Estimating groundwater storage changes for major river basins in France using a regional groundwater data set

Kuei-Hua (Bell) Hsu[1], Laurent Longuevergne[2], Annette Eicker[1], Mehedi Hasan[3], Andreas Güntner[3],

1) HafenCity University Hamburg
2) University of Rennes
3) GFZ German Research Center for Geosciences

Contact: kuei-hua.hsu@hcu-hamburg.de

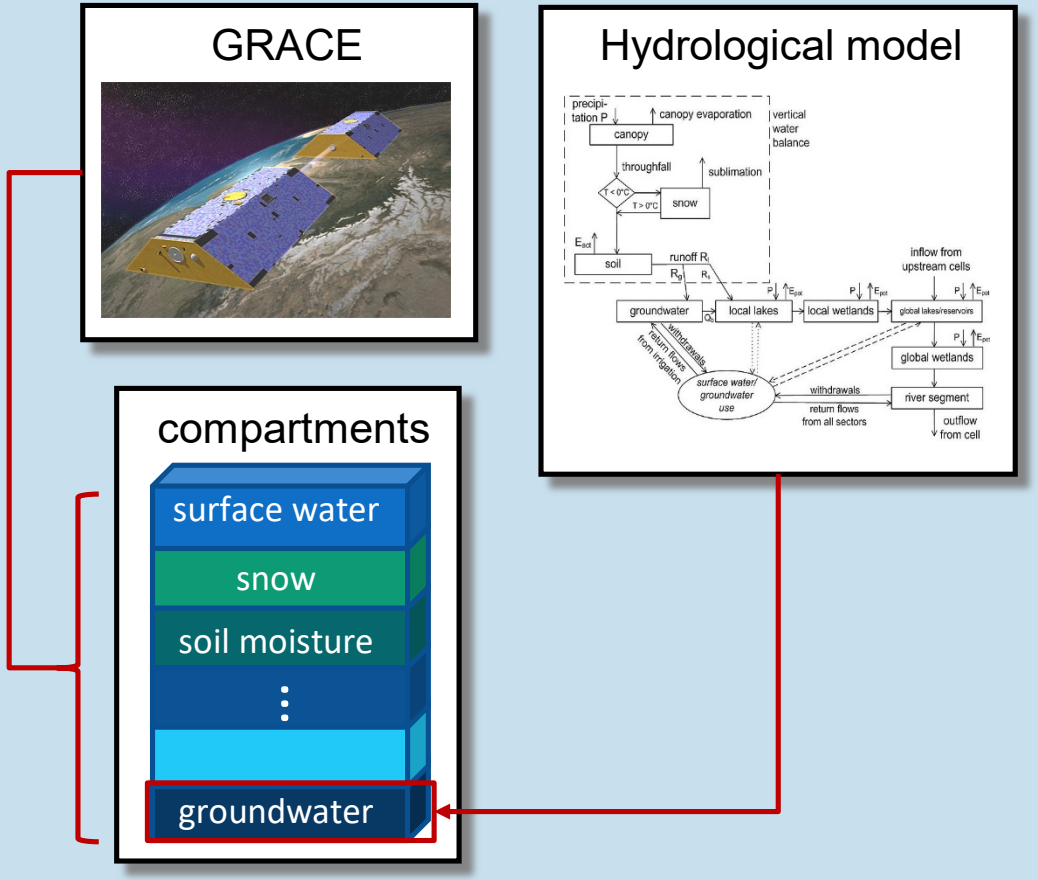
Introduction

Goal:
Observation-based large-scale **groundwater storage** data set for France from groundwater head (=level) measurements

- river basin scale
- grid cells
- higher resolution

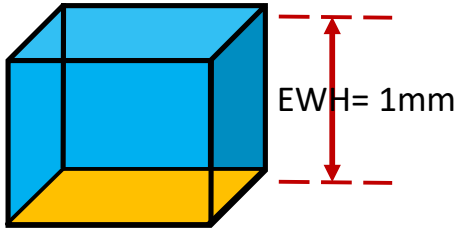
Use:

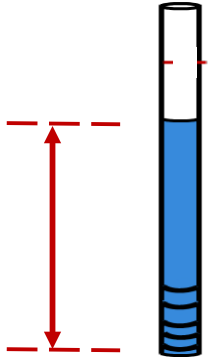
- comparison to GRACE-derived water storage
- validating hydrological model output (e.g. WGHM)



Groundwater storage: Challenges

GW storage change = * GW head variation

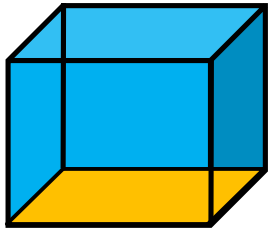




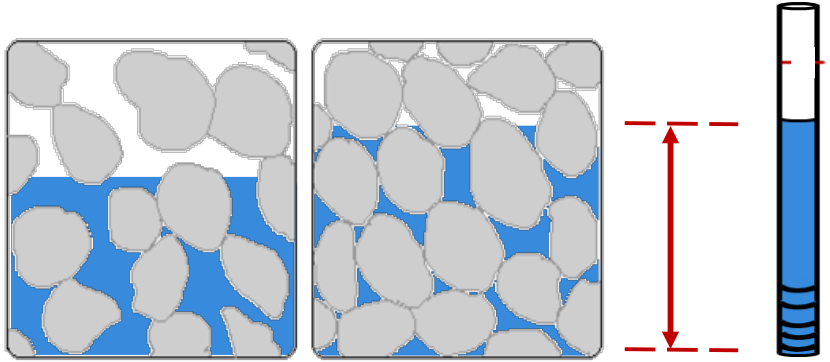
height of 1 kg water on 1 m^2 area is 1 mm, so called equivalent water height (EWH)

Groundwater storage: Challenges

GW storage change = conversion from level to storage * GW head variation

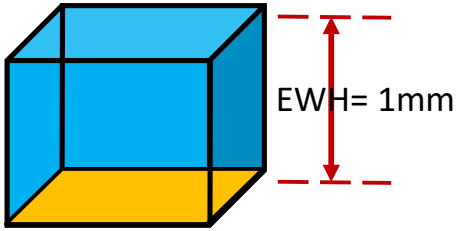


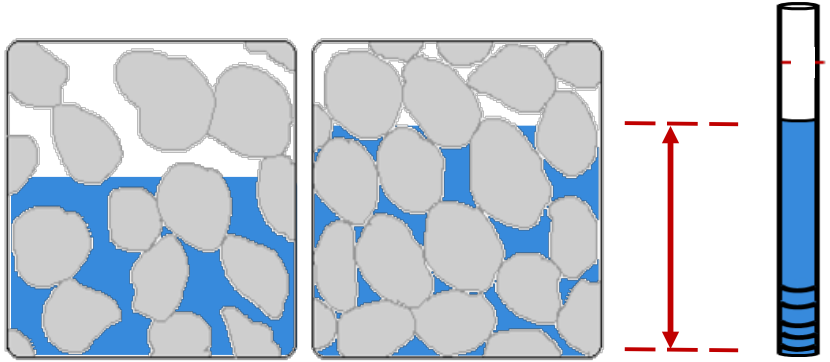
height of 1 kg water on 1 m^2 area is 1 mm, so called equivalent water height (EWH)



Groundwater storage: Challenges

GW storage change = 1 conversion from level to storage * 2 GW head variation





Challenges:

