Salt load to an agricultural catchment: "*seepage flux times concentration*", or is there more to it than that?

Insights from a multi-scale tracer study

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- Brackish seepage → water quality issues

- Counteracted by fresh water intake from river Rhine

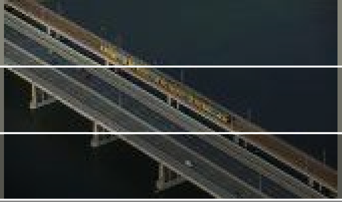
- Dry summers: fresh water scarcity (even in the Netherlands)

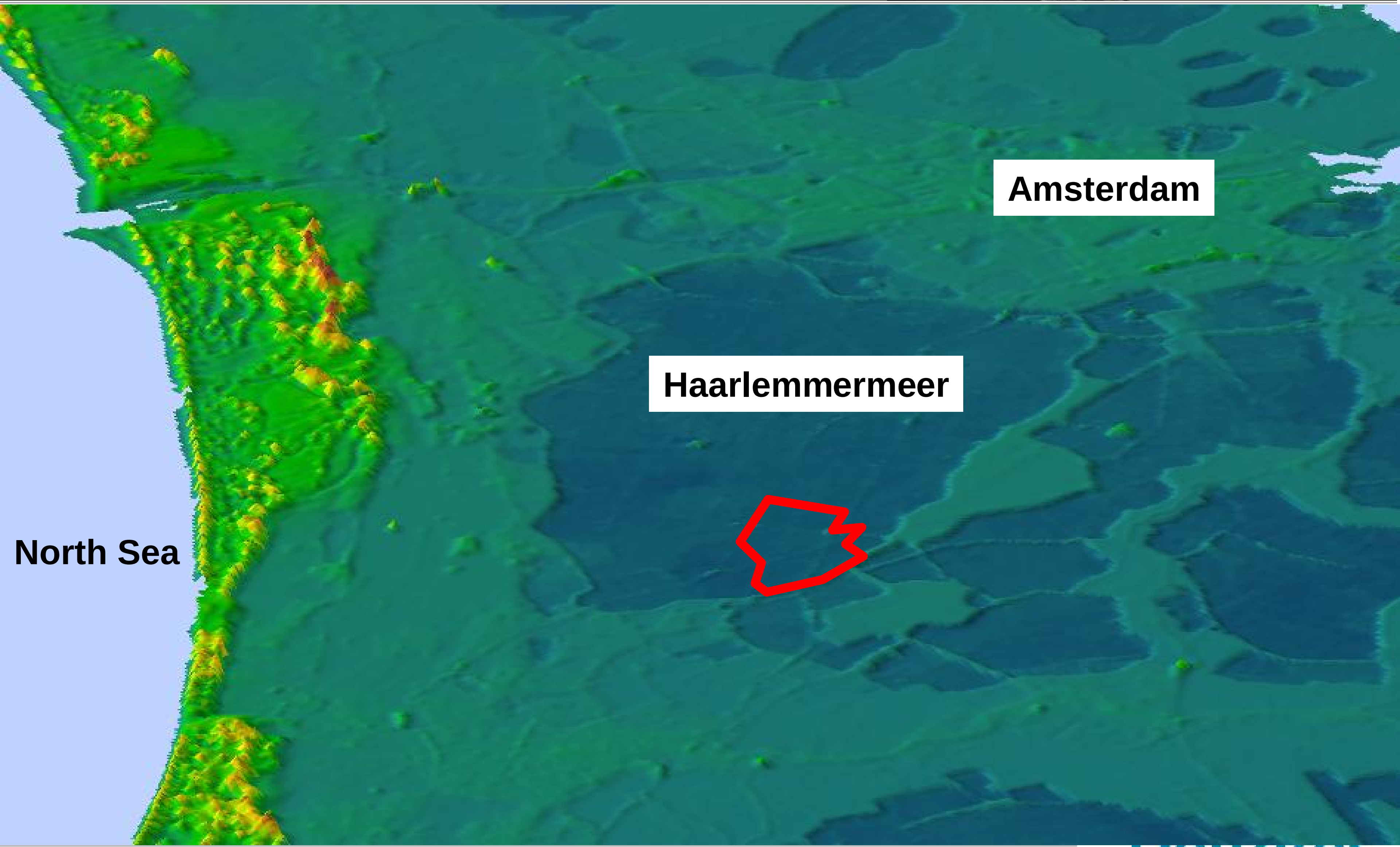
- Fresh water issues aggravated in future:
  - likely salt load increase
  - likely increase precipitation deficit
  - likely decrease Rhine discharge

→ **Investigate mechanisms driving water and salt fluxes in lowland polders**

→ **By separating hydrograph in sources using tracers**

Study area





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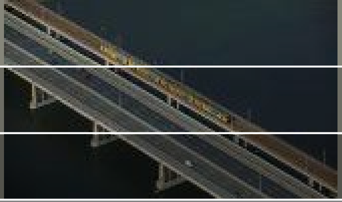
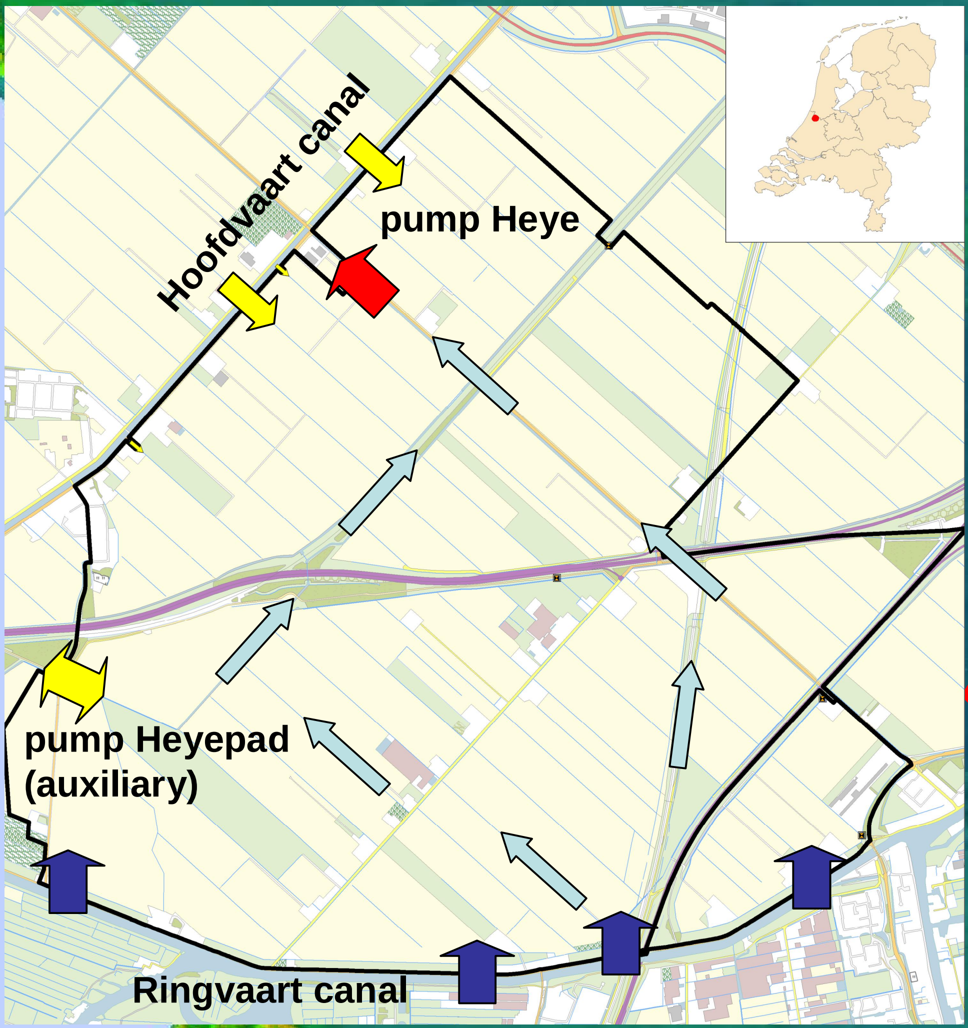
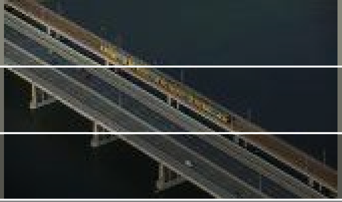


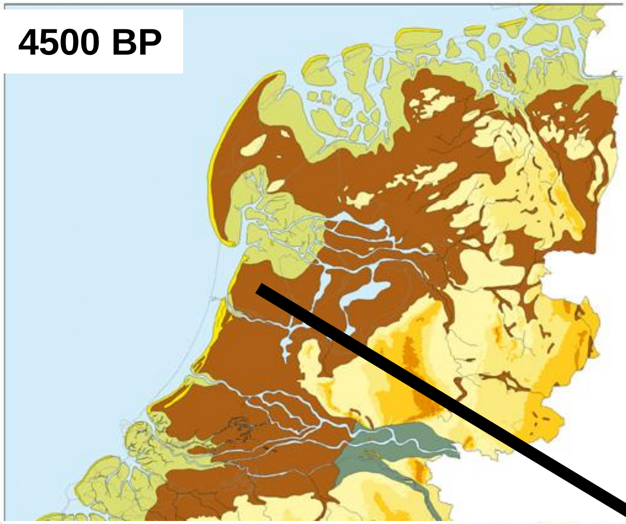


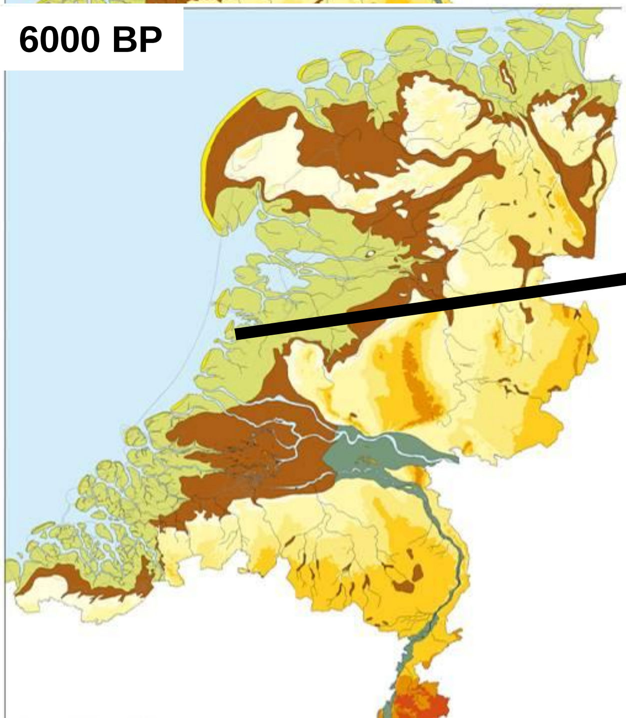
- Dutch deep polder catchment
- 10 km^2
- 5 m –MSL, artificially drained
- 70 km ditches, tile drains
- Agricultural: potatoes, beets and flowerbulbs

