EGU2025
Darcy Lecture

Developments in hydrological modelling: from Darcy's work on public fountains to observations by the public

Jan Seibert

With inputs from Franziska Clerc-Schwarzenbach, Sandra Pool, Ilja van Meerveld, Marc Vis, …

University of Zurich[UZH]

Slides as pdf
on my homepage

https://user.geo.uzh.ch/jseibe/2025_EGU_Darcy_janseibert.pdf

Who was Henry Darcy?

LES

FONTAINES PUBLIQUES

DE LA VILLE DE DIJON

EXPOSITION ET APPLICATION

DES PRINCIPES A SUIVRE ET DES FORMULES A EMPLOYER

DANS LES QUESTIONS

DE

DISTRIBUTION D'EAU

OUVRAGE TERMINÉ

PAR UN APPENDICE RELATIF AUX FOURNITURES D'EAU DE PLUSIEURS VILLES

AU FILTRAGE DES EAUX

ET

A LA FABRICATION DES TUYAUX DE FONTE, DE PLOMB, DE TÔLE ET DE BITUME

PAR

HENRY DARCY

INSPECTEUR GÉNÉRAL DES PONTS ET CHAUSSÉES.

La bonne qualité des eaux étant une des choses qui contribuent le plus à la santé des citoyens d'une ville, il n'y a rien à quoi les magistrats aient plus d'intérêt qu'à entretenir la salubrité de celles qui servent à la boisson commune des hommes et des animaux, et à remédier aux accidents par lesquels ces eaux pourraient être altérées, soit dans le lit des fontaines, des rivières, des ruisseaux où elles coulent, soit dans les lieux où sont conservées celles qu'on en dérive, soit enfin dans les puits d'où naissent des sources.

(De Jussieu, *Hist. de l'Académie royale des sciences*, 1733, p. 351.)

PARIS

VICTOR DALMONT, ÉDITEUR,

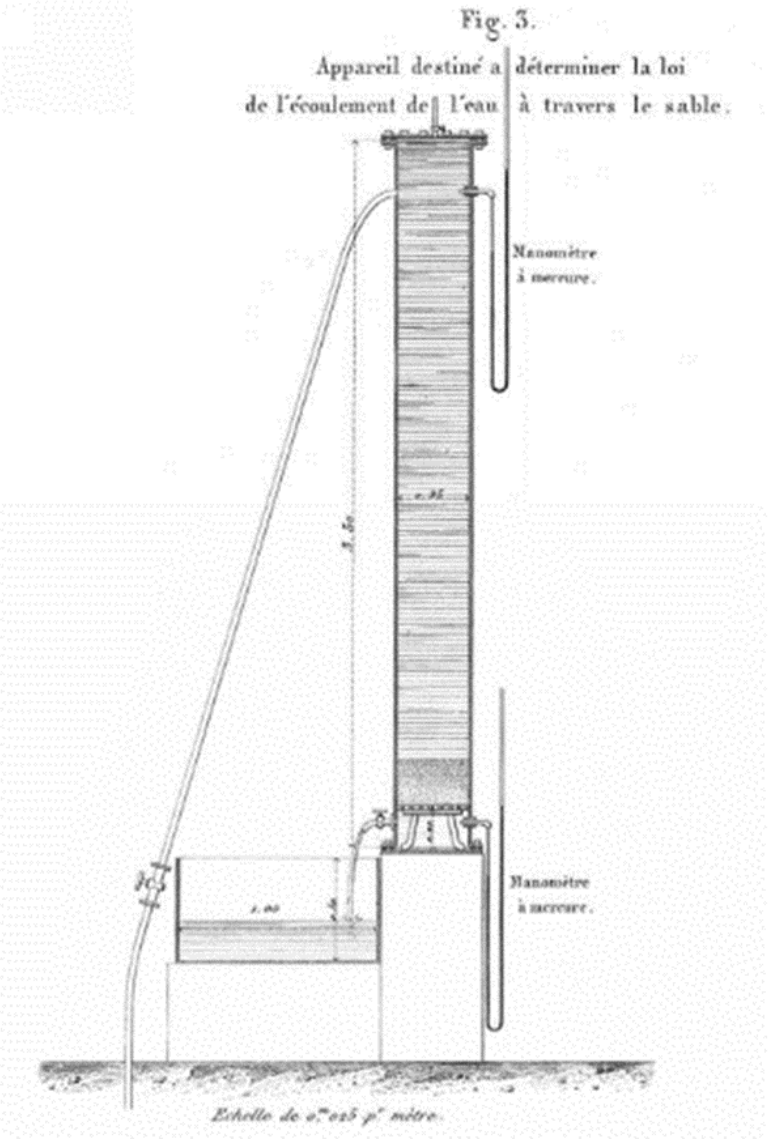
Successeur de Carilian-Gœury et Vve Dalmont,

LIBRAIRE DES CORPS IMPÉRIAUX DES PONTS ET CHAUSSÉES ET DES MINES,

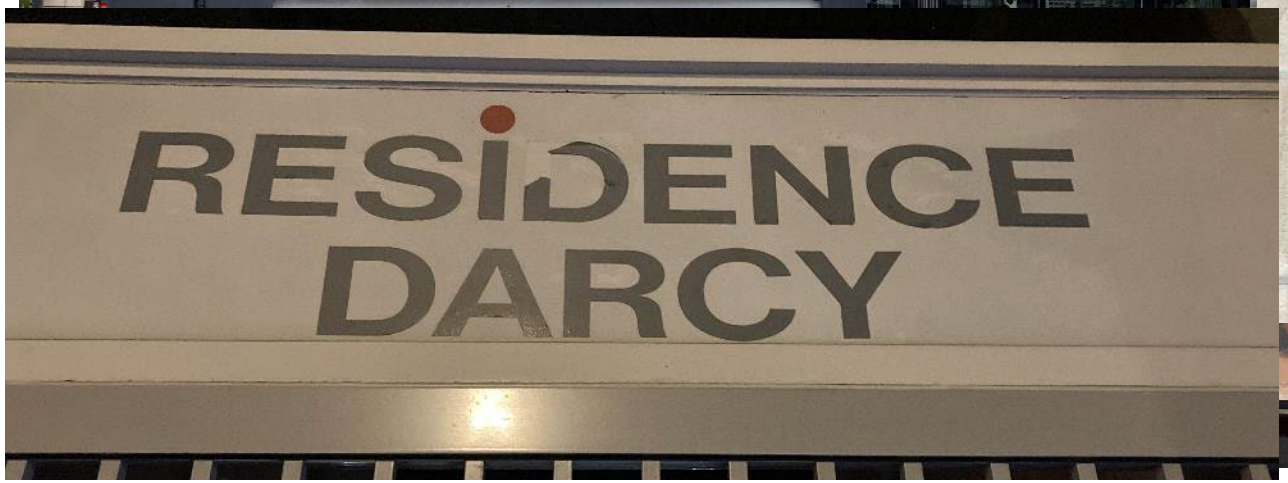
Quai des Augustins, 49.