1 Conversion ideally based on specific yield (difficult to obtain)

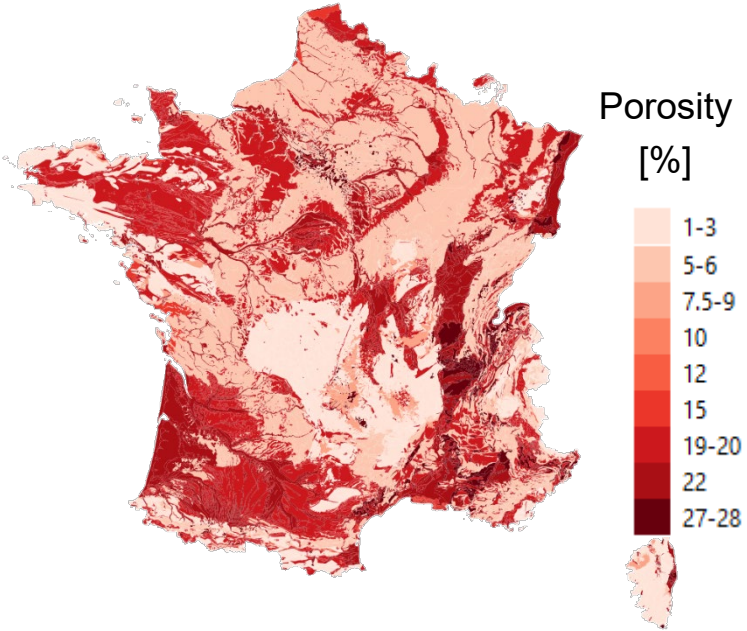
Groundwater storage: Challenges

GW storage change = 1 conversion from level to storage * 2 GW head variation

1 Conversion from level to storage based on porosity values from global lithology maps (Gleeson et al. 2018)

Drawbacks:

- low spatial resolution, descrepancies compared to national data set
- porosity ≠ specific yield
  => overestimation of storage



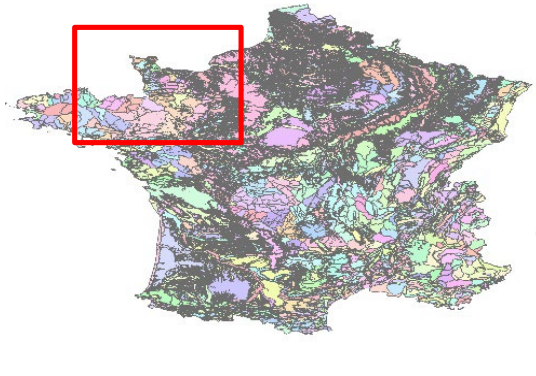
Groundwater storage

1

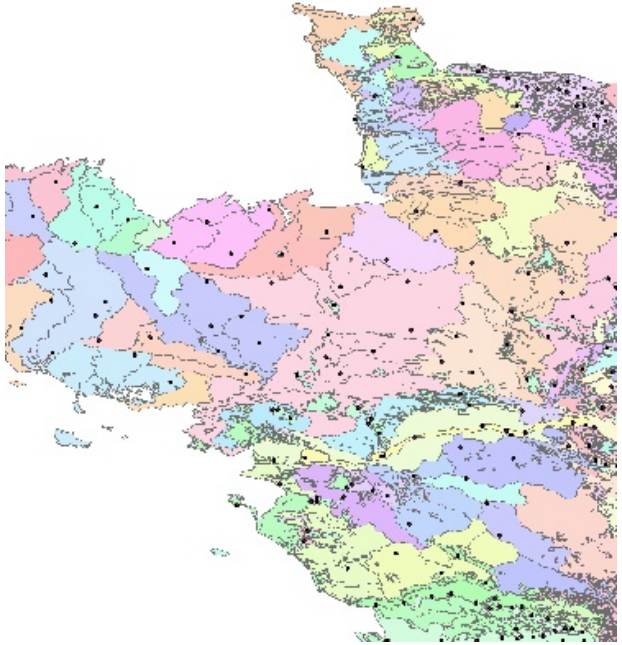
GW storage change = Sy * GW head variation

1

Goal:
Derive high-resolution **specific yield (Sy)** map based on **national data set (BDLISA)**



60219 polygons
(=lithology units)



(colors just indicate different polygons)

1 How Sy is obtained?

BDLISA table:

BGRM (French geological survey)

code | description → convert → Type & Formation → Sy

accessed via

60219 Polygons (lithology units)

104AG10	Marnes de Saint-Nicolas-de-Pierrepont du Quaternaire du bassin de Sainteny-Marchésieux	unconsolidated	marl	2
104AG10	Marnes de Saint-Nicolas-de-Pierrepont du Quaternaire du bassin de Sainteny-Marchésieux	unconsolidated	marl	2
104AG10	Marnes de Saint-Nicolas-de-Pierrepont du Quaternaire du bassin de Sainteny-Marchésieux	unconsolidated	marl	2
104AG11	Faluns de Bohon du Quaternaire du bassin de Sainteny-Marchésieux	rock	limestone	5.25
104AG11	Faluns de Bohon du Quaternaire du bassin de Sainteny-Marchésieux	rock	limestone	5.25
104AG12	Complexe du Bosq d'Aubigny du Plio-Quaternaire du sous-bassin de Marchésieux	rock	marl	2
104AG12	Complexe du Bosq d'Aubigny du Plio-Quaternaire du sous-bassin de Marchésieux	rock	marl	2
104AG14	Faluns de Bléhou du Néogène du sous-bassin de Sainteny	rock	limestone	5.25
104AG14	Faluns de Bléhou du Néogène du sous-bassin de Sainteny	rock	limestone	5.25

a

Table 8.1 Representative values of porosity (η), specific yield (S_y) and specific retention (S_r) of geological materials. (After Morris and Johnson 1967; Hamill and Bell 1986)

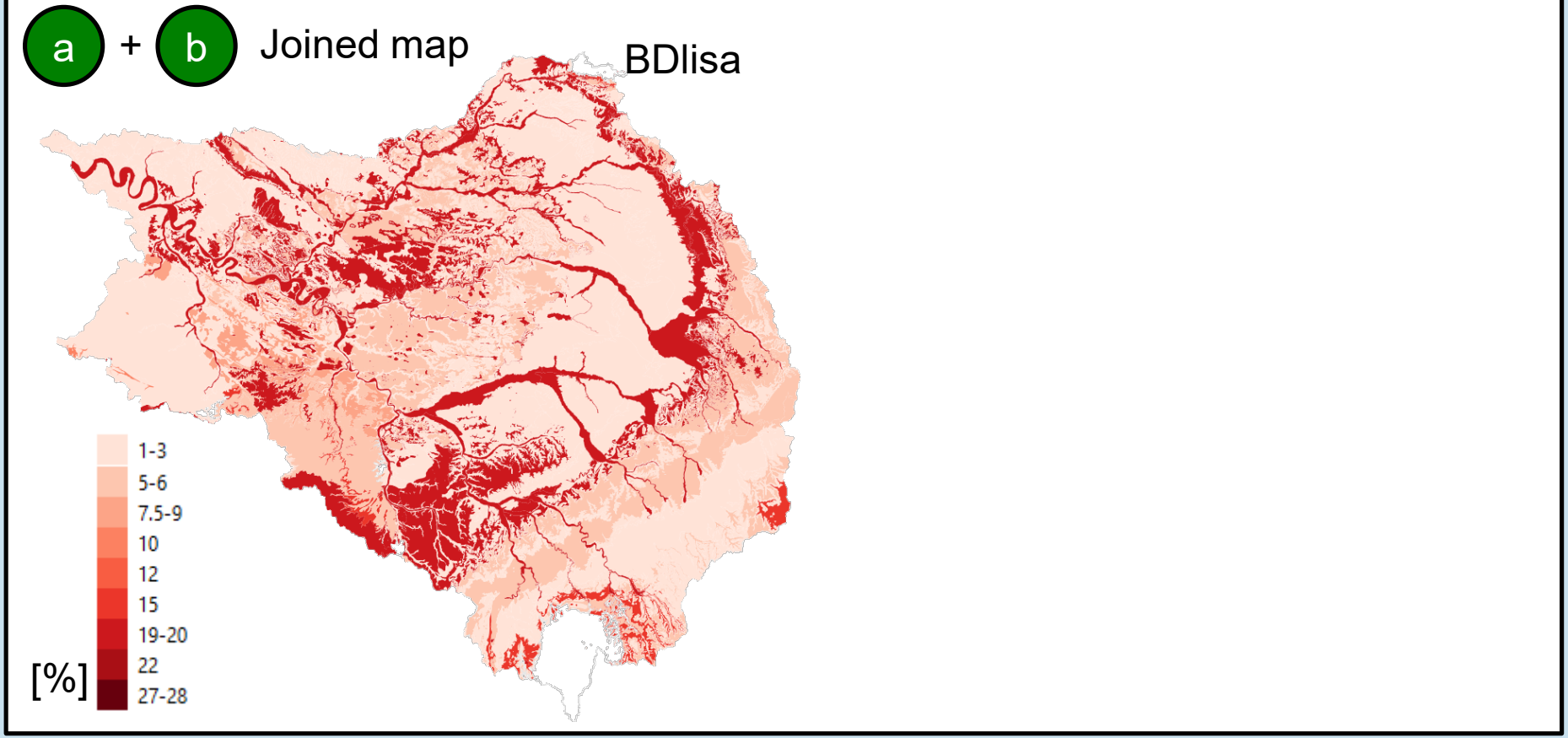
Geological formation	η(%)	S_y(%)	S_r(%)
Unconsolidated deposits			
Gravel	28–34	15–30	3–12
Sand	35–50	10–30	5–15
Silt	40–50	5–20	15–40
Clay	40–60	1–5	25–45
Dune Sand	40–45	25–35	1–5
Loess	45–50	15–20	20–30
Rocks			
Sandstone	15–30	5–25	5–20
Limestone, dolomite	10–25	0.5–10	5–25
Shale	0–10	0.5–5	0–5
Siltstone	5–20	1–8	5–45
Till	30–35	4–18	15–30
Dense crystalline rock	0–5	0–3	–
Fractured crystalline rock	5–10	2–5	–
Weathered crystalline rock	20–40	10–20	–
Basalt	5–30	2–10	–