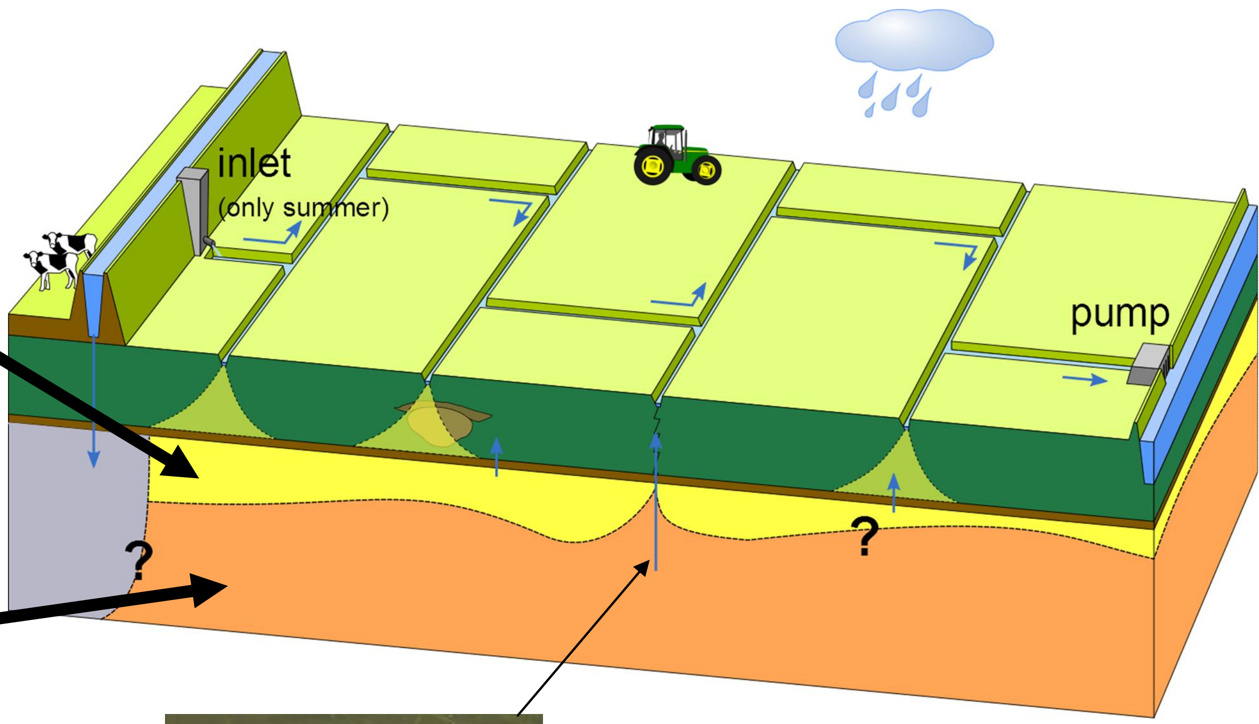
- Brackish seepage ~0.5 mm/d
- Seepage concentrated in boils
- Summer intake of Rhine water

Hydrogeology

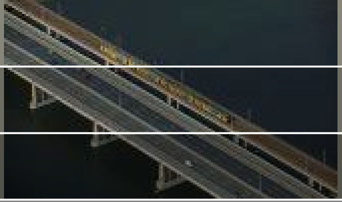








Method: End-member mixing

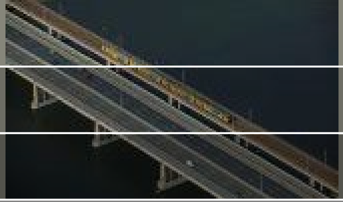


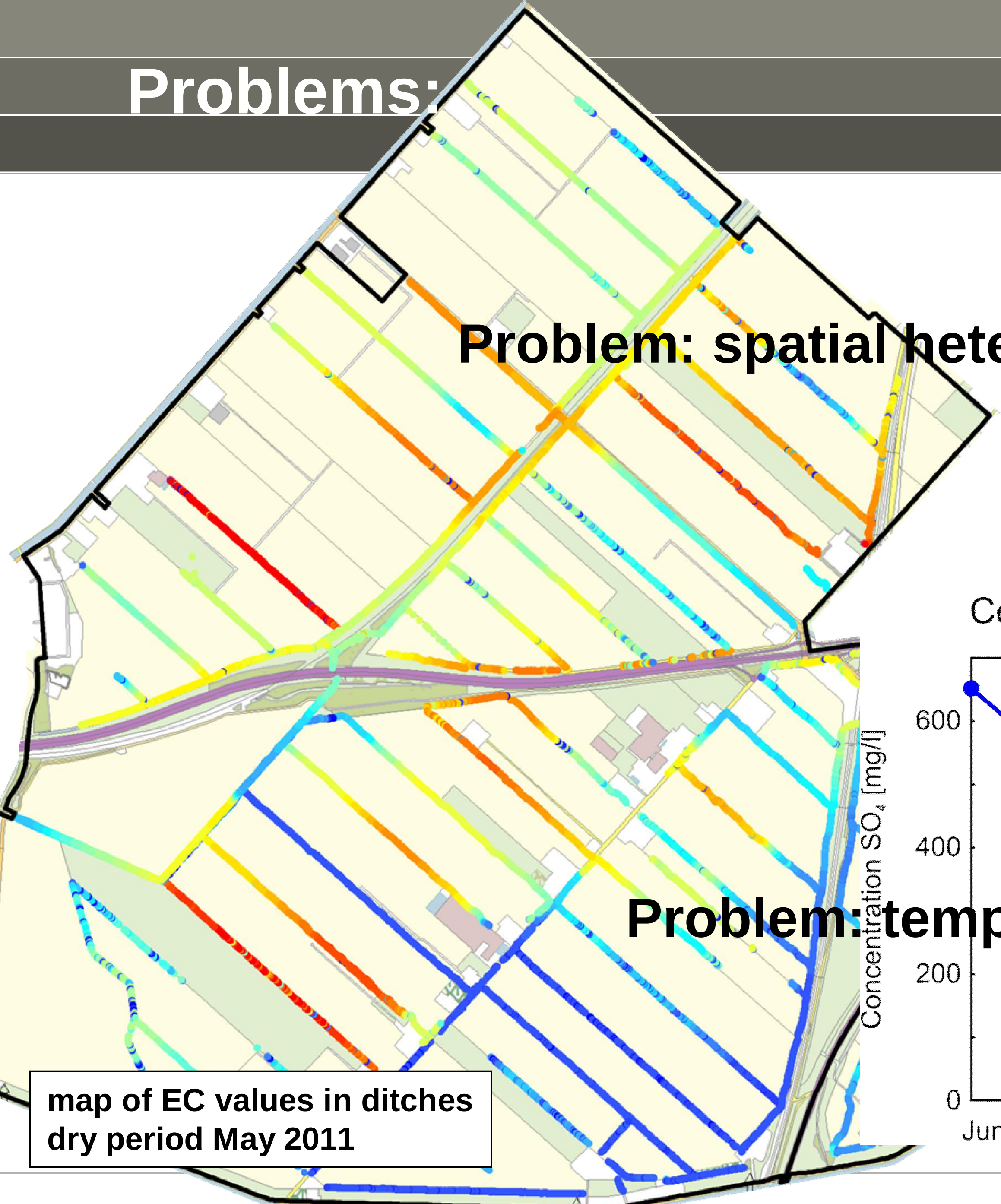
Hypothesis: Streamwater can be explained as a conservative mixture of different source solutions (end-members)

End-Member Mixing Analysis (EMMA): (Christophersen & Hooper, 1992; Hooper, 2003)

- Hydrograph separation using multiple tracers *simultaneously*
- Use more tracers than necessary (over-defined system) to test consistency of tracers → principal components
- Source solutions called "end-members"
  - Concentration more extreme than stream
  - Bound stream mixture

Problems:

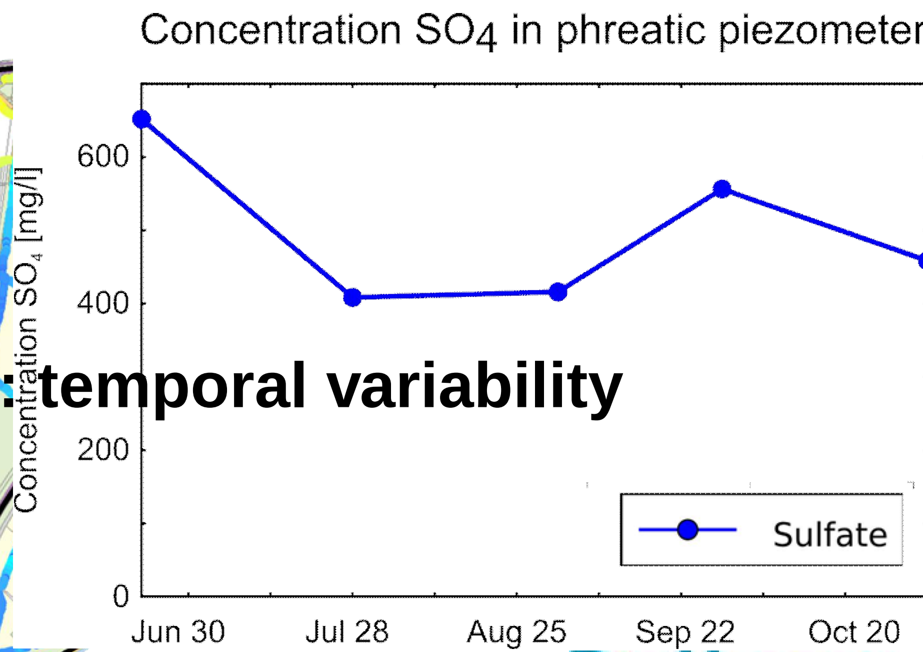


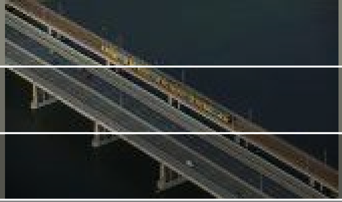


Problem: spatial heterogeneity

map of EC values in ditches
dry period May 2011

Problem: temporal variability





Extension: G(LUE-)EMMA

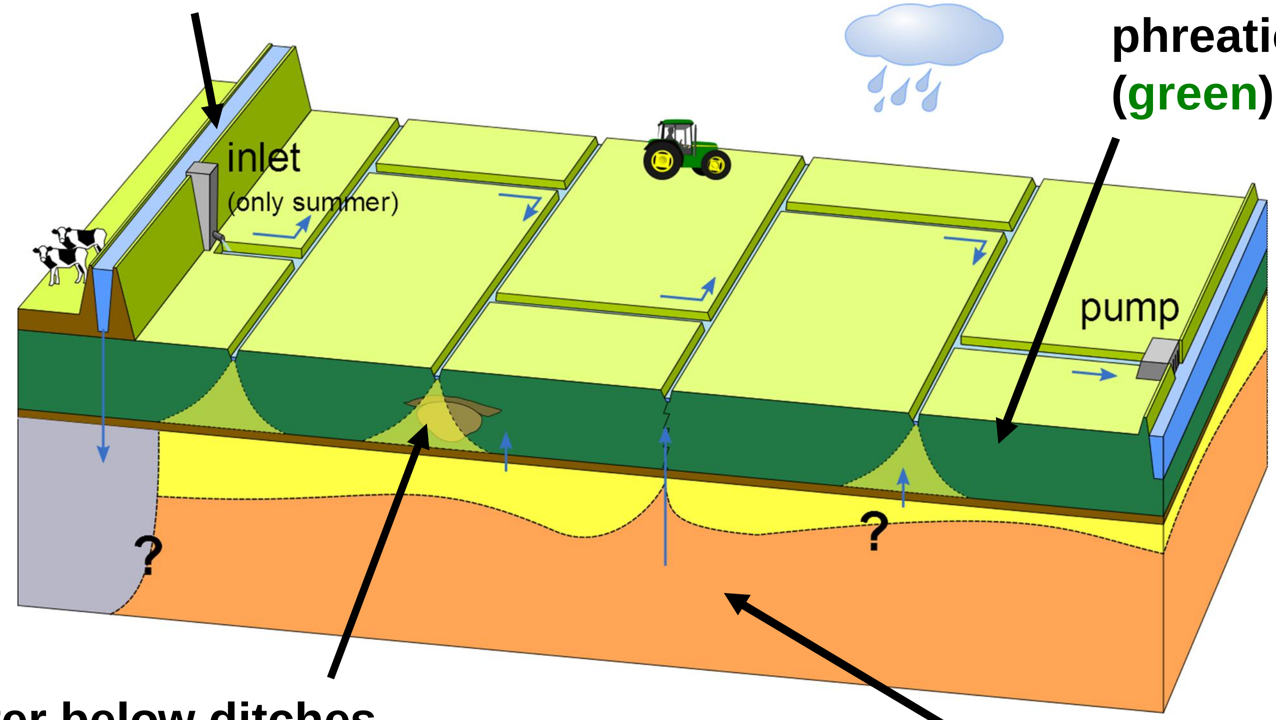
- Objective: **Quantify inherent uncertainty** in EMMA

- A GLUE (Beven & Binley, 1992) approach to EMMA:
  1. Determine uncertainty range of all end-member (and stream) solute concentration
  2. Monte Carlo:
     1. Draw n times from concentration ranges
     2. Solve inverse problem (least squares)
  3. Accept or reject result ('behavioural' or 'non-behavioural')
     - Sum squared residuals < 0.1 * n solutes
  4. Range accepted results equals uncertainty range

Discerned end-members

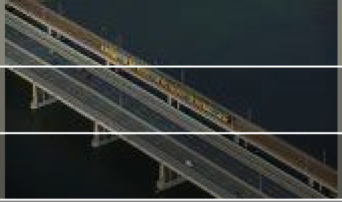
Inlet water
(blue)

Soil water /
phreatic groundwater
(green)



Groundwater below ditches
(yellow)

Deep aquifer groundwater
(orange)

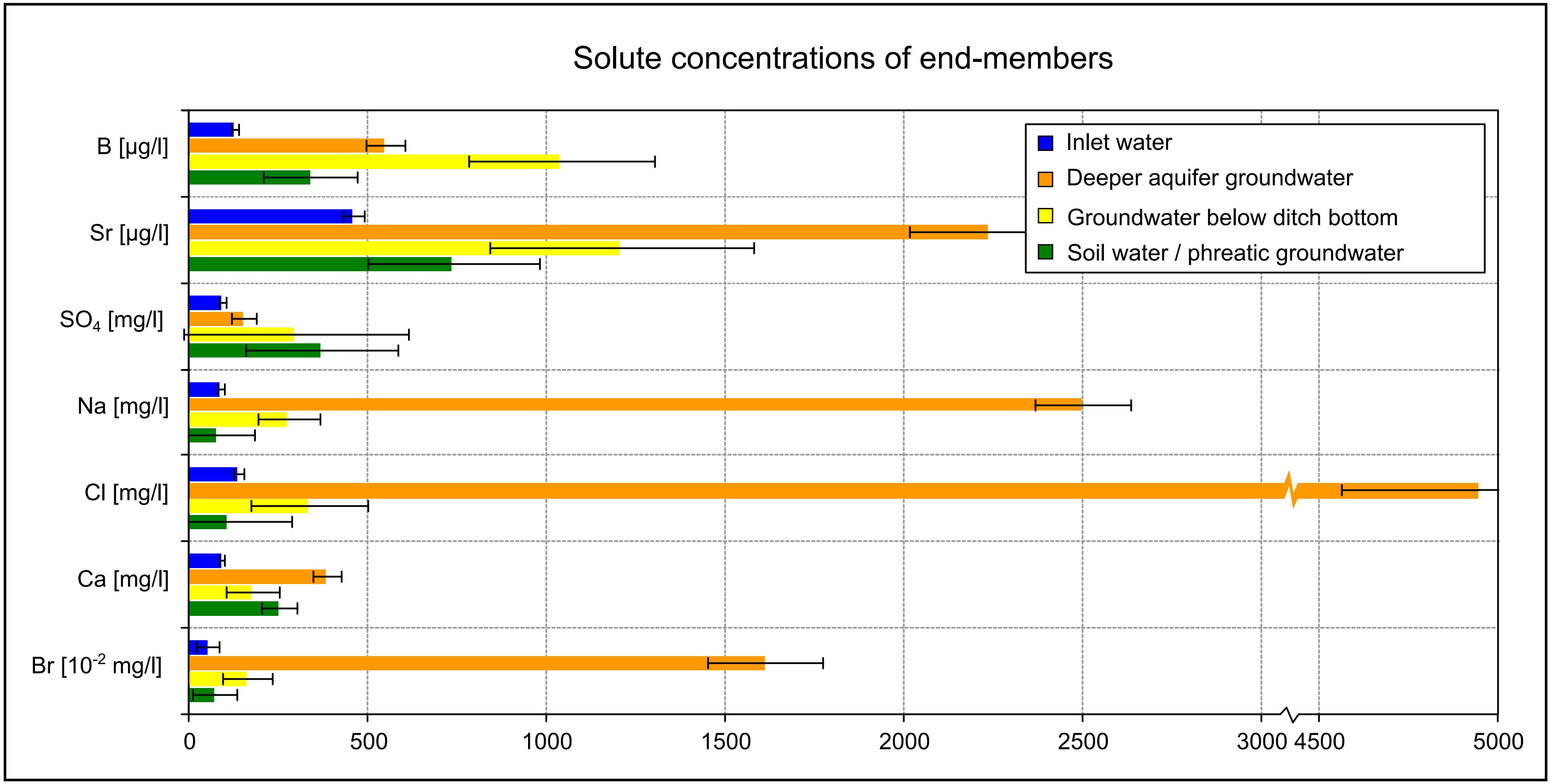


Sampling program

- Summer 2011: monthly sampling
  - Shallow piezometers
    - > on fields
    - > below ditch bottom
  - Intake water canal
  - Surface water in ditches
  - Precipitation
- October 2011: installation automatic sampler at catchment outlet
- Irregular sampling of end-member deep aquifer groundwater