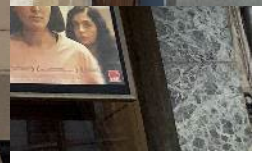
1856

Henry Darcy
1803-1858

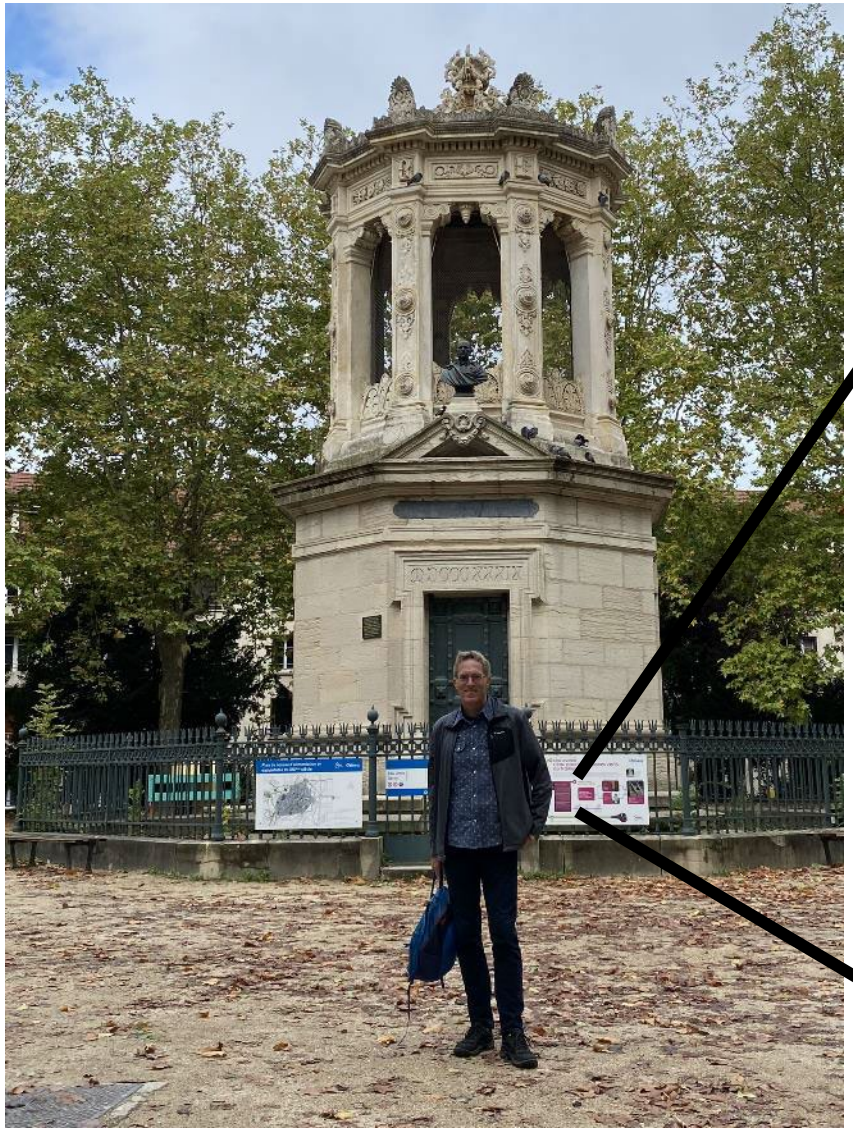


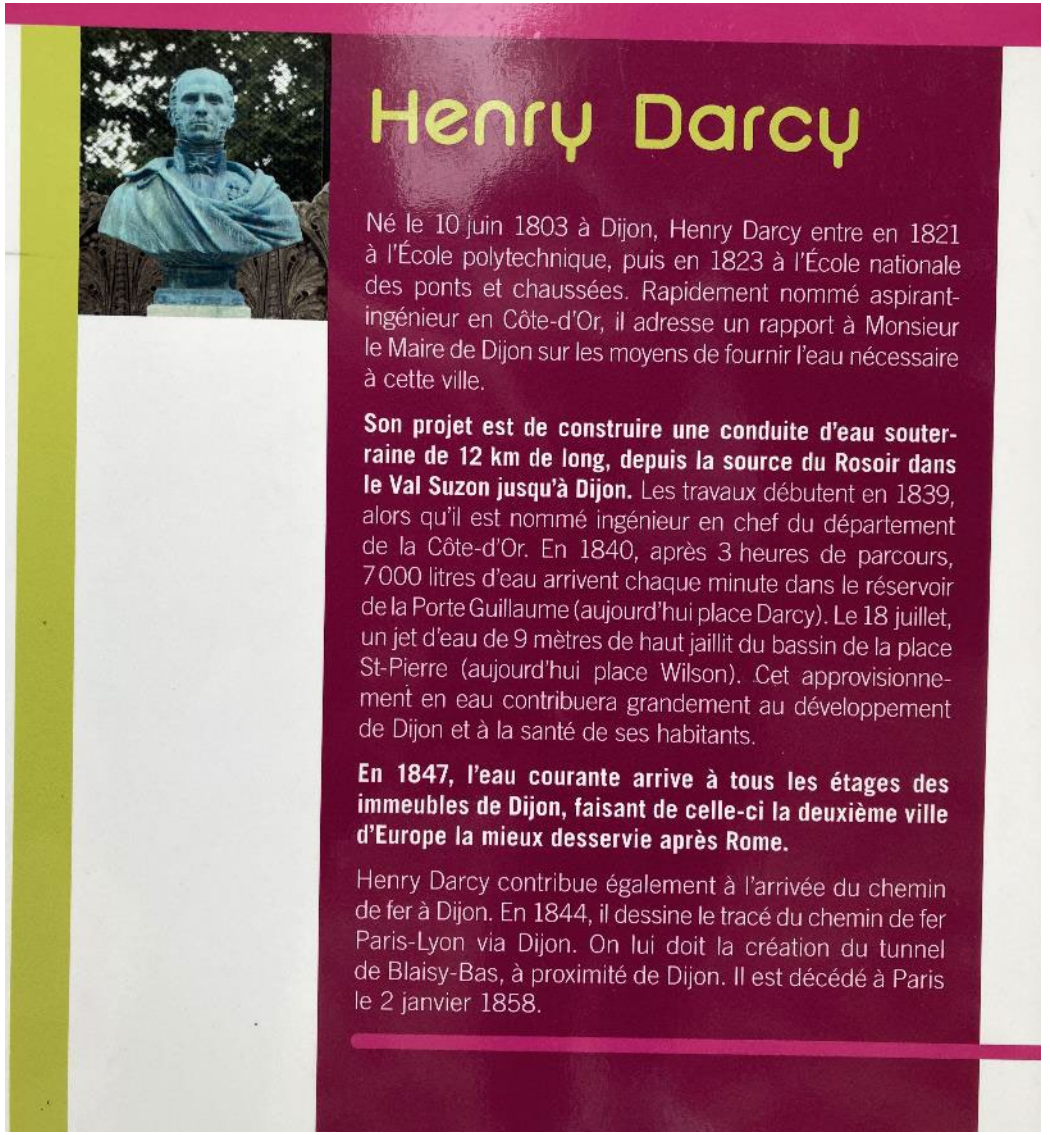
Searching Darcy in Dijon

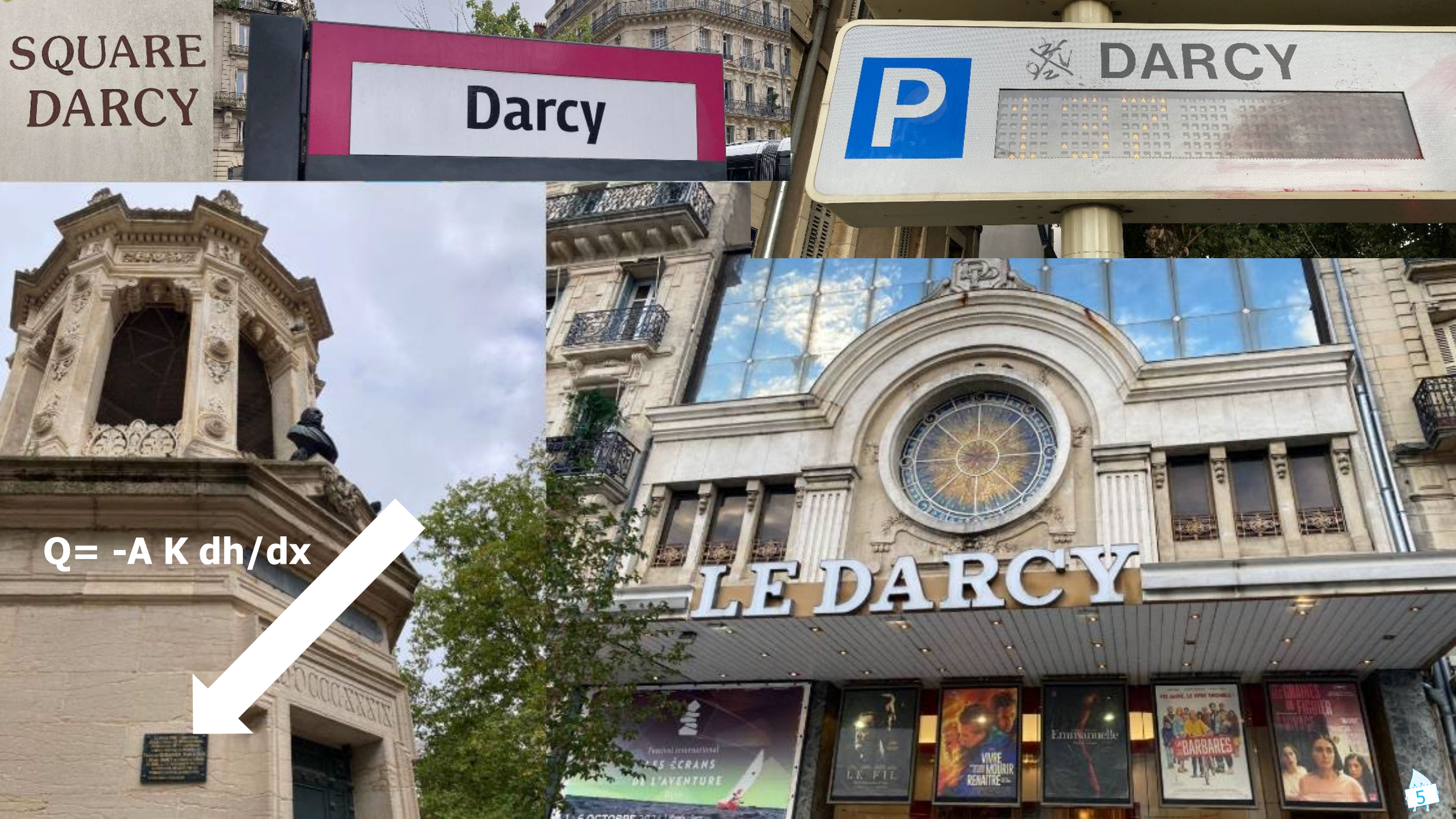


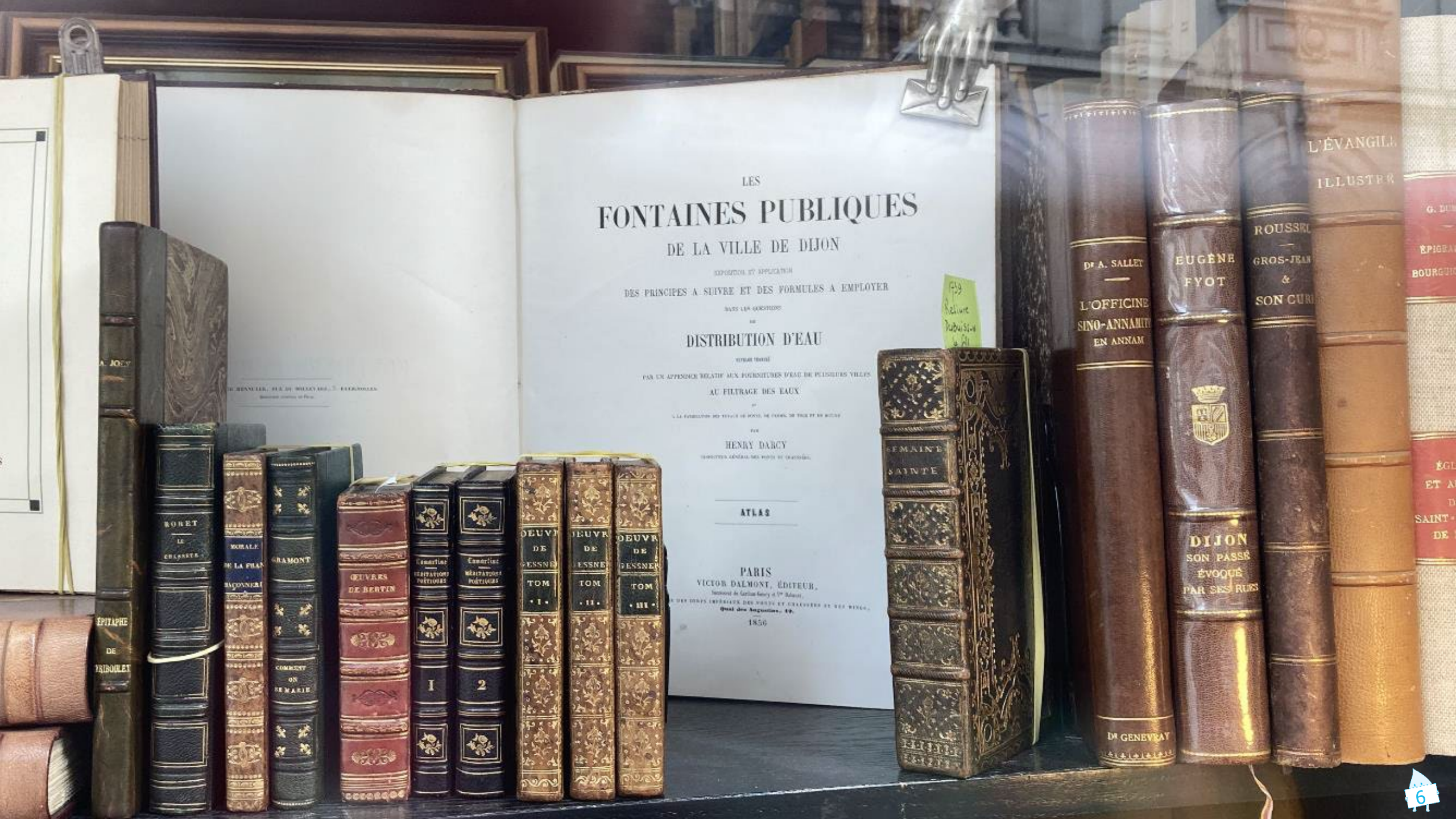


Finding a different Darcy






SQUARE
DARCY
Darcy
P
DARCY
Q= -A K dh/dx
LE DARCY
VIVRE MOURIR RENAITRE
Emmanuelle
BARBARES


LES
FONTAINES PUBLIQUES
DE LA VILLE DE DIJON
EXPOSITION ET APPLICATION
DES PRINCIPES A SUIVRE ET DES FORMULES A EMPLOYER
DANS LES QUESTIONS
DE
DISTRIBUTION D'EAU
SUIVIE D'UNE
ÉTUDE
PAR UN APPENDICE RELATIF AUX FOURNITURES D'EAU DE PLUSIEURS VILLES
AU FILTRAGE DES EAUX
ET
A LA FABRICATION DES TUYAUX DE BOIS, DE CIMENT, DE TÔLE ET DE BITUME
PAR
HENRY DARCY
INSPECTEUR GÉNÉRAL DES PONTS ET CHAUSSÉES.
ATLAS
PARIS
VICTOR DALMONT, ÉDITEUR,
Successeur de Carilian-Goeury et Vor Dalmont,
DES CORPS IMPÉRIAUX DES PONTS ET CHAUSSÉES ET DES MINES,
Quai des Augustins, 49.
1856
ROBERT LE CHASSEUR
MORALE DE LA FRANC MAÇONNERIE
GRAMONT COMMENT ON SE MARIE
ÉPITAPHE DE VRIBOULET
ŒUVRES DE BERTIN
Lamartine MÉDITATIONS POÉTIQUES
1
2
ŒUVRES DE GESSNER TOM I
ŒUVRES DE GESSNER TOM II
ŒUVRES DE GESSNER TOM III
SEMAINE SAINTE
Dr A. SALLET
L'OFFICINE SINO-ANNAMITE EN ANNAM
Dr GENEVRAY
EUGÈNE FYOT
DIJON SON PASSÉ ÉVOQUÉ PAR SES RUES
ROUSSEL
GROS-JEAN & SON CURÉ
L'ÉVANGILE ILLUSTRÉ

Desperately Seeking Darcy in Dijon

J. R. Philip*

ABSTRACT

Henry Darcy (born 1803, died 1858) is known to soil physicists as the founding father of the science of fluid flow in soils. This illustrated account of a short visit to Dijon, his native town, reveals little-known aspects of Darcy's character, life, and work. The central square and town gardens are named after Darcy, as are numerous commercial and public undertakings: a cinema, bus stop, a garage, a multistory car park, a pharmacy, and a shopping arcade. Inquiry revealed that Henry Darcy himself has been forgotten by the citizens of Dijon, and that his name persists only as a ubiquitous geographical label. It was not always thus. Darcy, with great vision and skill, designed and built a pure water supply system for Dijon, in place of previous squalor

the great m
I discovere
faintest ide
cerned, Da
cadilly in I
As many
kept on at t
if Dijon di
world knev
carried his
man was h
decided to

Henry Darcy (1803–1858): Immortalised b

Craig T. Simmons

Keywords Profiles · History of hydrogeology · Henry Darcy · Darcy's Law · France · Dijon

Introduction

Darcy's Law is the fundamental equation describing the flow of fluid through porous media including ground-

Law, he was
the falling h
He also ap
spring disch
Law, it is cl
Darcy's
in this artic
provided in

Finding Darcy at Dijon

Willi H. Hager[1] and Corrado Gisonni[2]

At that moment, we were not sure whether Darcy and Bazin

WATER RESOURCES RESEARCH, VOL. 38, NO. 7, 1106, 10.1029/2001WR000727, 2002

Henry Darcy and the making of a law

G. O. Brown

Department of Biosystems and Agricultural Engineering, Oklahoma State University, Stillwater, Oklahoma, USA

Received 19 June 2001; revised 28 November 2001; accepted 13 February 2002; published 17 July 2002.

[1] Henry Darcy was a distinguished engineer, scientist, and citizen who is remembered for his many contributions in hydraulics, including Darcy's law for flow in porous media. While he has been given full credit for the finding, little insight has been available on the process of his discovery. It is shown that his discovery was the logical result of a lifetime of education, professional practice, and research. Darcy understood both its significance and its relationship to the broader fields of hydraulics and groundwater hydrology. Besides the discovery of Darcy's law, he was the first to show that significant flow resistance occurs within aquifers, the first to recognize the law's similarity to Poiseuille flow, and the first to combine the law with continuity to obtain a solution for unsteady flow. *INDEX TERMS:* 1719 History of Geophysics: Hydrology; 1829 Hydrology: Groundwater hydrology; 5114 Physical Properties of Rocks: Permeability and porosity; *KEYWORDS:* Darcy's law, Corps of Ponts et Chaussées, Dijon, France

1. Introduction

[2] In 1856, Henry Philibert Gaspard Darcy (1803–1858), in a report on the construction of the Dijon, France, municipal water system, published a relationship for the flow rate of water in sand filters [*Darcy*, 1856]. In terms only slightly different from his own, Darcy's law was given as

$$Q = AK\frac{(h_1 + z_1) - (h_2 + z_2)}{L}, \qquad (1)$$

detailed obituaries based on firsthand accou
excellent documents, but each suffers fro
historical perspective. *Tarbé de St-Hardouin*
Fancher [1956] based their short biograph
saines' account, while in turn most recent
are based on them. *Hubbert* [1969] revie
experiment, while *Rao* [1968] summarized D
contributions to hydraulics. R. Freeze in
Freeze and Back [1983] performed a parti
of *Darcy* [1856] as part of an excellent colle
groundwater papers. An interesting nontechn

Henry Darcy, 1803-1958

"A city that cares for the interest of the poor should not limit their water." (Darcy, 1856)

Freeze RA. 1994. Henry Darcy and the fountains of Dijon. *Ground Water* 32 (1): 23–30

Philip JR. 1995. Desperately seeking Darcy in Dijon. *Soil Science Society of America Journal* 59: 319–324

Hager WH, Gisonni C. 2002. Finding Darcy at Dijon. *Journal of Hydraulic Engineering* 128 (5): 454–459 DOI: 10.1061/(asce)0733-9429(2002)128:5(454)

Brown GO. 2002. Henry Darcy and the making of a law. *Water Resources Research* 38 (7): 11-1-11–12 DOI: 10.1029/2001wr000727

Simmons CT. 2003. Happy 200th birthday Mr Darcy and our thanks for your law! A tribute editorial celebrating the life and times of the father of our science, Henry Darcy (1803?1858). *Hydrogeology Journal* 11 (6): 611–614 DOI: 10.1007/s10040-003-0301-5

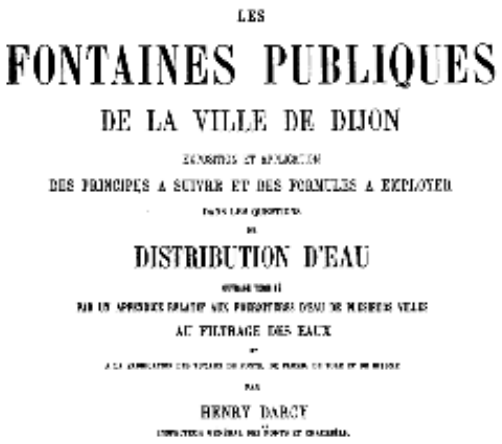
Sharp JM, Simmons CT. 2005. The Compleat Darcy: New lessons learned from the first english translation of Les Fontaines Publiques de la Ville de Dijon. *Ground Water* 43 (3): 457–460 DOI: 10.1111/j.1745-6584.2005.0076.x

Ritzi RW, Bobeck P. 2008. Comprehensive principles of quantitative hydrogeology established by Darcy (1856) and Dupuit (1857). *Water Resources Research* 44 (10): 1–14 DOI: 10.1029/2008WR007002

Simmons CT. 2008. Henry Darcy (1803-1858): Immortalised by his scientific legacy. *Hydrogeology Journal* 16 (6): 1023–1038 DOI: 10.1007/s10040-008-0304-3

From Darcy to today's lecture

- Public fountains
- Value of his efforts
- 23+12 sand column experiments / one parameter


LES

FONTAINES PUBLIQUES

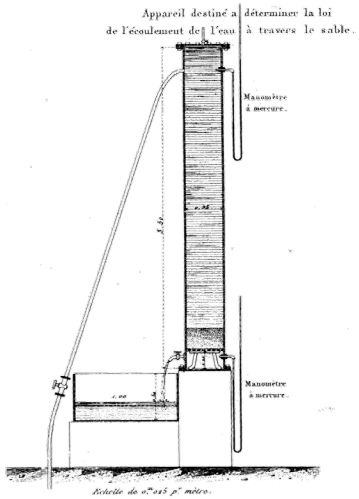
DE LA VILLE DE DIJON

DES PRINCIPES A SUIVRE ET DES FORMULES A EMPLOYER

DISTRIBUTION D'EAU

AU FILTRAGE DES EAUX

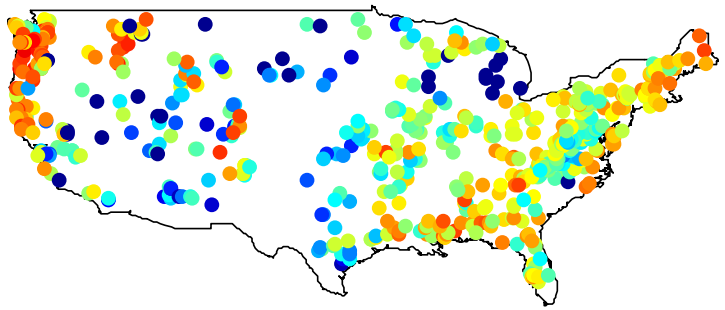
HENRY DARCY



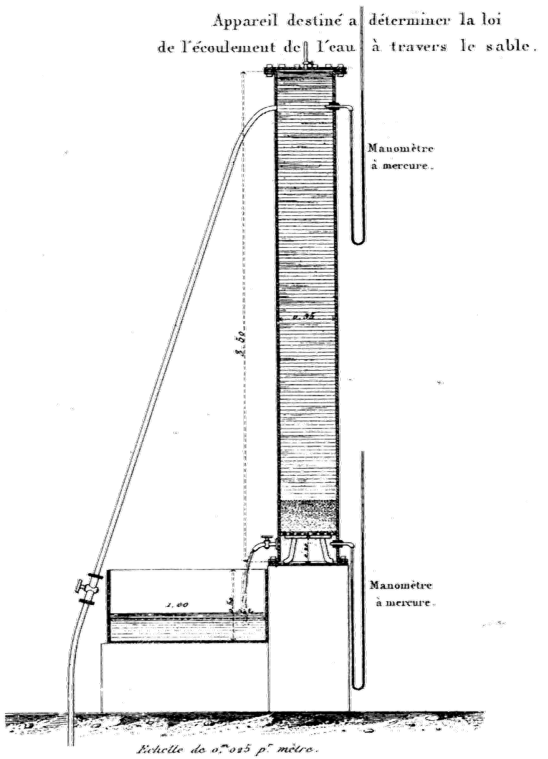
$$Q = -A K \frac{dh}{dx}$$

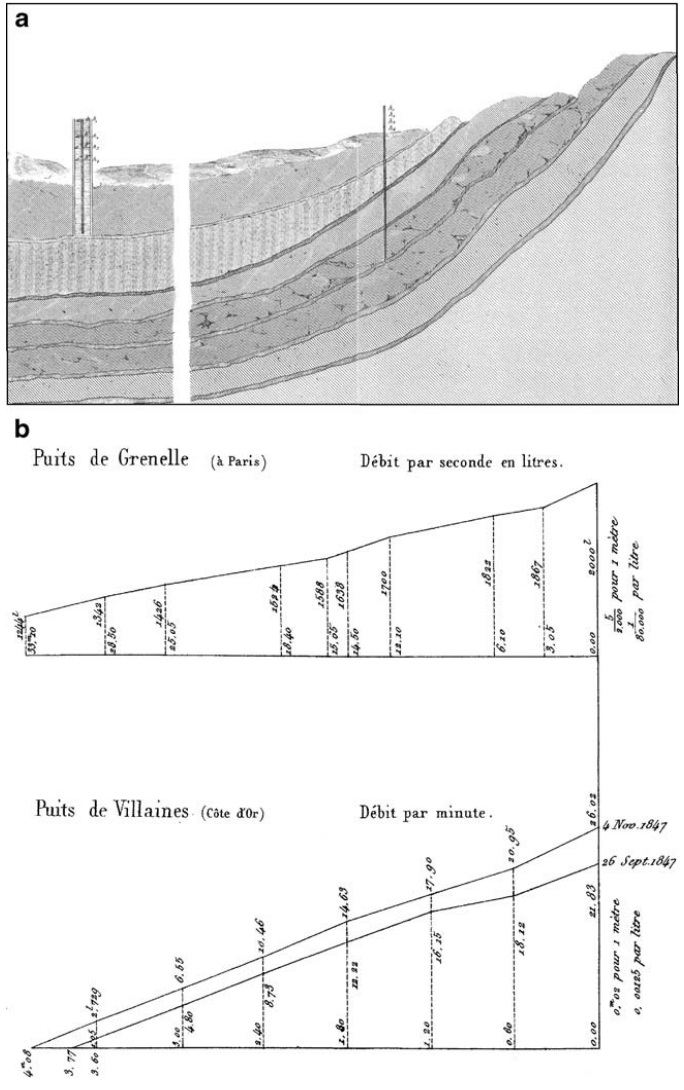
- Public observations
- Value of data
- 100s of catchments / several parameters

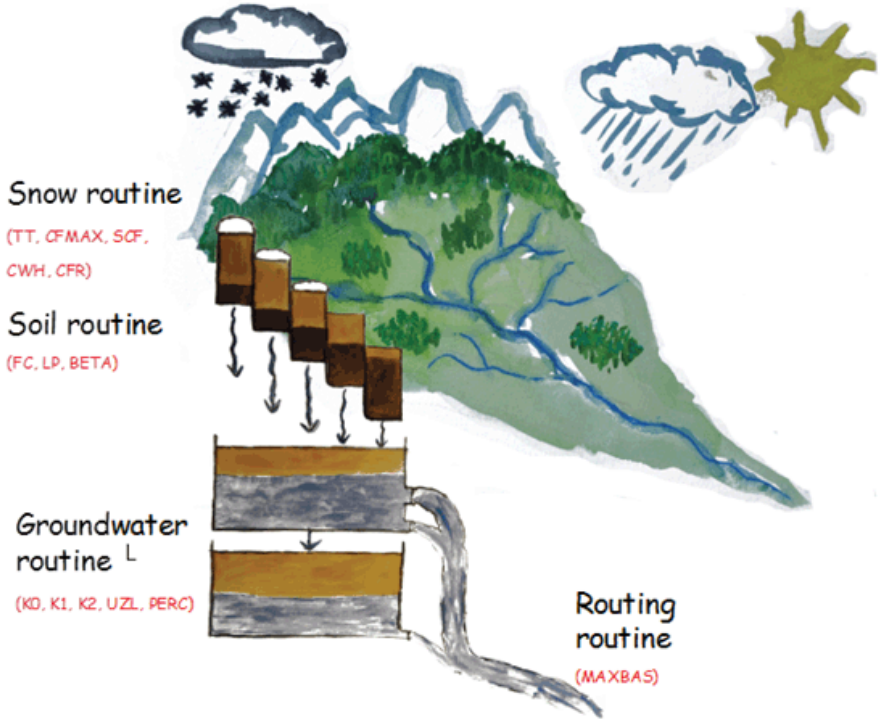
crowd water



From sand columns to catchments







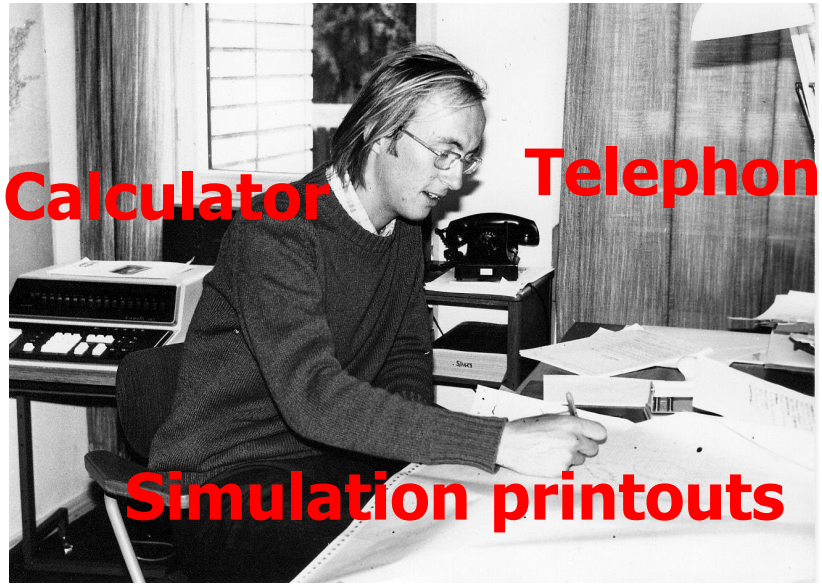
(drawing by Petra Seibert)