Two different ways to get Sy:

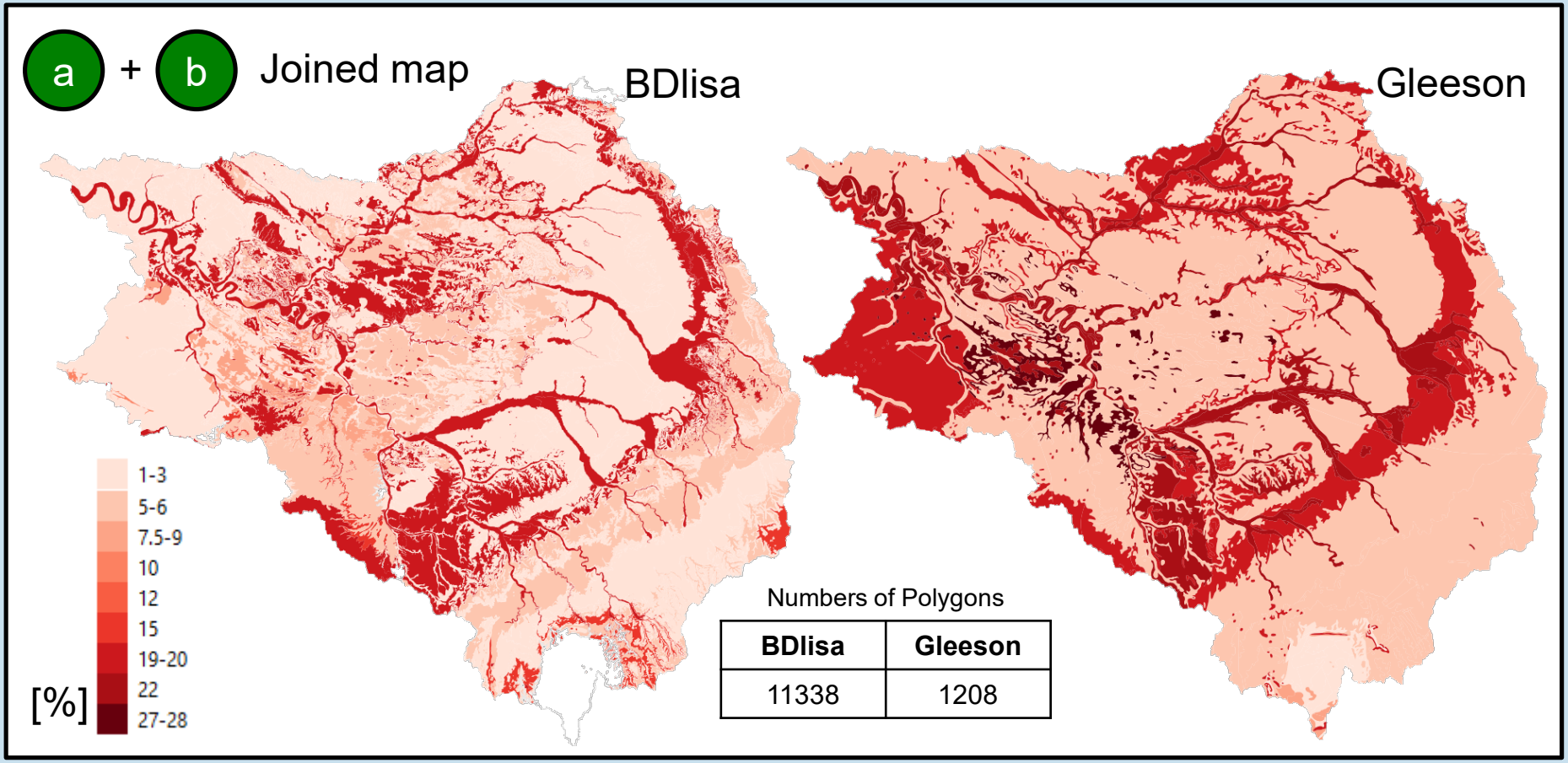
a **General lithology** from qualitative BDLISA description ("formation") + literature values for Sy

b For some polygons, specific Sy are provided directly by BDLISA based on **detailed lithology** of the unit.

Specific yield map for Seine



Specific yield map for Seine



Numbers of Polygons

BDlisa	Gleeson
11338	1208

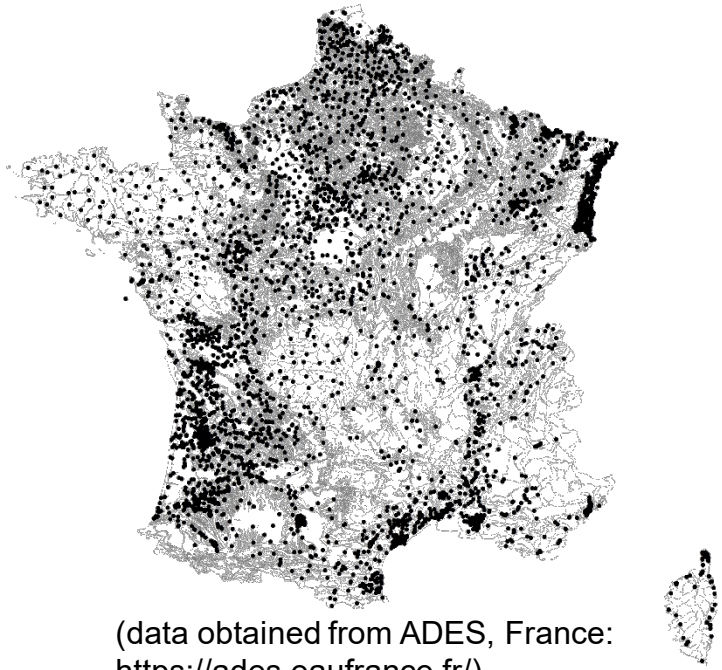
Groundwater storage: Challenges

2

GW storage change = conversion from level to storage * GW head variation

Available boreholes

3963



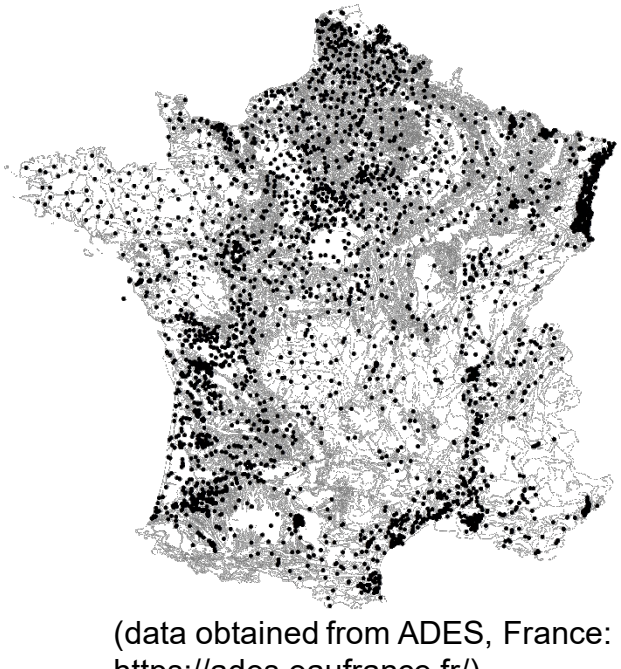
(data obtained from ADES, France: https://ades.eaufrance.fr/)