End-member chemical signature

Solutes selected as tracer: B, Br, Cl, Ca, SO_4, Sr



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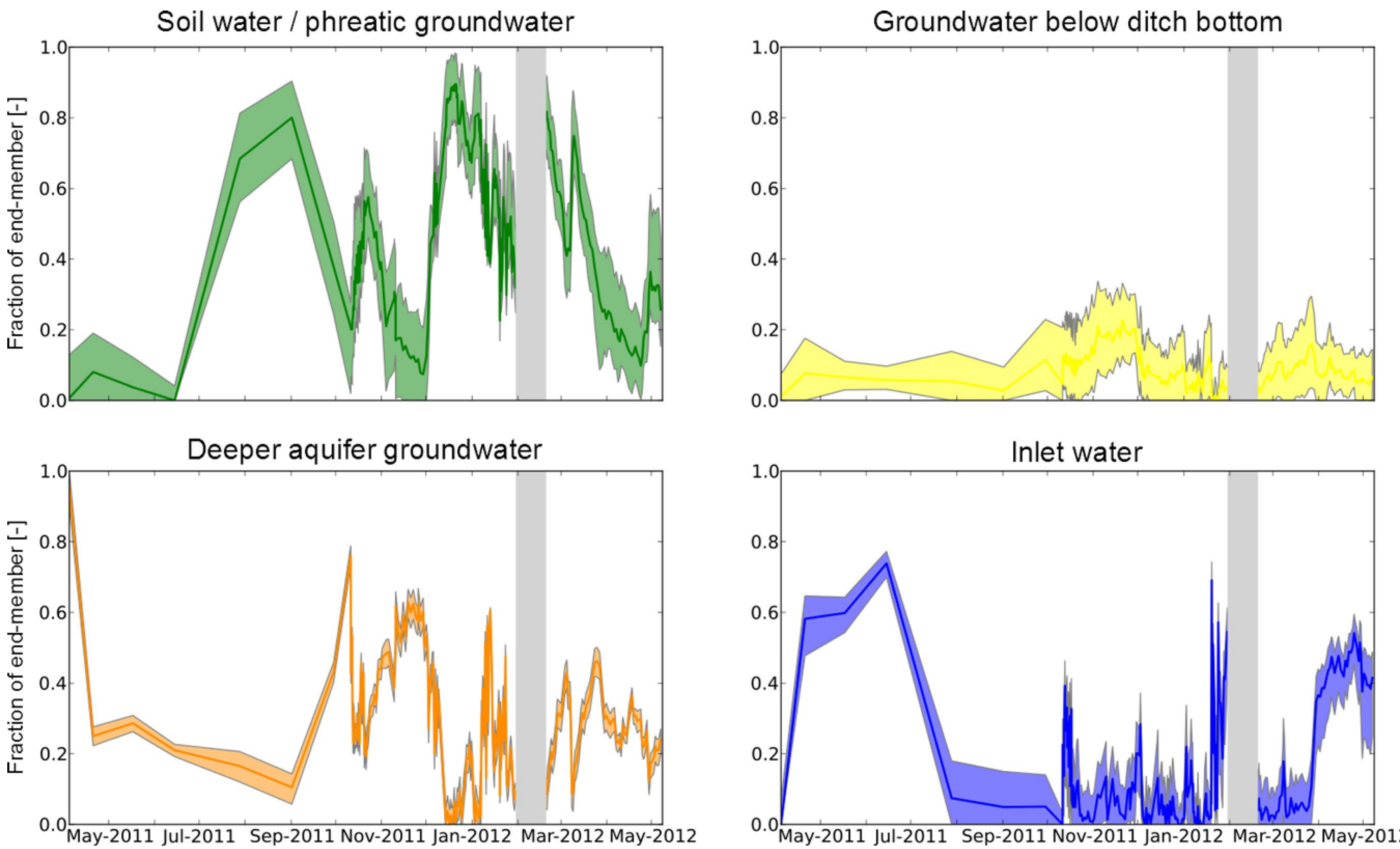
Result: End-member fractions + uncertainty



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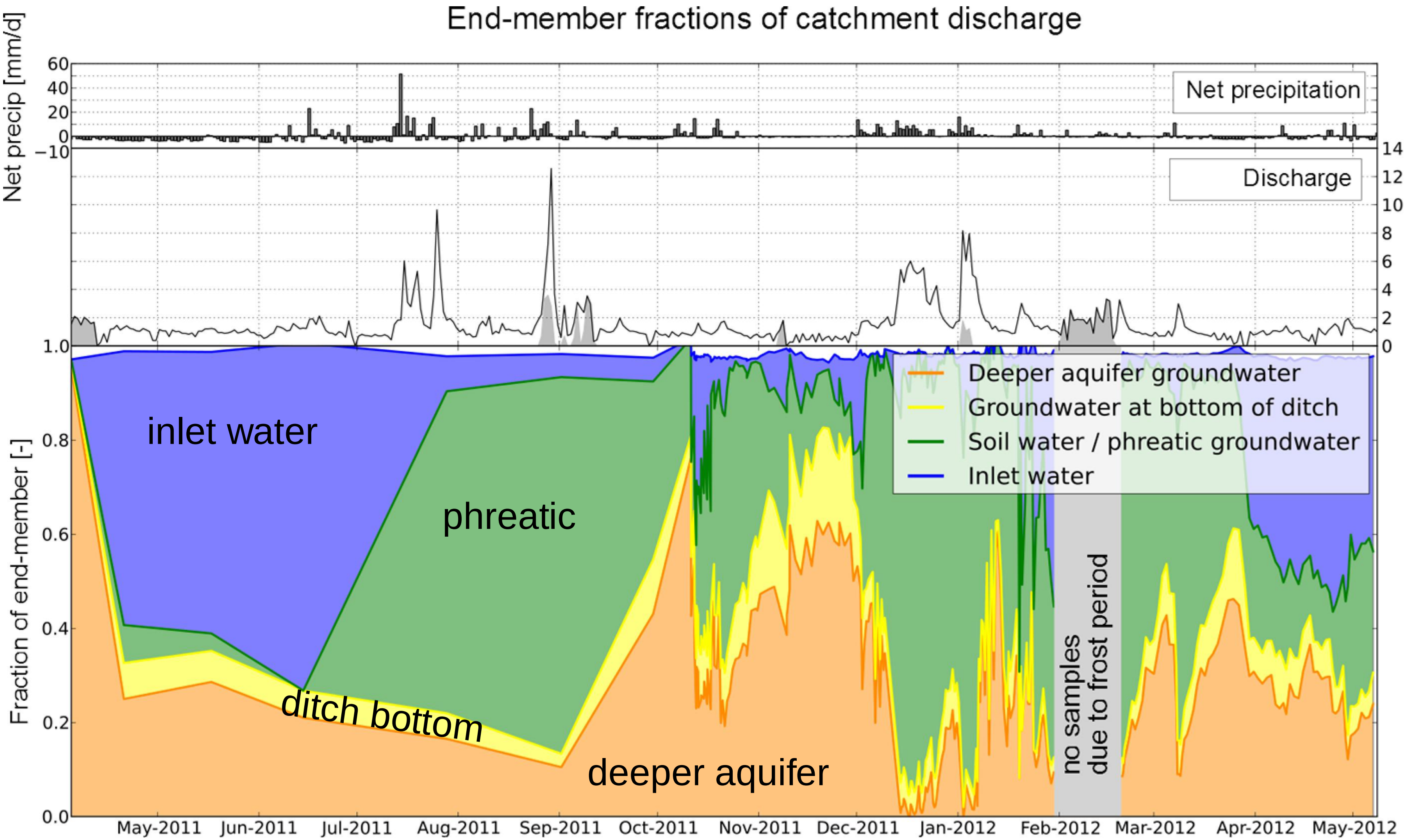
End-member fractions