Q= -A K dh/dx

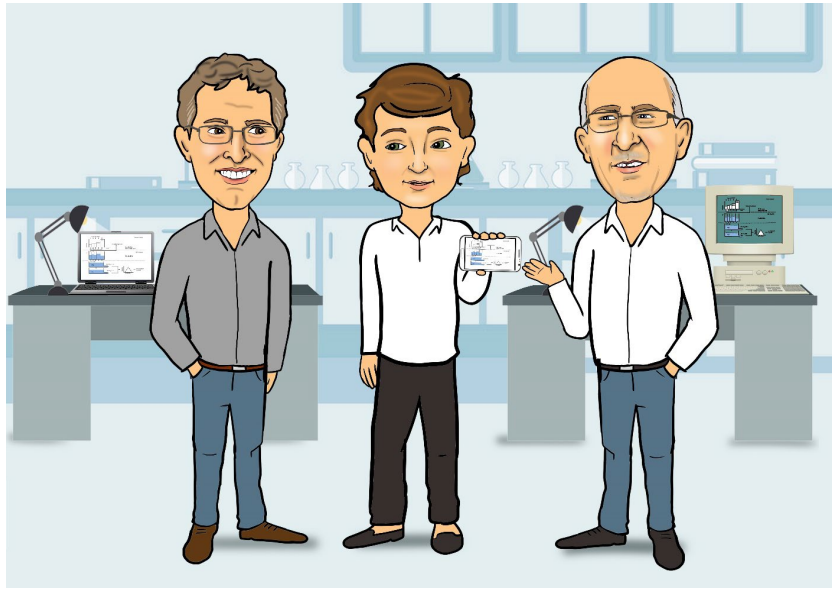
Darcy (1856)

HBV model
Developed by Sten Bergström ~1970
Typical 'bucket-type' model
12-15 parameters

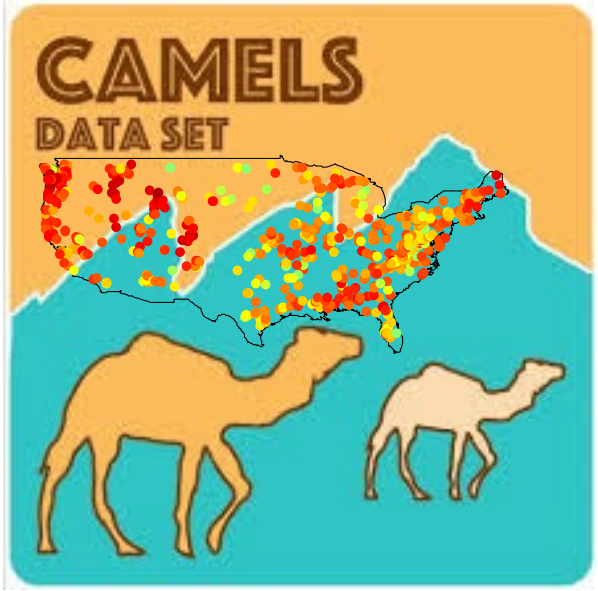
Hydrological modelling continues to change



Picture of Sten Bergström, taken in Stockholm ~1975

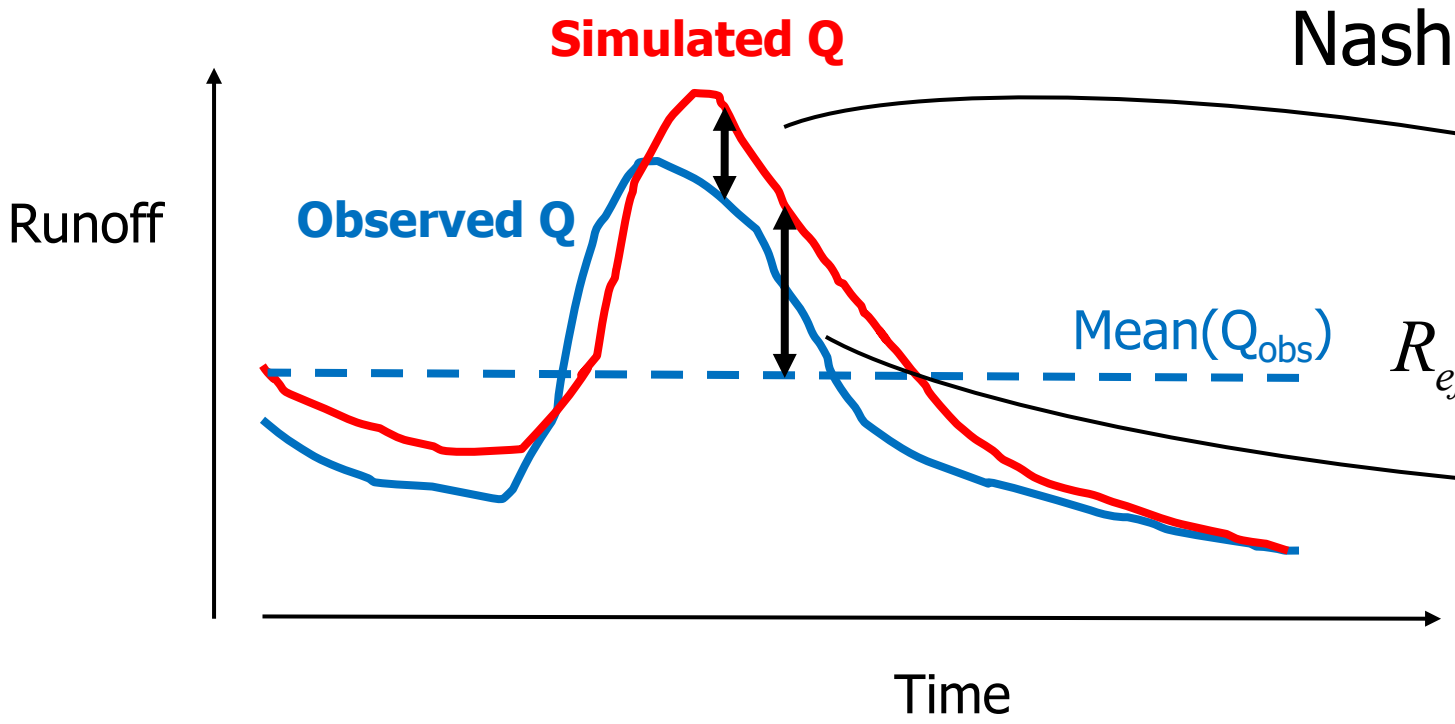


From Seibert and Bergström, 2022, HESS



Newman et al., 2015; Addor et al., 2017

Short note: From NSE to KGE to NPE (non-parametric efficiency)



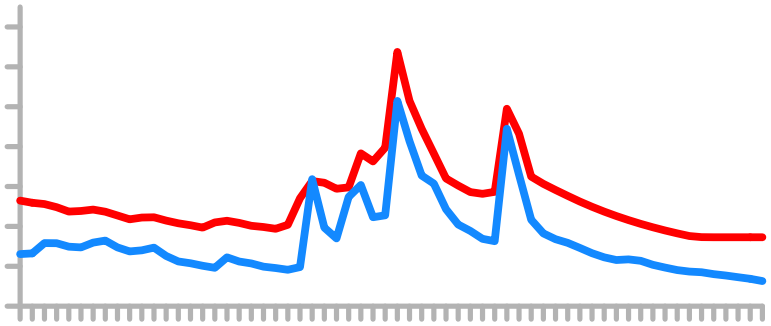
Nash-Sutcliffe Efficiency (NSE)

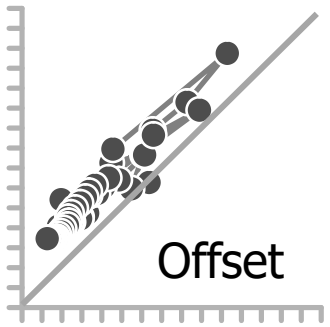
$$R_{eff} = 1 - \frac{\sum (Q_{Sim}(t) - Q_{Obs}(t))^2}{\sum (Q_{Obs}(t) - \overline{Q}_{Obs})^2}$$

Nash & Sutcliffe (1970)

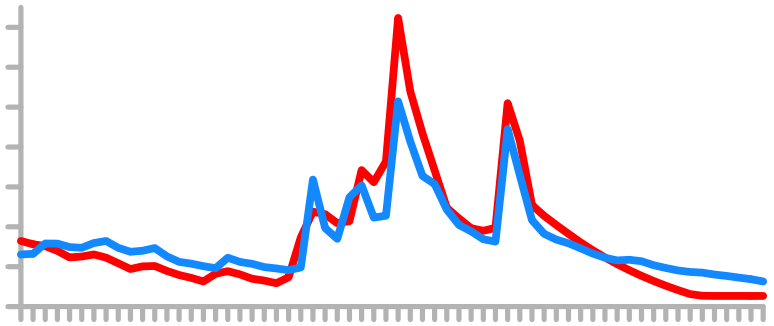
Short note: From NSE to KGE to NPE (non-parametric efficiency)

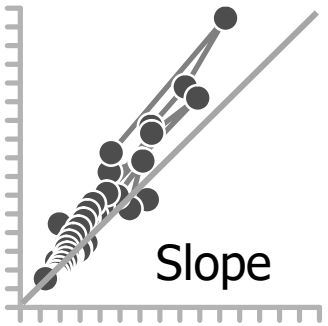
Mean



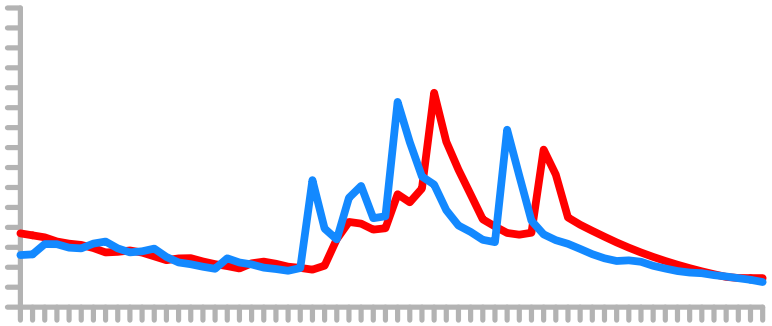


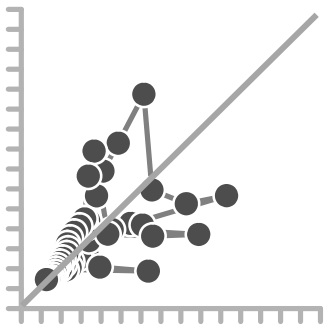
Variation





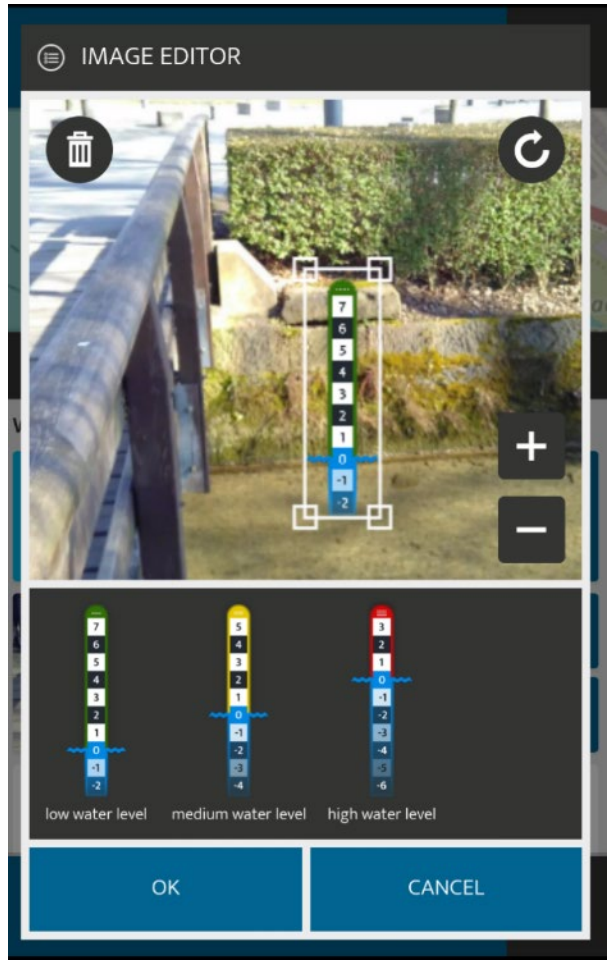
Timing





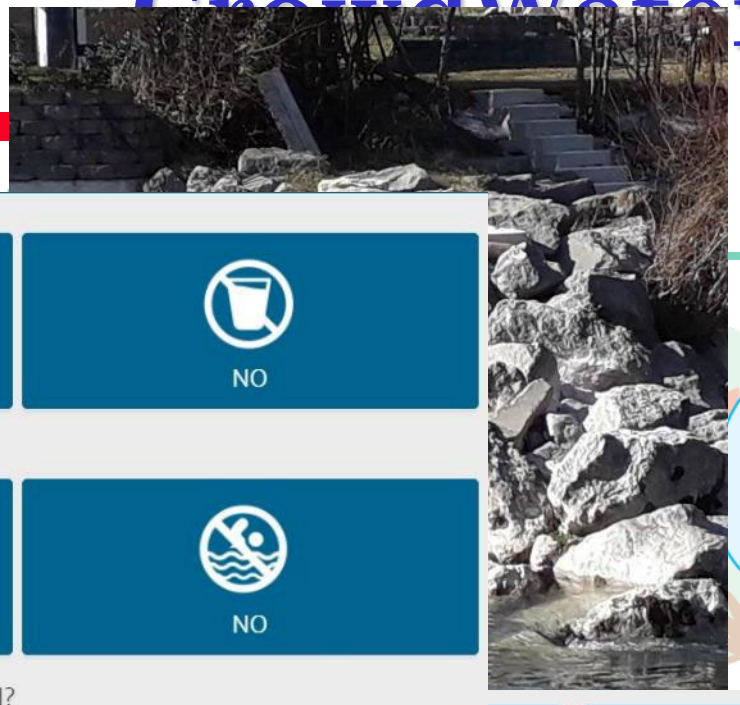
KGE	NPE
Mean	Mean
Standard deviation	Flow duration curve (normalized)
Pearson correlation	Spearman rank correlation
Gupta et al., 2009, JoH; Gupta and Kling, 2011, WRR	*Pool et al., 2018, HSJ*

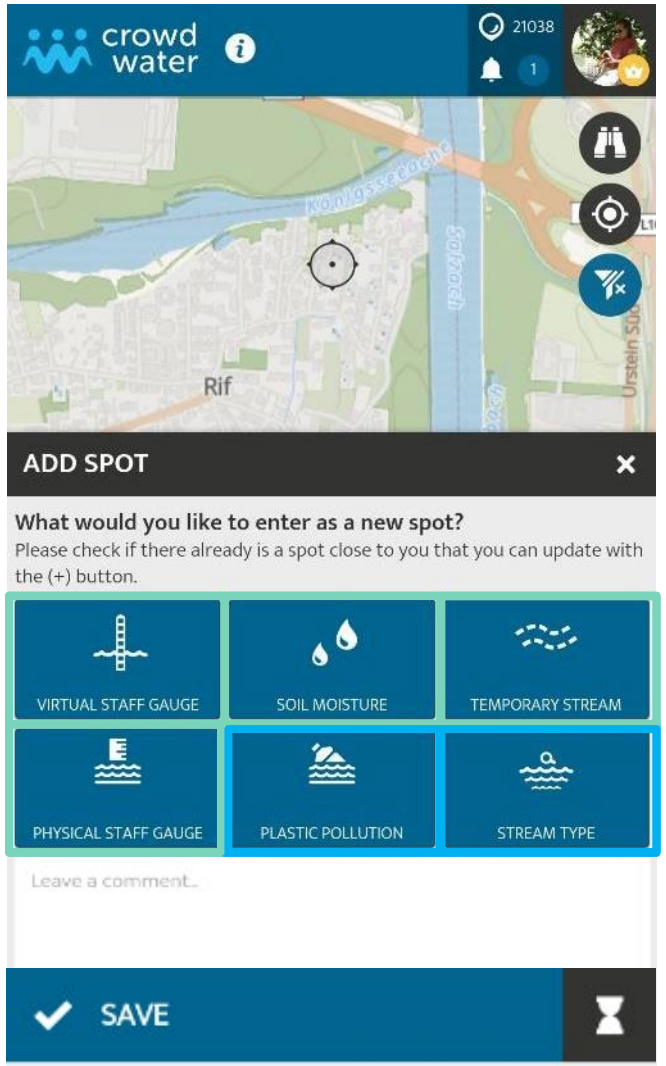
Public observations in CrowdWater: Water level classes