Groundwater storage: Challenges

2

GW storage change = conversion from level to storage * GW head variation

Available boreholes	remove pumping, irrigation, industry
3963	3424



(data obtained from ADES, France: https://ades.eaufrance.fr/)

Groundwater storage: Challenges

2

GW storage change = conversion from level to storage * GW head variation

Available boreholes

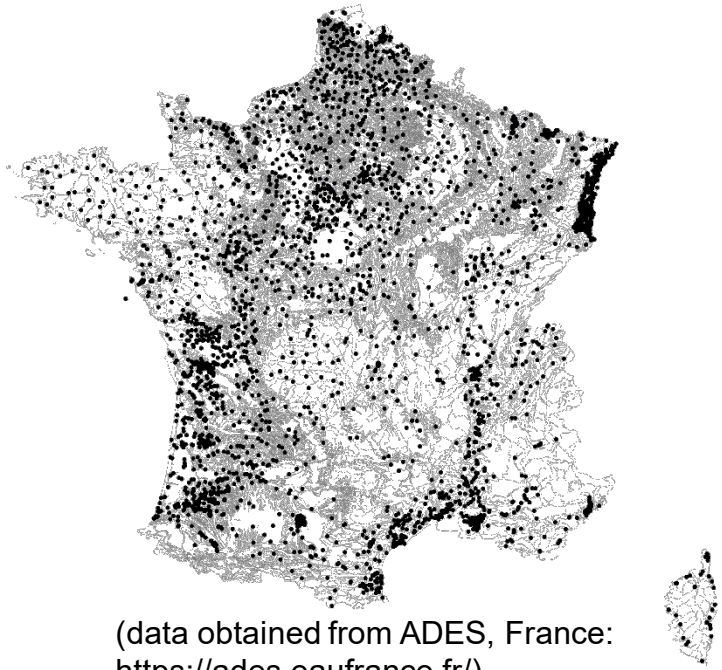
3963

remove pumping, irrigation, industry

3424

Remove non-sense time series

3360



(data obtained from ADES, France: https://ades.eaufrance.fr/)

Groundwater storage: Challenges

GW storage change = conversion from level to storage * GW head variation (2)

Available boreholes: 3963	remove pumping, irrigation, industry: 3424
Remove non-sense time series: 3360	Focus on unconfined aquifers: 1765

Challenges:

(2) Uneven spatial distribution of boreholes, aggregation to basin scale

(data obtained from ADES, France: https://ades.eaufrance.fr/)

2 Unevenly distributed wells

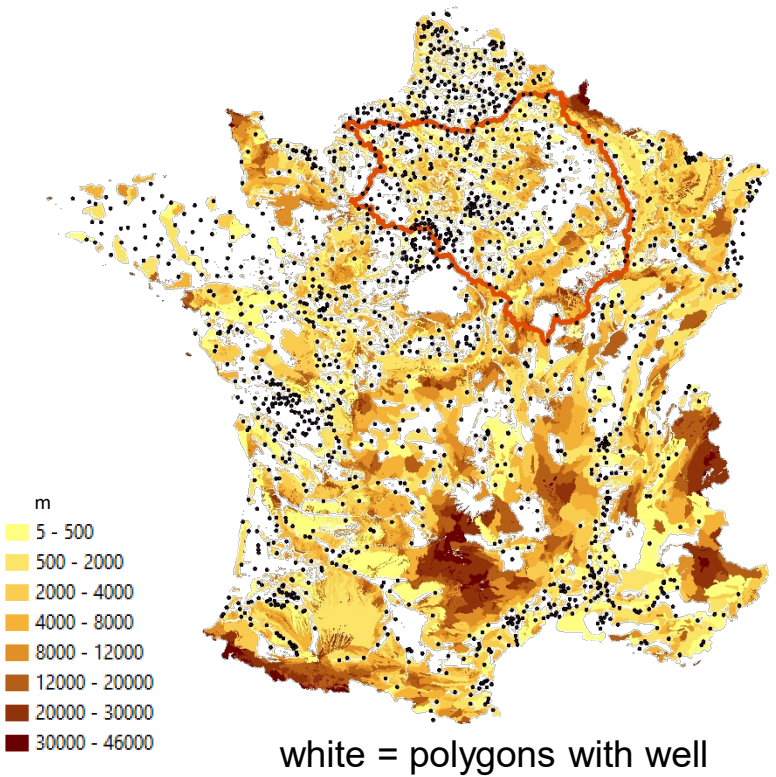
Aggregation of level data to **basin averages** based on area fraction of corresponding polygons

Question: How to define the GW level time series of a polygon without a borehole?

Attempt: Assign the nearest borehole (head variation) to the polygon which does not have a borehole.

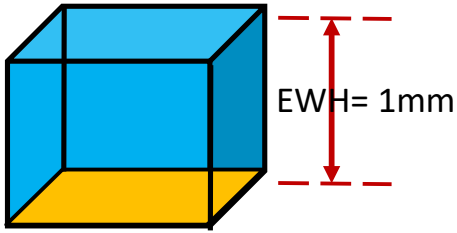
How representative is the nearest well?