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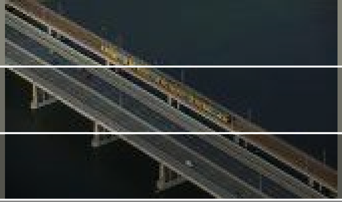
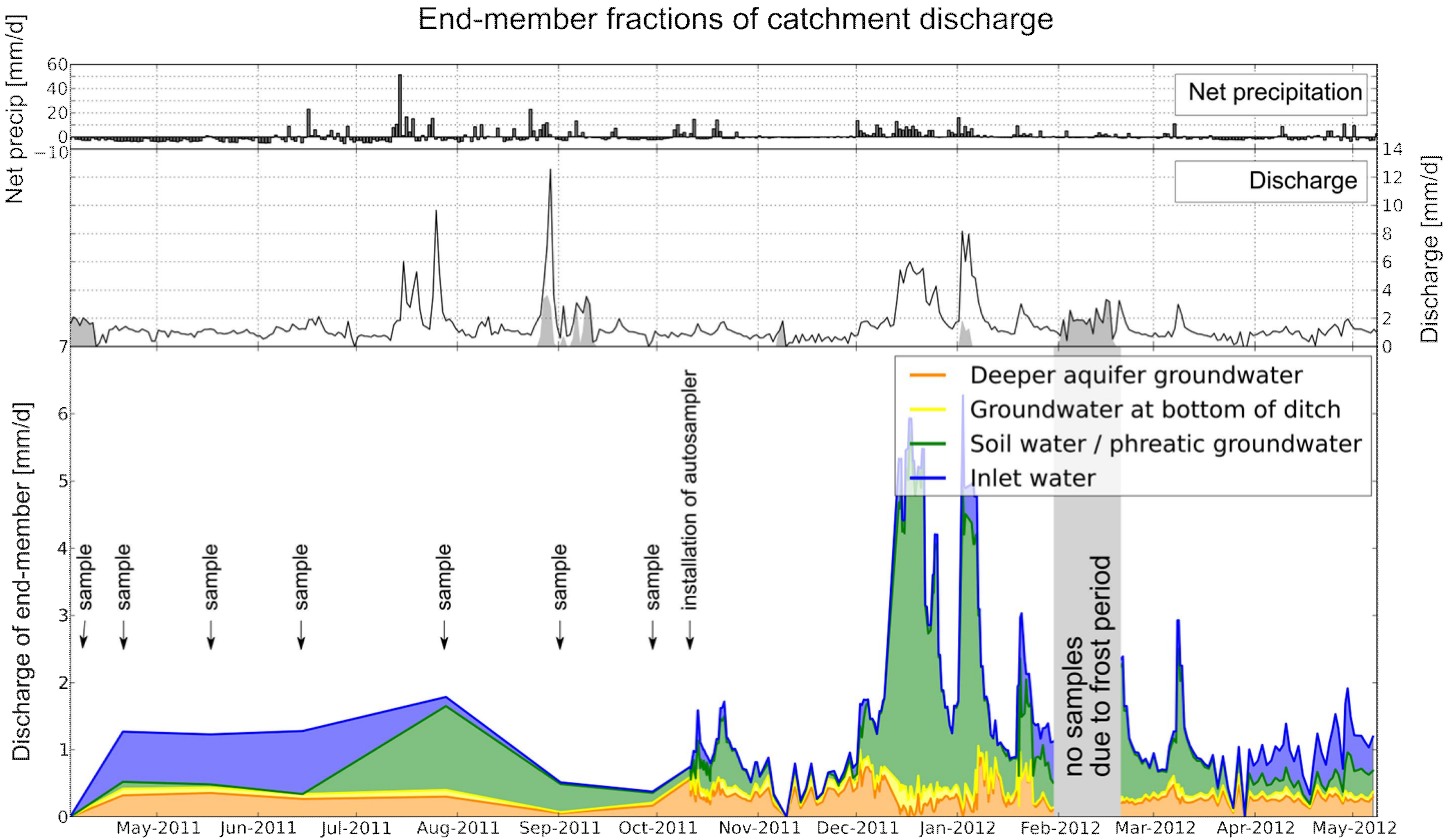
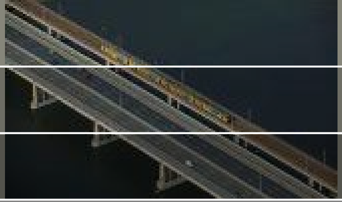
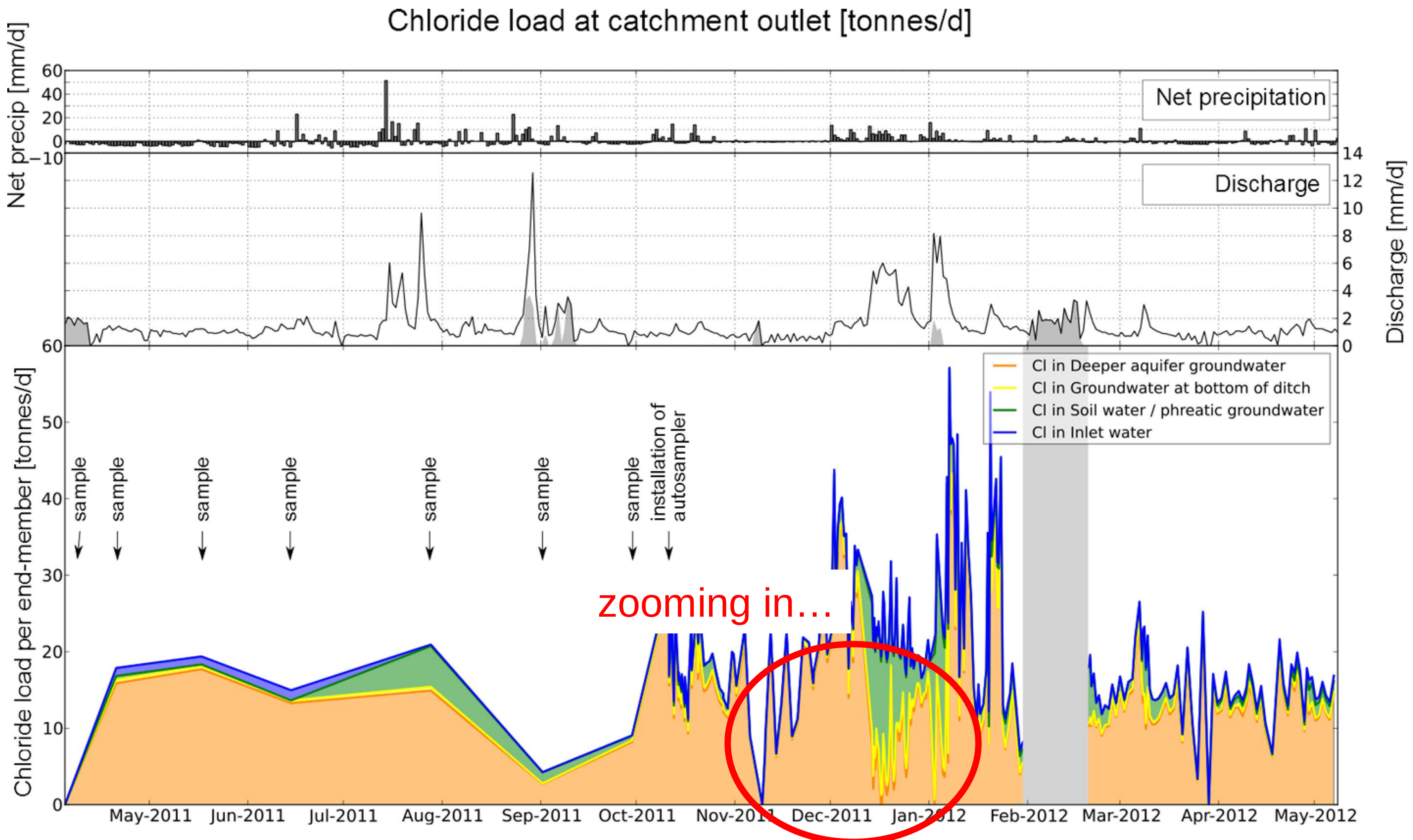
Fractions of hydrograph





Fractions of chloride load





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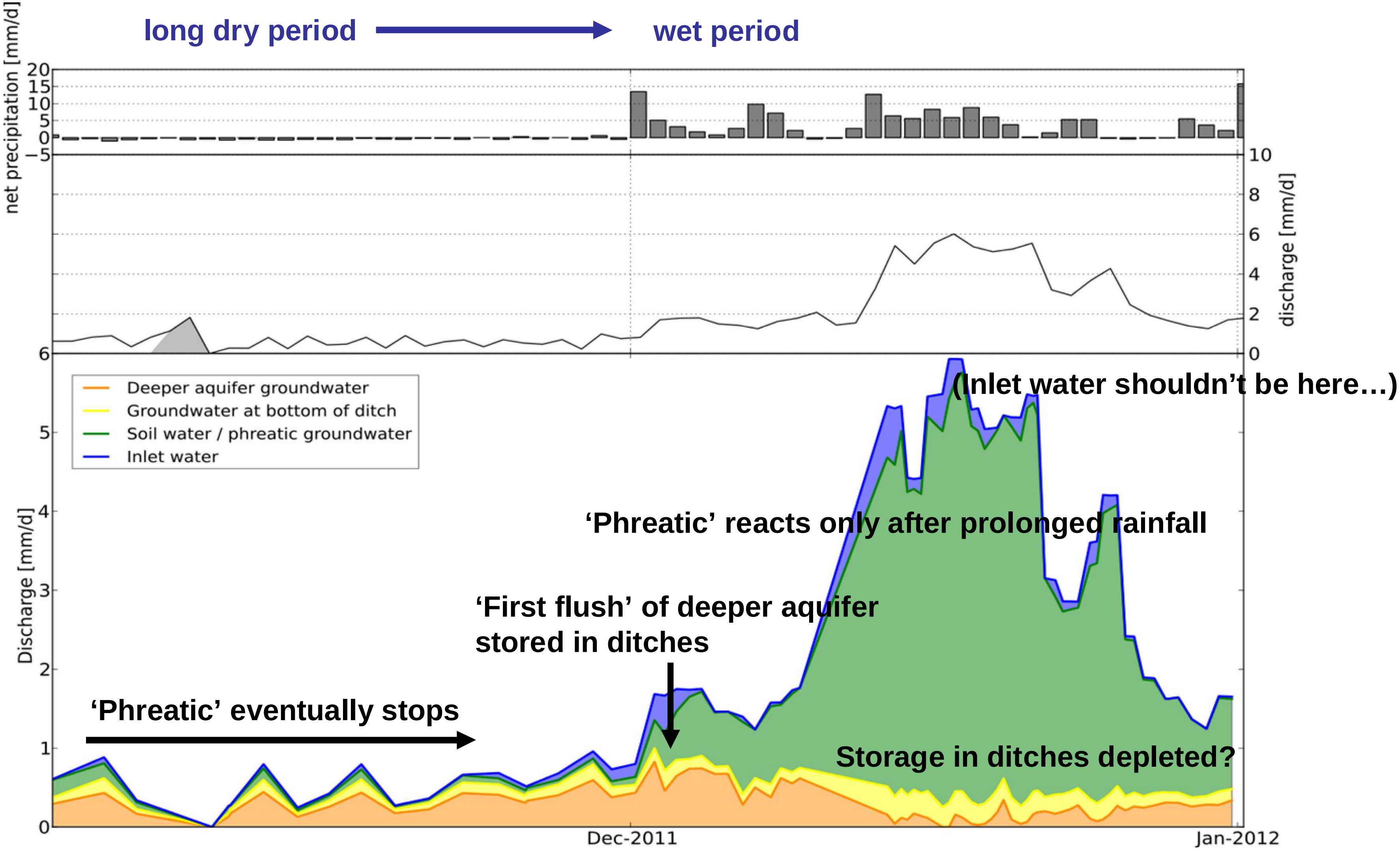
Zooming in… - hydrograph