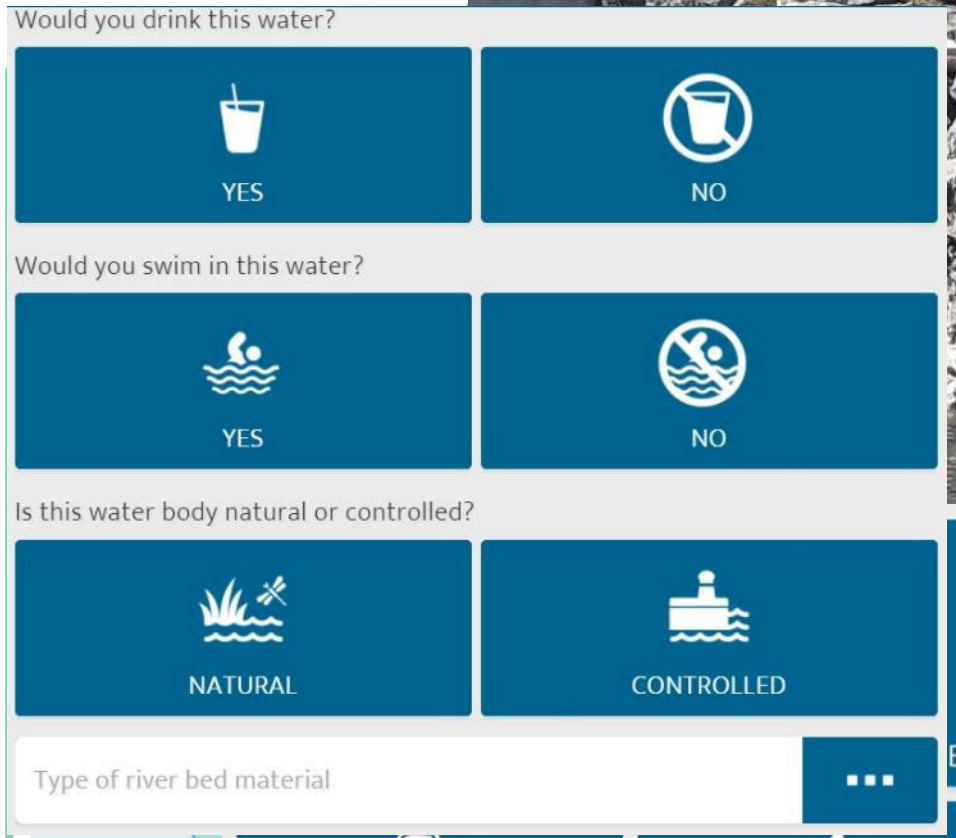


Seibert et al., 2019, Frontiers

CrowdWater App





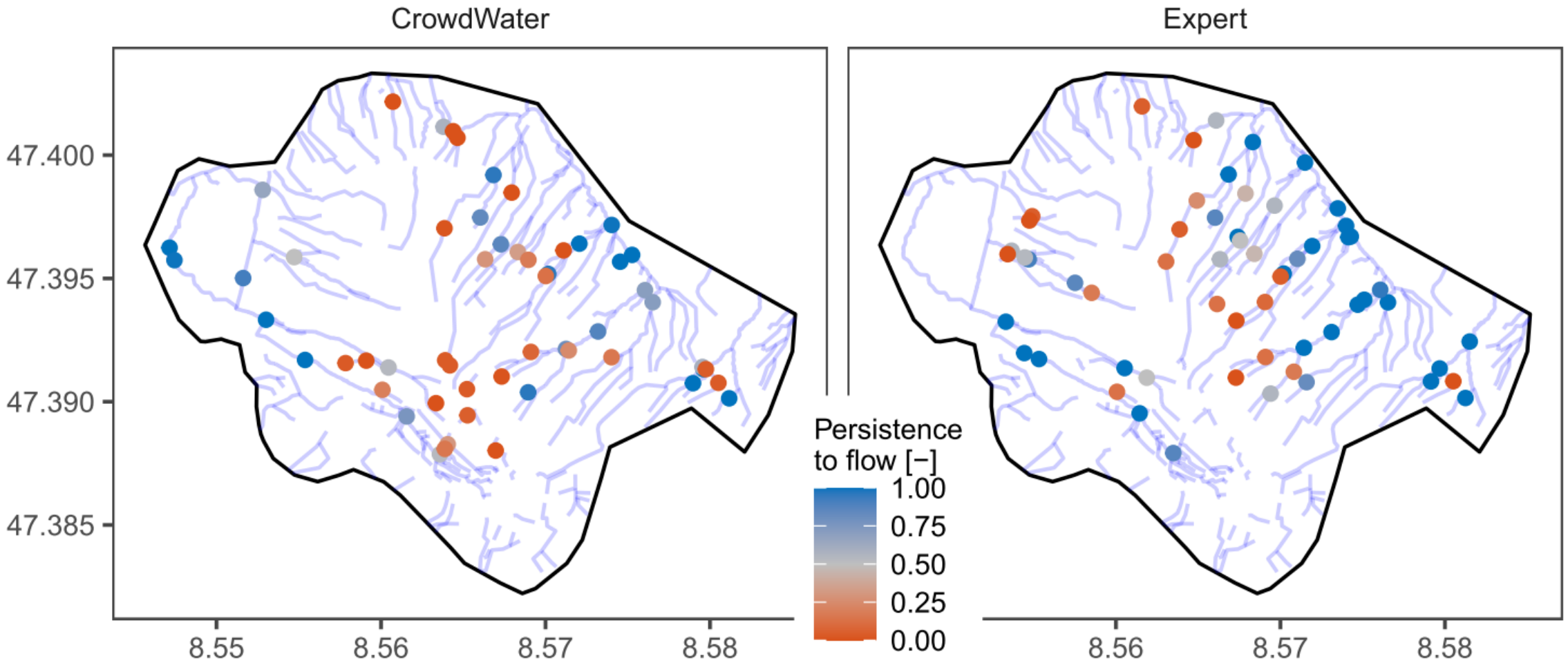


CONDITION OF THE WATER?

Temporary streams

Data: https://www.spotteron.com/crowdwater/spots/280547

Temporary streams: 'Public' vs. 'Expert'



Scheller et al., in review

More info on CrowdWater

CrowdWater App

Download on the App Store

GET IT ON Google Play

www.crowdwater.ch

Social media

@crowd_water

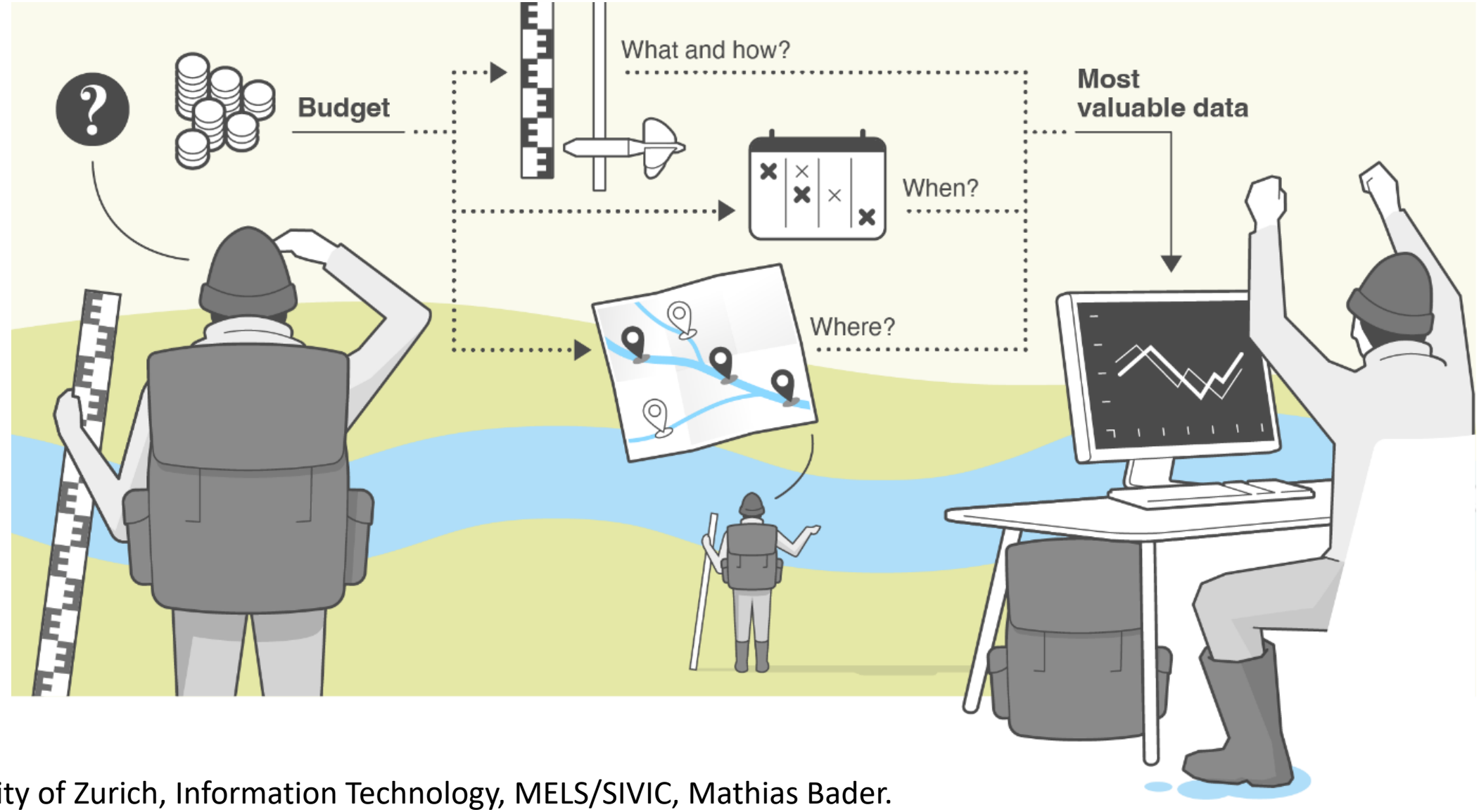
@crowdwater

CrowdWater Channel

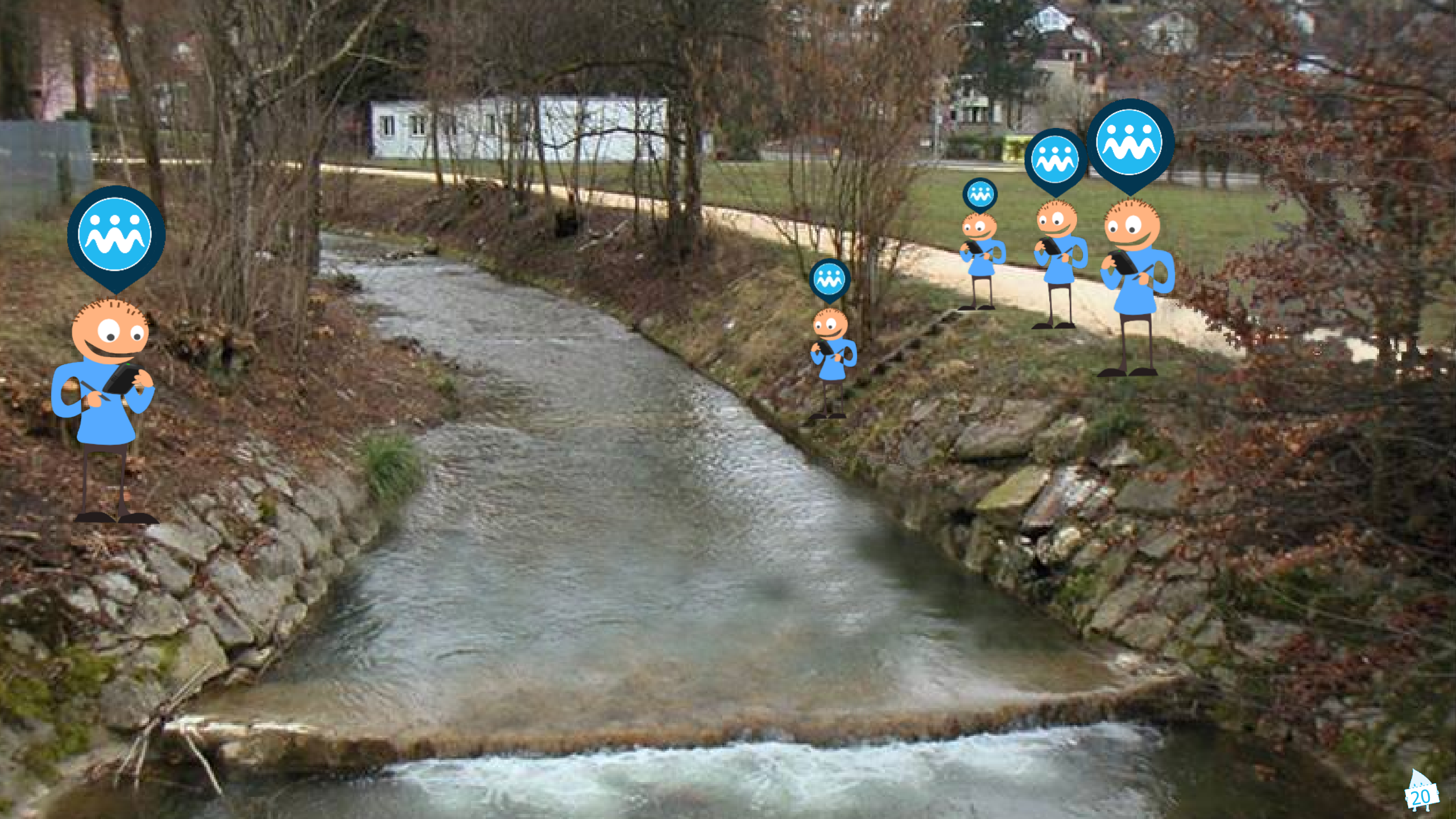
crowdwater.bsky.social

crowd water

Value of data – what to measure when and where?

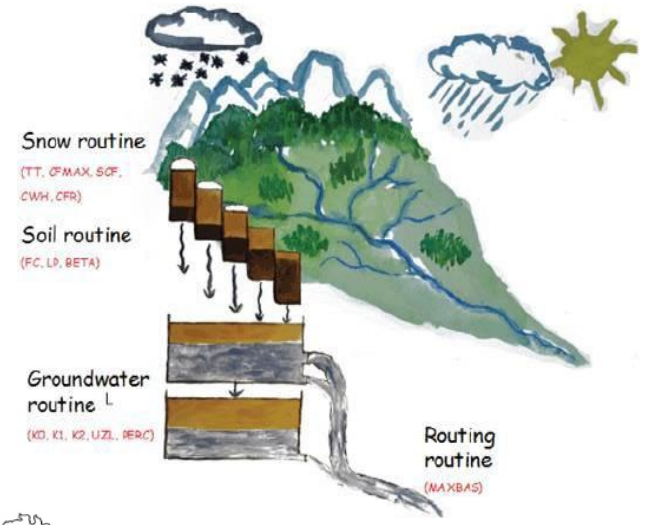


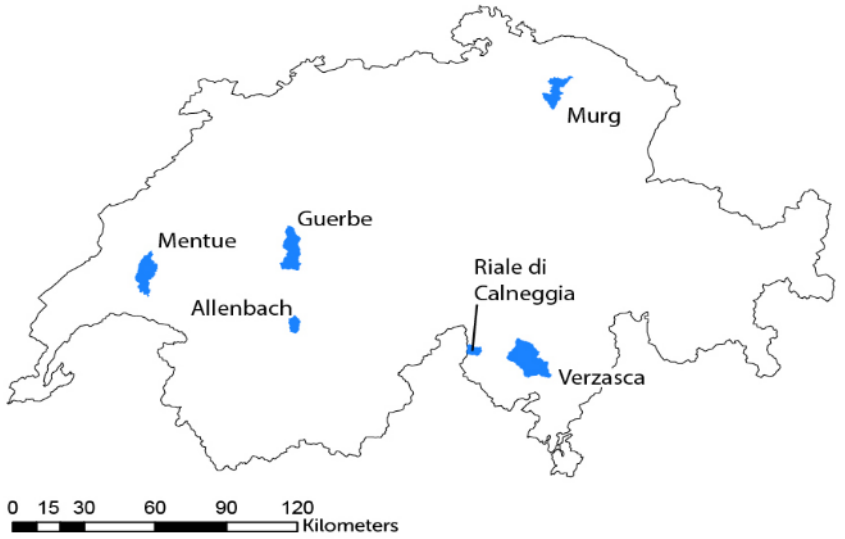
Seibert et al., 2024, HP



Value of citizen science observations

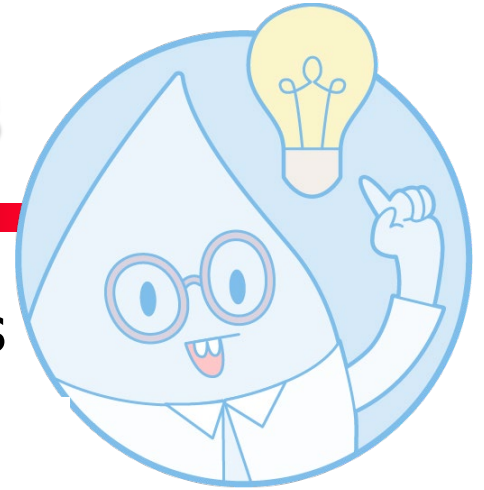
- HBV model
- Six catchments in Switzerland
- Calibration on synthetic citizen science data
  - Different temporal resolution of data
  - Different (random) error magnitudes
- Validate on observed streamflow for a different year



