26th Groundwater Resources Association Annual Meeting | Oct. 10, 2017

Stochastic Management of Non-Point Source Contamination

Joint Impact of Aquifer Heterogeneity and Well Characteristics

Christopher V. Henri and Thomas Harter

UCDAVIS
UNIVERSITY OF CALIFORNIA

Department of
LAND, AIR AND WATER RESOURCES
University of California, Davis
Climate Change • Sustainable Agriculture
Environmental Quality • Landscape Processes

CALIFORNIA
Water Boards

Motivation

Non-point source (NPS) contamination: large scale, long term, low intensity pollution (best example → agrochemicals)

Initial steps for groundwater management:

- When will the contaminant reach an extraction well (travel time)?
- From where does the contaminant come from (contributing area)?

Base for development of GW quality improvement strategies

Motivation

- Heterogeneity in aquifer hydraulic properties
    - Large uncertainty (poor characterization)

Zhangye, Gansu province, People's Republic of China

designed by Tim Babb

Motivation

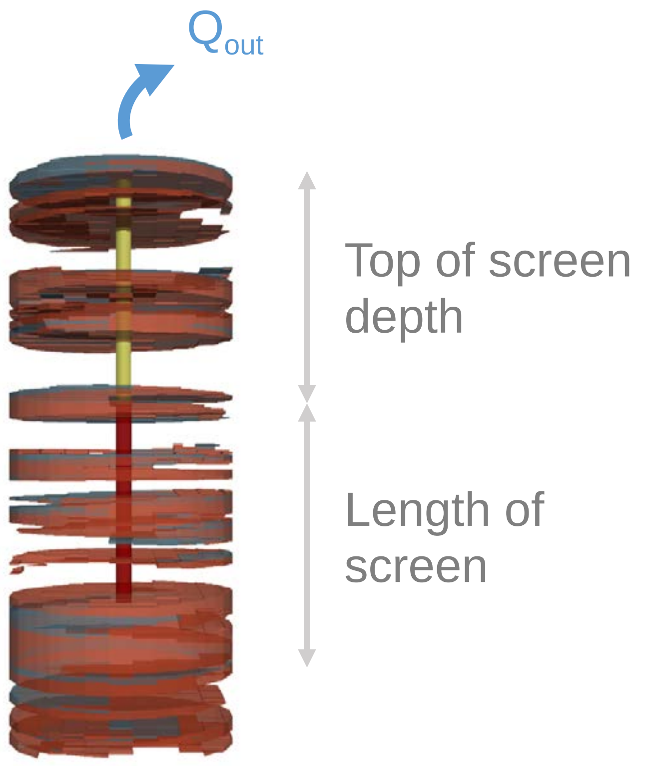
- Heterogeneity in
  - Significant co
  - Uncertainty pr

preferential channels

zones of low-velocity

Motivation

- Well characteristics
  - Extraction rate, screen length and depth
  - Significant controlling factor of the contaminant mass arrival



Objectives

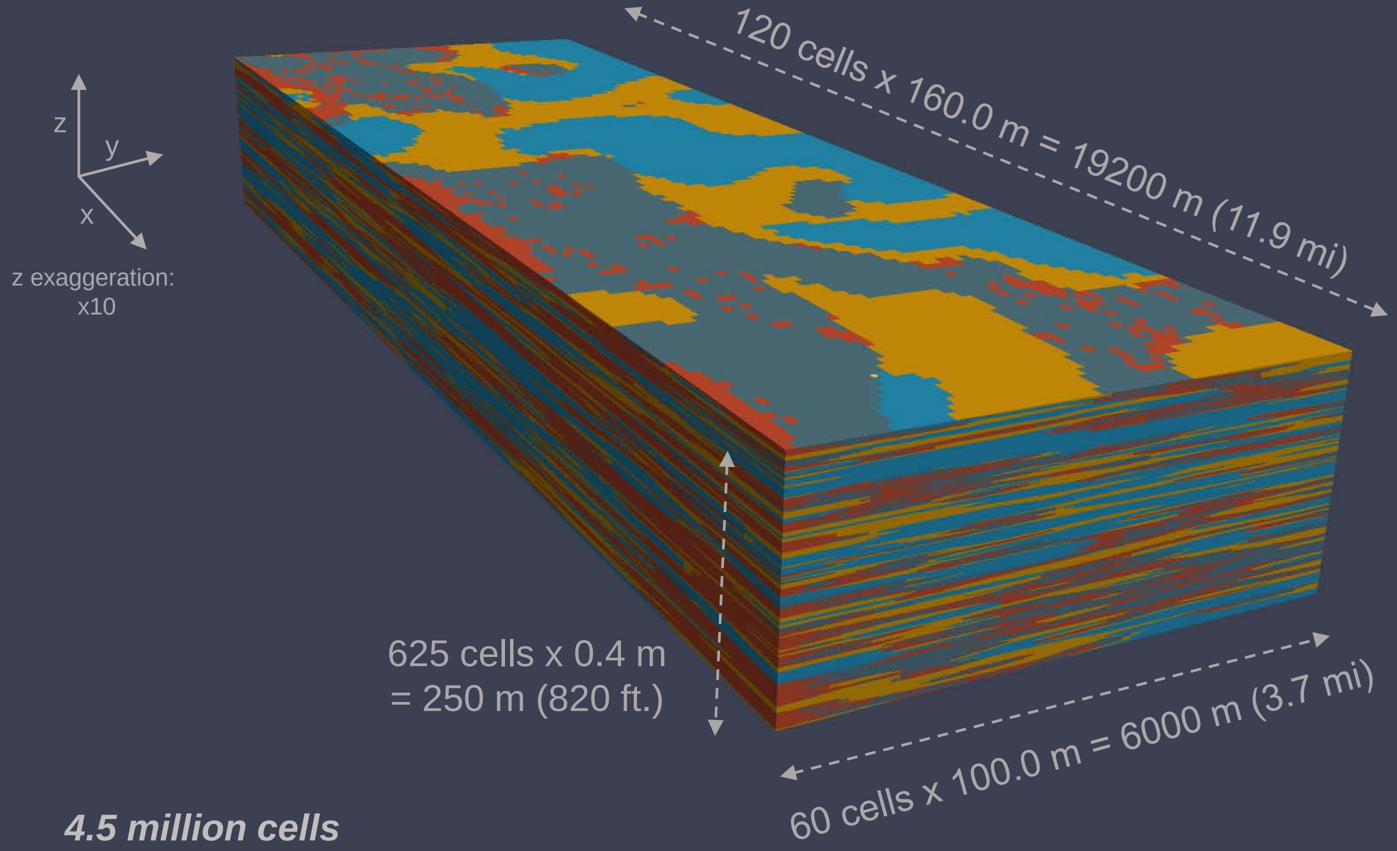
- Characterize **travel time** and **extension of the contributing area** in typical Central Valley NPS contamination.

- Evaluate the joint impact of **aquifer heterogeneity** and **extraction wells characteristics** on travel times and contributing area uncertainty.

- Meta-model: is there a **simple ("effective" or "equivalent") model** to predict travel time and capture zone?