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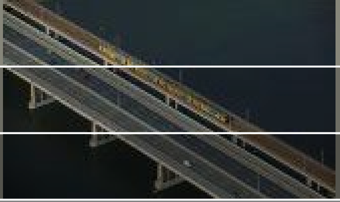
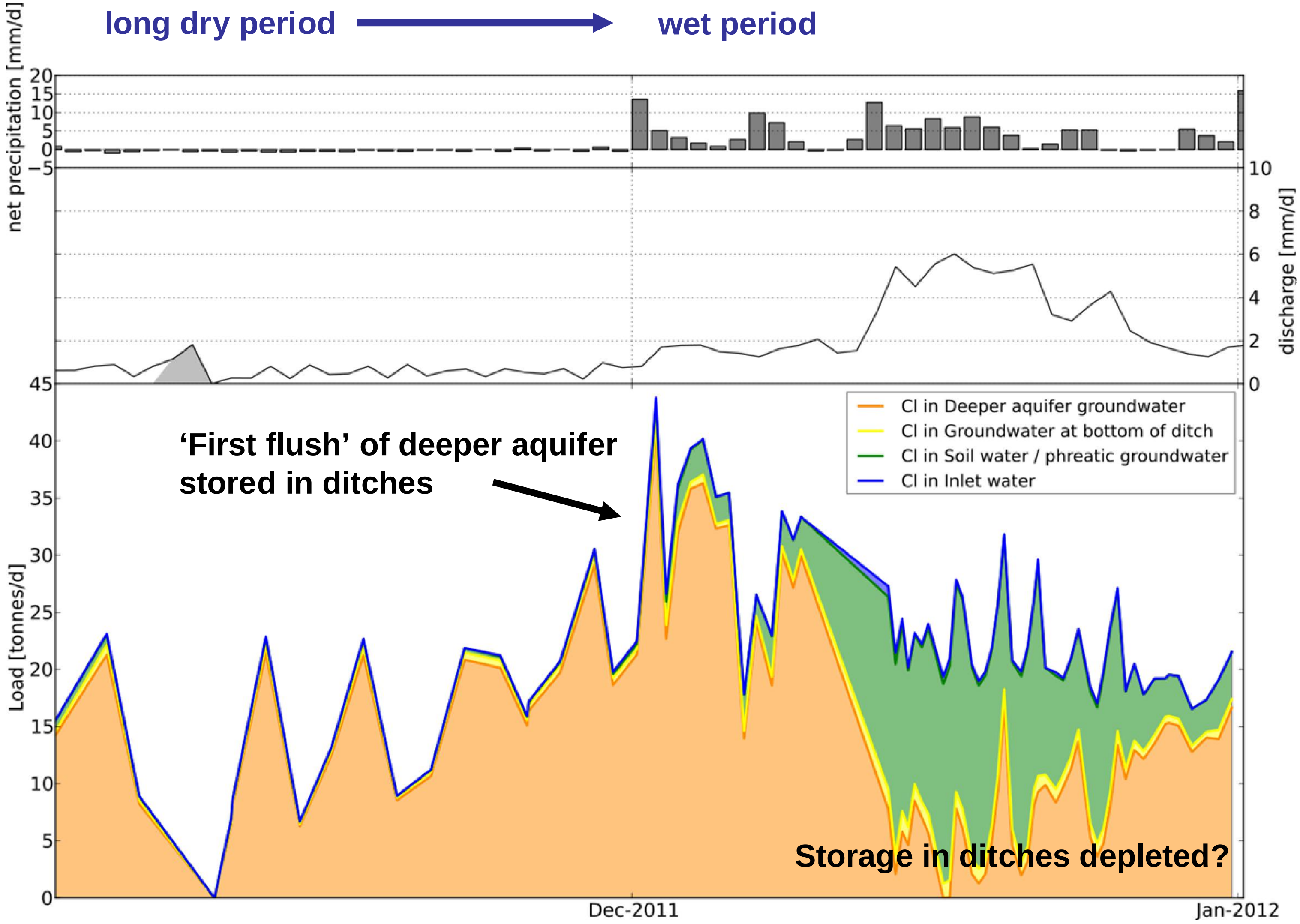
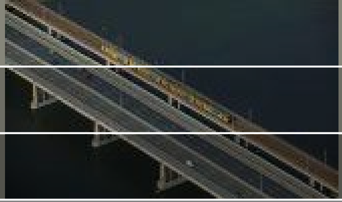
Zooming in… - chloride load