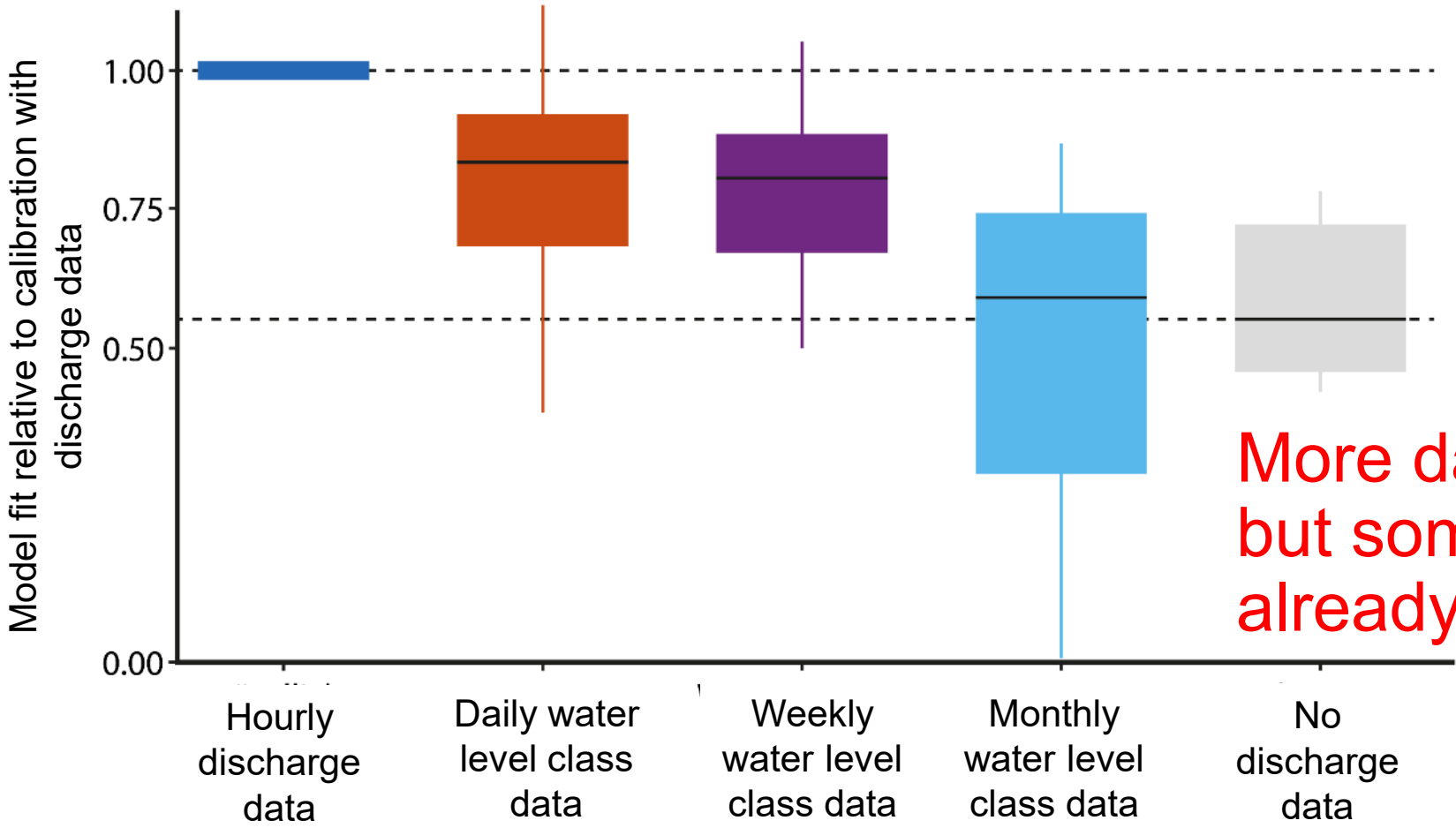


Etter et al., 2018, 2020

Value level data as collected by citizens



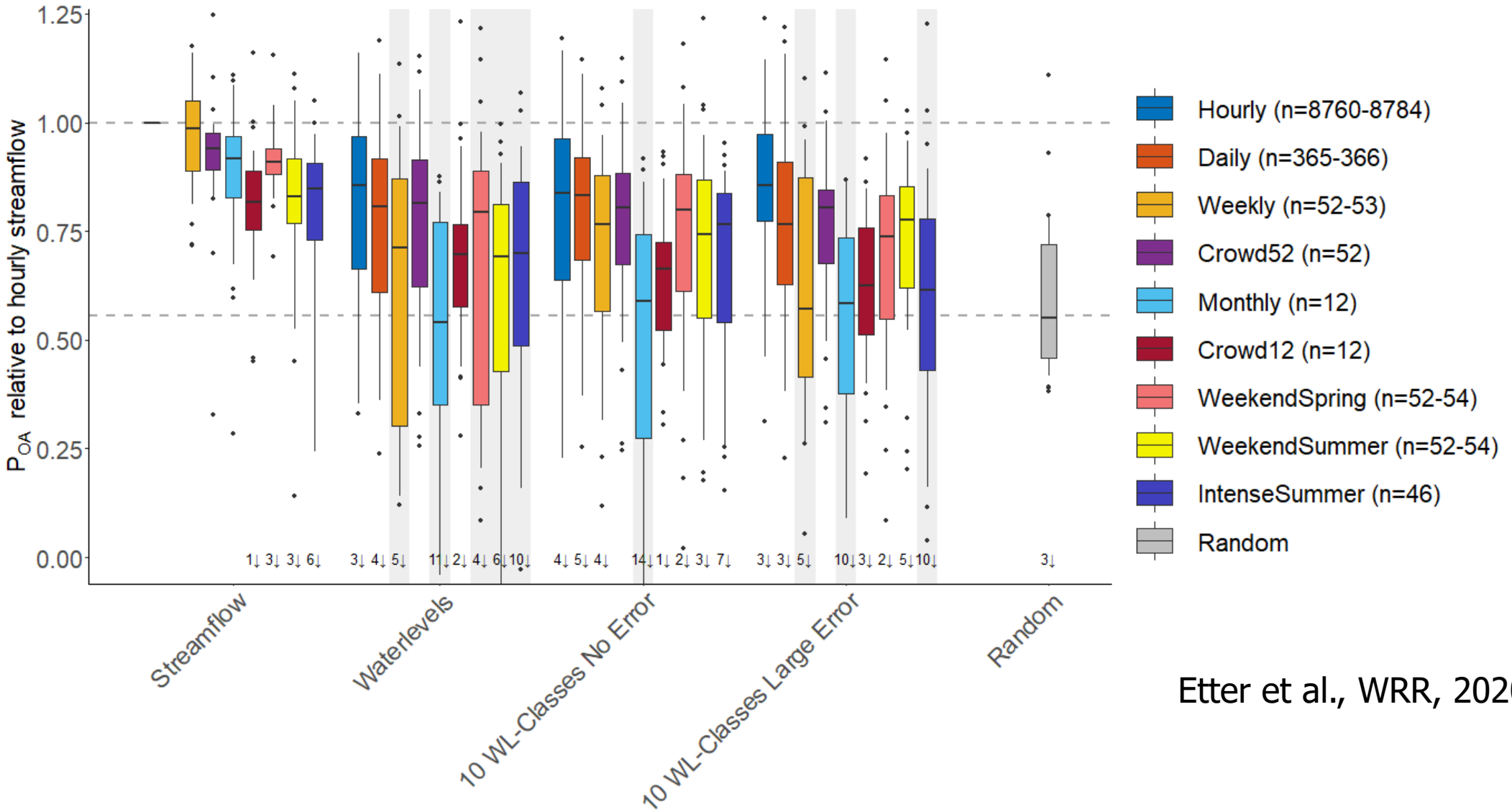
Test with different frequencies and errors for six Swiss catchments



More data is better but some data is already good! ☺

Etter et al. 2020, WRR

Value of water level class data by citizens in more detail

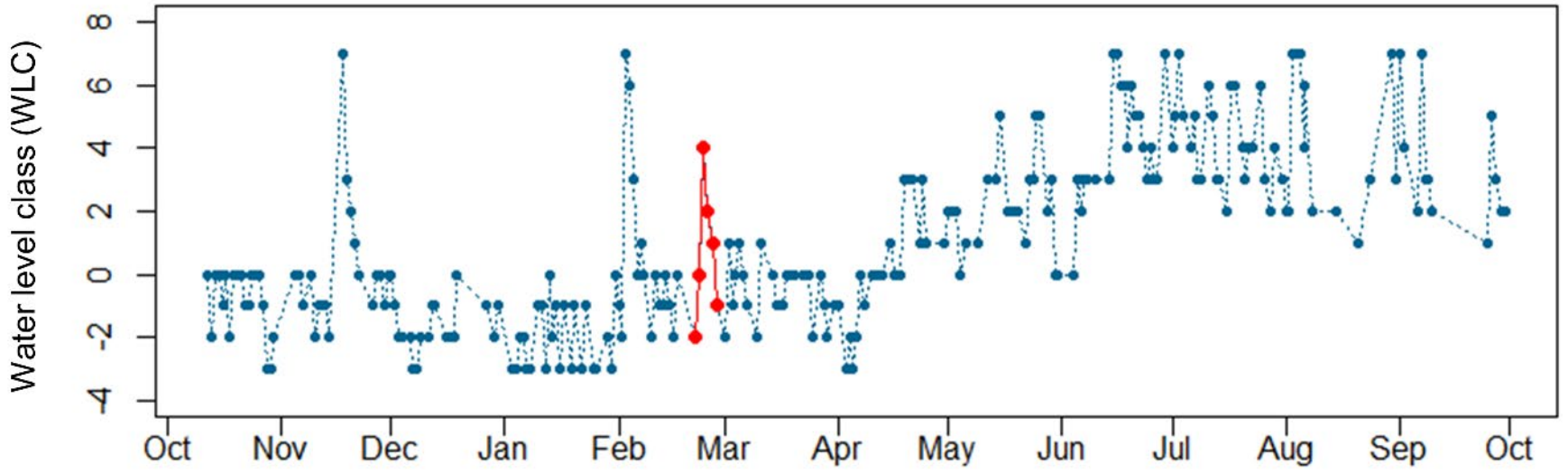


Etter et al., WRR, 2020

Calibration of a model with ‘real’ water level class data

Reference image 17.08.18 | 22.02.20 | 23.02.20 | 24.02.20 | 25.02.20 | 27.02.20 | 28.02.20

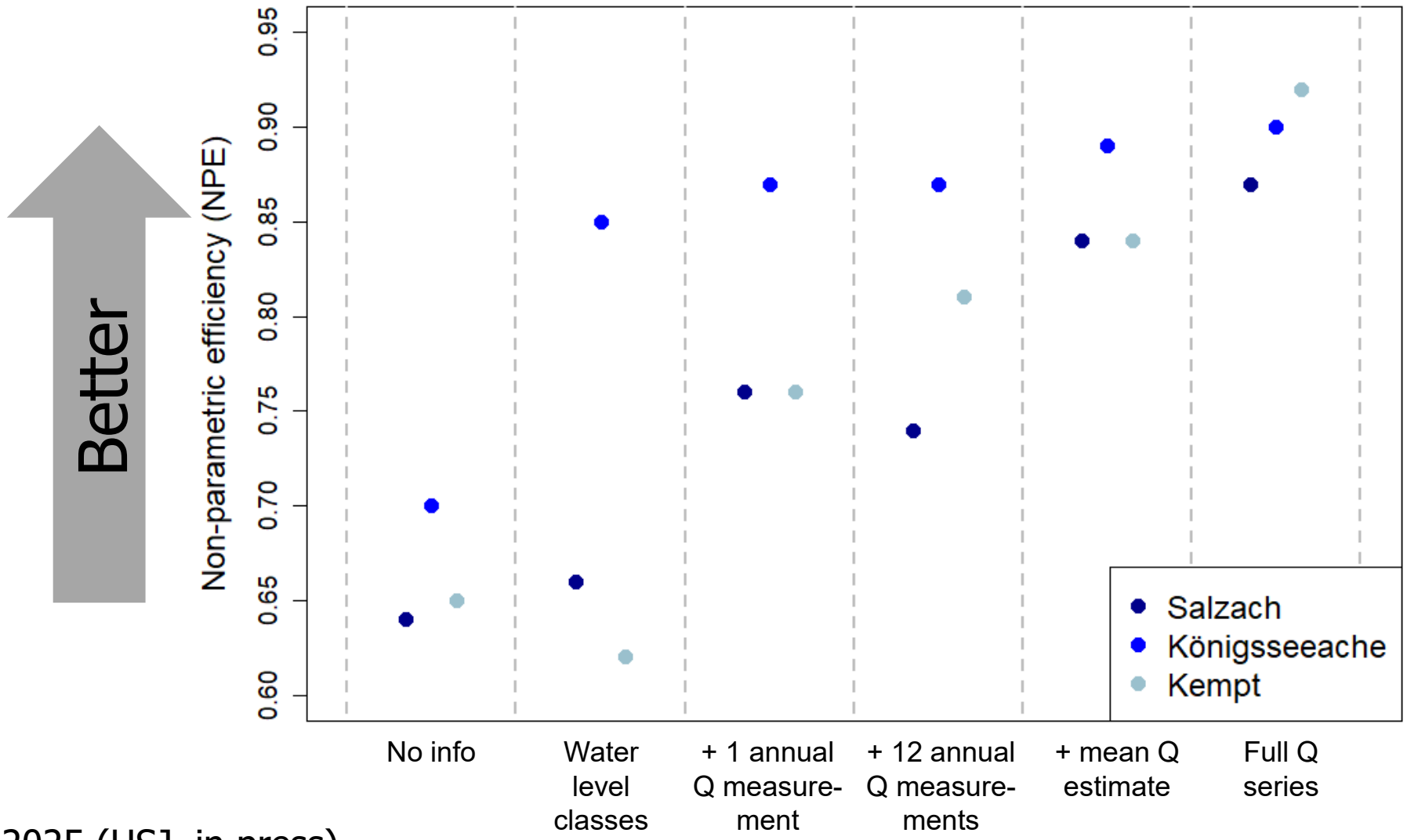
(b)



Clerc-Schwarzenbach et al., 2025 (HSJ, in press)

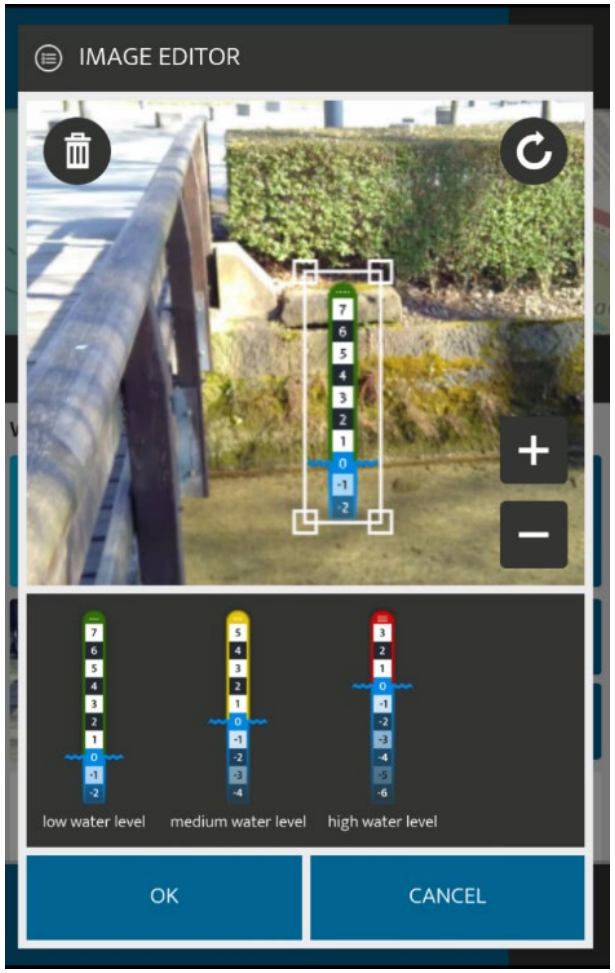
Calibration of a model with 'real' water level class data

Value of water level class data and additional information related to flow magnitudes?



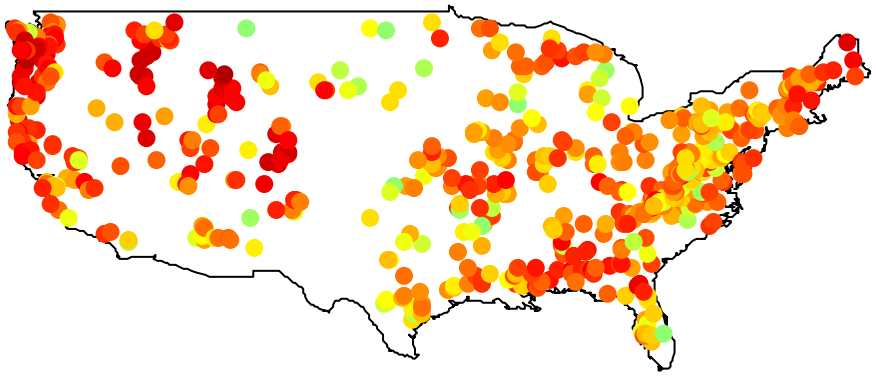
Clerc-Schwarzenbach et al., 2025 (HSJ, in press)

Value of water level data?