Method

Geostatistical model:
Transition probability method (T-PROGS) [Carle and Fogg (1996), Carle (1999)]



4.5 million cells

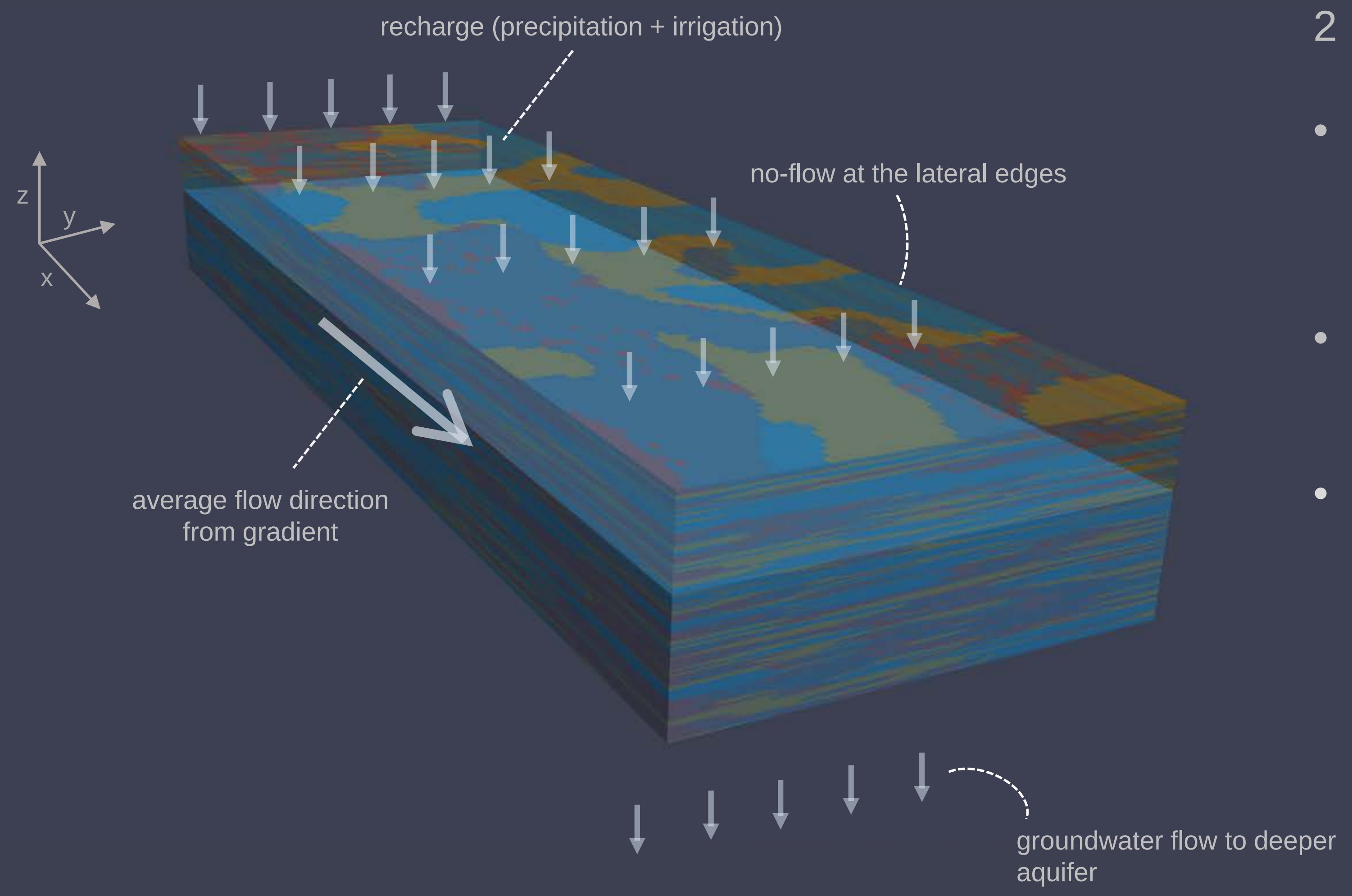
4 categories:
gravel (g); sand (s);
muddy-sand (ms); mud (m)

	g	s	ms	m
Proportion [%]	0.10	0.35	0.25	0.3
Hydraulic conductivity [m/d]	200.0	50.0	0.5	0.01

	g	s	ms	m
Mean length x direction [m]	800.0	1500.0	1000.0	b
Mean length y direction [m]	500.0	850.0	900.0	b
Mean length z direction [m]	2.0	3.5	2.0	b

Inspired by Central Valley's aquifers modeling by Weismann et al. (1999), Hua's Master Thesis (2006)

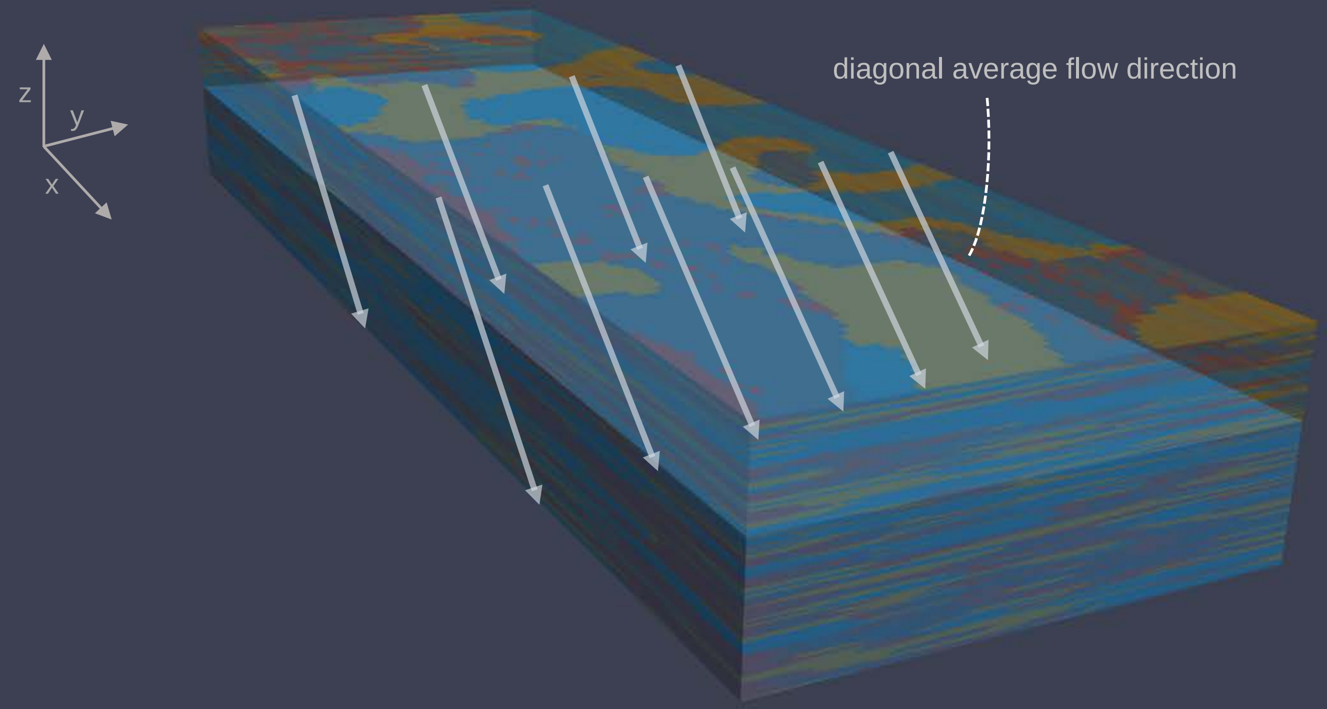
Method
Regional flow conditions



2 main large scale controlling forces:

- Uniform recharge rate (transverse vertical flux):
  6×10^{-4} m/d (9 in/y)
- Regional gradient (longitudinal flux):
  0.001
- Steady-state