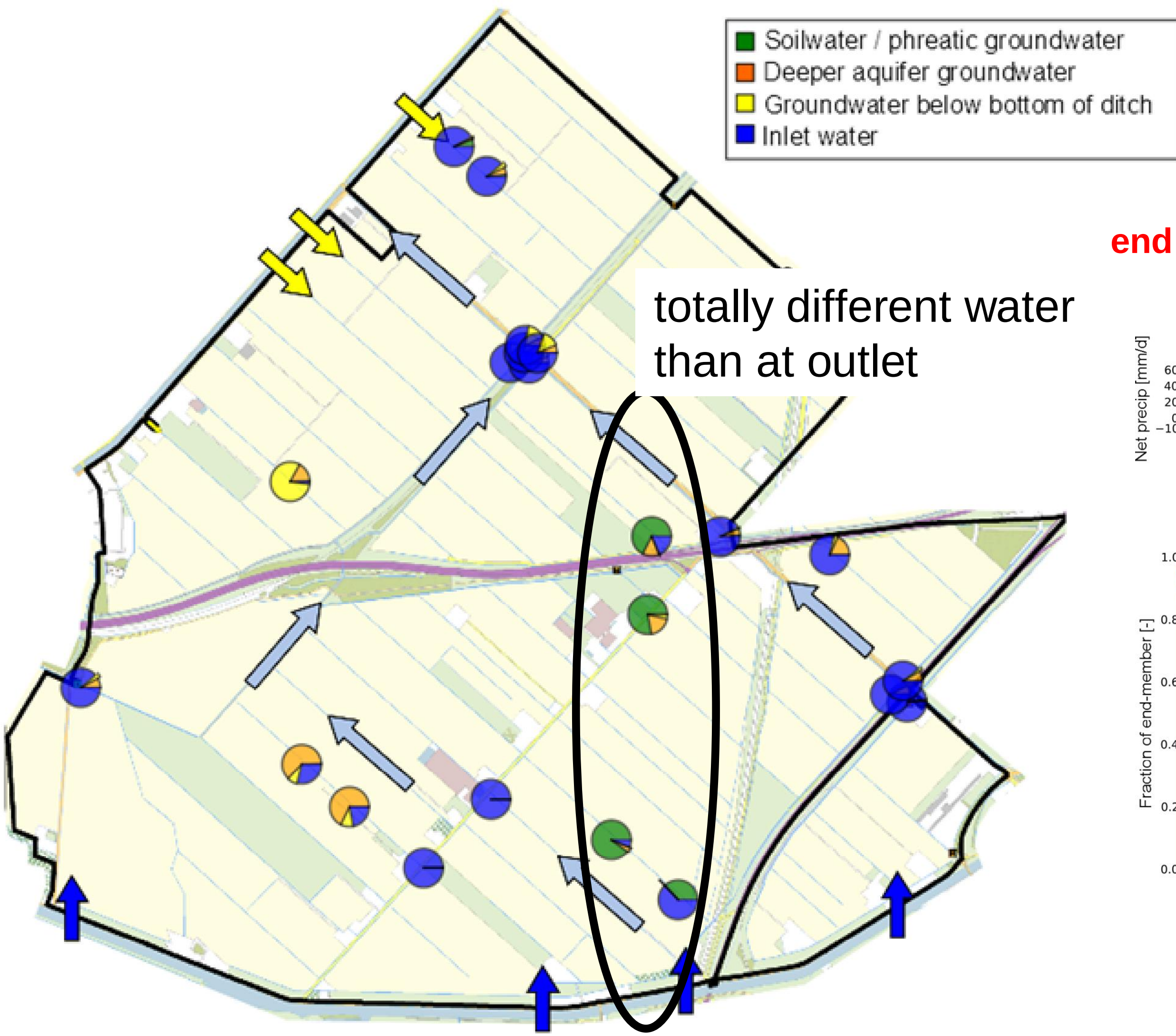




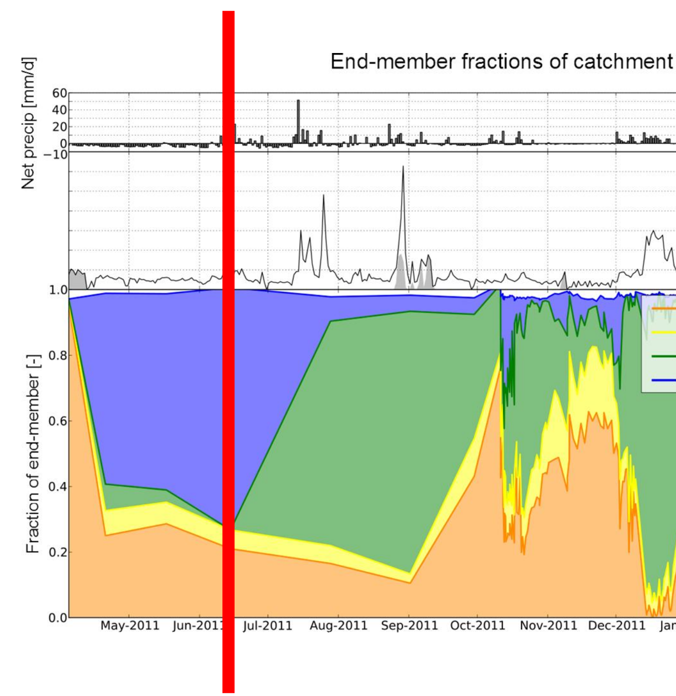
Spatial patterns



End-member fractions on 14 June 2011



end of prolonged dry period



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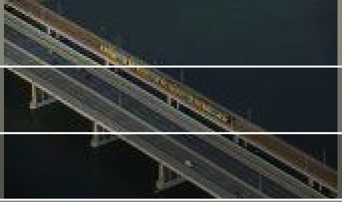
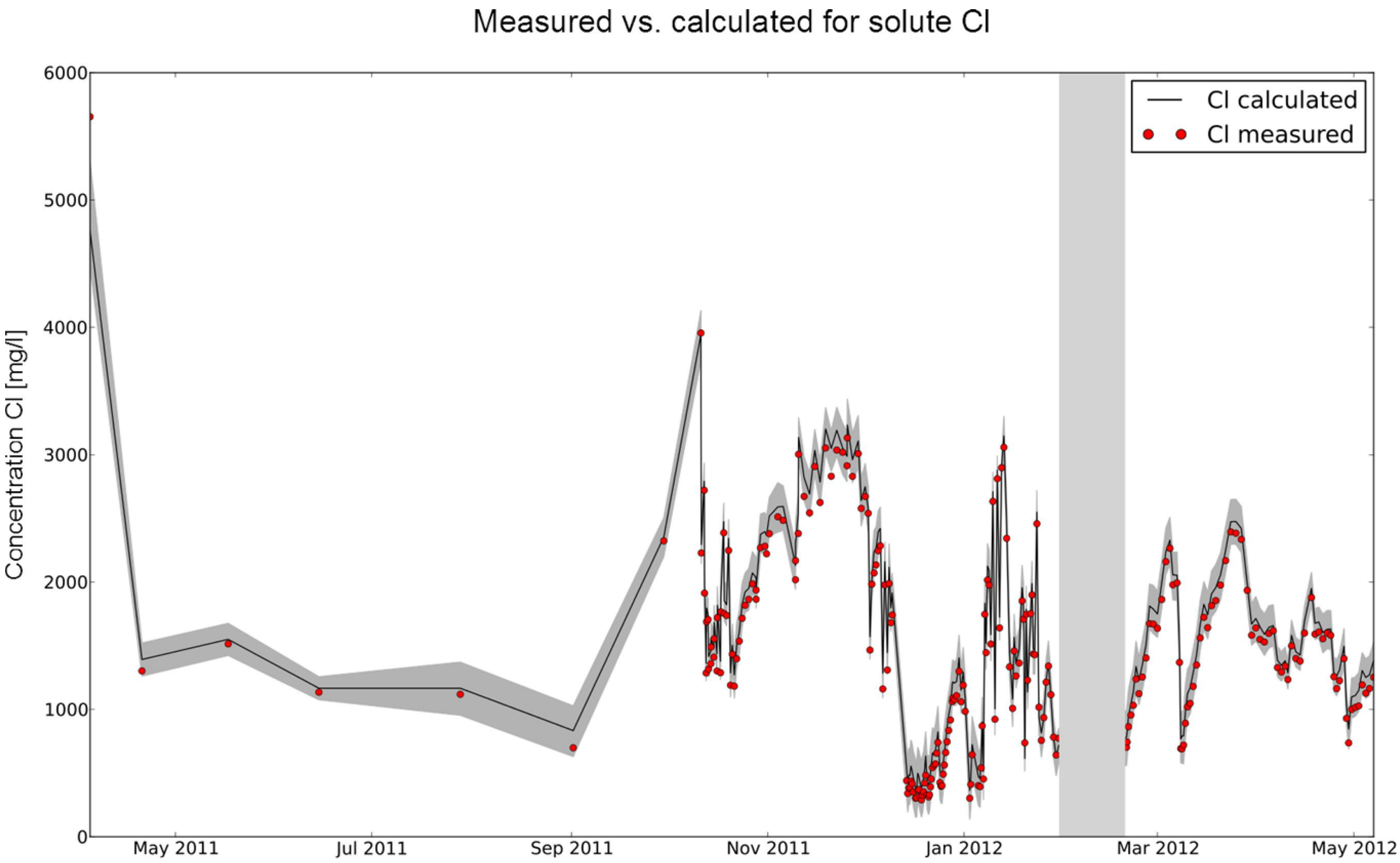
Conclusions



- End-member mixing analysis valuable tool in understanding catchment processes
- Different pathways dominate discharge in different periods
- Deeper aquifer almost always dominant in chloride load
- Buffering processes form important control on chloride load
- Catchment “at two speeds”: decoupling of smaller ditches

Measured vs. calculated Cl concentrations



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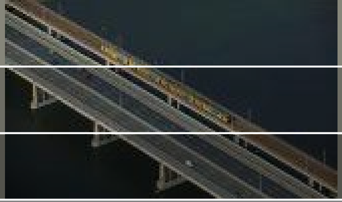
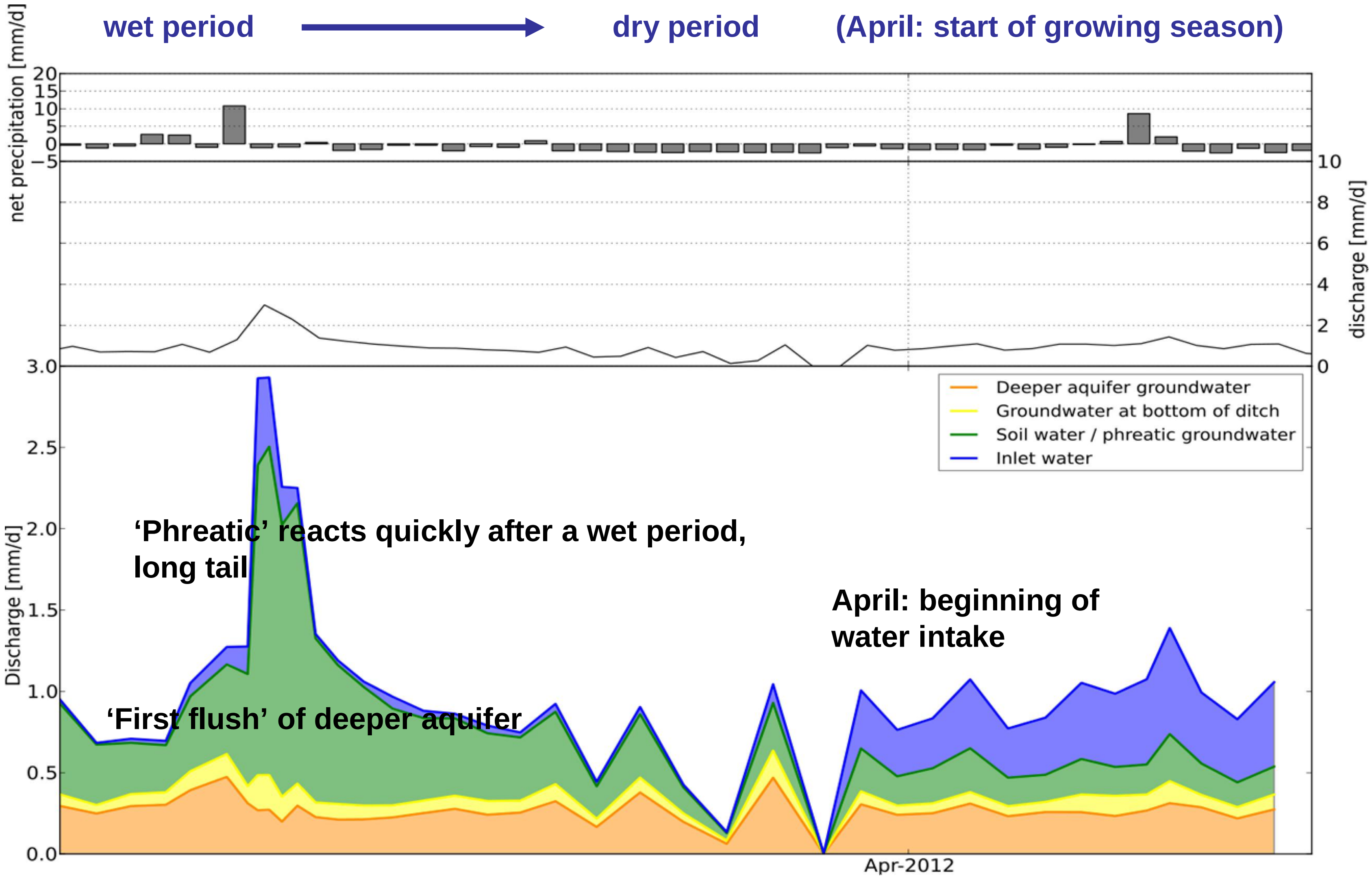
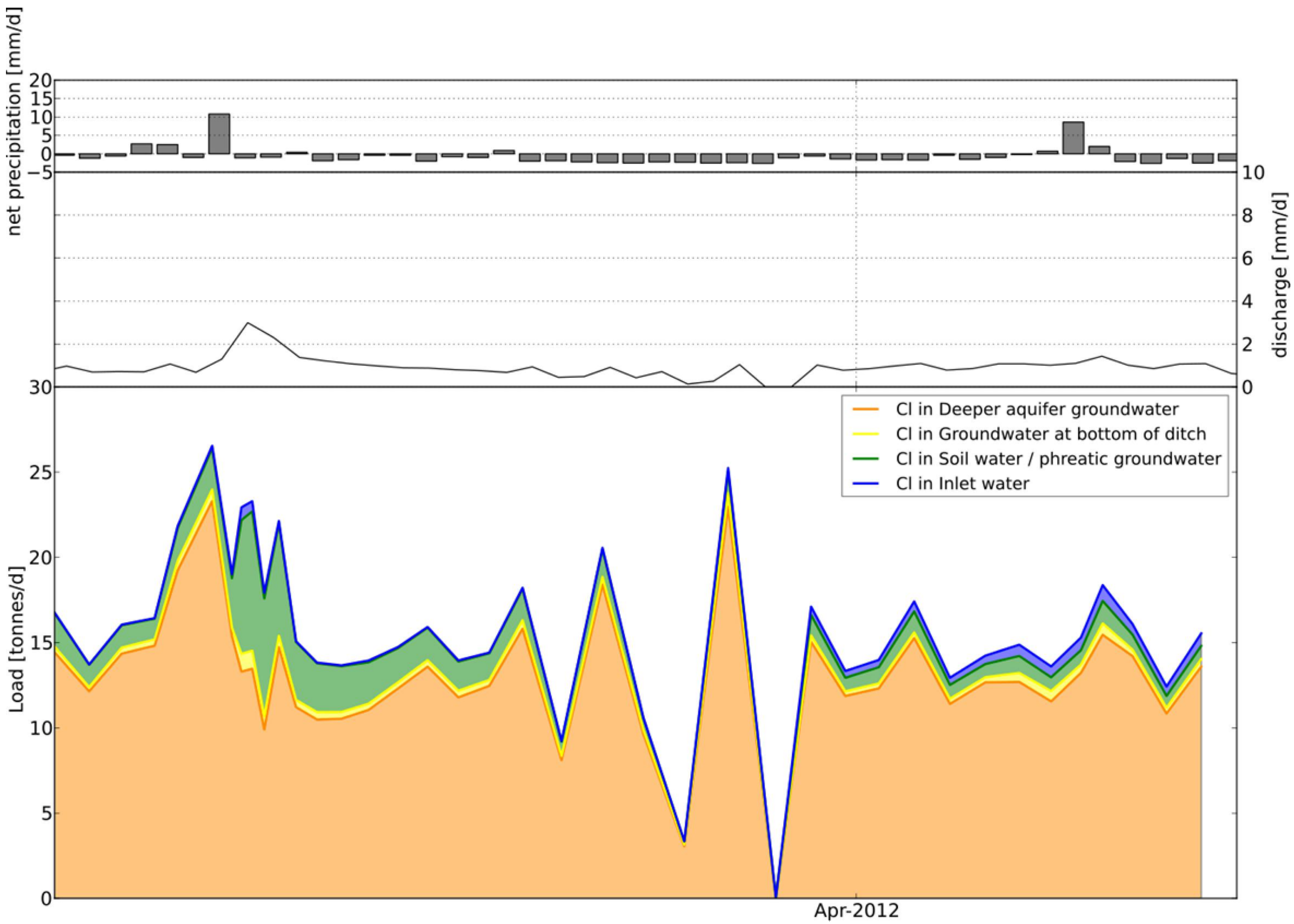
Zooming in… (2)