Distance of polygon outline from nearest well



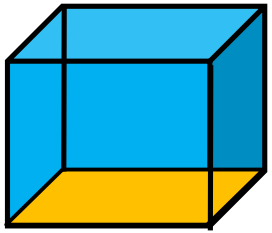
white = polygons with well

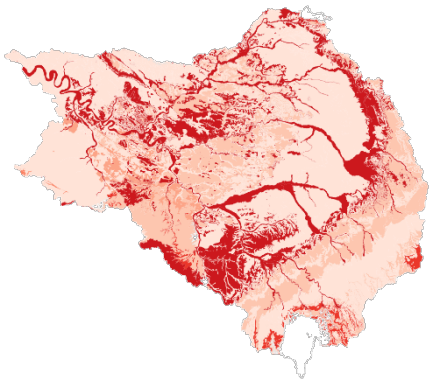
GW storage in Seine river basin

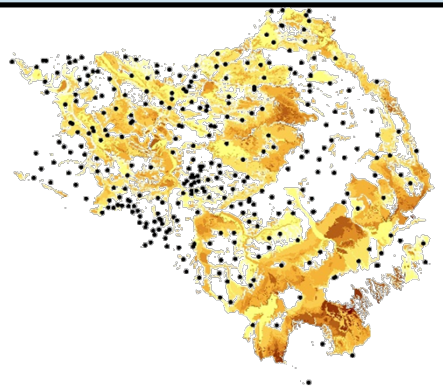


GW storage change = *

GW storage in Seine river basin

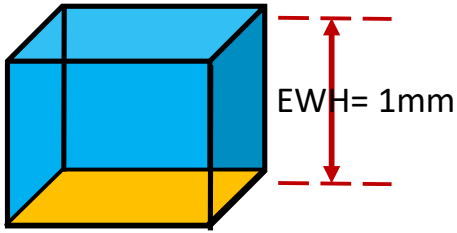


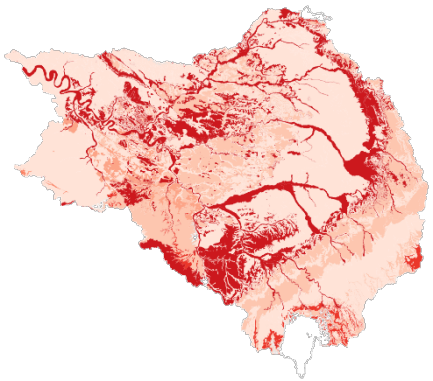


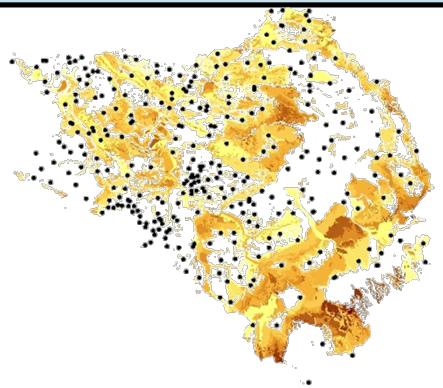


GW storage change = Sy * GW head variation

GW storage in Seine river basin







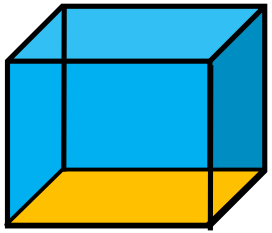
GW storage change = Sy * GW head variation

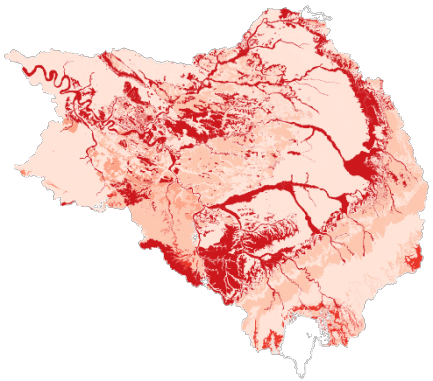
- Each well has the same contribution (=**simple average**)
- Assuming aquifers are homogeneously distributed and have the same activeness

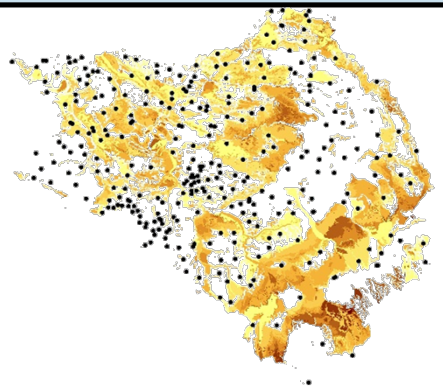
$$EWH_{SA} = \frac{1}{B}\sum_{b=1}^{B} Sy_b * \Delta head_b$$

b = borehole well
b= 1-113

GW storage in Seine river basin







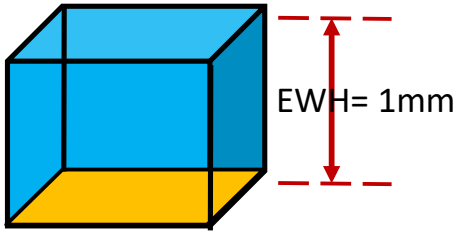
GW storage change = Sy * GW head variation

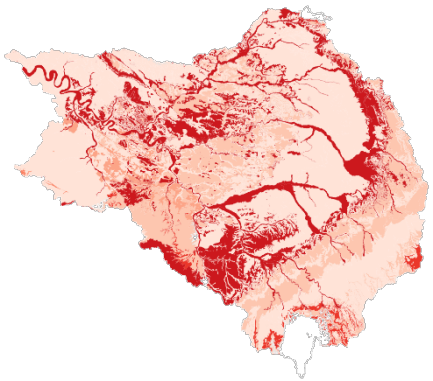
$$EWH_W =$$

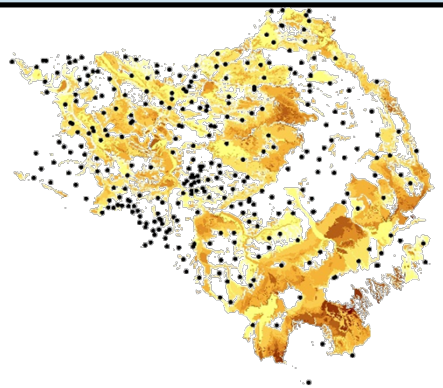
W_p: area weight of each polygon

P = polygon (lithology unit)
P = 1-11338

GW storage in Seine river basin







GW storage change = Sy * GW head variation

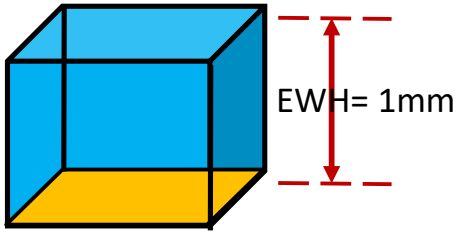
- Take area of geological units (polygons) into account (=**area-weighted average**)

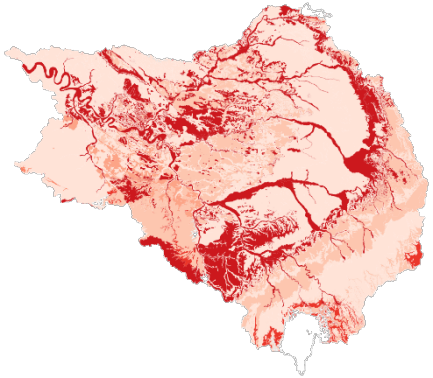
$$EWH_W = \sum_{p=1}^{P} W_p$$

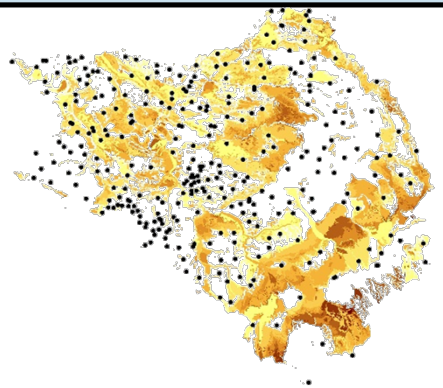
W_p: area weight of each polygon

P = polygon (lithology unit)
P = 1-11338

GW storage in Seine river basin







GW storage change = Sy * GW head variation

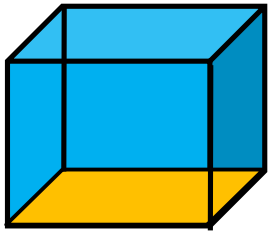
- Take area of geological units (polygons) into account (=**area-weighted average**)

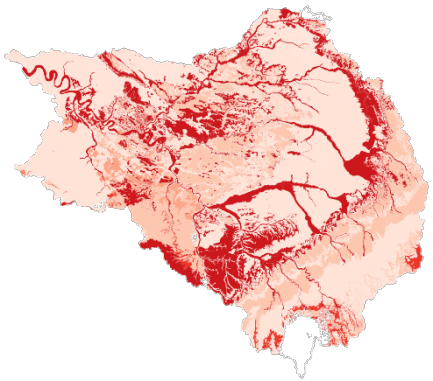
$$EWH_W = \sum_{p=1}^{P} W_p * Sy_p * \Delta head_p$$