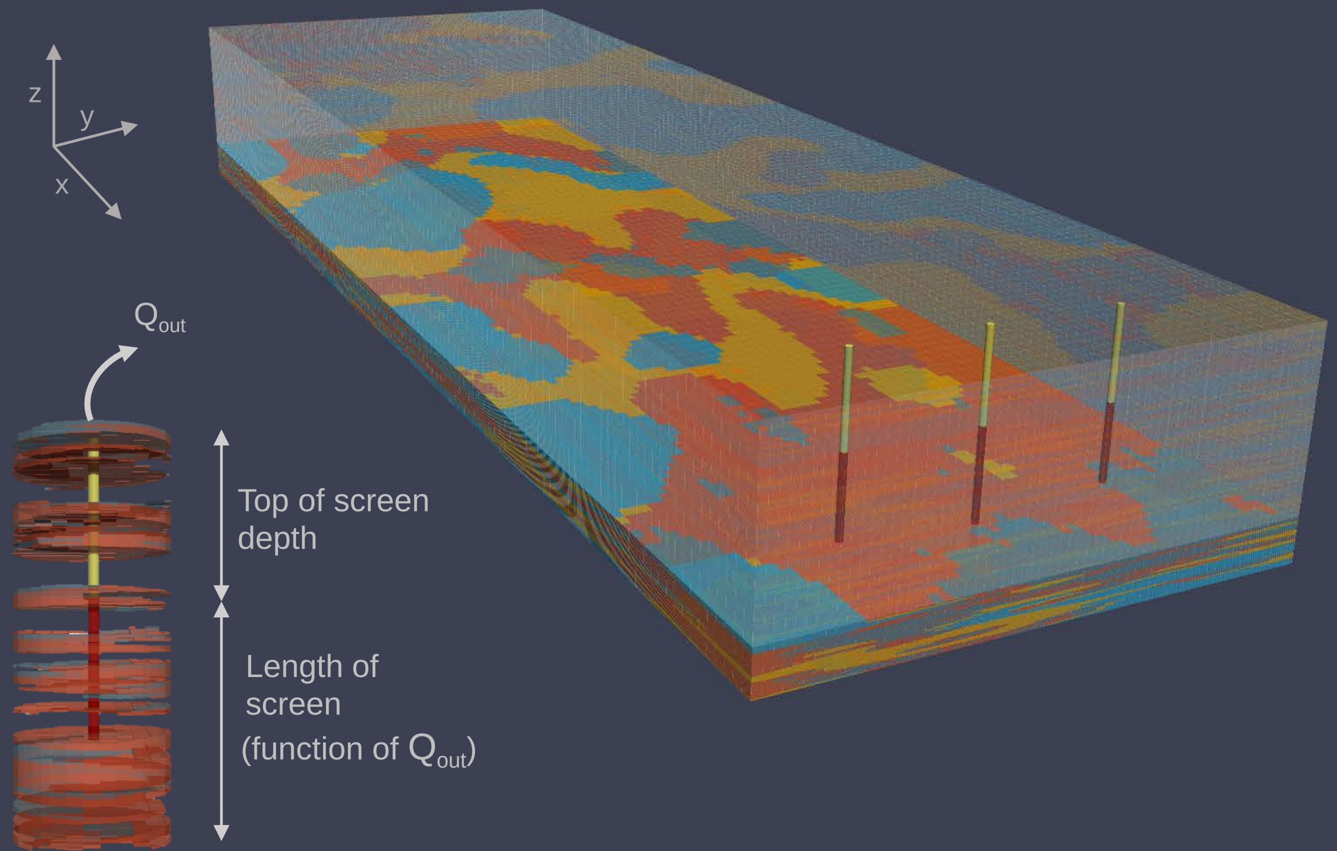
Method
Regional flow conditions



2 main large scale controlling forces:

- Uniform recharge rate (transverse vertical flux):
  $6x10^{-4}$ m/d (9 in/y)
- Regional gradient (longitudinal flux): 0.001
- Steady-state

Method
Extraction wells



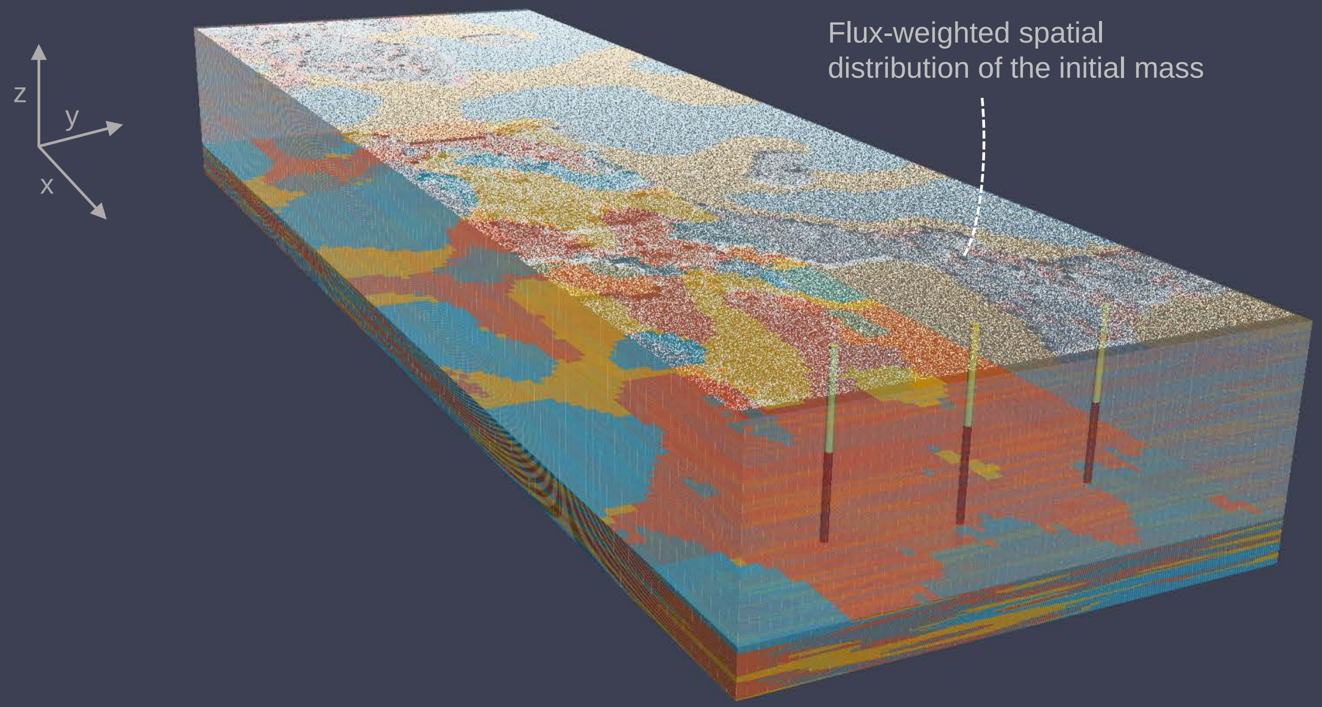
3 extraction wells

- Extraction rates:
  750.0, 1500.0, 3000.0, and 6000.0 m^3/d
  137.6, 275.2, 550.4, 1100.7 g/mn
- Top of the screen depth:
  50.0, 100.0, and 150.0 m
  164.0, 328.1, 492.1 ft

- Length of the screen depends on the facies crossed by the well:
  10 ft. of sand and gravel for every 100 gpm of pumping