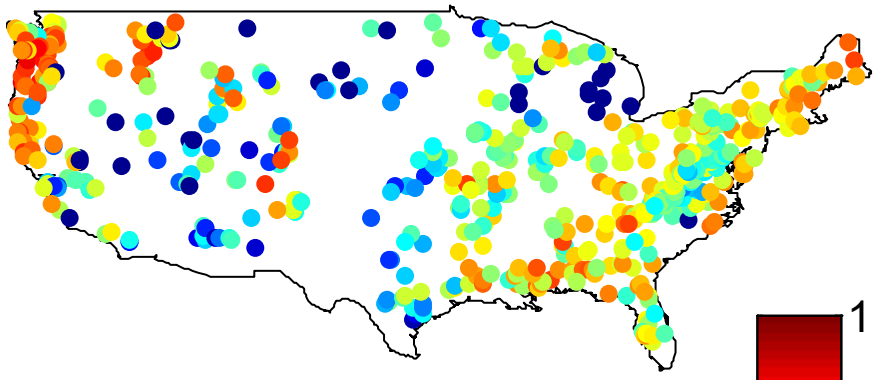


Model performance (R_{eff} for flow)
Calibration period

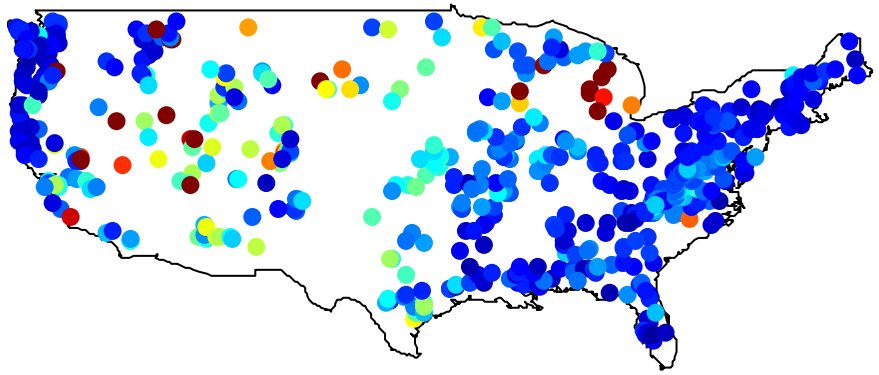
Calibrated using flow

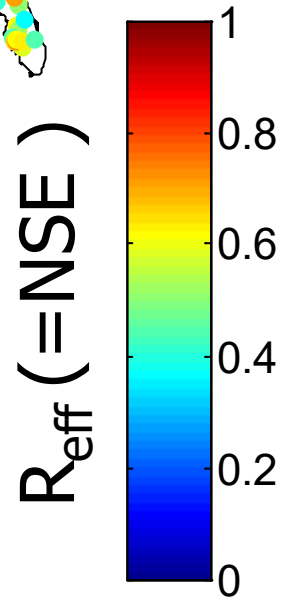


Calibrated using levels



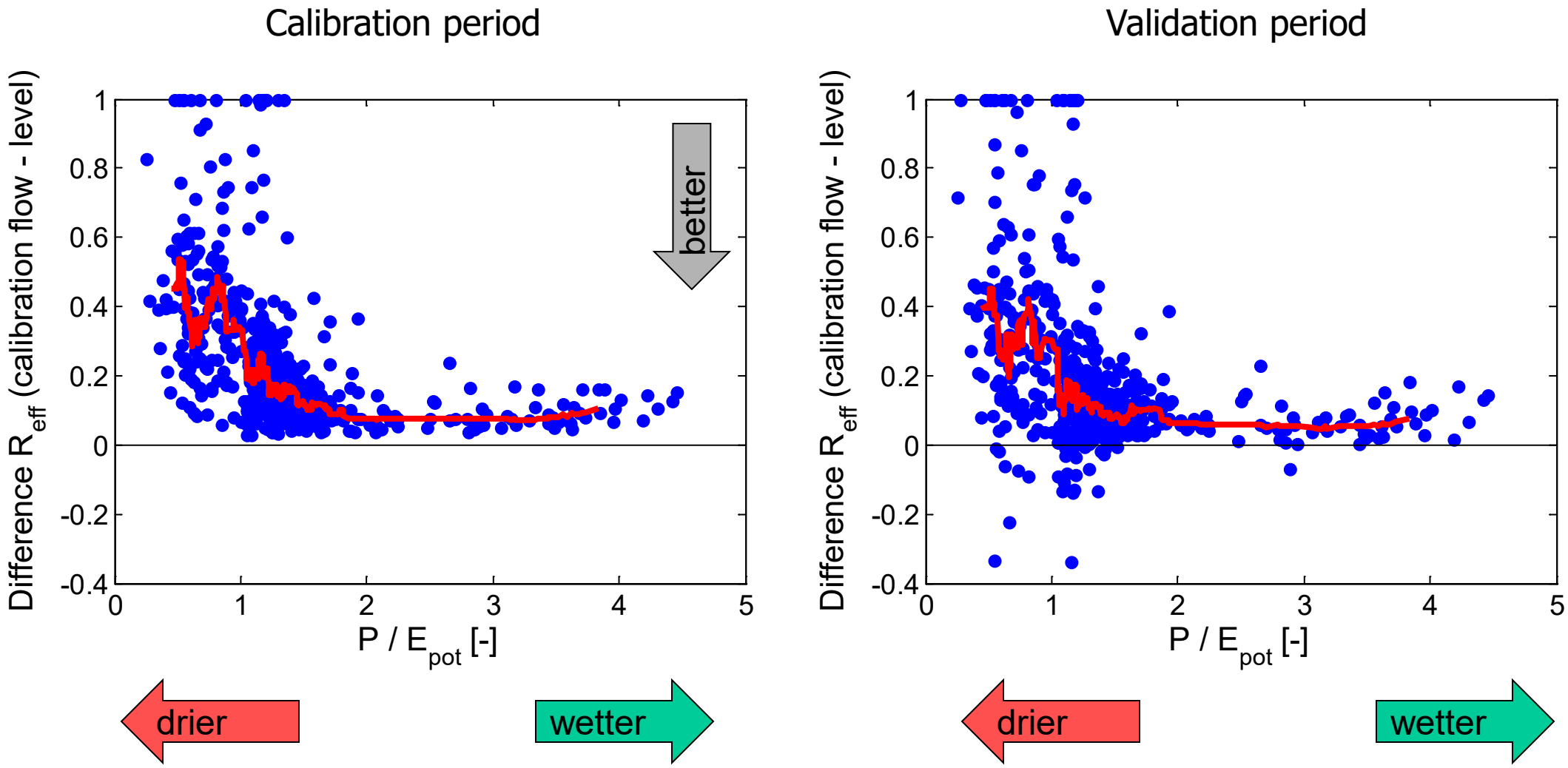
Difference





Seibert & Vis, 2016, HP

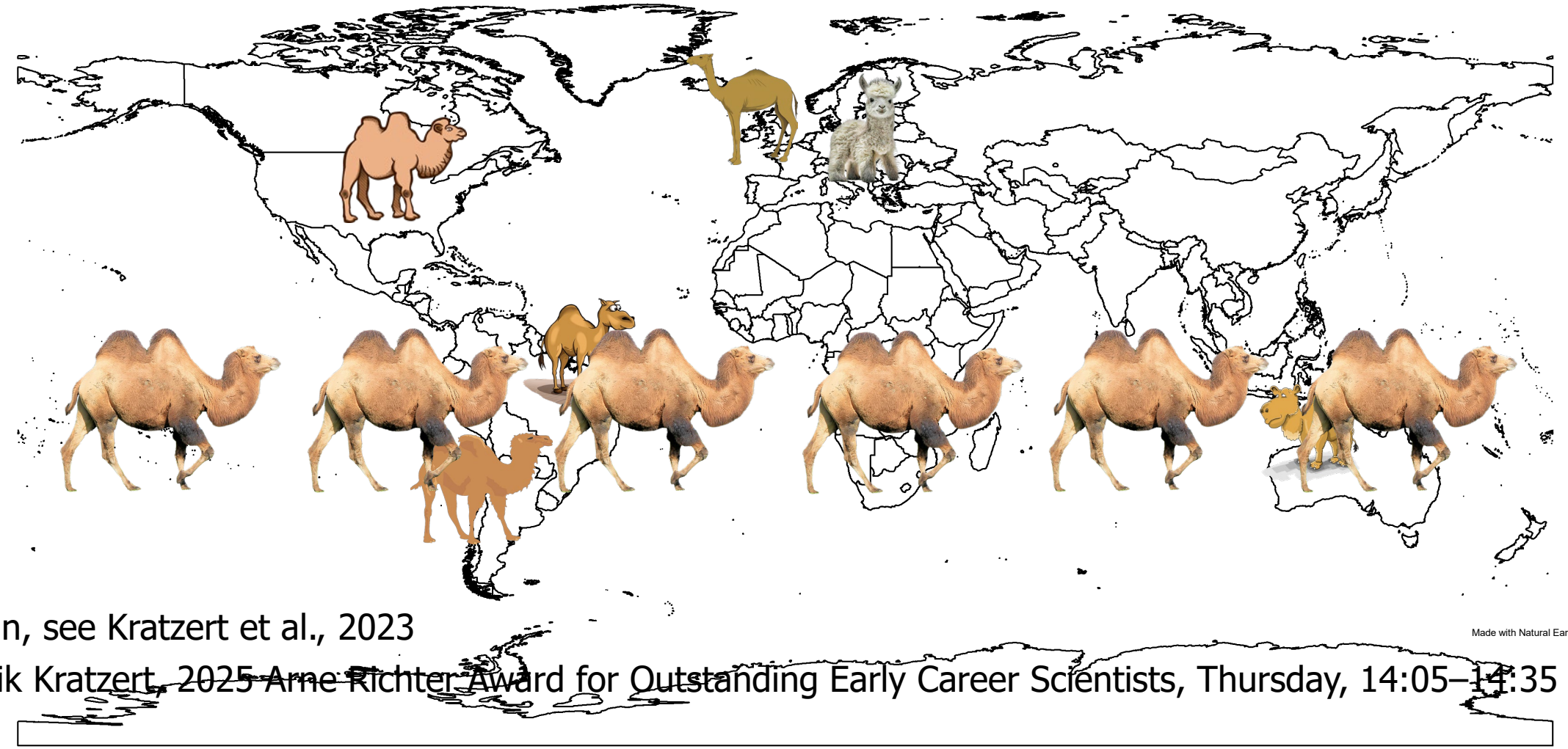
Performance difference versus aridity (precipitation / potential evaporation)



Seibert & Vis, 2016, HP

Red line: running median, window 21 catchments

CAMELS and Caravan



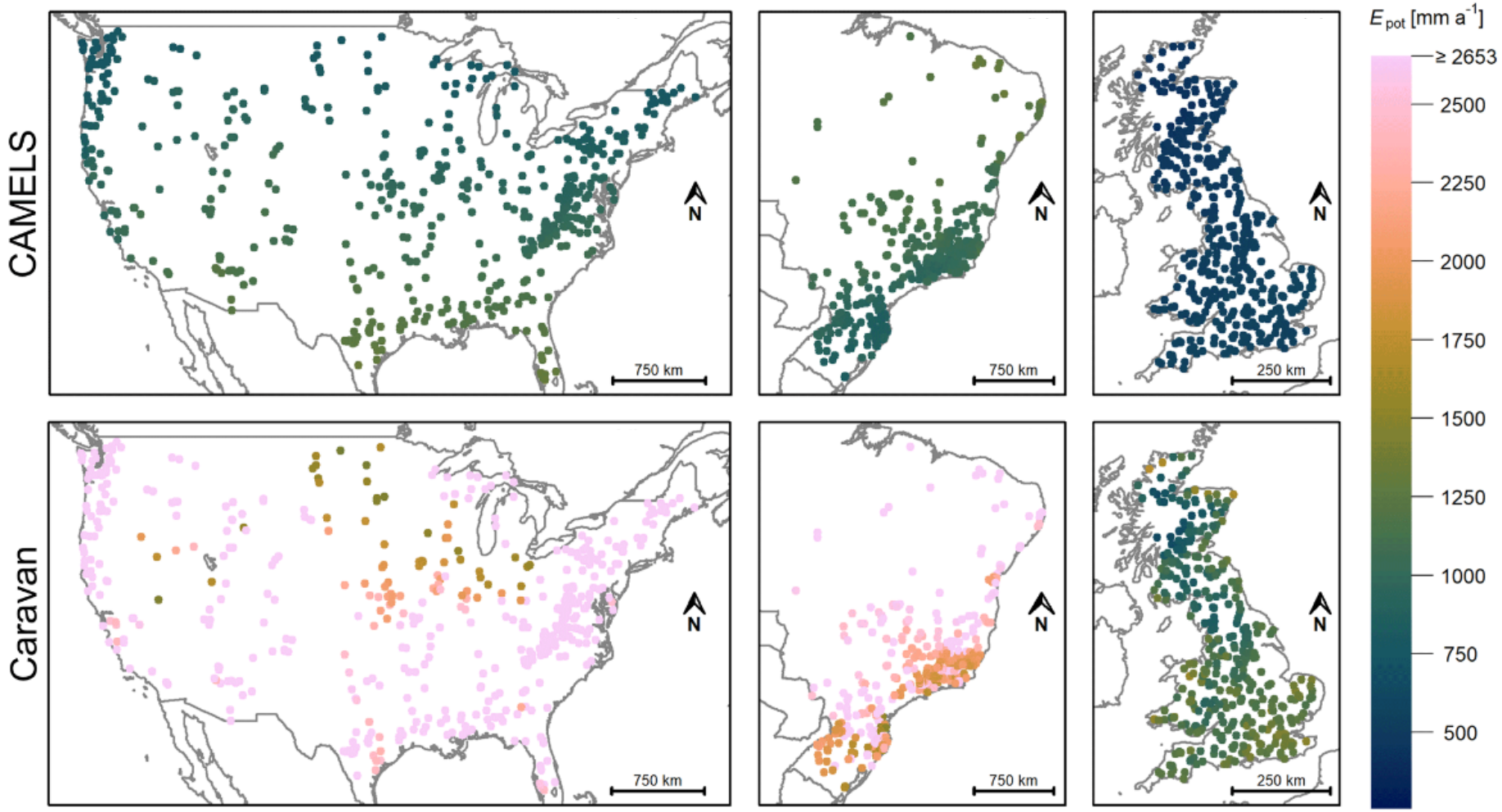
Caravan, see Kratzert et al., 2023

Frederik Kratzert, 2025 Arne Richter Award for Outstanding Early Career Scientists, Thursday, 14:05–14:35

E_{pot} in CAMELS and Caravan

ERA5-Land E_{pot}-values in Caravan too high

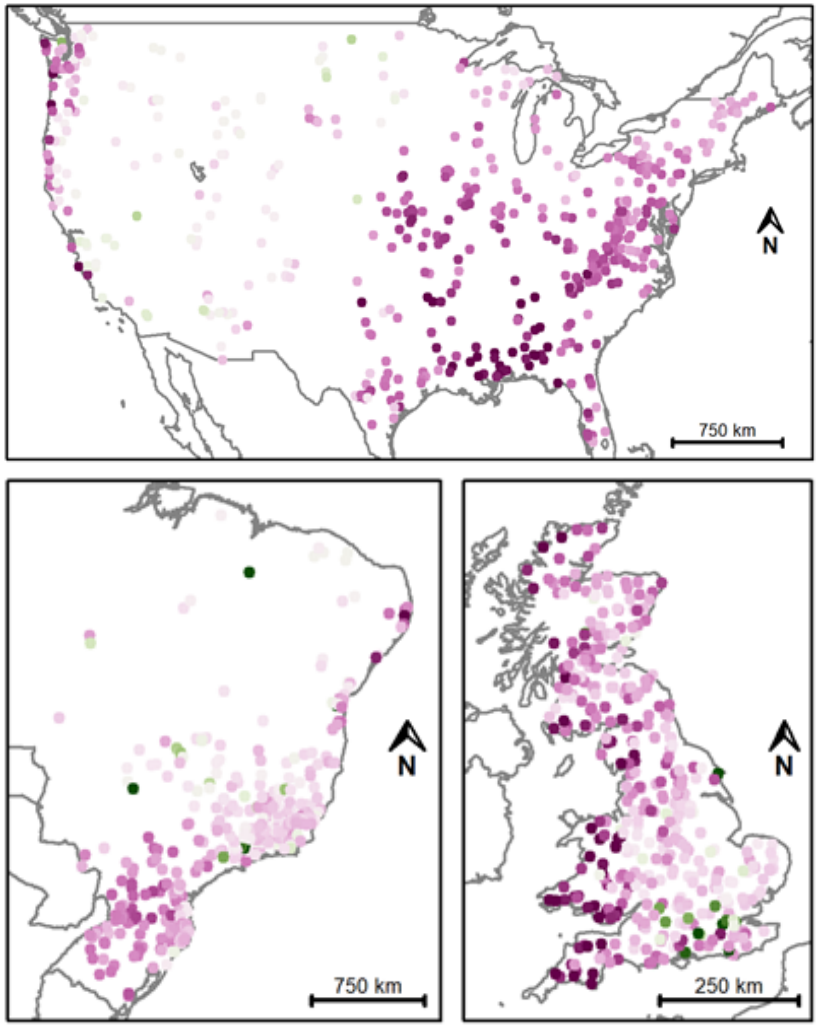
(alternative E_{pot}-values added in new Caravan version)

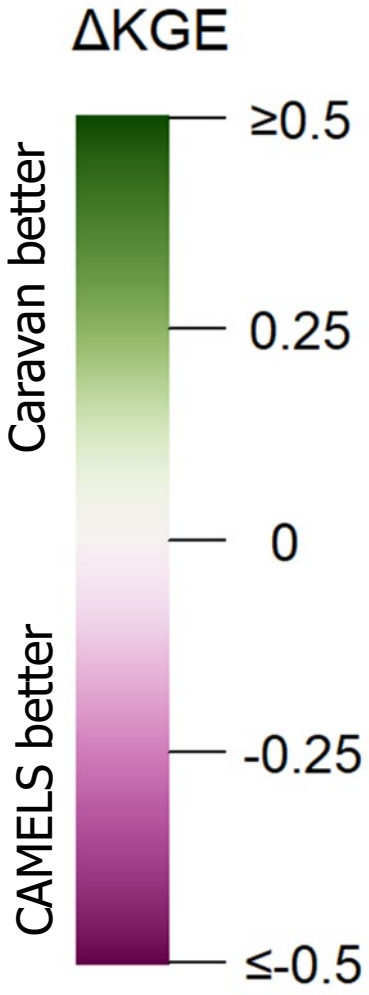


Clerc-Schwarzenbach et al., 2024, HESS

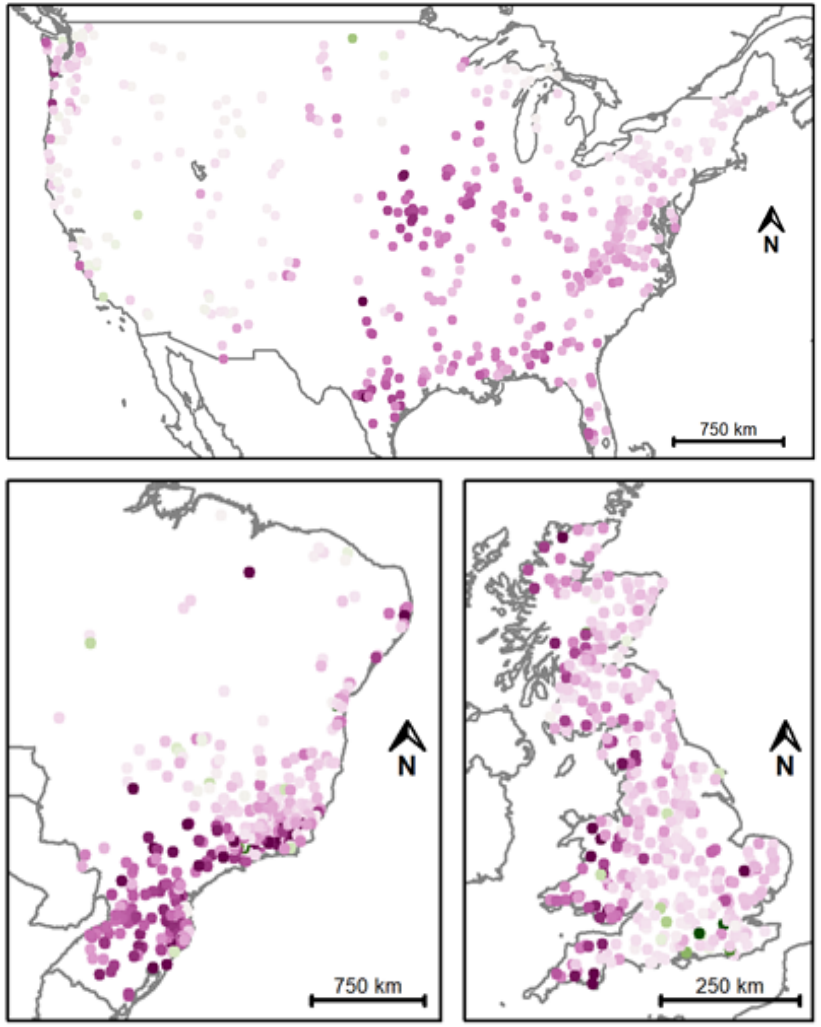
Model performance comparison Caravan-CAMELS