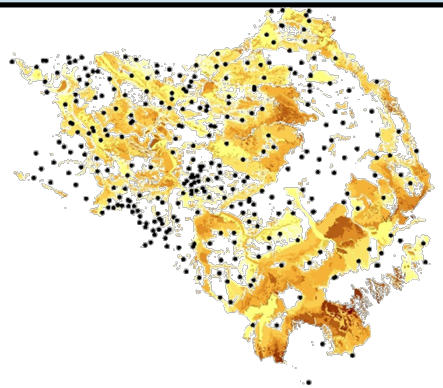
W_p: area weight of each polygon

P = polygon (lithology unit)
P = 1-11338

GW storage in Seine river basin







GW storage change = Sy * GW head variation

- Take area of geological units (polygons) into account (=**area-weighted average**)

$$EWH_W = \sum_{p=1}^{P} W_p * Sy_p * \Delta head_p$$

sum=1

W_p: area weight of each polygon

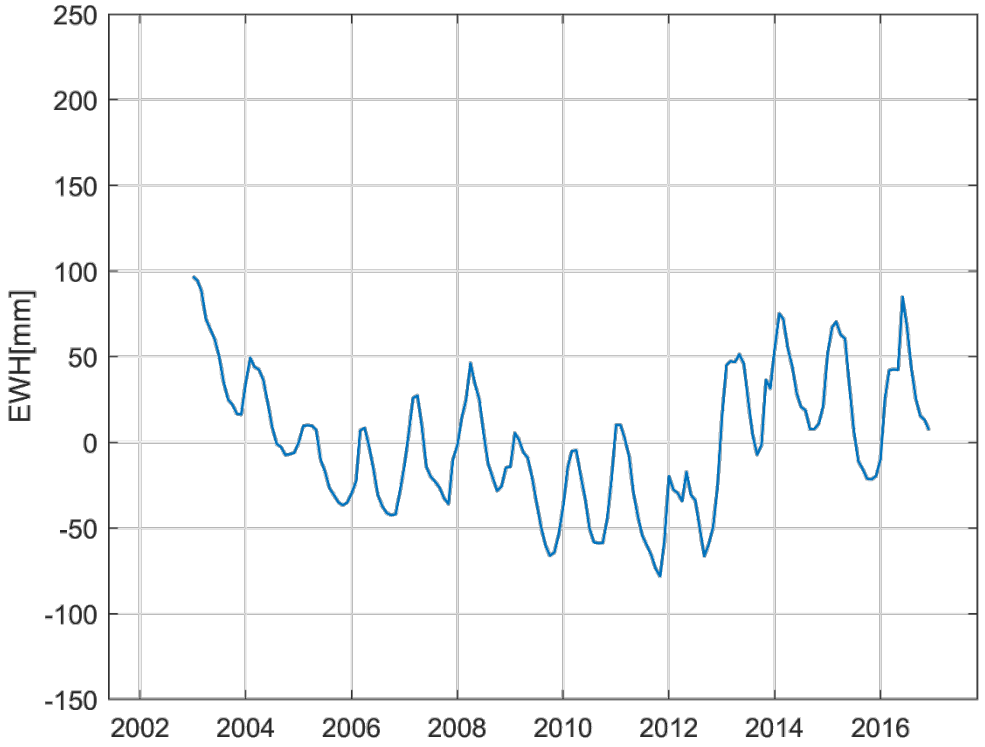
P = polygon (lithology unit)
P = 1-11338

Challenges		
Conversion from level to storage	Gleeson porosity Polygons: 1208	BDlisa specific yield Polygons:11338

Challenges		
Conversion from level to storage	Gleeson porosity Polygons: 1208	BDlisa specific yield Polygons:11338
Unevenly distributed boreholes	Simple average $EWH_{SA} = \frac{1}{B}\sum_{b=1}^{B} Sy_b * \Delta head_b$ b = borehole well b= 1-113	Area-weighted average $EWH_W = \sum_{p=1}^{P} W_p * Sy_p * \Delta head_p$ W_p: area weight of each polygon P = polygon (lithology unit) P = 1-11338

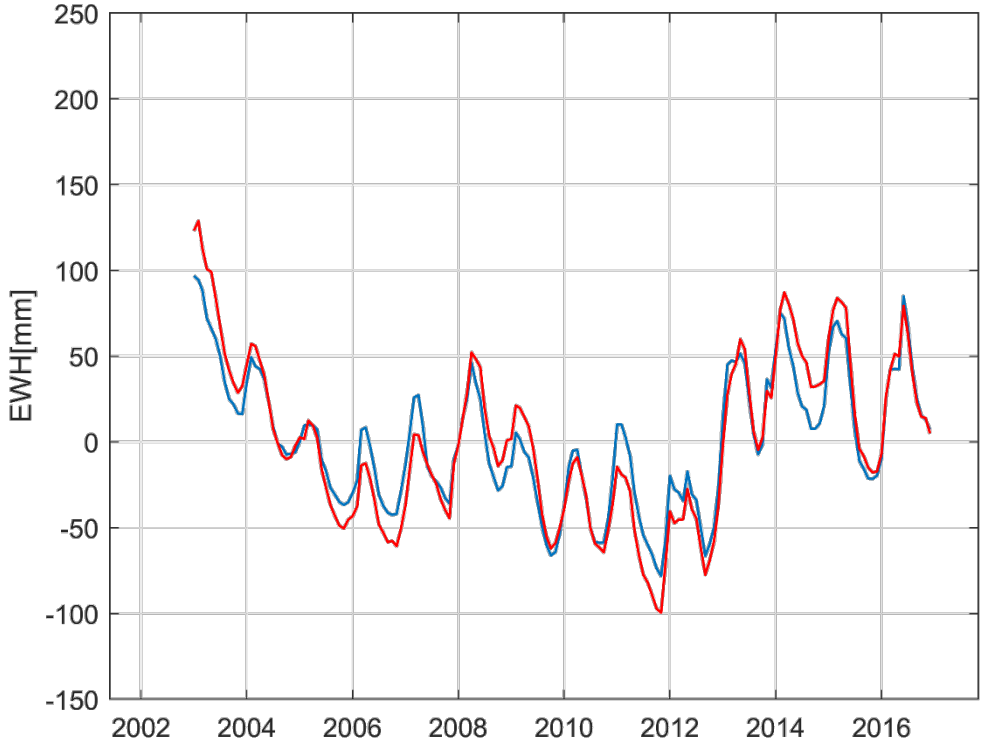
Challenges		
Conversion from level to storage	Gleeson porosity Polygons: 1208	BDlisa specific yield Polygons:11338 
Unevenly distributed boreholes	Simple average $EWH_{SA} = \frac{1}{B}\sum_{b=1}^{B} Sy_b * \Delta head_b$ b = borehole well b= 1-113 Ignore individualities of each well and aquifer	Area-weighted average $EWH_W = \sum_{p=1}^{P} W_p * Sy_p * \Delta head_p$ W_p: area weight of each polygon P = polygon (lithology unit) P = 1-11338 

GW storage in Seine basin



Challenges		
Conversion from level to storage	Gleeson porosity Polygons: 1208	BDlisa specific yield Polygons:11338
Unevenly distributed boreholes	Simple average	Area-weighted average

