Field and numerical experiments of an urban aquifer thermal energy storage system

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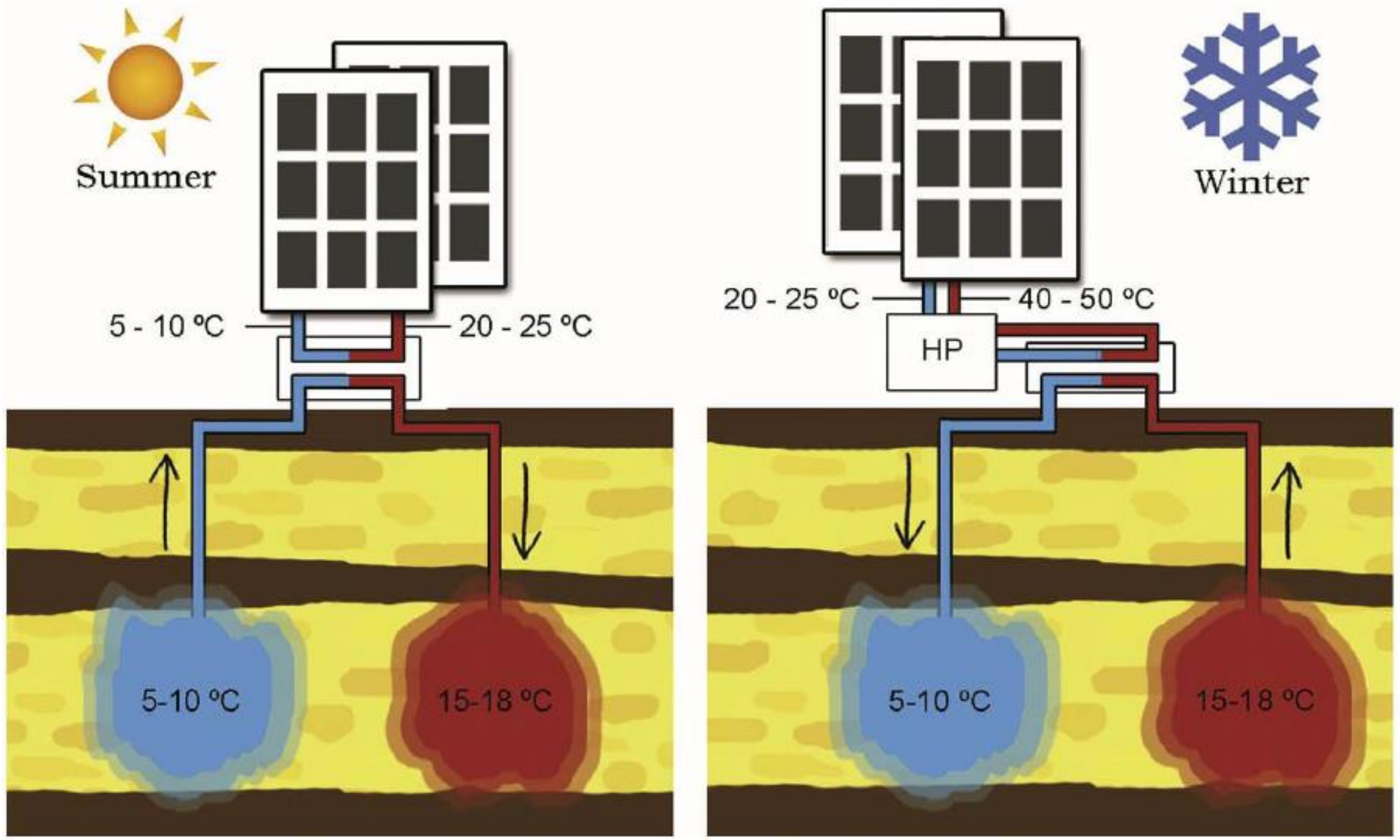
Introduction

- Building of a new Knowledge and Resource Centre in Liège, targeting energy independence.
- First open-loop well-doublet ATES system in Wallonia.
- Injection and recovery in the Meuse alluvial aquifer.
- Main goals:
  - Create a predictive 3D hydrogeological model.
  - Check the ATES system technical feasibility and intial implementation, based on building thermal needs.

What is ATES?



Bloemendal & Hartog, 2018 (Geothermics 71)

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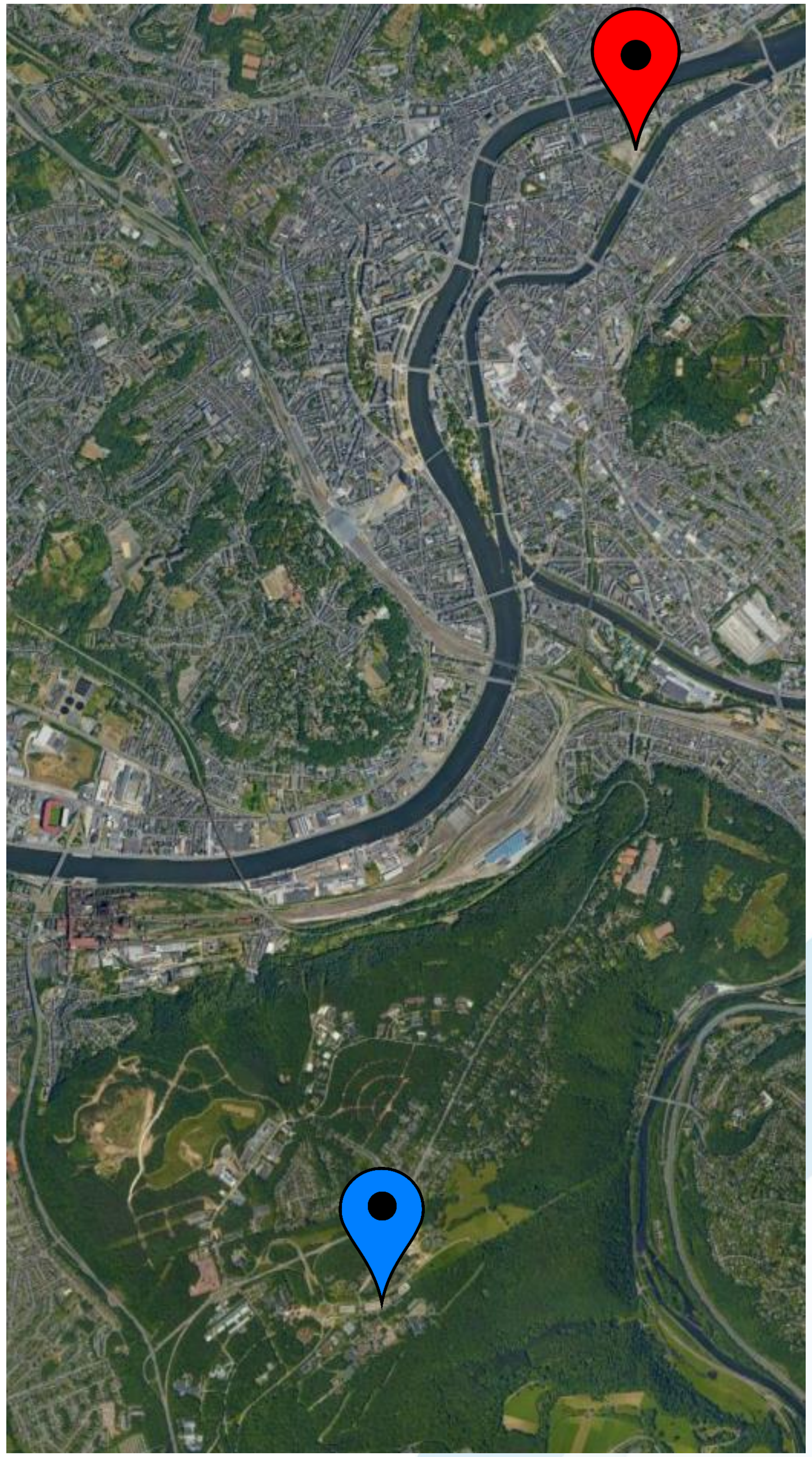
Location