Method

Contaminant transport



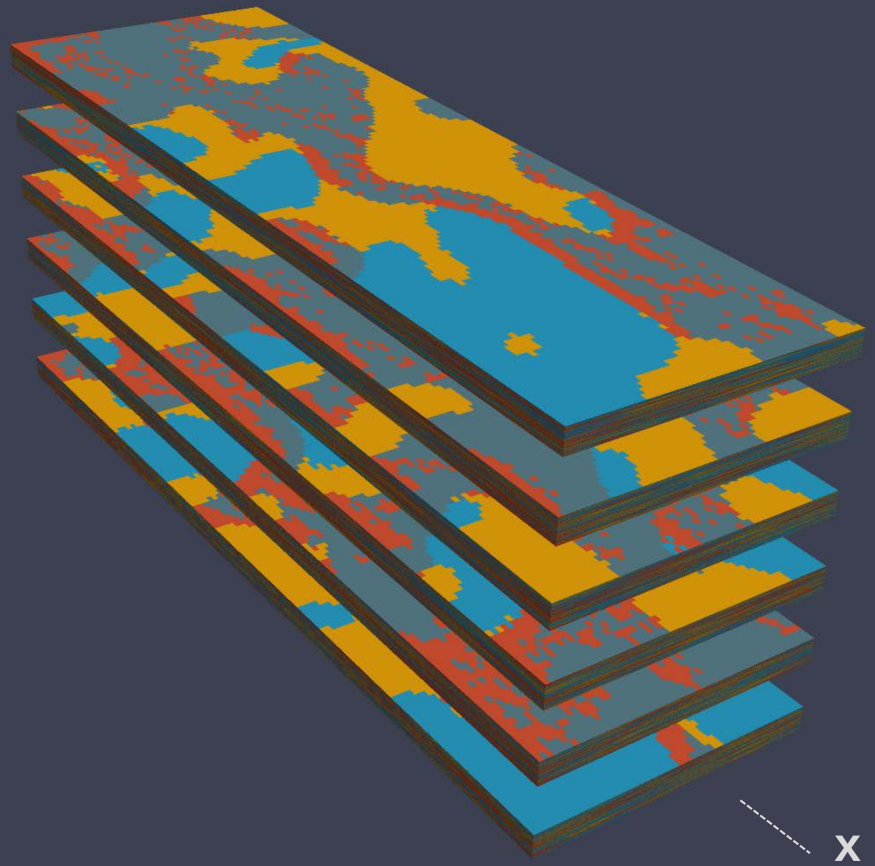
Advective transport using particle tracking (RW3D)

Following 1 000 000 particles for 400 years of simulations (all are recharged at t=0)

Outputs (for each well):

- Cumulative breakthrough curves (arrival times)
- Contributing areas (original location of particles reaching a well)

Method
Stochastic framework



Generate 50 equally probable hydraulic conductivity fields to:

- Account for uncertainty in the spatial distribution of the hydraulic property;

or

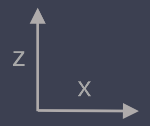
- Analysis of 3 x 50 wells at different locations.

① Generate realization → ② Solve flow → ③ Solve transport → ④ Breakthrough curves & contributing areas

Plume spatiotemporal evolution

) years long
ulation

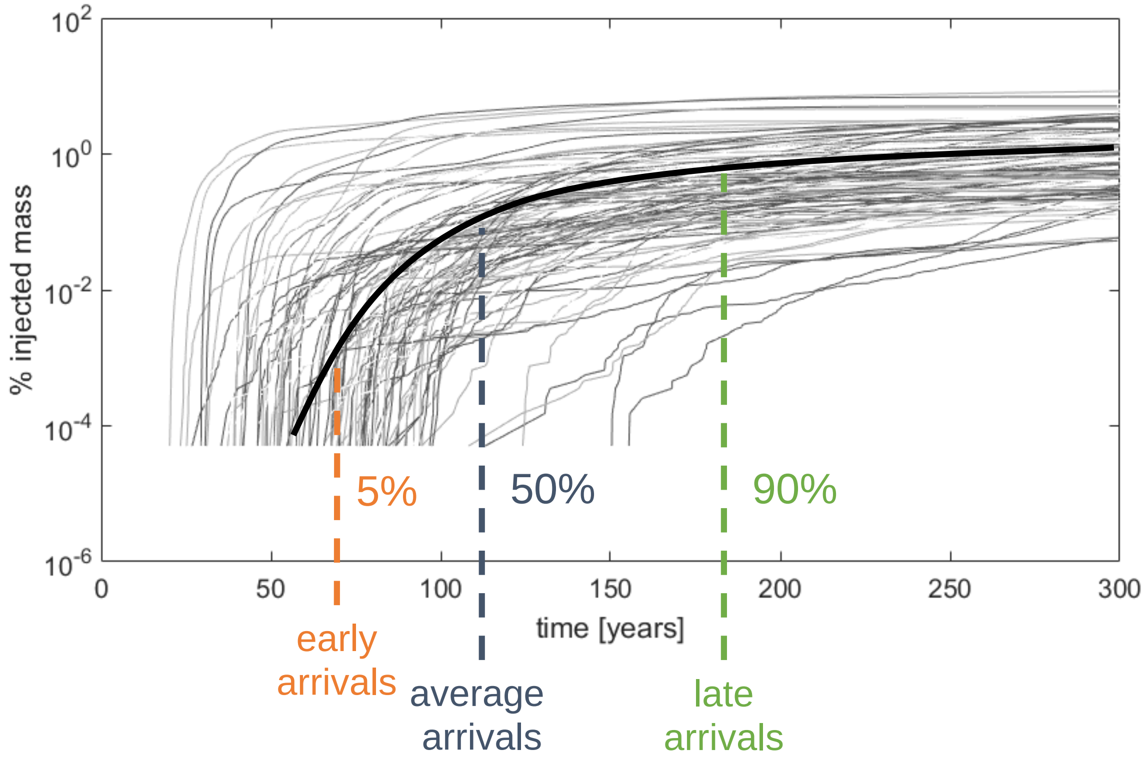
ears between each
pshot



Results

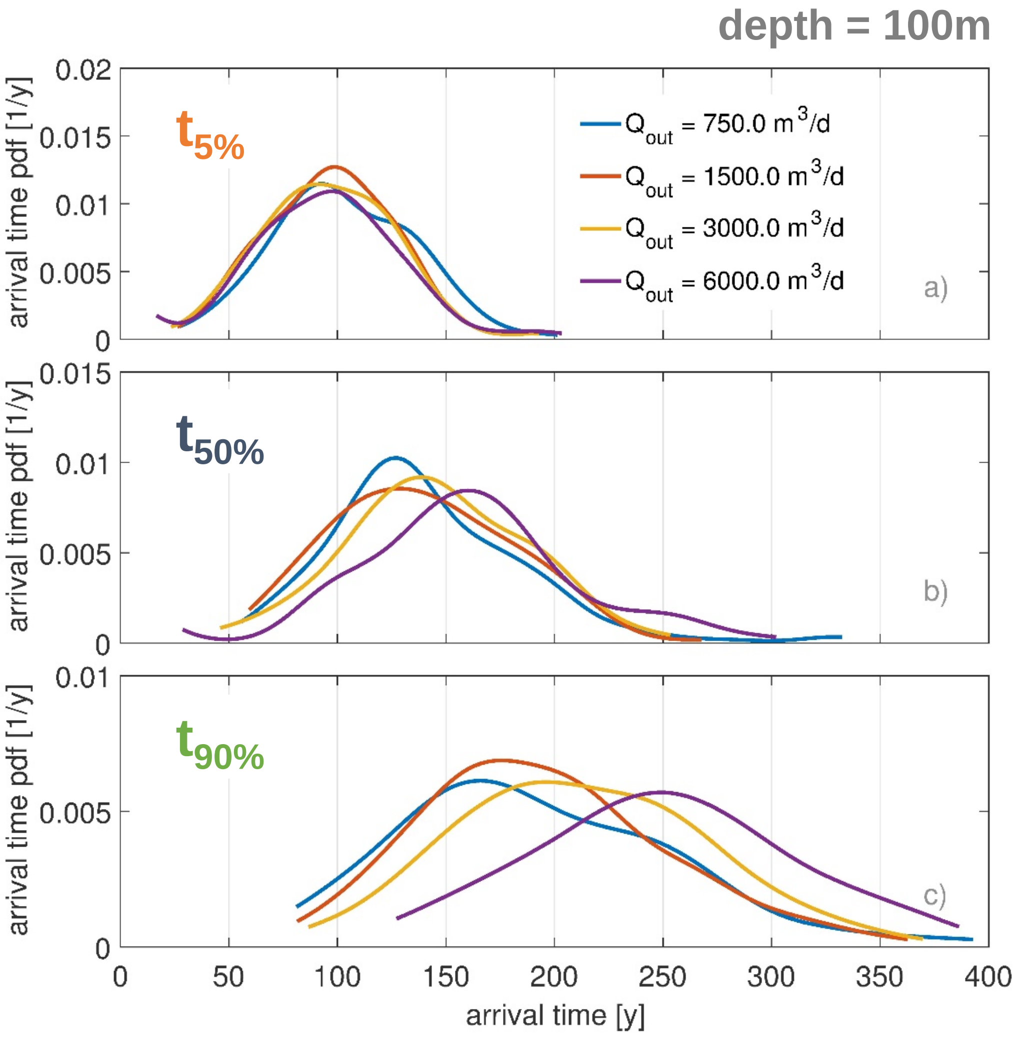
Impact of extraction rate: Travel times

150 wells: breakthrough curves (for each set of well parameters)