GW storage in Seine basin

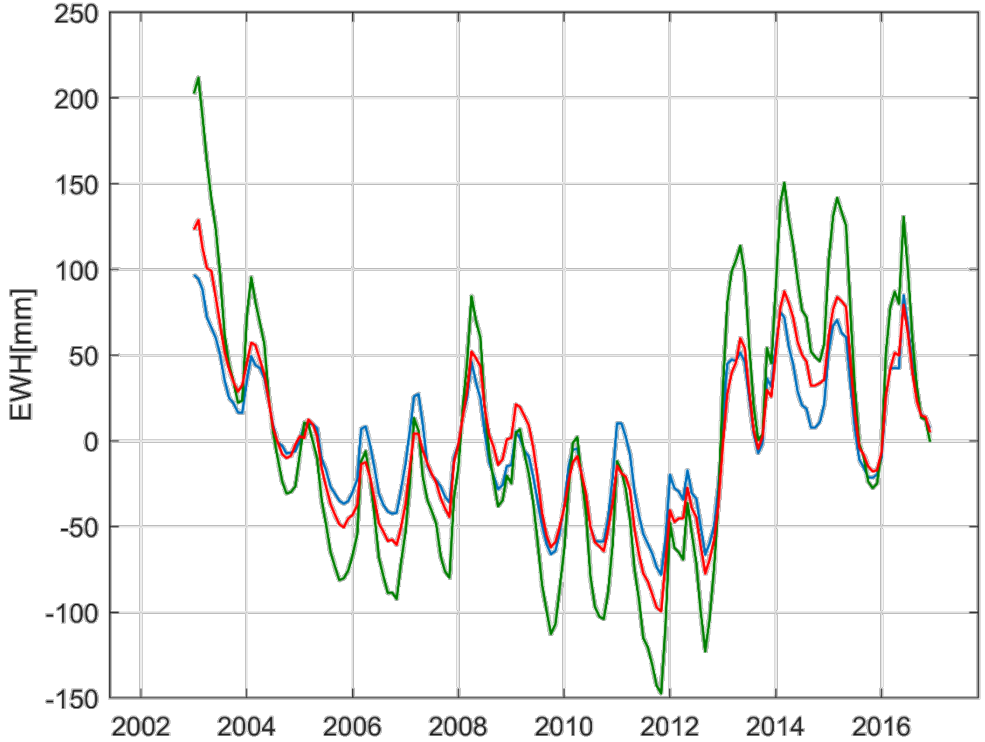


BDlisa Simple average

BDlisa Area weighted

Challenges		
Conversion from level to storage	Gleeson porosity Polygons: 1208	BDlisa specific yield Polygons:11338
Unevenly distributed boreholes	Simple average	Area-weighted average

GW storage in Seine basin



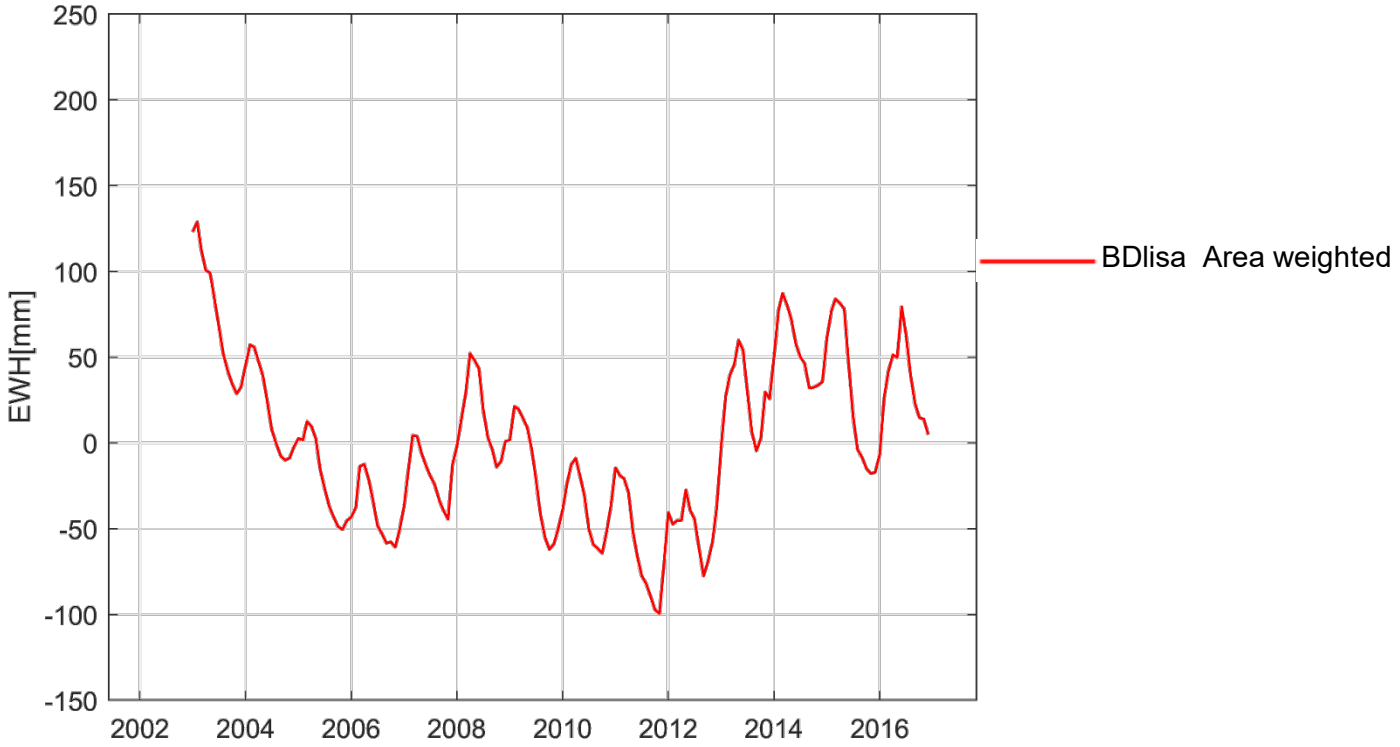
BDlisa Simple average

BDlisa Area weighted

Gleeson Area weighted

Challenges		
Conversion from level to storage	Gleeson porosity Polygons: 1208	BDlisa specific yield Polygons:11338
Unevenly distributed boreholes	Simple average	Area-weighted average