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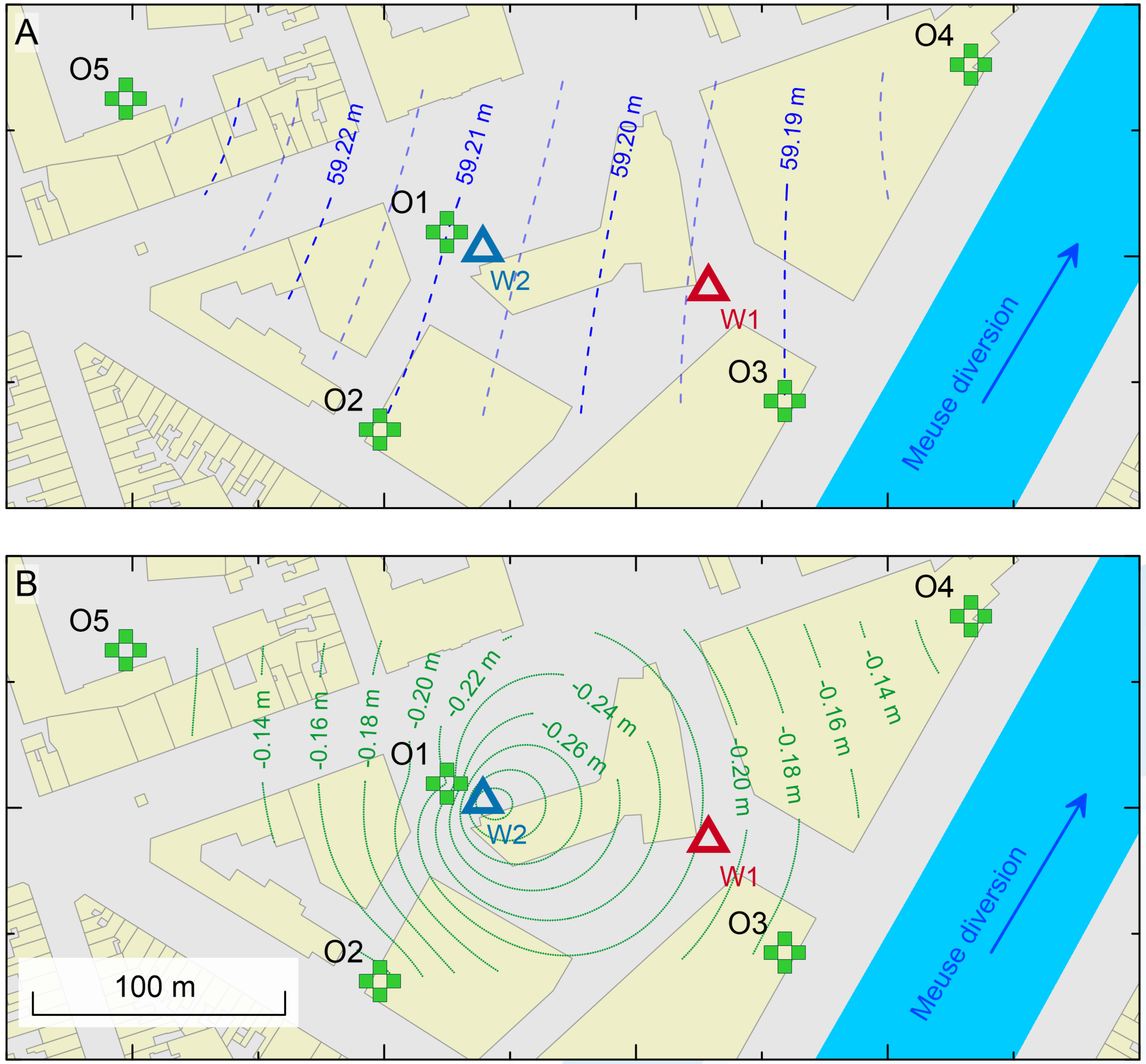
Field work



- Head and Temperature monitoring (O1 to O5).
- Pumping tests (21 to 63 m^3/h) in W1 & W2.
- Na-naphtionate tracer test: 50 L (20 g/L) injection at O1, monitoring at W2.
- Heat tracer test: background T = 14 °C, 28 m^3 injected at T = 48 °C (ΔT = 34 K).
- 4D time-lipse Electrical resistivity tomography (ERT) monitoring of the heat tracer test. But didn't succeed.