All data from Caravan



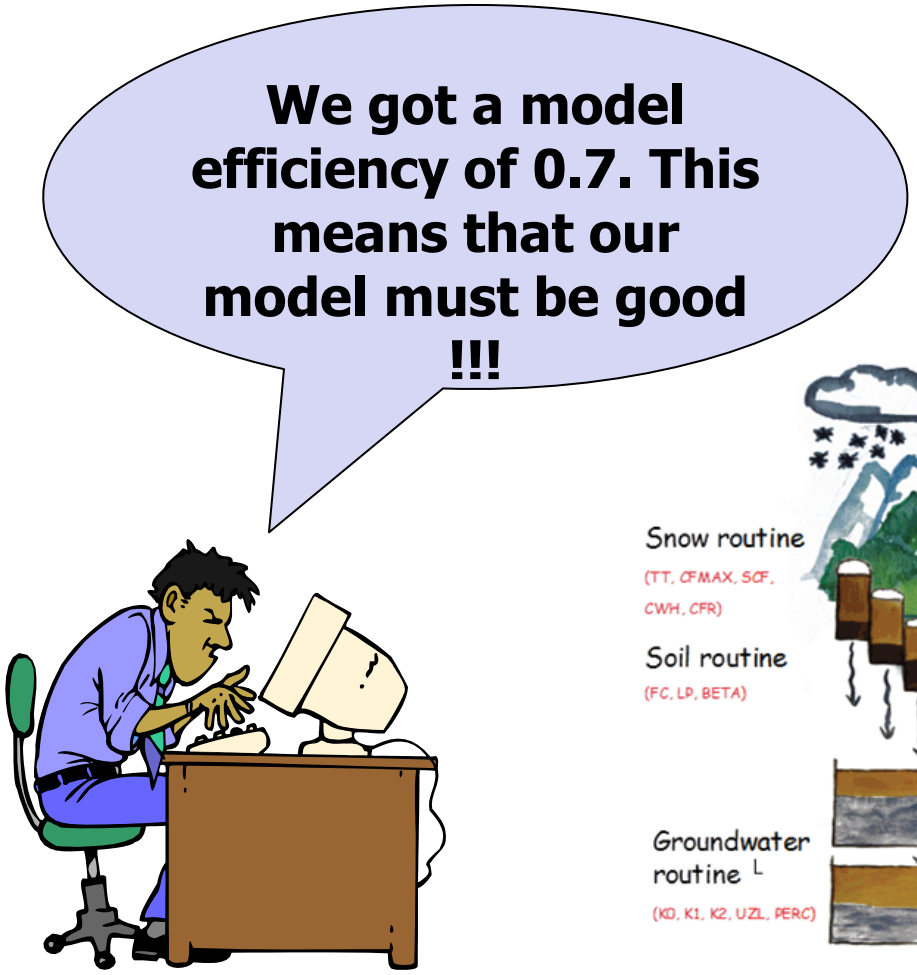


Only precipitation from Caravan

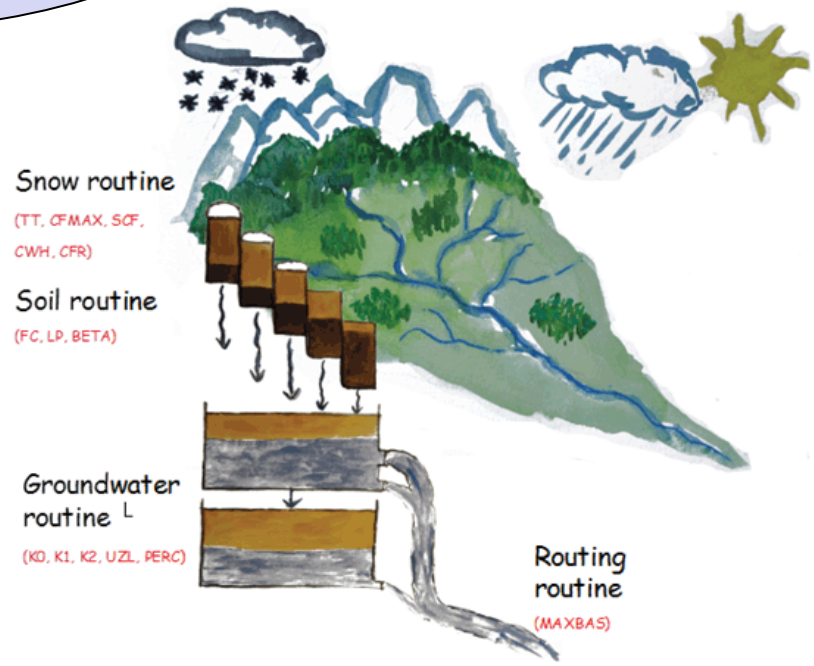


Clerc-Schwarzenbach et al., 2024, HESS

Upper and lower benchmarks



Seibert et al., 2018, HP



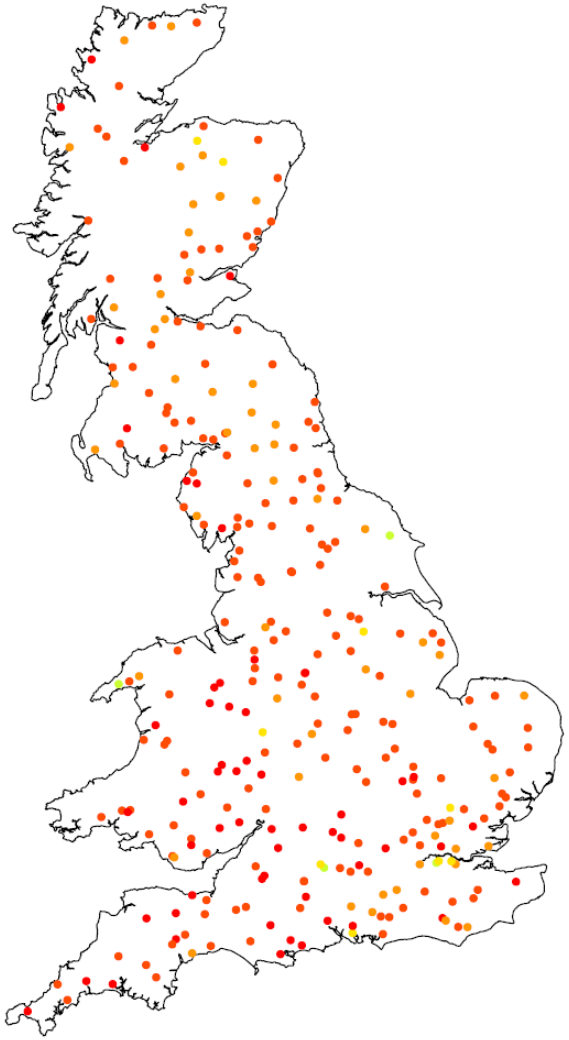
HBV model (drawing by Petra Seibert)

Parameter values

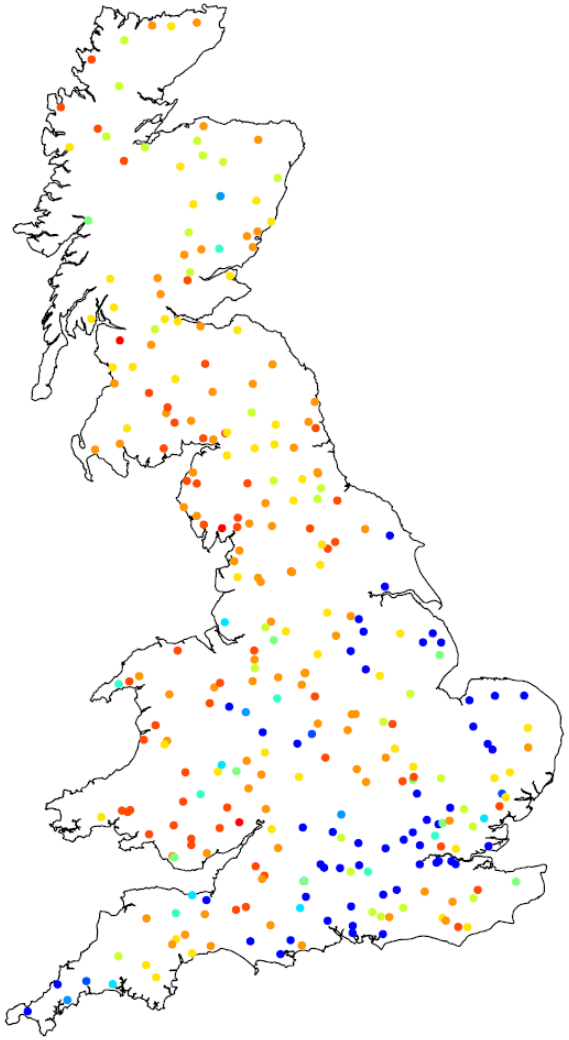
P, T, E_{pot}

Simulated runoff

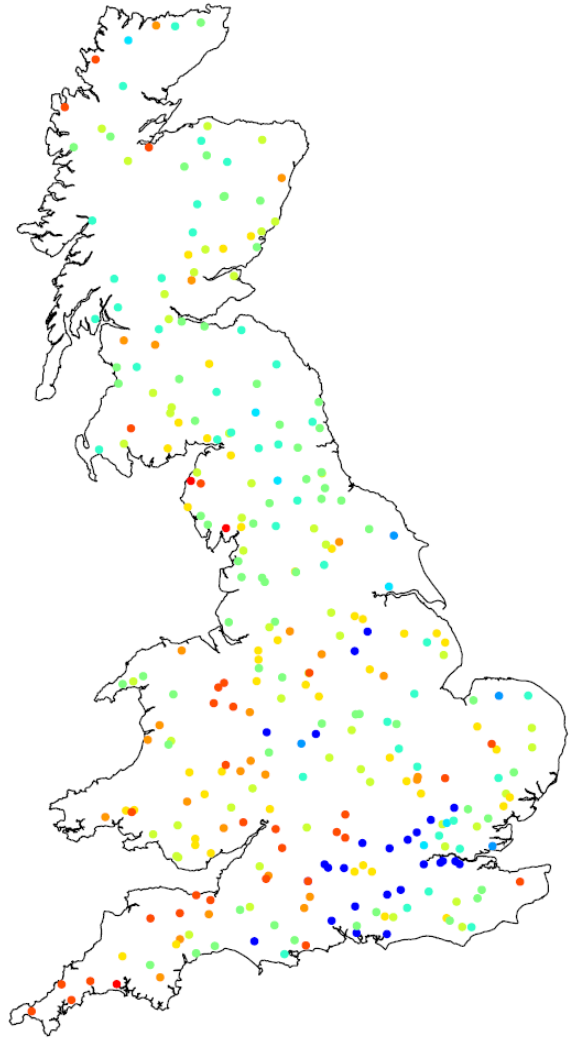
SHETRAN and benchmarks



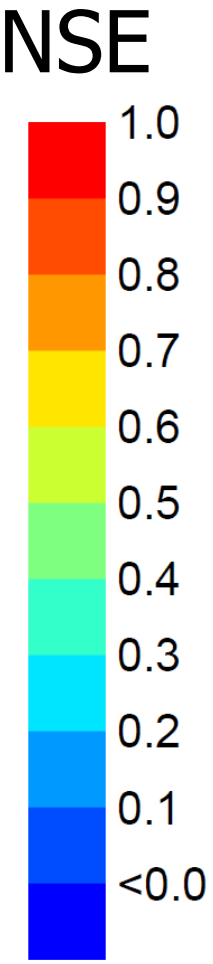
Upper benchmark



SHETRAN



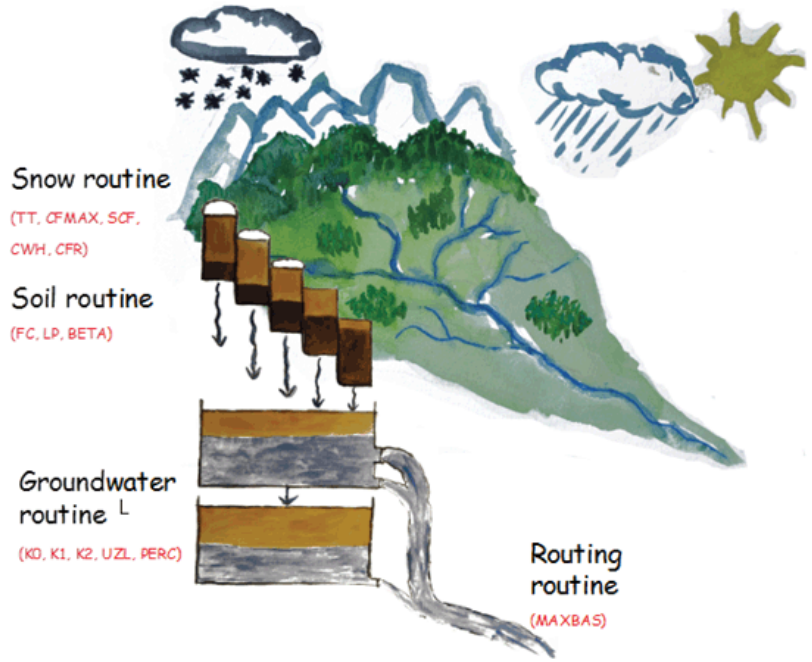
Lower benchmark (random)



Seibert et al., 2018, HP

Computing lower benchmarks

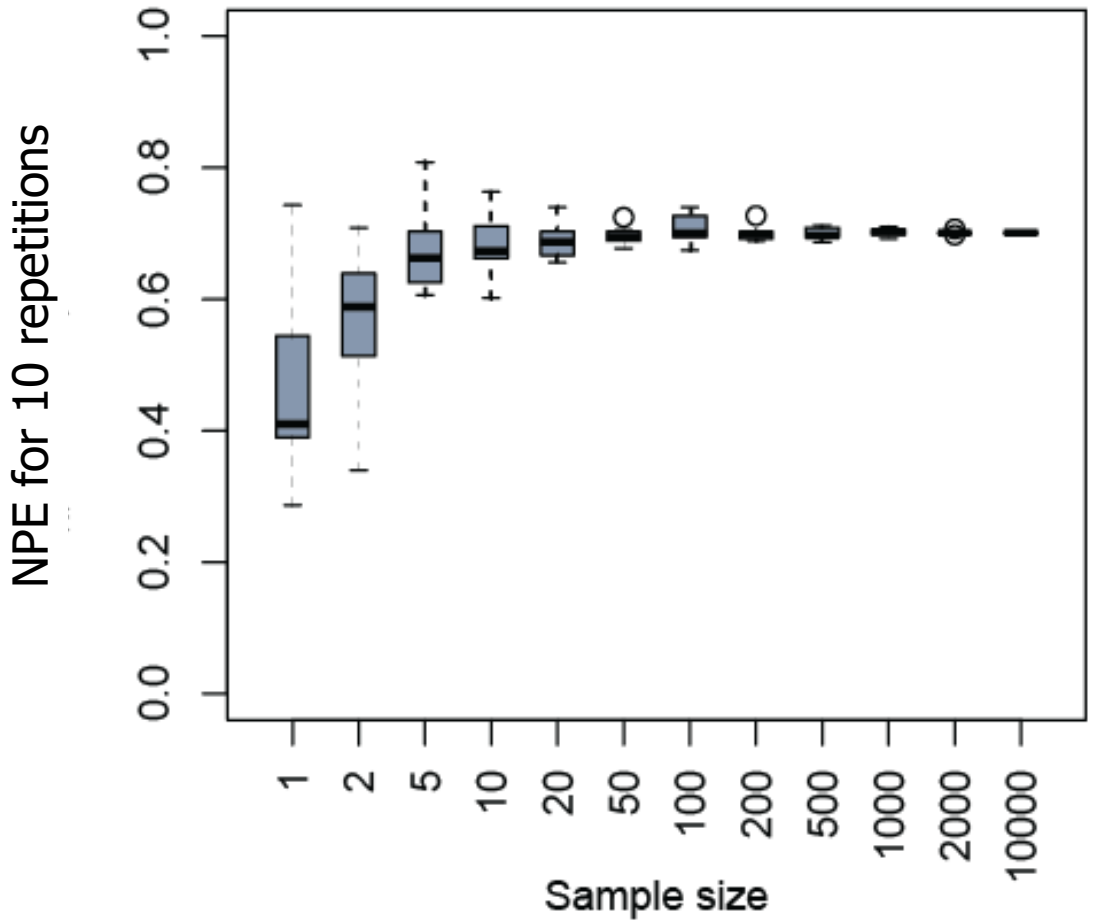
- X random parameter sets
- X time series of simulated runoff
- Aggregate the X series to 1 ensemble mean time series
- **What is a suitable number for X?**

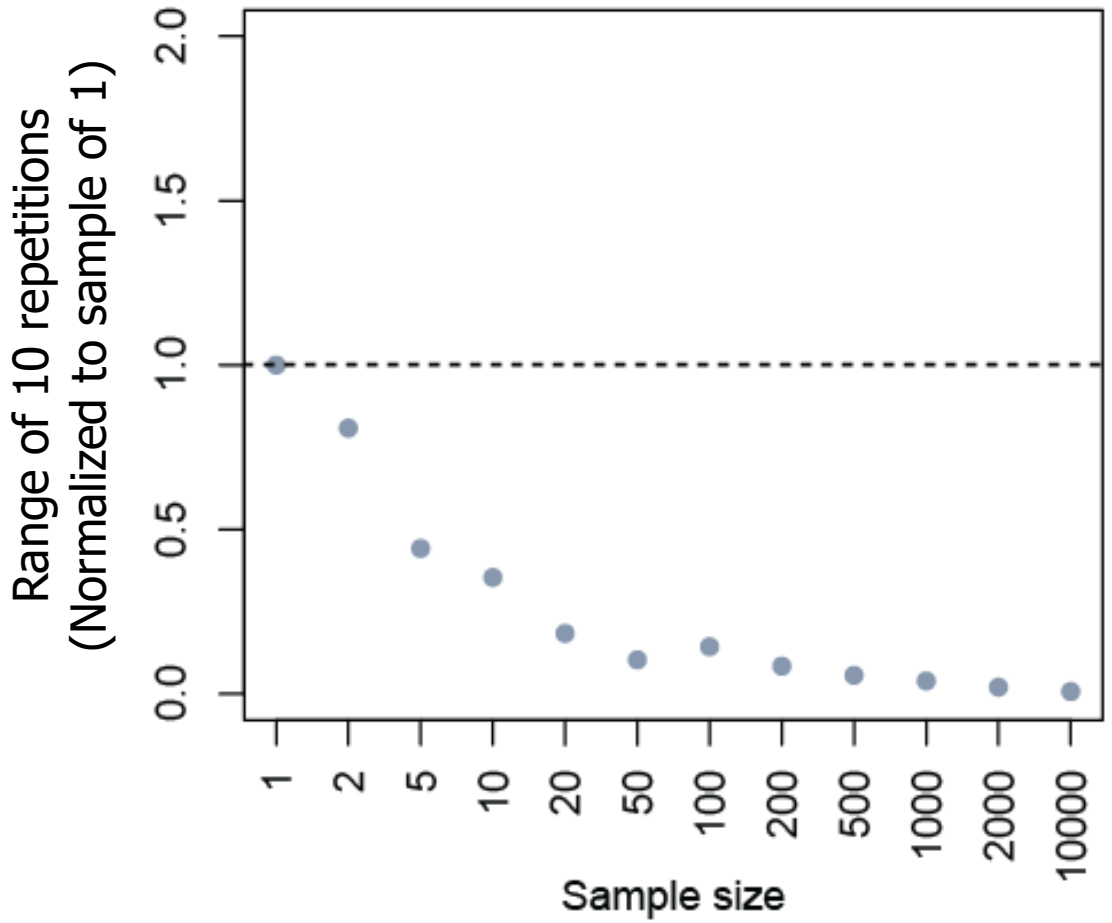


HBV model (drawing by Petra Seibert)

Seibert, Vis, Pool, in progress

How large should the ensemble be?