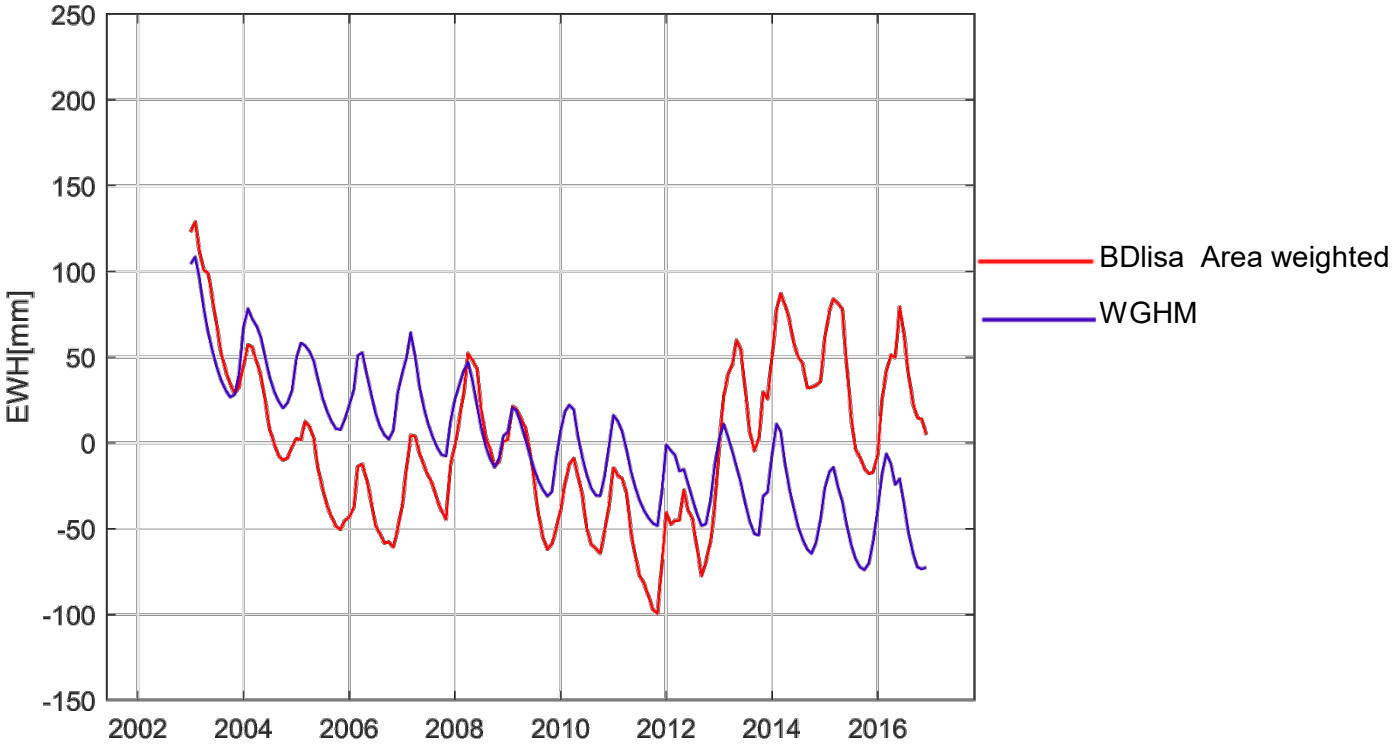
GW storage in Seine basin



GW storage in Seine basin

Correlation

0.29

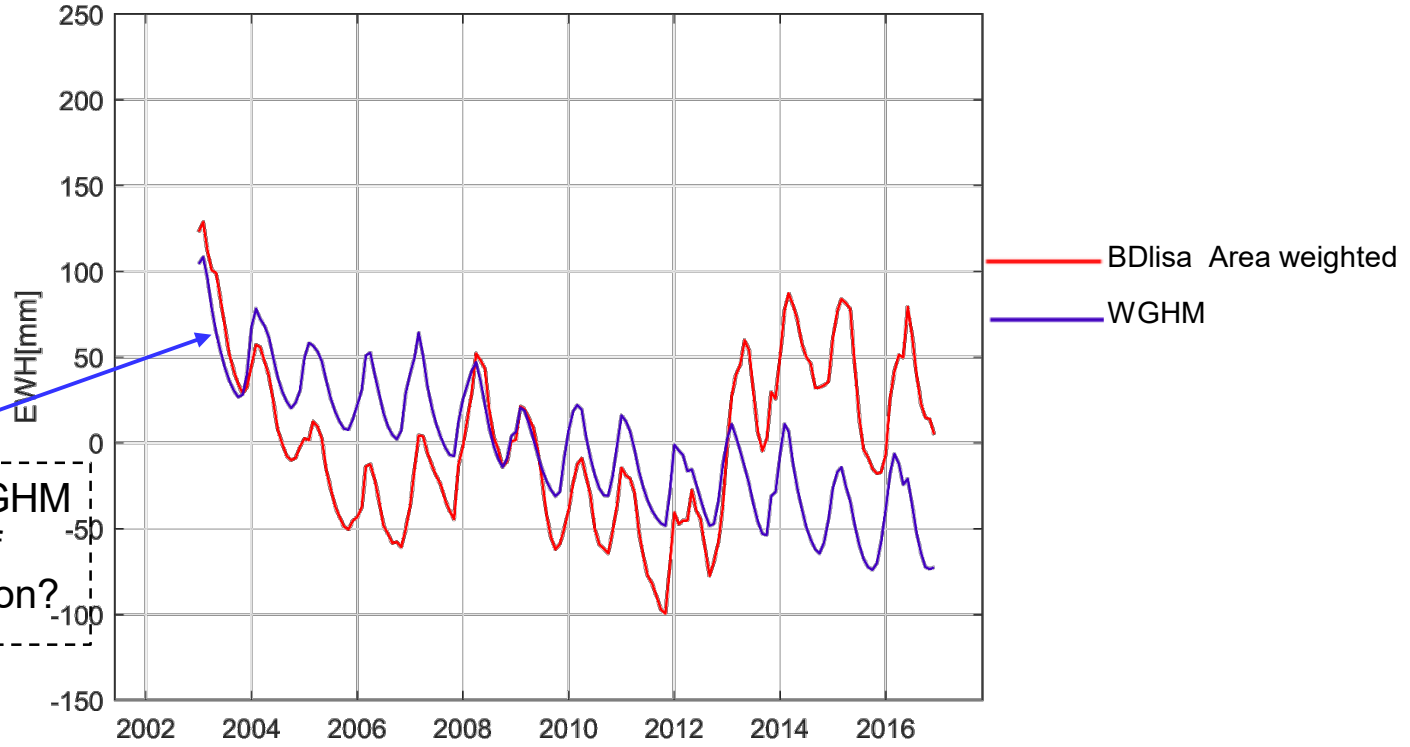


GW storage in Seine basin

Correlation

0.29

Negative trend in WGHM
=> over-estimation of
human GW abstraction?

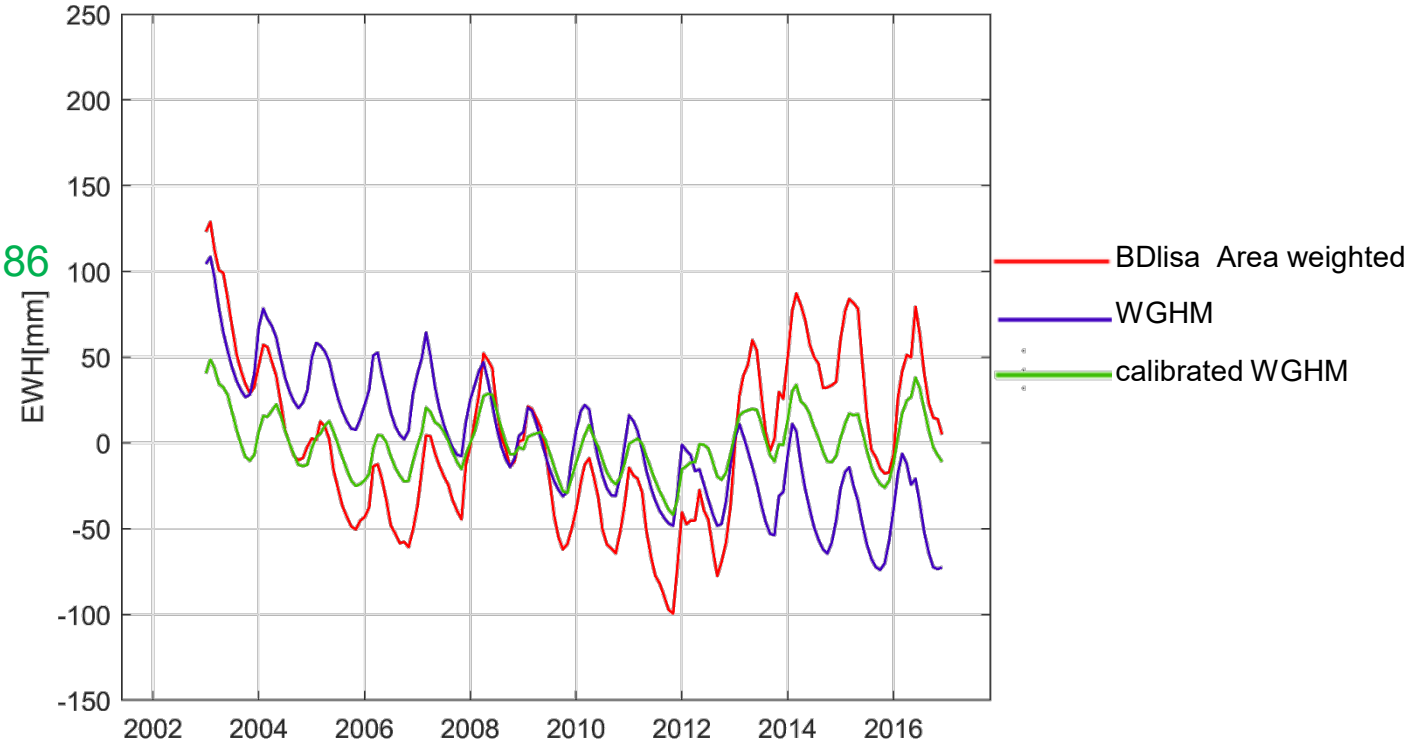


GW storage in Seine basin

0.29 → 0.86

Discharge

GRACE



Take home messages

- We present high resolution data sets of GW level and lithology for France.
- We use these data sets to estimate GW storage of large river basins in France.
- The GW storage data are used for validating hydrological models, such as WGHM.
- Calibration against discharge and Total Water Storage improves the GW simulation of WGHM.

Thanks!

Contact: kuei-hua.hsu@hcu-hamburg.de