Results

Impact of extraction rate: Travel times

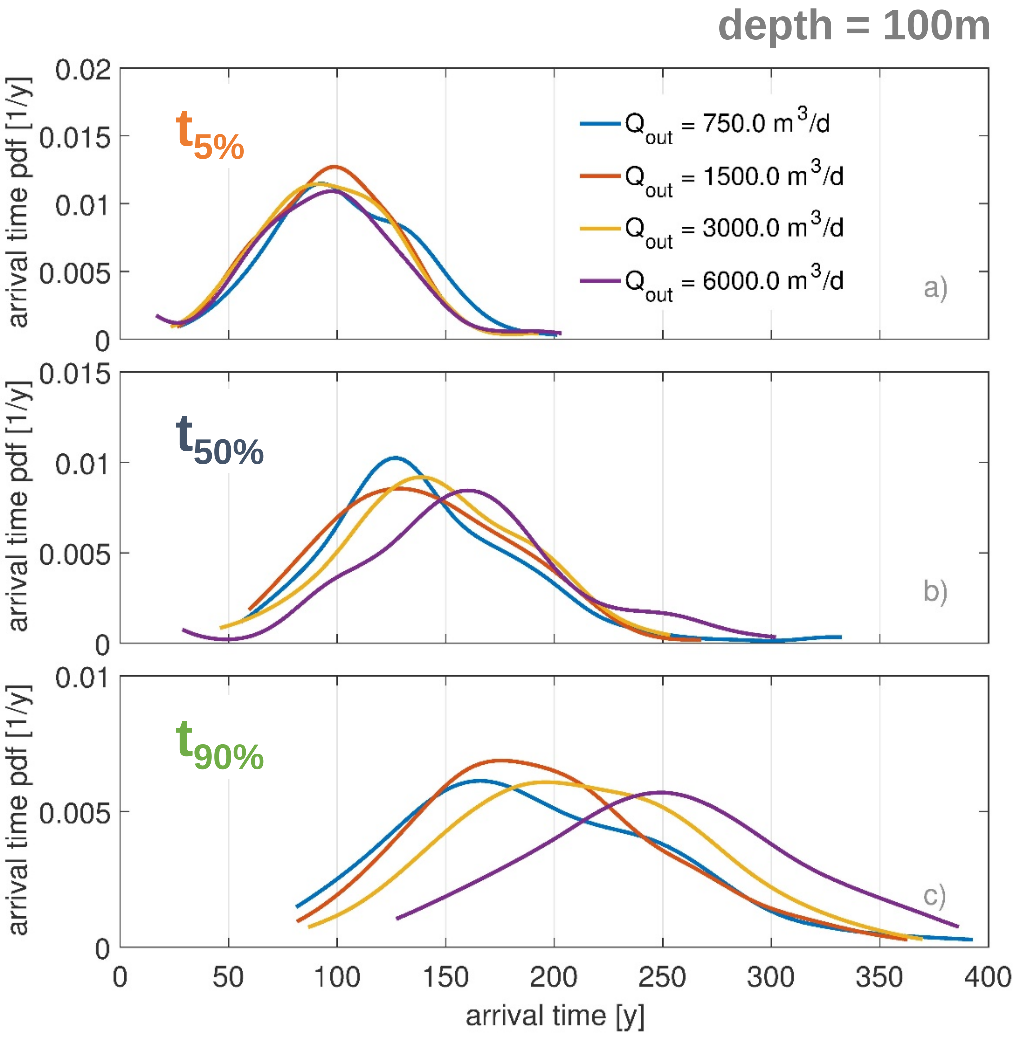


Observations:

- 5% of the total mass typically arrives after 50 - 140 years
- 50% of the total mass typically arrives after 100 - 200 years
- 90% of the total mass typically arrives not before 120 years
- With very **high uncertainty**

Results

Impact of extraction rate: Travel times

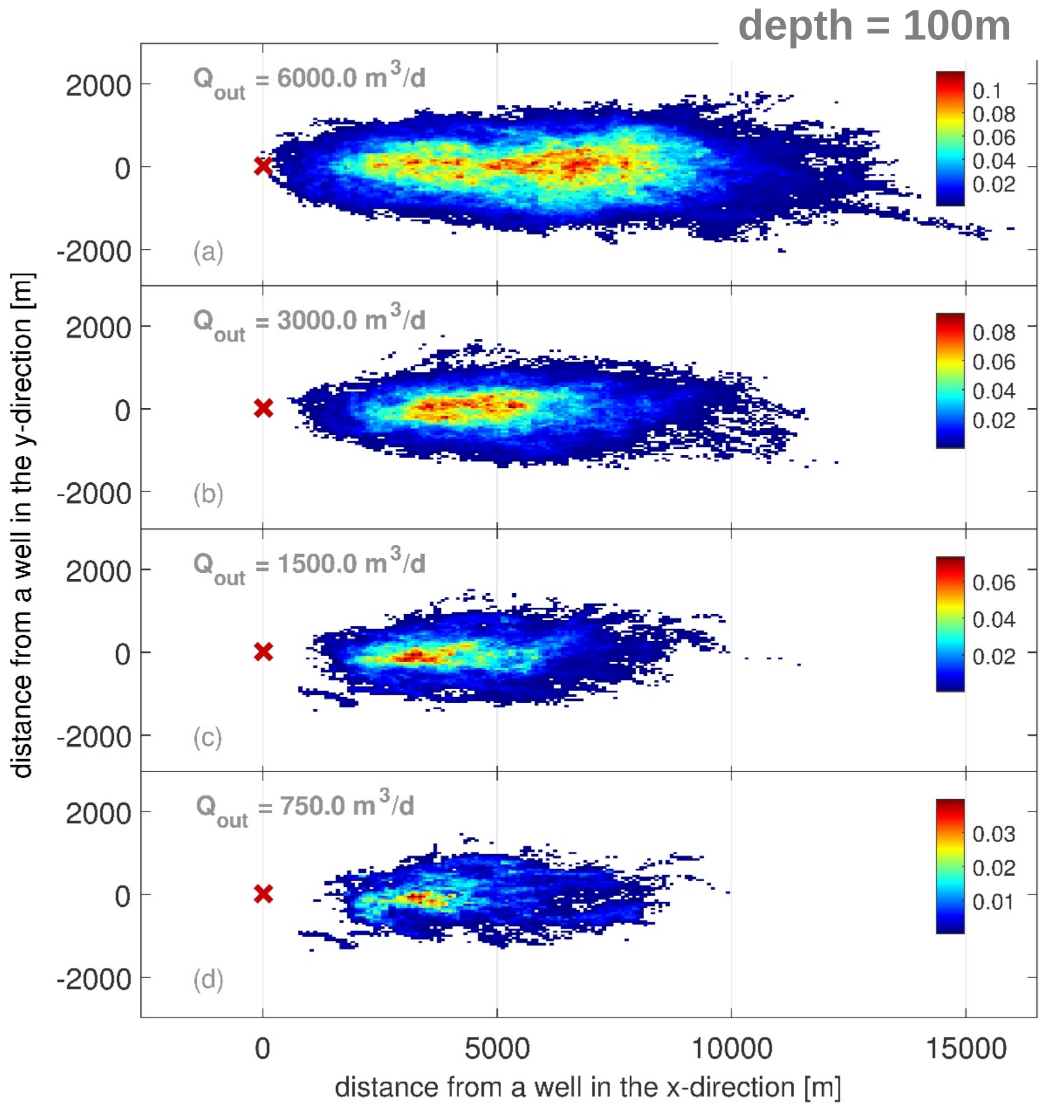


Observations:

- No real impact of Q_{out} on early arrivals
- Delayed late arrivals for high Q_{out} due to increased amount of recorded mass (larger length of screens)

Results

Impact of extraction rate: Contributing areas



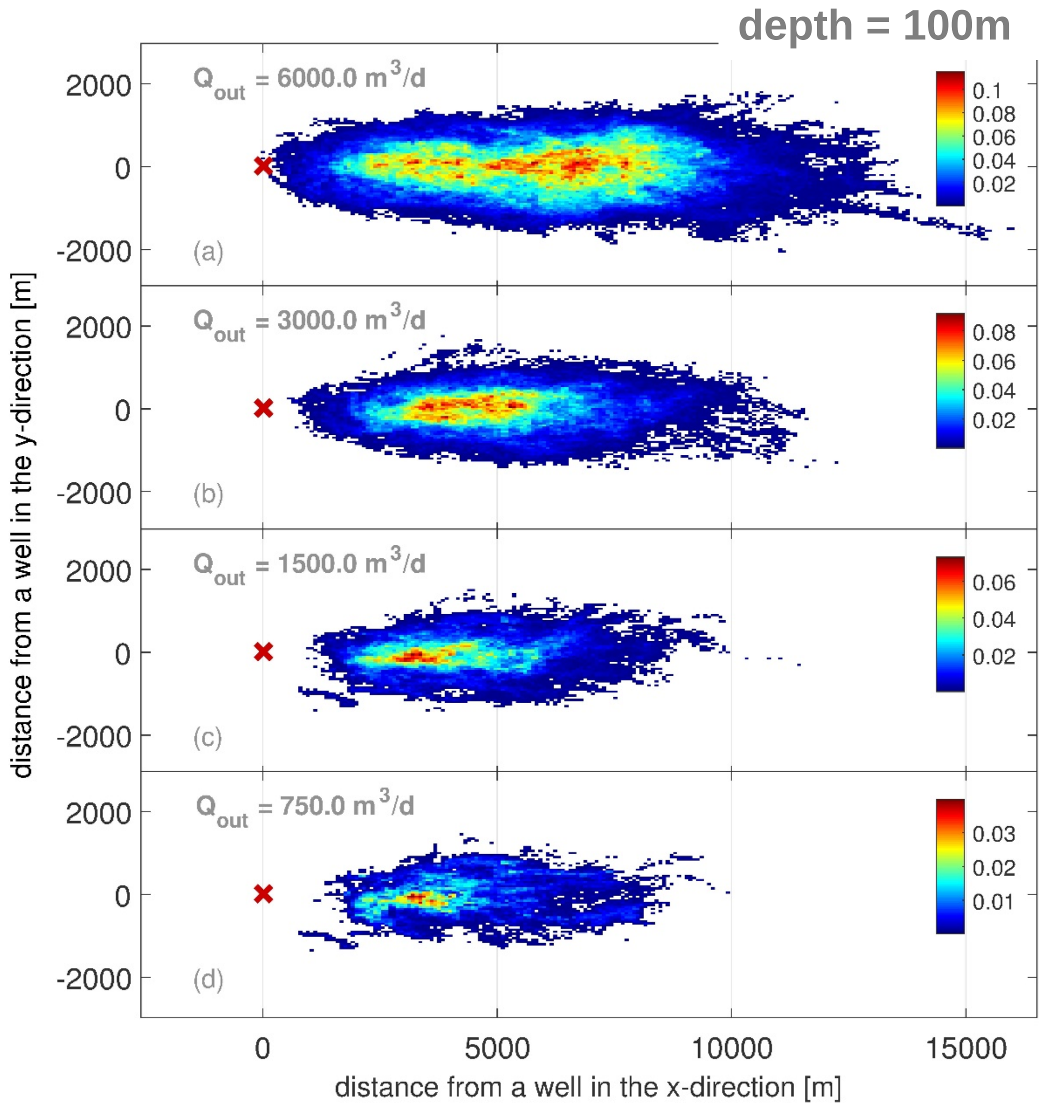
Probability of a pollutant leaving a location to reach an extraction well
(proportion of particle leaving a given cell that reached a well)

Observations:

- Probable contributing area (CA) extended over 12x3 km (7.5x1.9 mi)
- Low probability to reach the well on a very large portion of the CA
- More spatially restricted *hot spot* (area of large probability to reach a well)

Results

Impact of extraction rate: Contributing areas



Probability of a pollutant leaving a location to reach an extraction well
(proportion of particle leaving a given cell that reached a well)

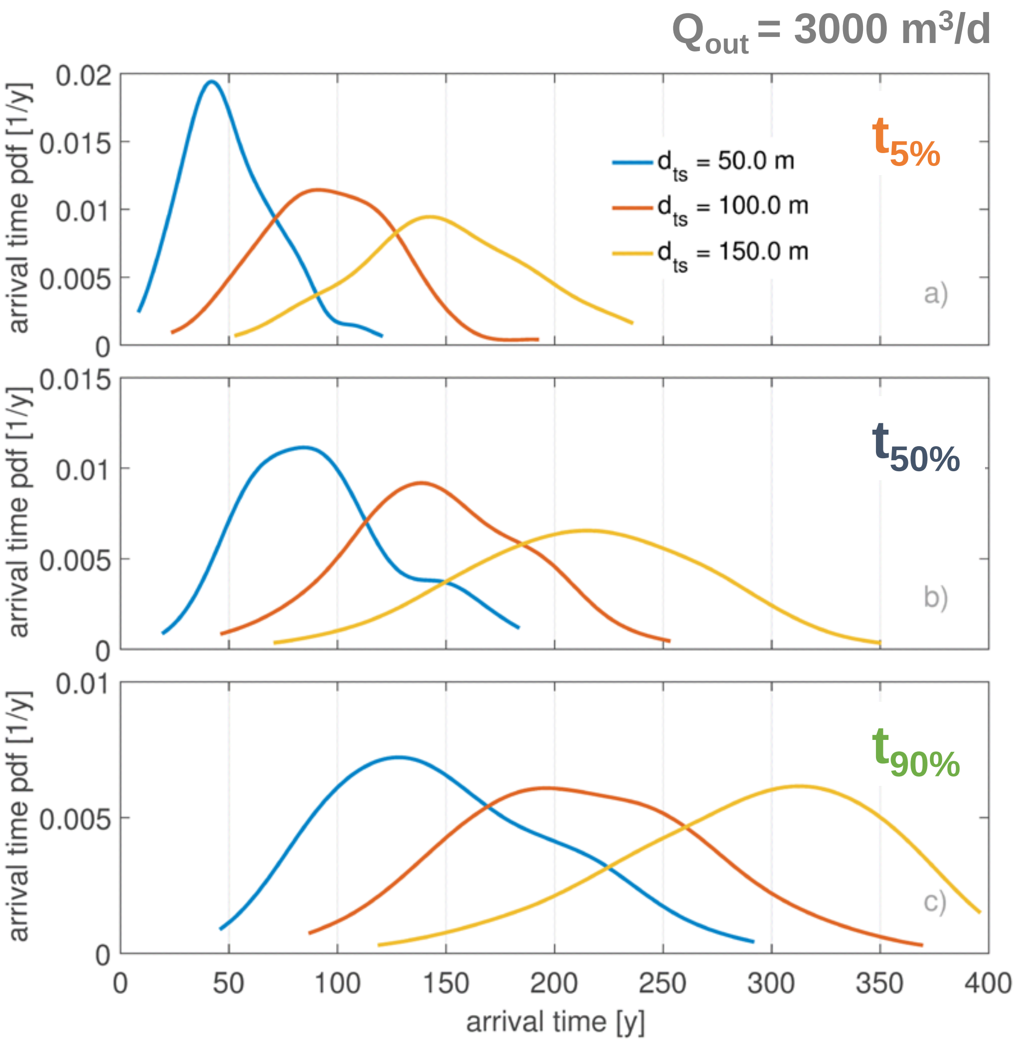
Observations:

- More extended CA and *hot spot* for large Q_{out}

  Could be explained by deeper wells for large Q_{out}

Results

Impact of well depth: Travel times

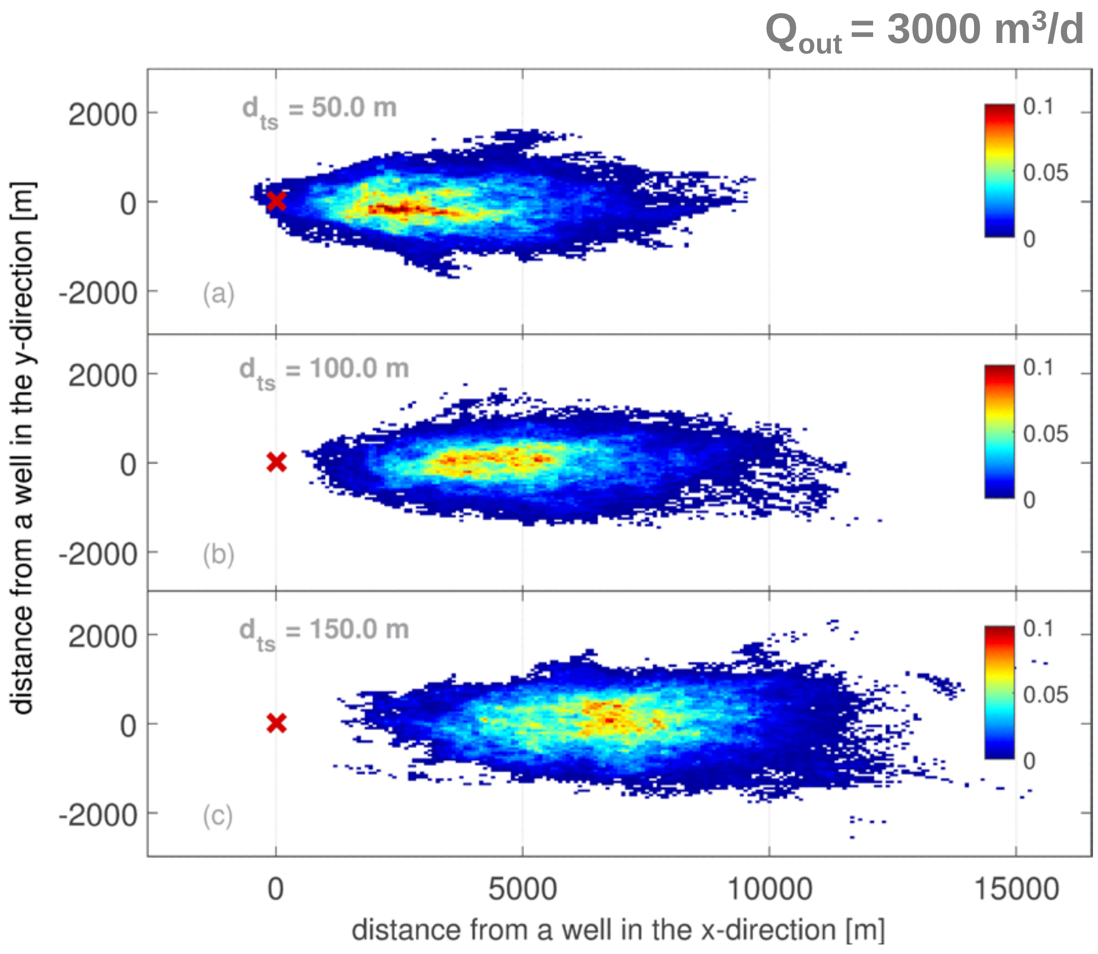


Observations:

- Great impact of well depth on arrival times
- Deeper wells increase travel times and **uncertainty**

Results

Impact of well depth: Contributing areas



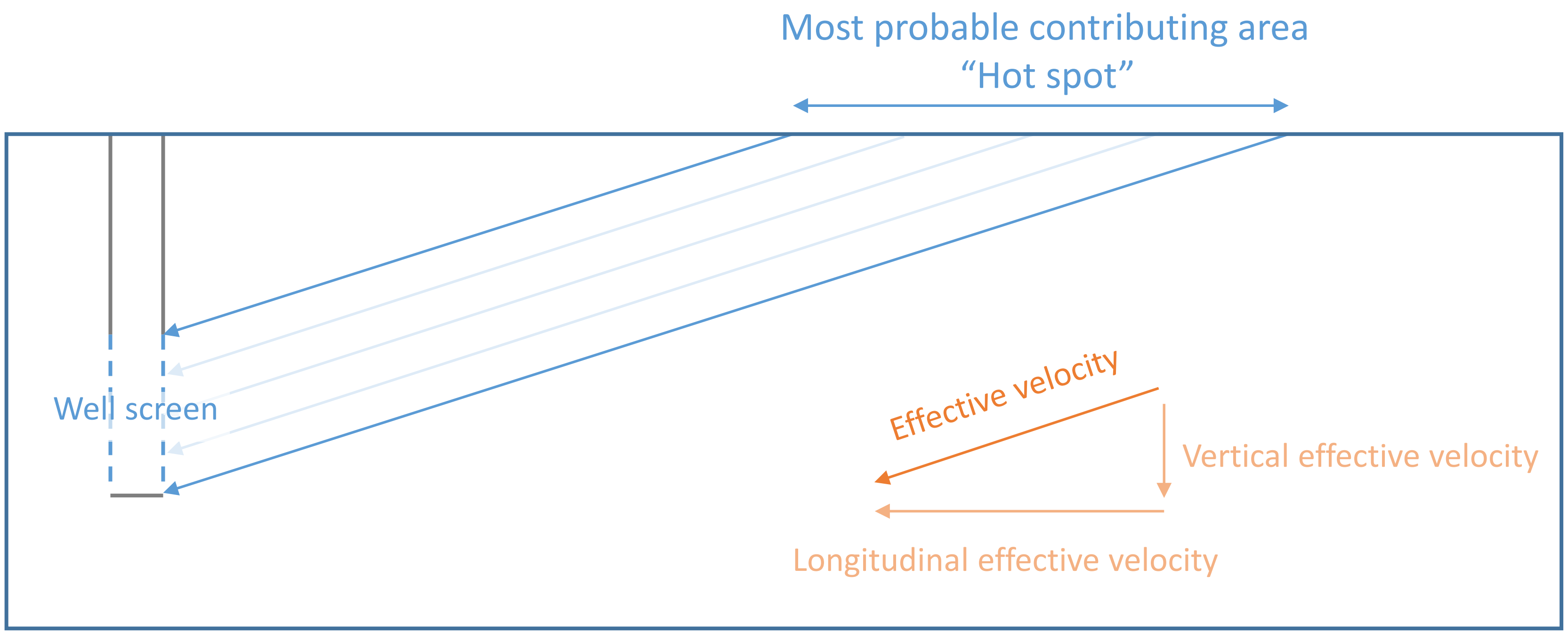
Probability of a pollutant leaving a location to reach an extraction well
(proportion of particle leaving a given cell that reached a well)

Observations:

- Contributing area and hot spot moved upstream
- Globally identical extension of the capture zone

