and model groundwater level time series
- A four-part online course will introduce you to how to use Pastas to solve groundwater problems
- The course will cover the theory behind impulse response functions, and provide hands-on experience and scripts to model your own data



More info:

https://awschool.com.au/training/modelling-groundwater-pastas/

Thank you for your attention! Questions?