wet period → dry period (April: start of growing season)



Chloride load, zoomed (2)



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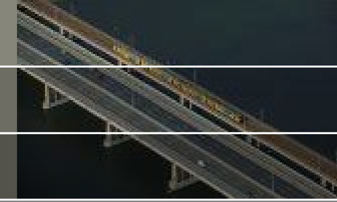
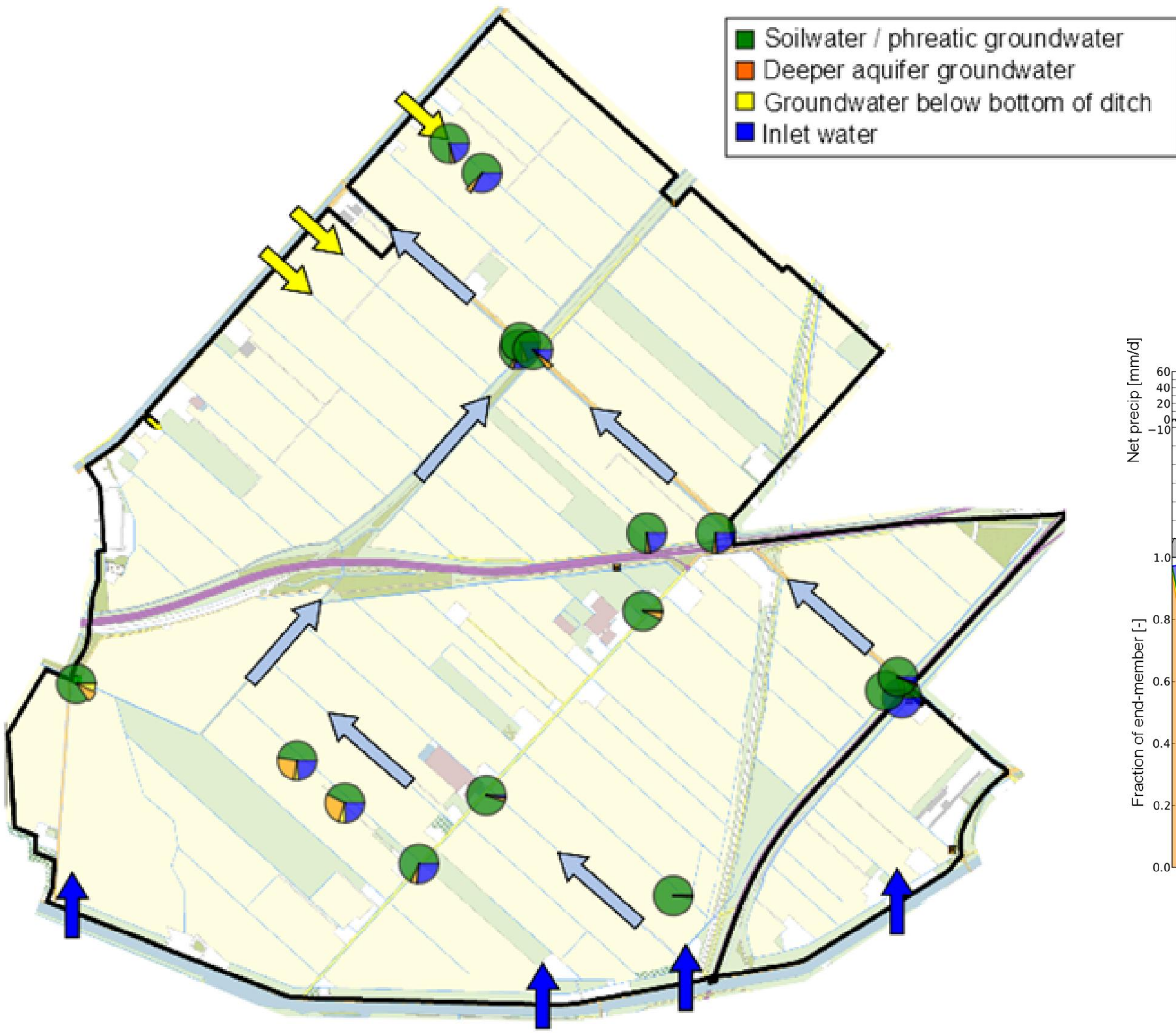
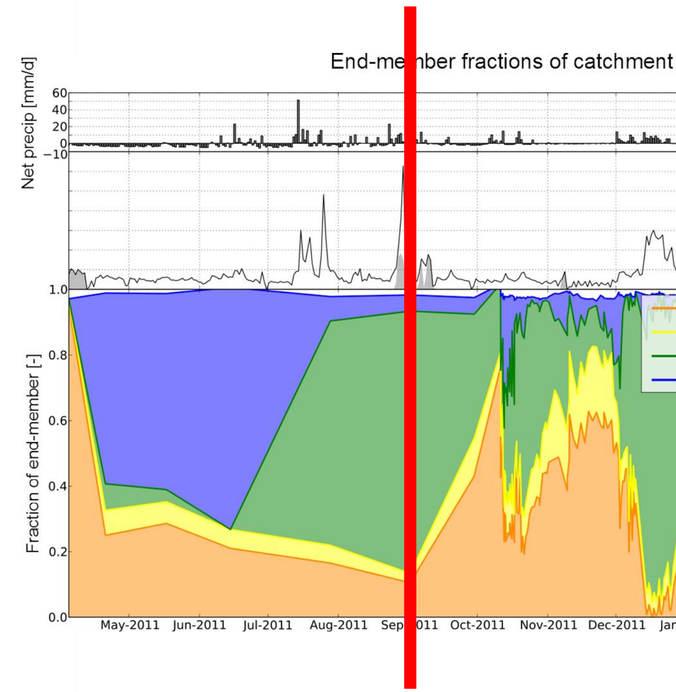


Spatial patterns (2)

End-member fractions on 1 September 2011



after heavy rainfall



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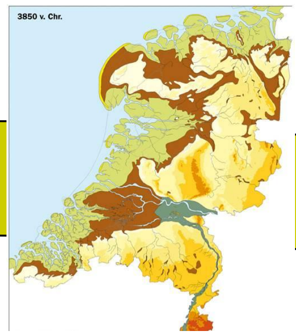
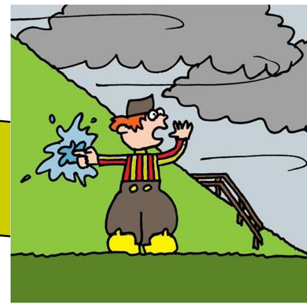
Salinization problems in Dutch coastal polders

1. Holocene transgressions (8000 yBP) salinized coastal groundwater

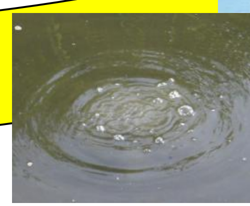




2. Man started building levees and draining the land, causing soil subsidence (1000 yBP)

3. Peat cutting led to formation of inland fresh water lakes

7. Future?



4. Which were subsequently reclaimed (250 yBP)

5. Low elevations in these deep polders give rise to strong brackish seepage flux

6. Necessitating large amounts of fresh water from river Rhine

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