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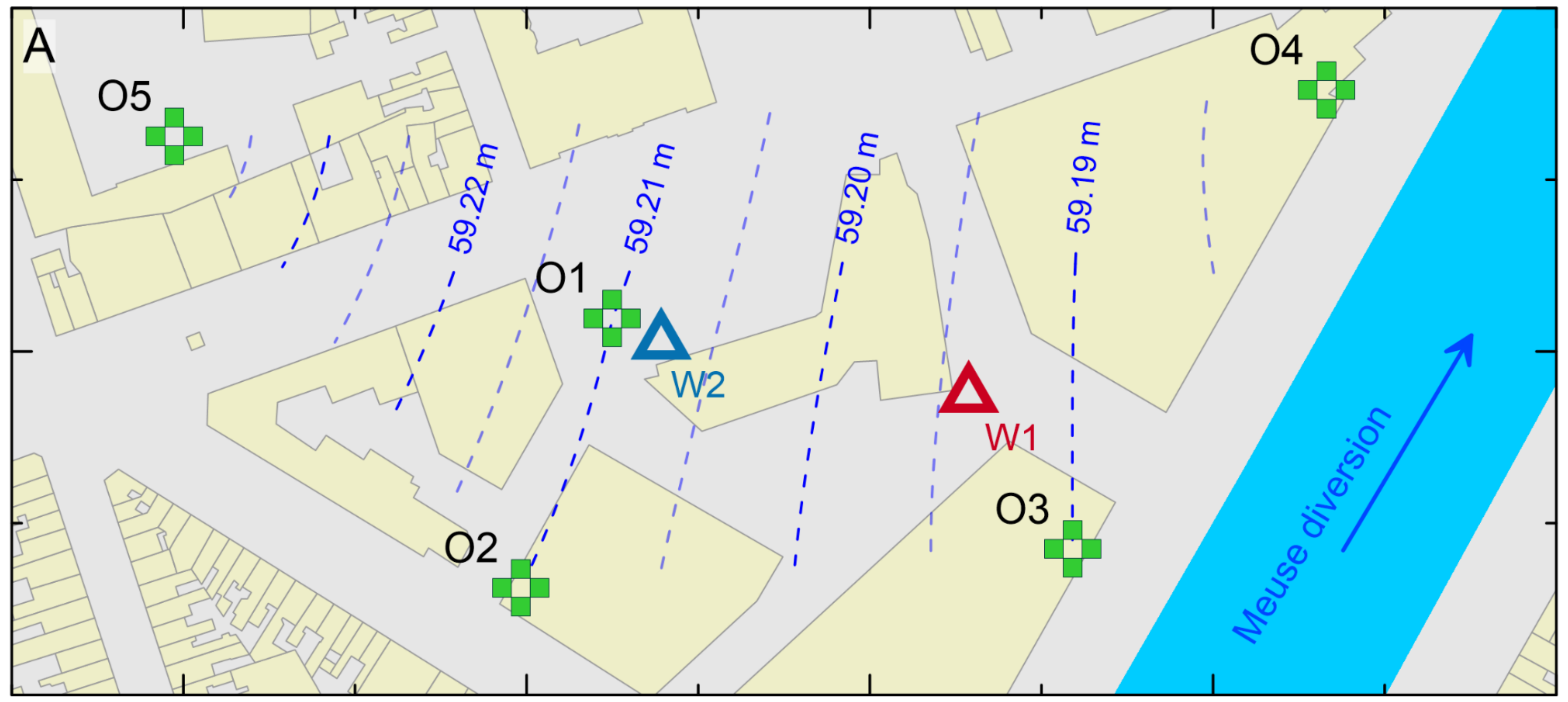
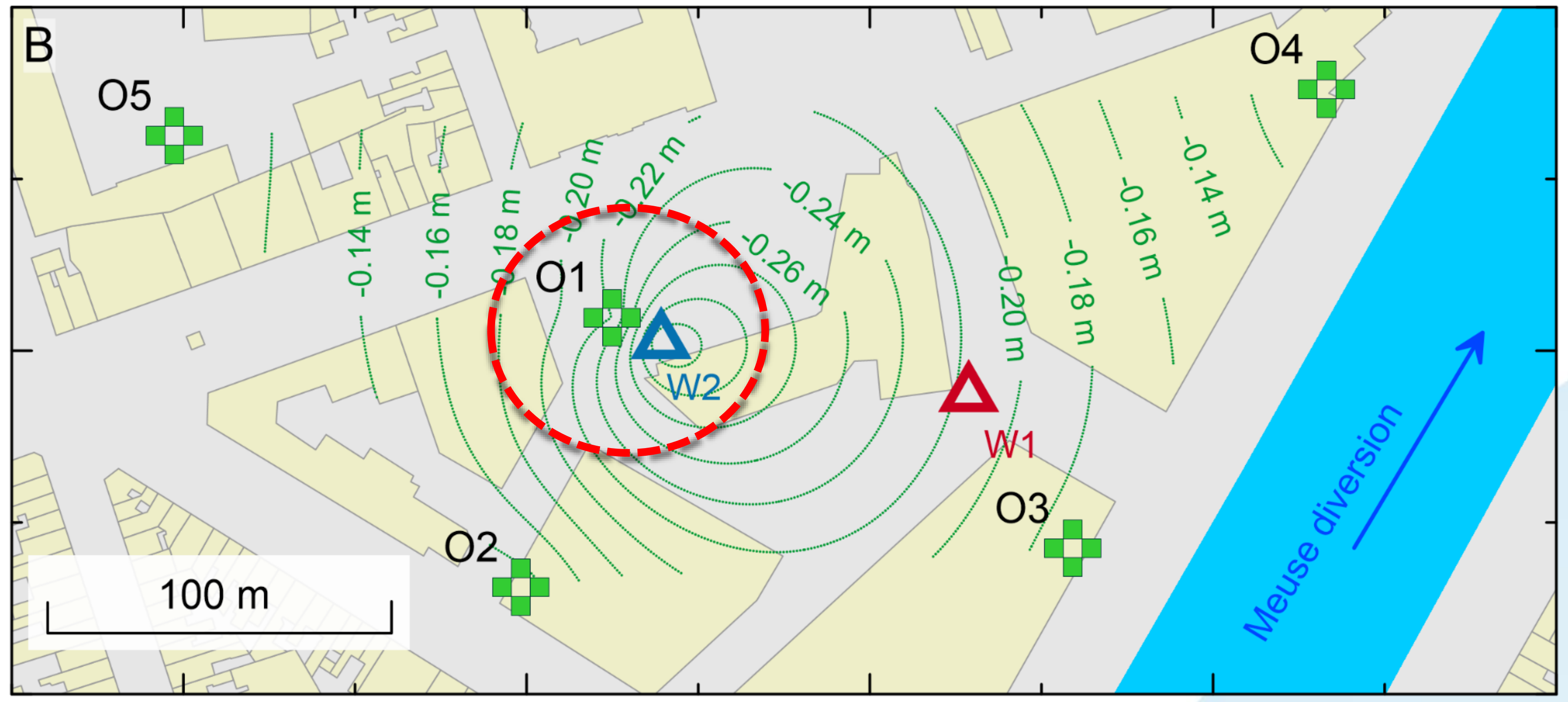