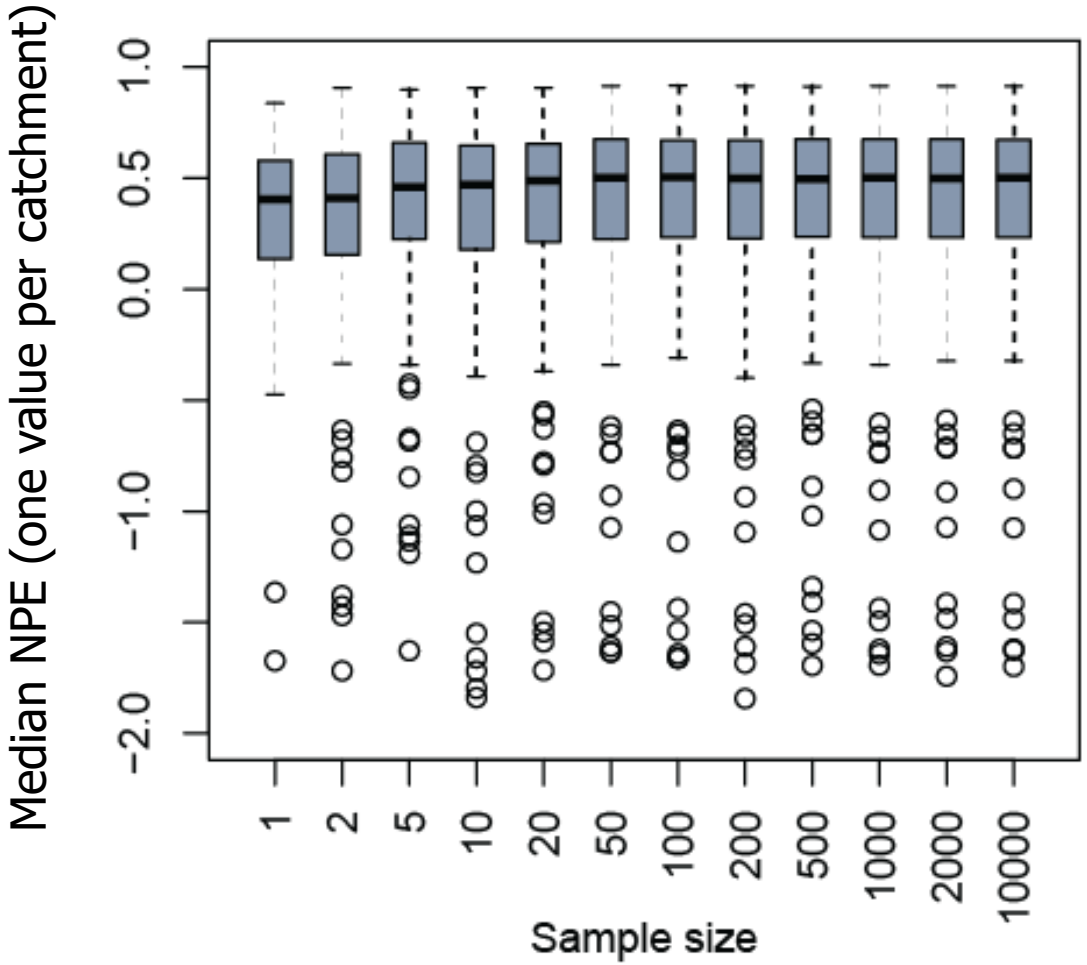


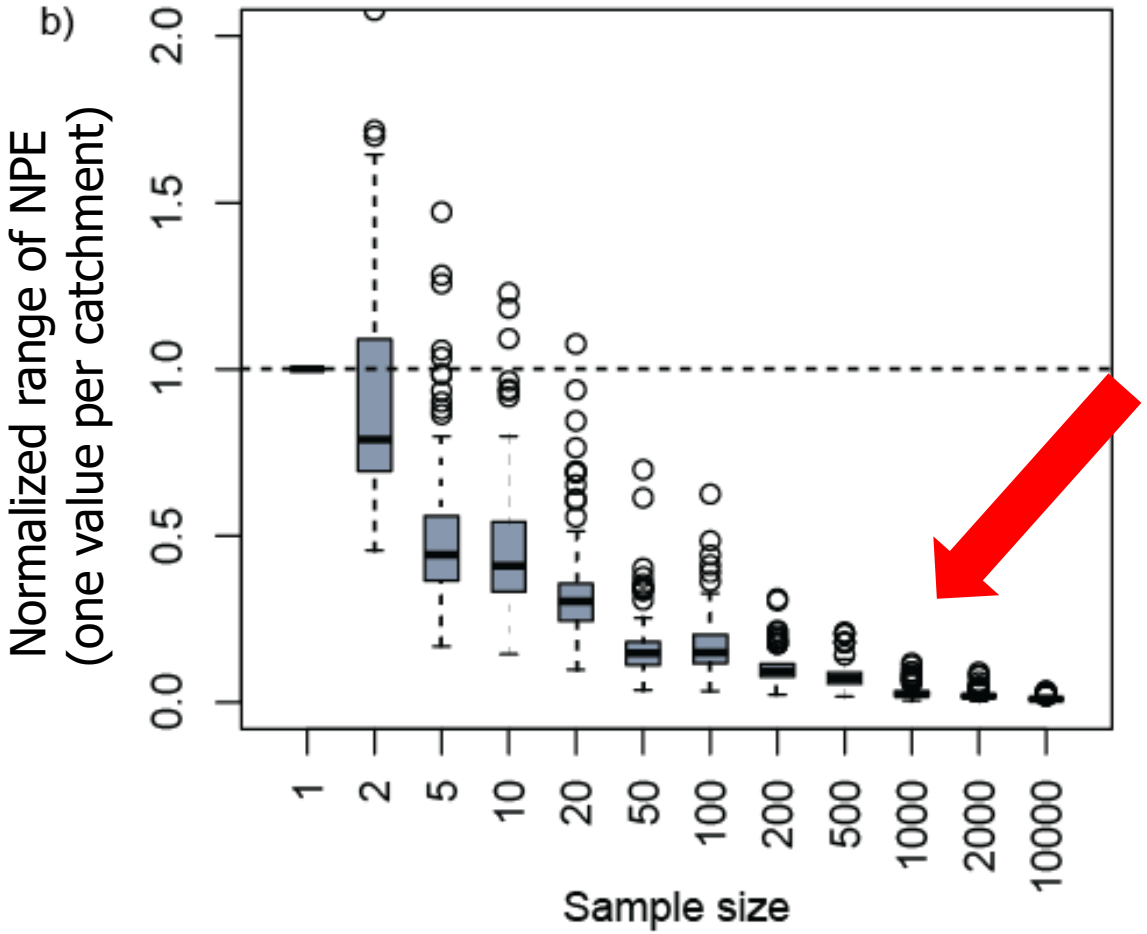


Example for one catchment

Seibert, Vis, Pool, in progress

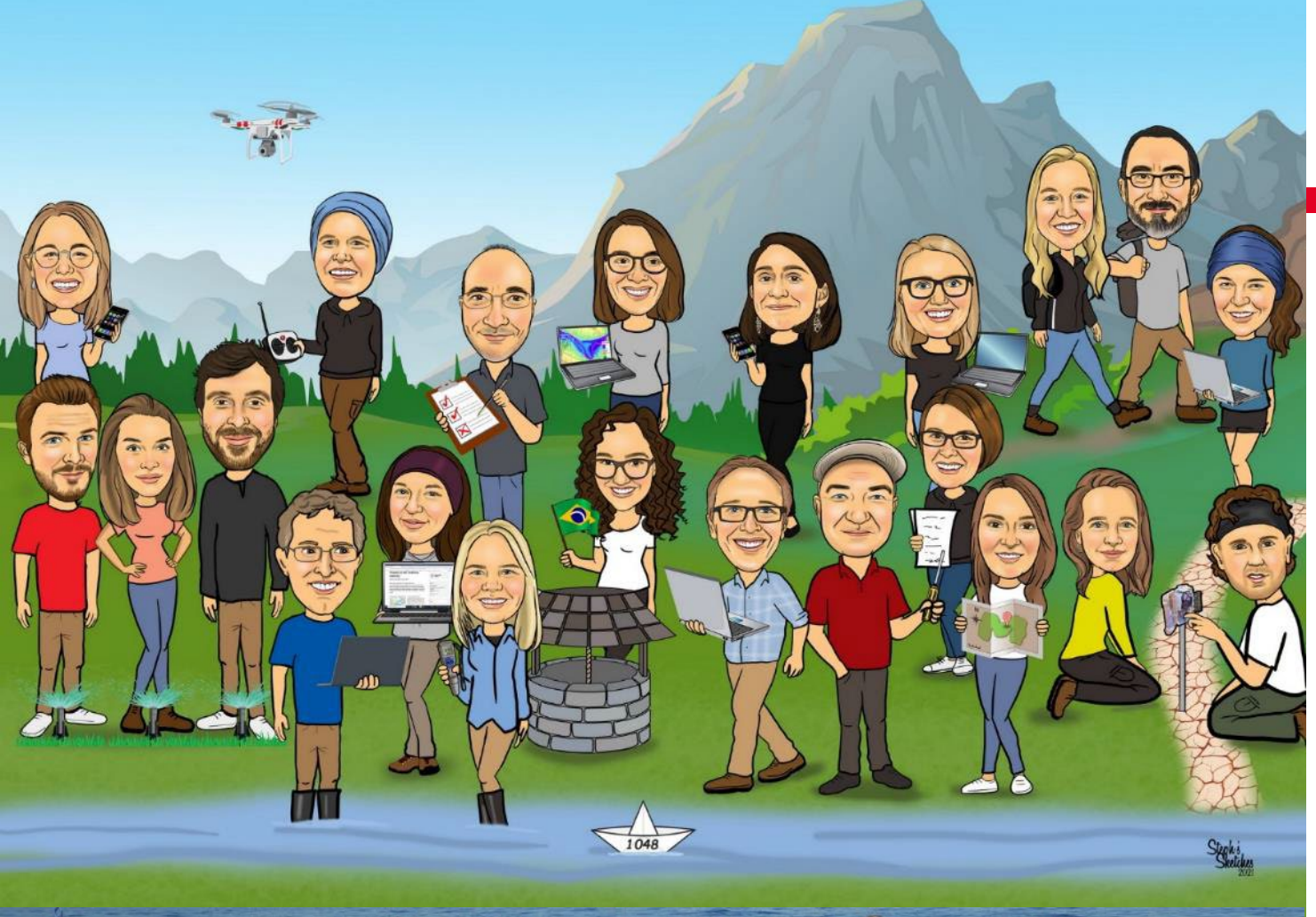
Results for all 671 catchments (CAMELS-US)





Seibert, Vis, Pool, in progress

Looking at water is fun …

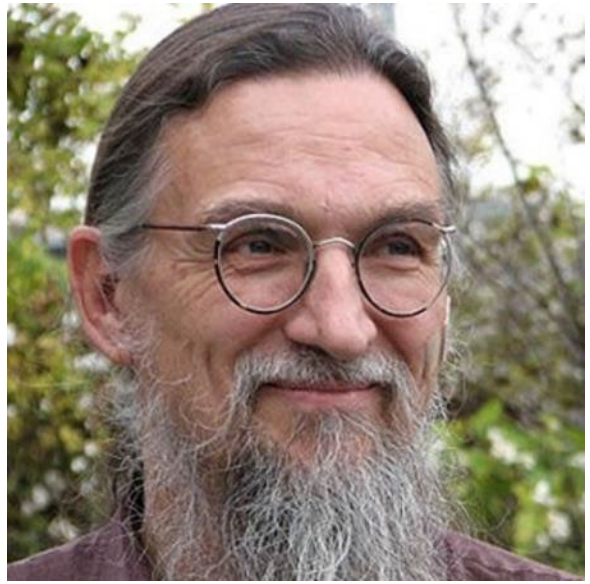


Research group H2K (Hydrology and Climate) at UZH

… especially together!

Dream team of senior scientists:
Ilja van Meerveld, Daniel Viviroli,
Maria Staudinger Marc Vis

Inspiring supervisors, colleagues and friends from my early water days in Sweden and Oregon



Sven Halldin

Allan Rodhe

Kevin Bishop

Lars Nyberg

Lars-Christer Lundin (†)

Jeff McDonnell

Revisting a field site from my PhD work
Several generations of supervisors & students

Östfora, Sweden, June 2024

Wonderful PhD students, part 1

















Wonderful PhD students, part 2

Recently finished






Soon finishing




Finishing 2026+



More (former) group members (Postdocs, associated PhD students, …)





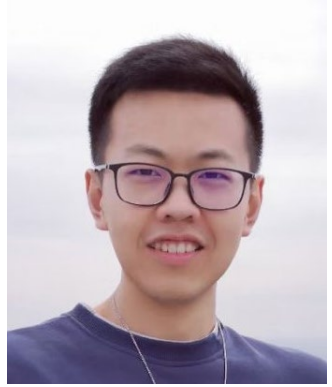



Whoever
I
forgot










AWARDS & MEDALS

Outstanding Student and PhD candidate Presentation (OSPP) Awards 2024

Franziska Clerc-Schwarzenbach

HS

Mirjam Scheller

HS

Sarah Hanus

HS

Abigail McConnell

AS

Alexander Platter

AS

Anja Katzenberg

AS

Adele Zaini

BG

Anna Siems

BG

Sofia Michail

EMRP

Meike D. W. Scherrenberg

CL

Katrina Lutz

CR

Laura Gabriel

CR

Patrick Sogno

HS

Rui Guo

HS

Sarah Hanus

HS

Michael Aich

ITS

Pietro Giaretta

ITS

Dominic Sett

NH

Kalpana Hamal

NH

Sara Pini

NH

Abdallah Aoude

NP

Lavanya Veerabhadrappa

SSS

Leonard Schulz

ST

Mélinda Martins

SSP

Julia Schmitz

TS

Patrick Bianchi

TS

Nora Krebs

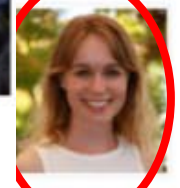
CR

agdalena uermann

M

Márton Pál

GM



iska Clerc hwarzenbach

S

Mirjam Schell

HS

abel Lange

RE

Dong Wang

GMPV

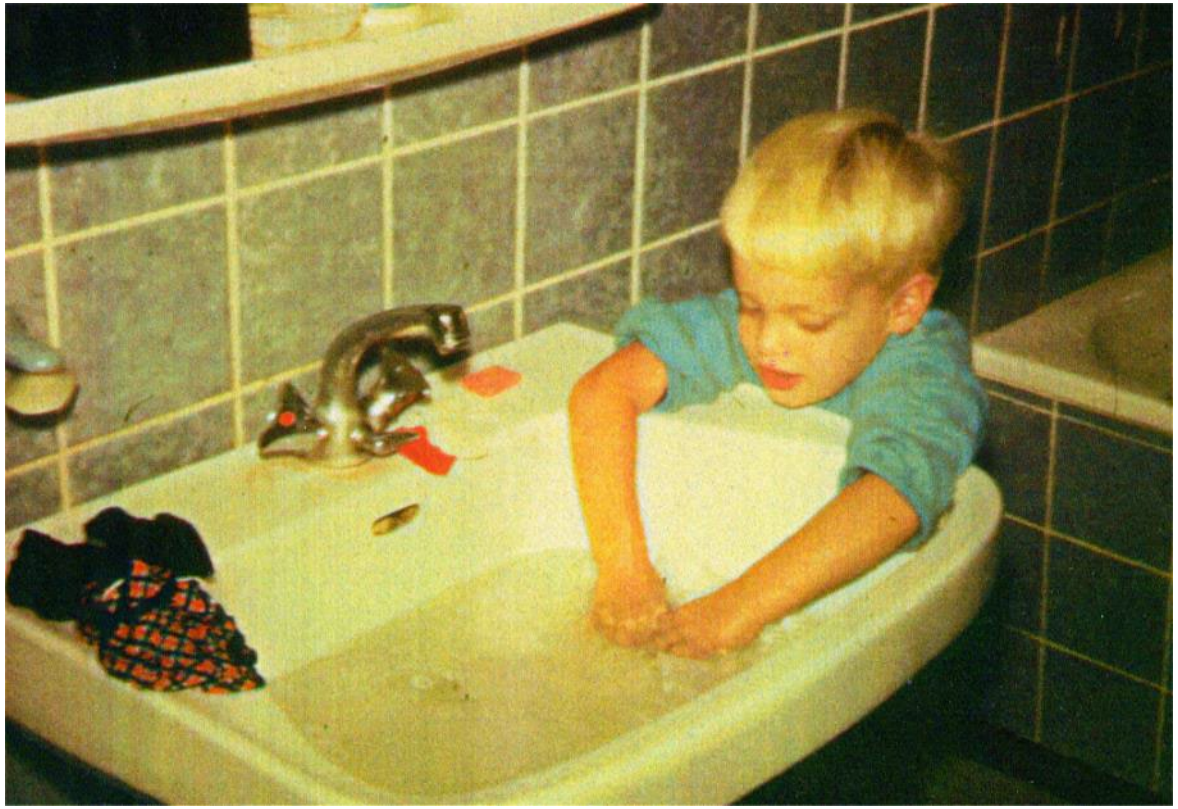
unsoo Seo

S

Fabian Schumacher

ESSI

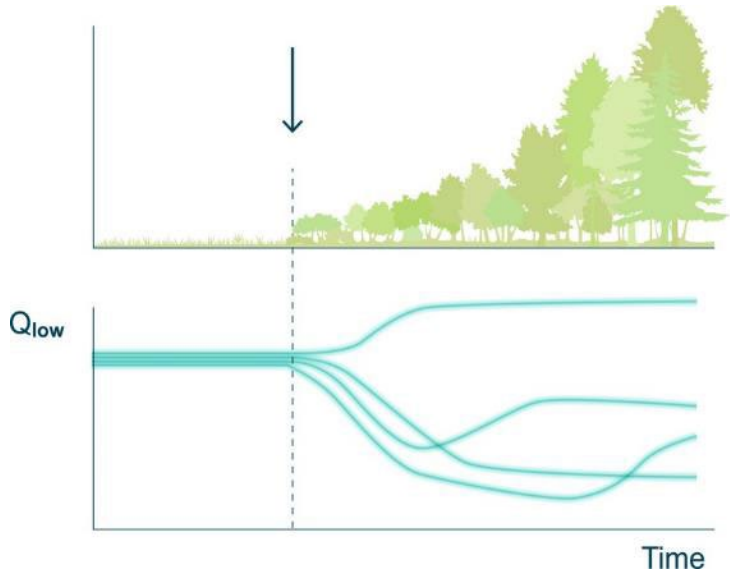
Early water studies



My water family

2009

2024



van Meerveld and Seibert, 2024, Wires Water

Author-Provided Video

Reforestation effects on low flows: Review of public perceptions and scientific evidence

by Ilja van Meerveld, Jan Seibert

https://wires.onlinelibrary.wiley.com/doi/full/10.1002/wat2.1760

… on frozen water

Thanks to …

- **EGU** and award committee
- **Colleagues and friends** who contributed to this nomination
- **My group** (current and former, formal and informal)
- **You** for listening