Discussion

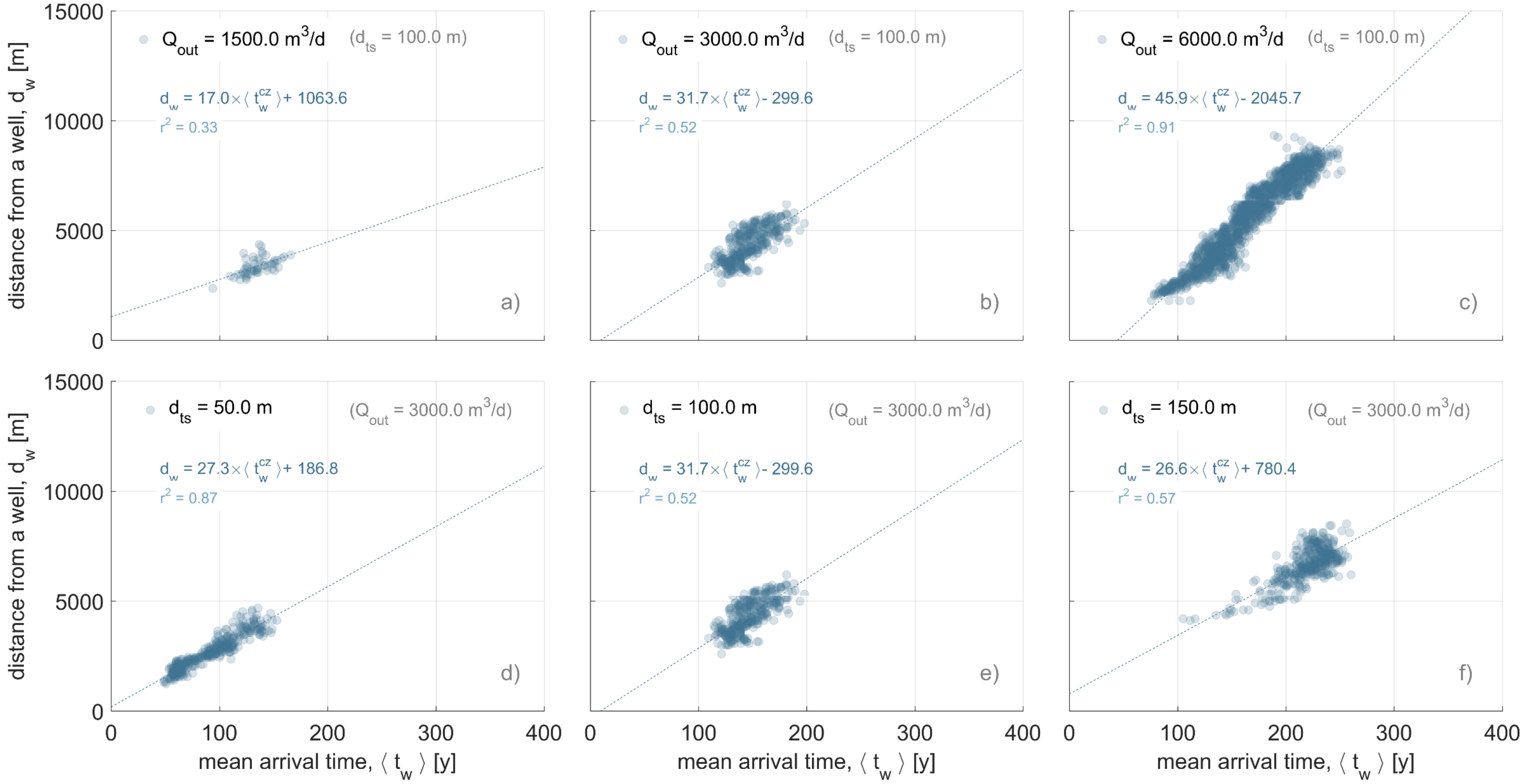
Predicting the hot spot location?



Could we predict hot spot location from sub-regional scale effective velocities?

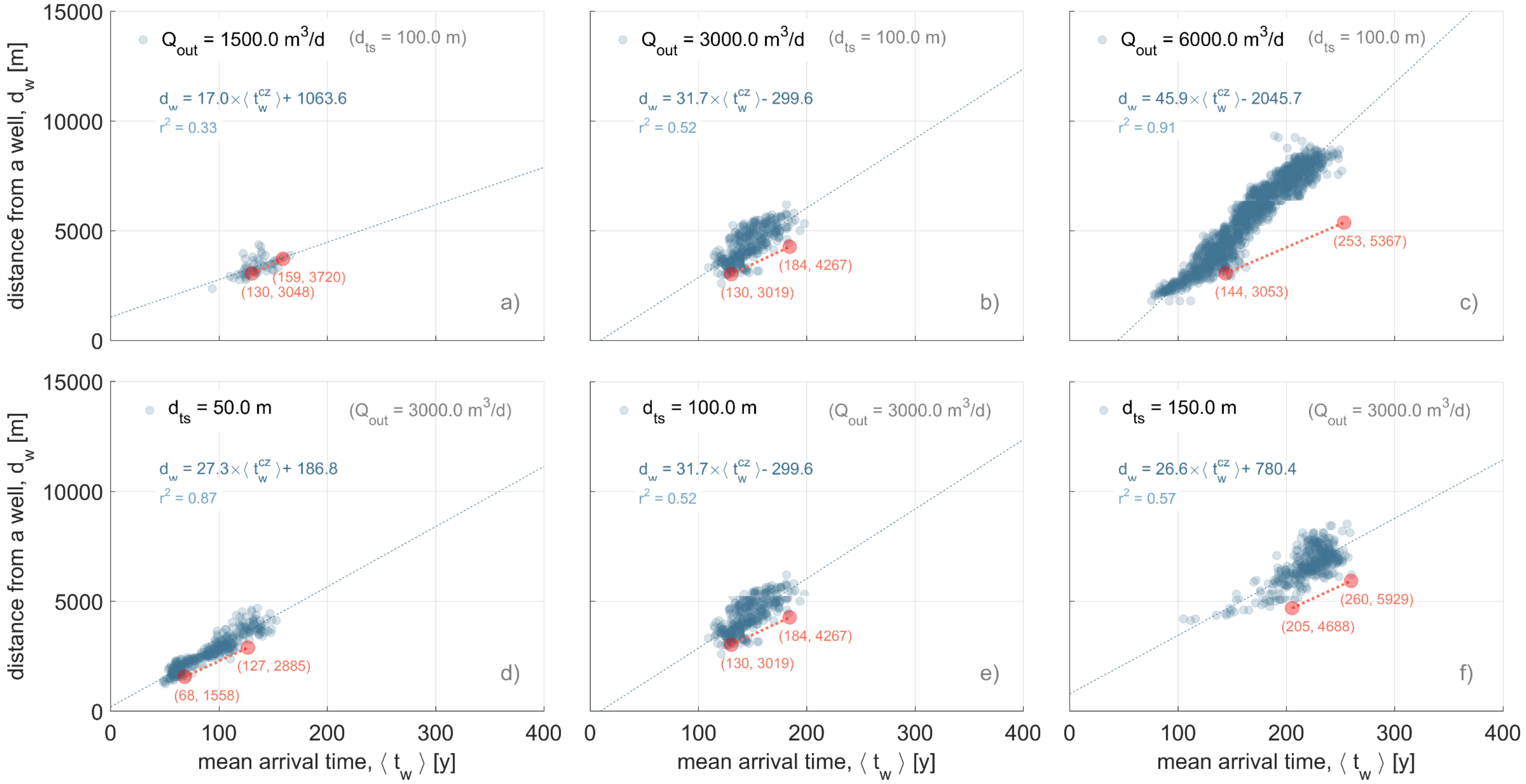
Discussion

Predicting the hot spot location?



Discussion

Predicting the hot spot location?



Concluding remarks

- First mass arrival after decade(s), late arrivals after century(-ies)
- Probable capture zone over kilometers, but more restricted hot spot
- Well extraction rate impacts late arrivals and the extension of the capture zone
- Well depth impacts all arrivals and the capture zone (and hot spot) location + increase prediction uncertainty
- Regional flow conditions could predict arrival times and contributing areas of shallow domestic / observation wells

Thank you