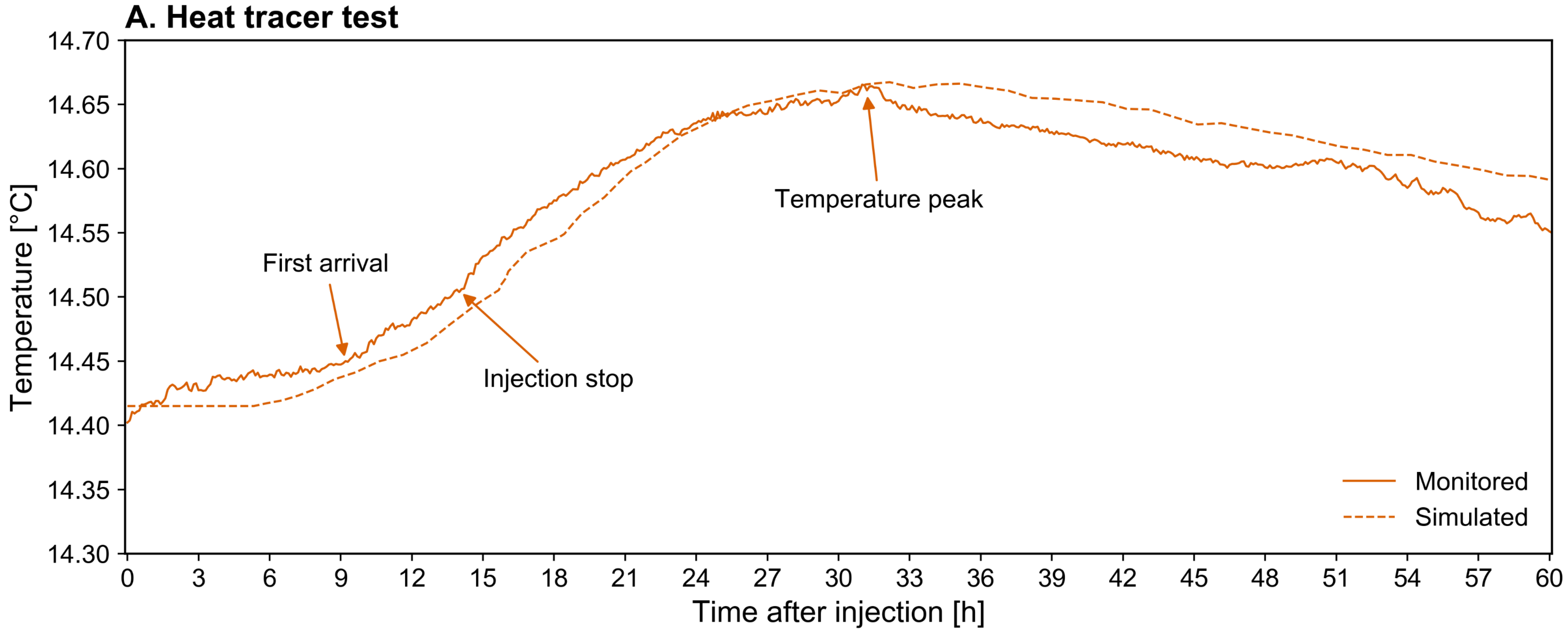
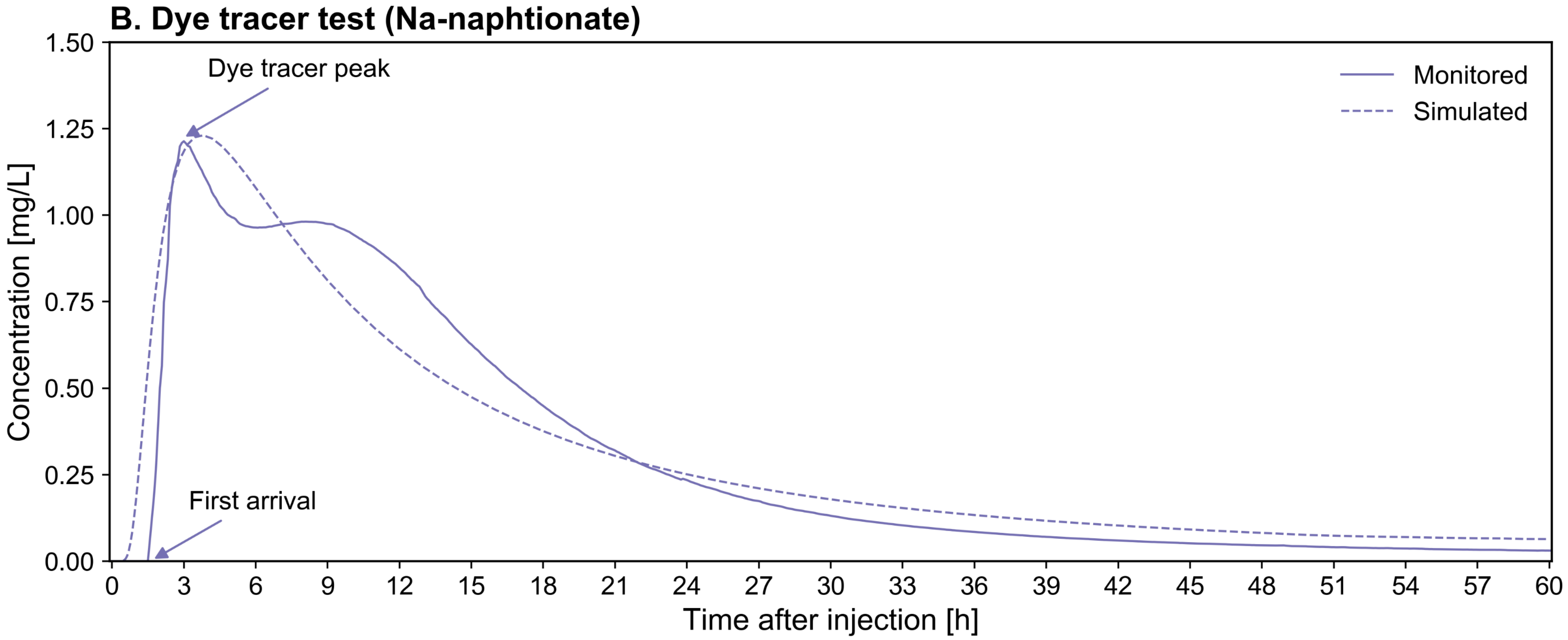
Field work


A
O5
O4
O1
W2
W1
O2
O3
59.22 m
59.21 m
59.20 m
59.19 m
Meuse diversion

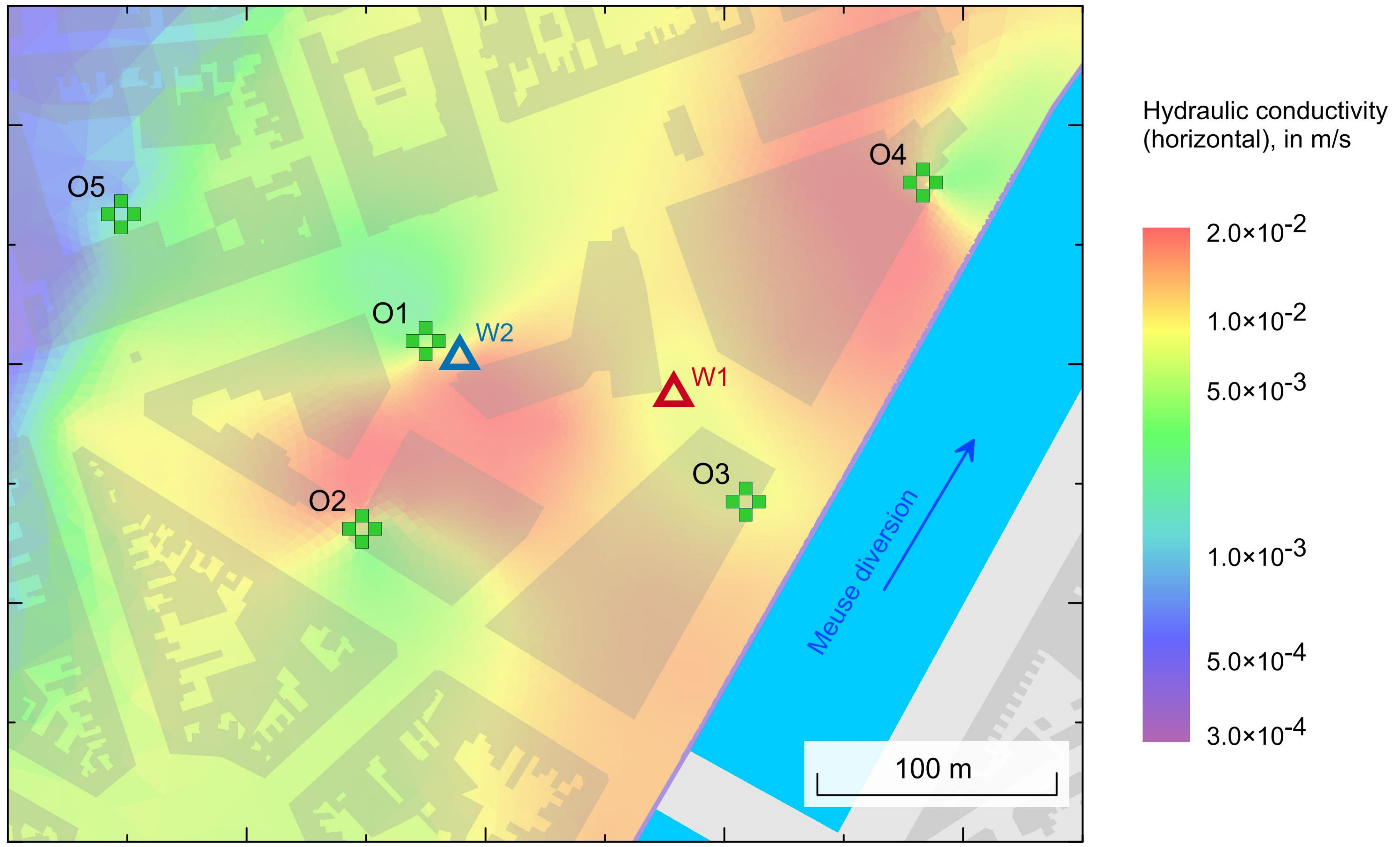

B
O5
O4
O1
W2
W1
O2
O3
-0.14 m
-0.16 m
-0.18 m
-0.20 m
-0.22 m
-0.24 m
-0.26 m
100 m
Meuse diversion

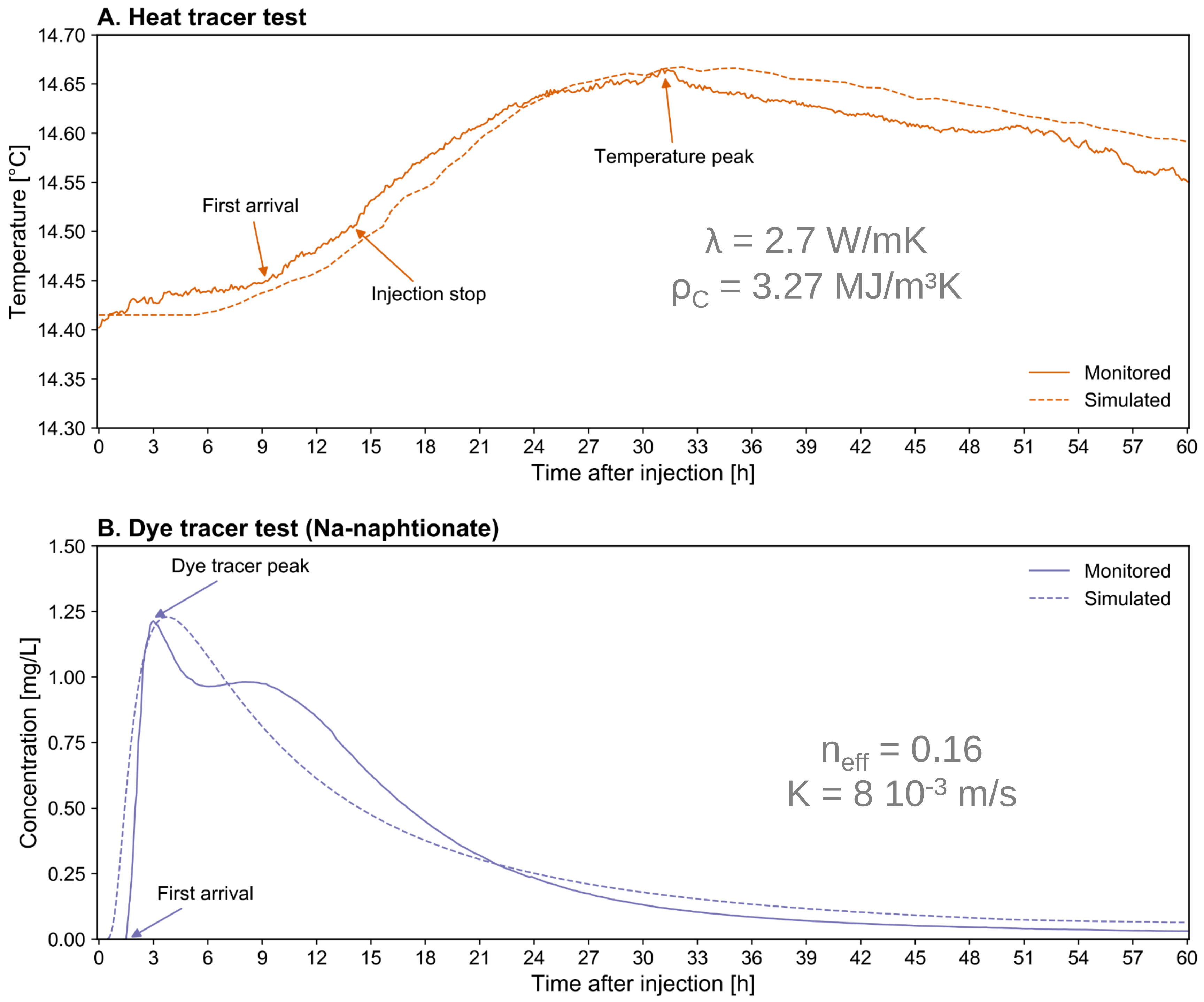

A. Heat tracer test
Temperature [°C]
Time after injection [h]
First arrival
Injection stop
Temperature peak
Monitored
Simulated


B. Dye tracer test (Na-naphtionate)
Concentration [mg/L]
Time after injection [h]
Dye tracer peak
First arrival
Monitored
Simulated

Numerical model

- Modeling code: FEFLOW®.
- Groundwater flow / mass & heat transport.
- Transient simulations, fully saturated conditions.
- Groundwater flow:
  automatic calibration against hydraulic head, with pilot points (PEST; Doherty, 2015, 2016).
- Mass/heat transport:
  manual calibration against breakthrough curve at W2.





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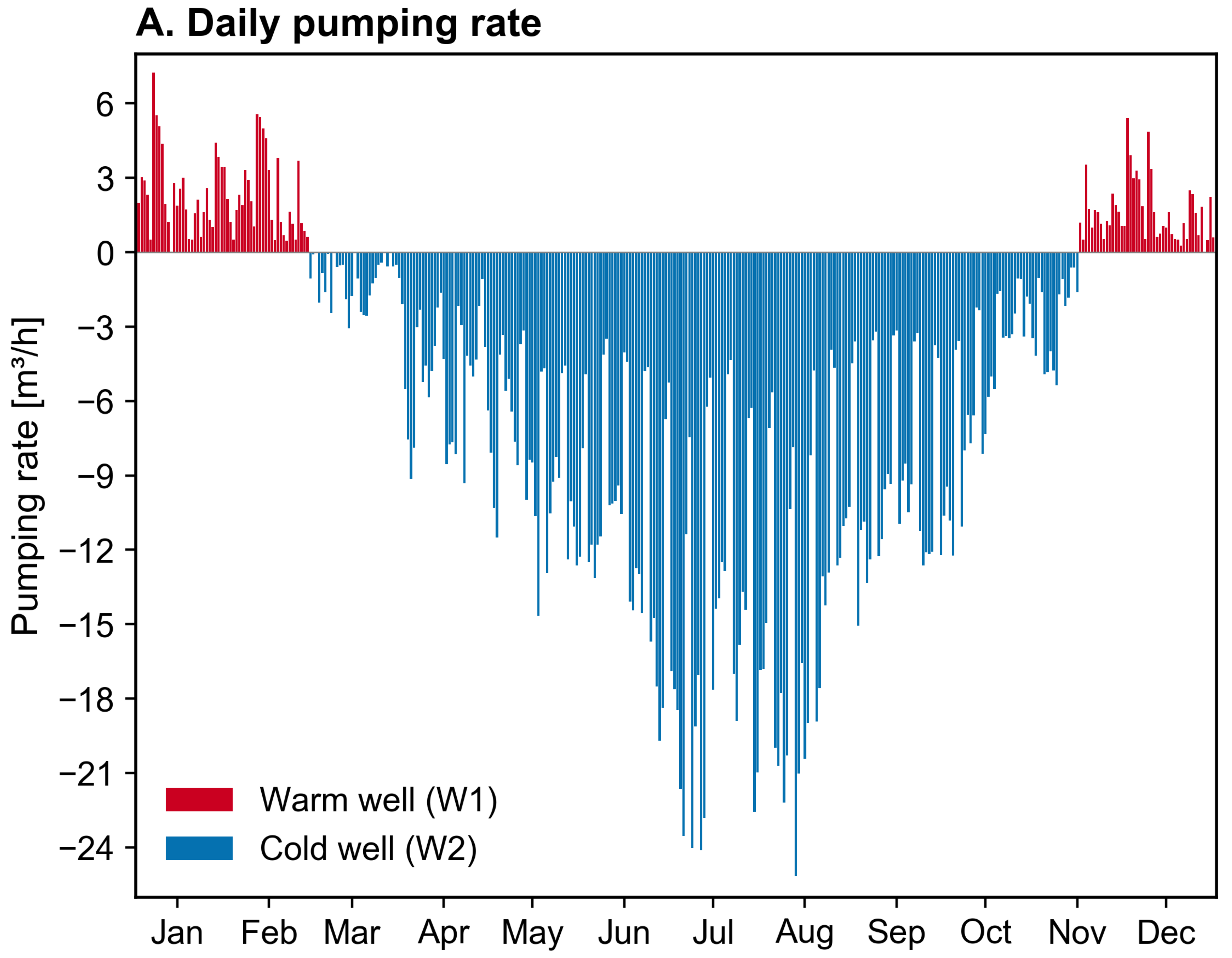
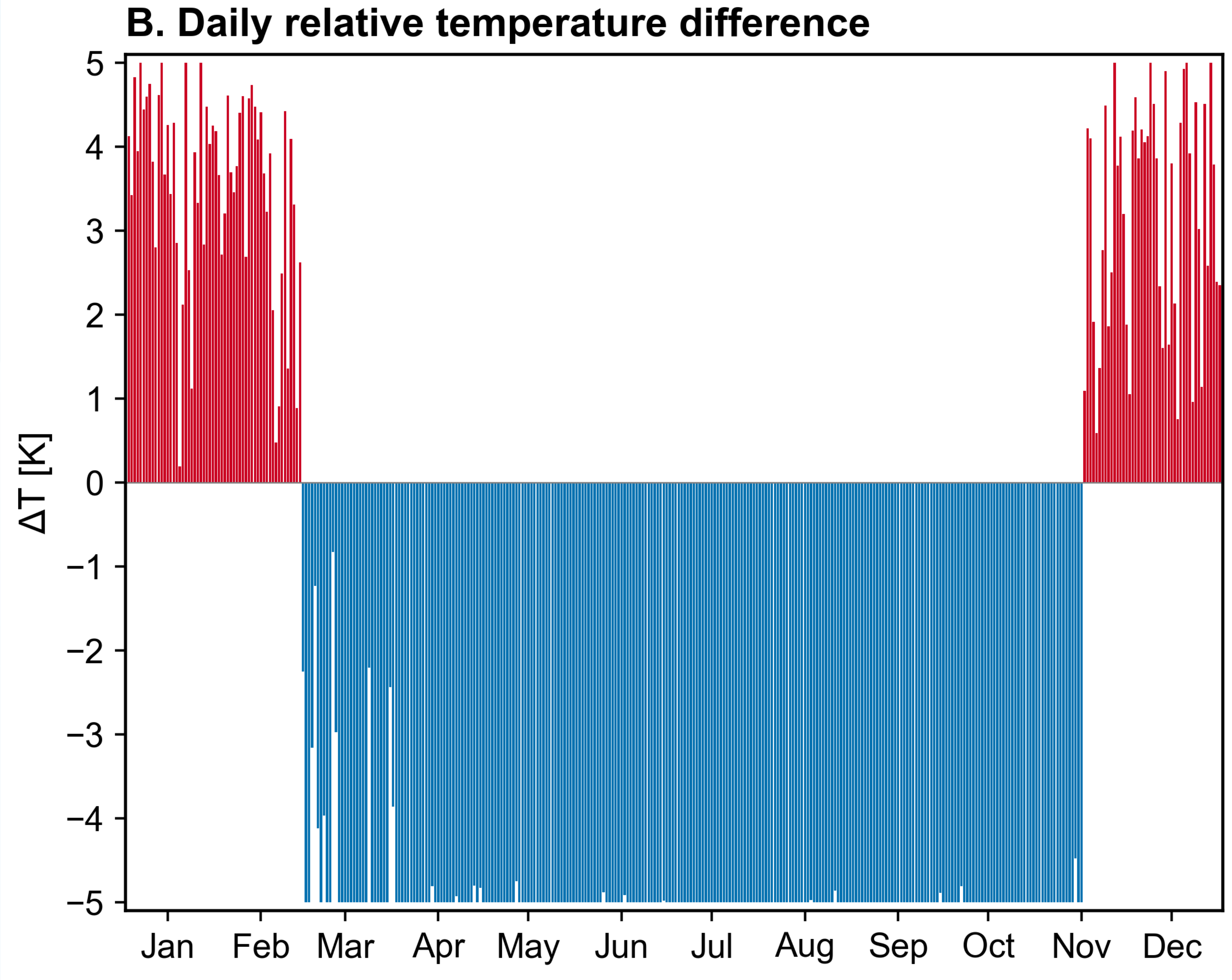
Predictive simulation

- Groundwater flow / heat transport.
- 10-year simulation, based on building energy needs estimated data.
- Injection and recovery, up to 24 m^3/h.
- Max. authorized operational $\Delta T = 5$ K
- COP = 4.5 / EER = 7.0

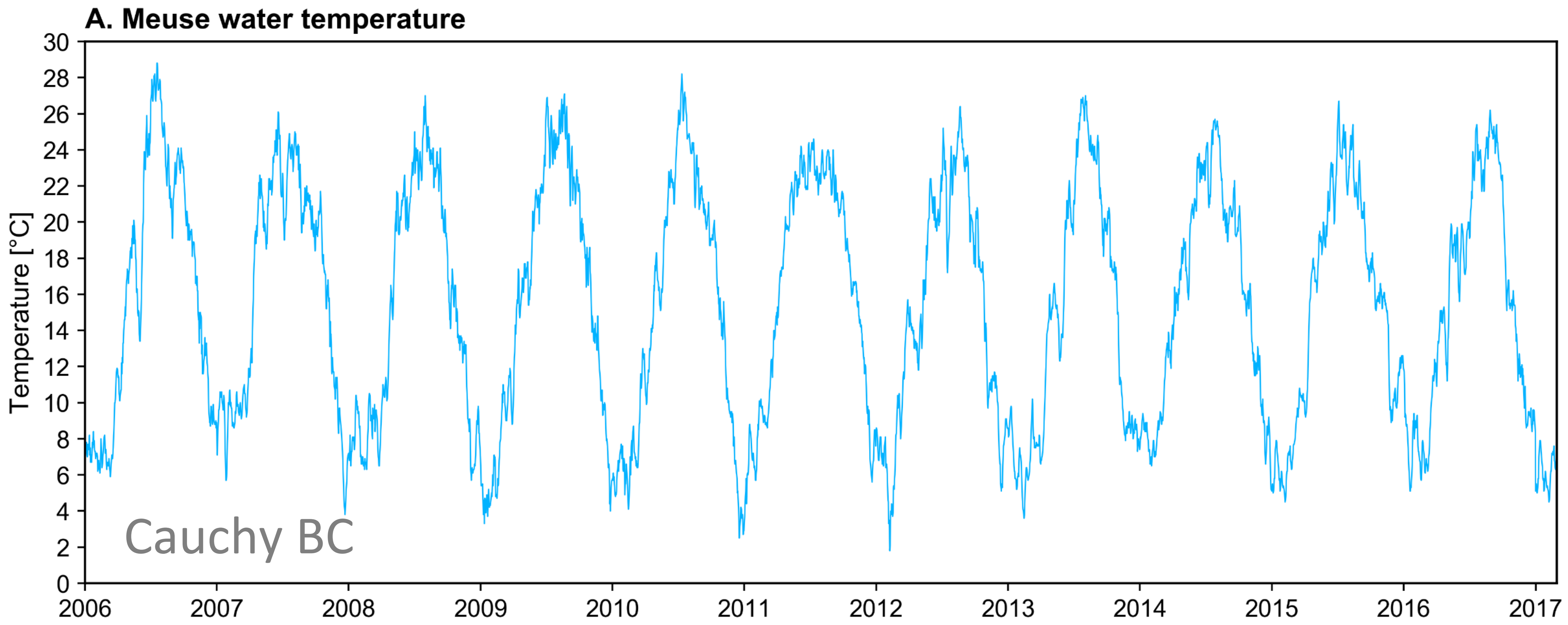
	Heating season	Cooling season
Duration [d]	105	260
Max. Q [m^3/h]	7.2	25.1
Stored volume [m^3]	5 100	50 000

$\Delta = 44\,900\ m^3$

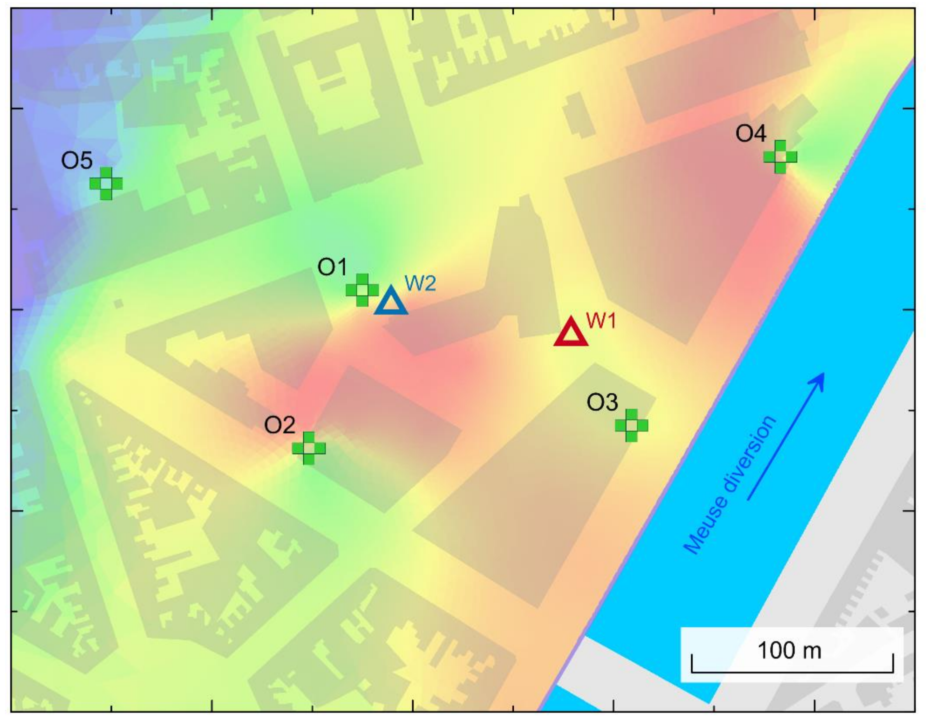


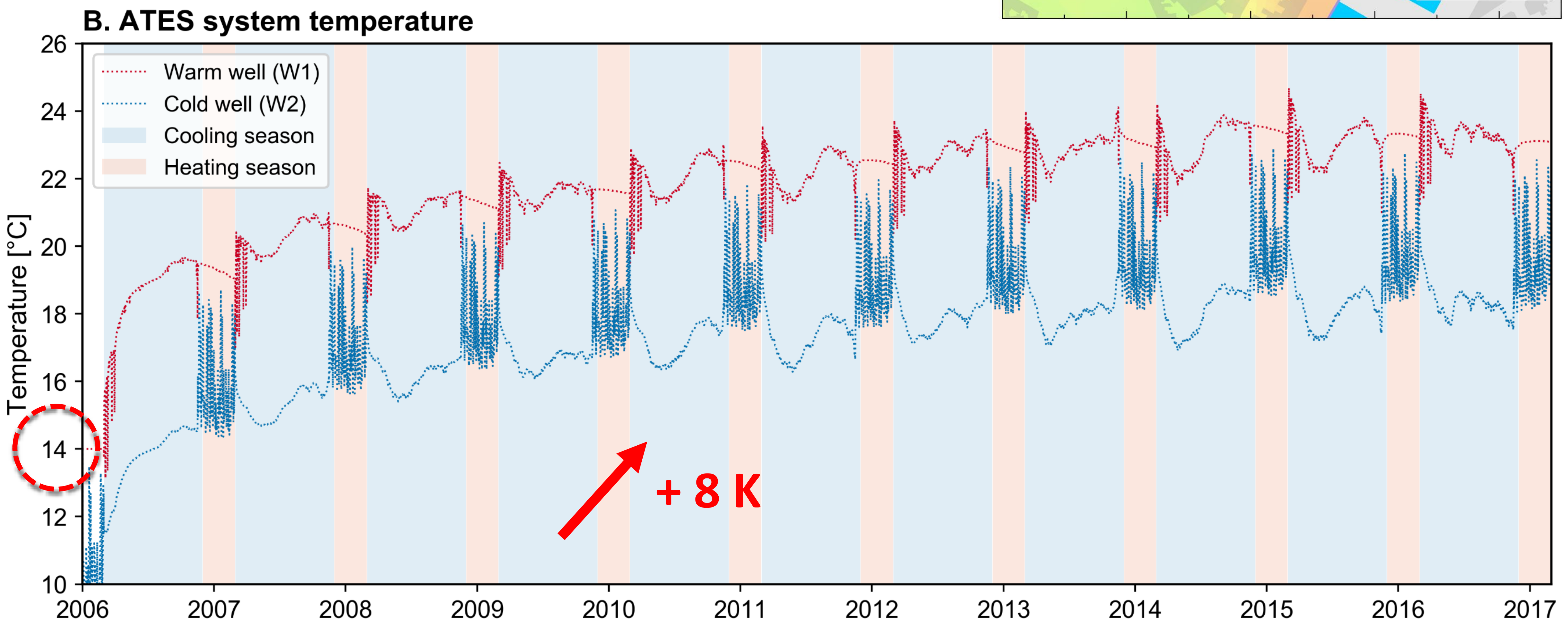


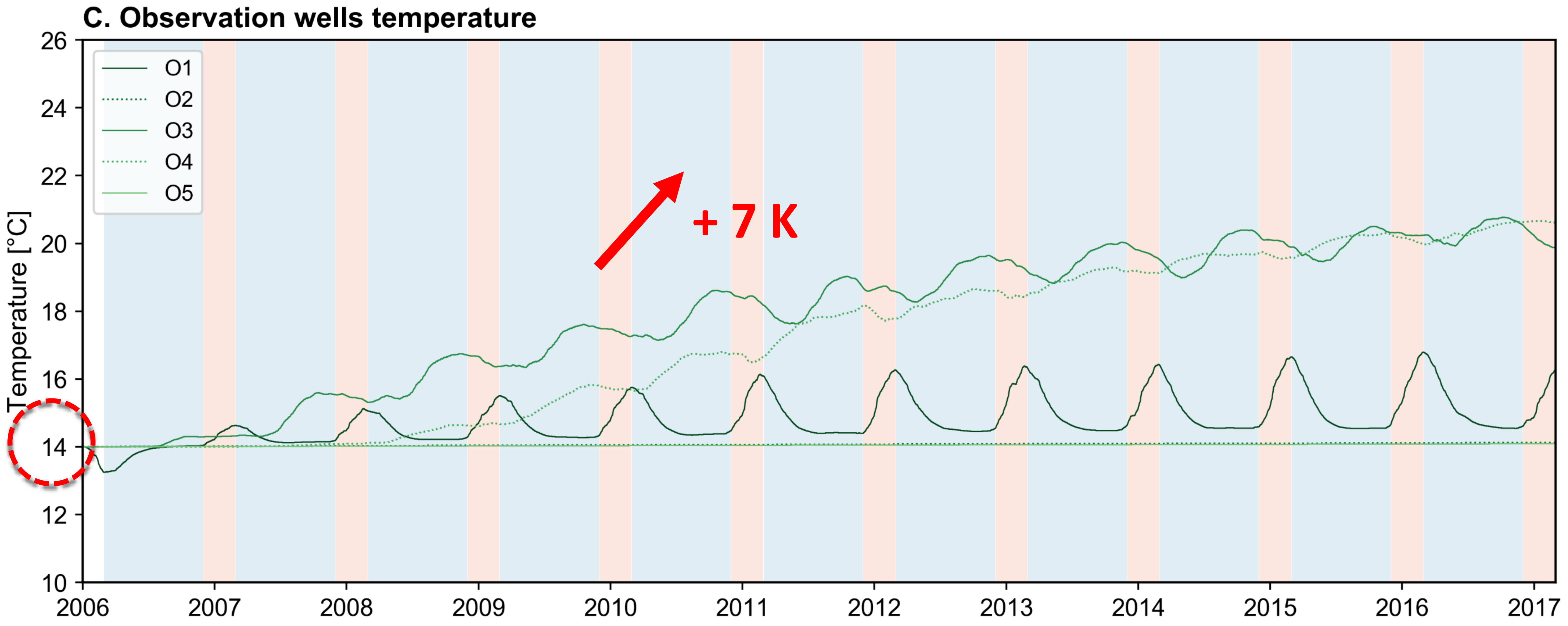
Simulated groundwater temperature



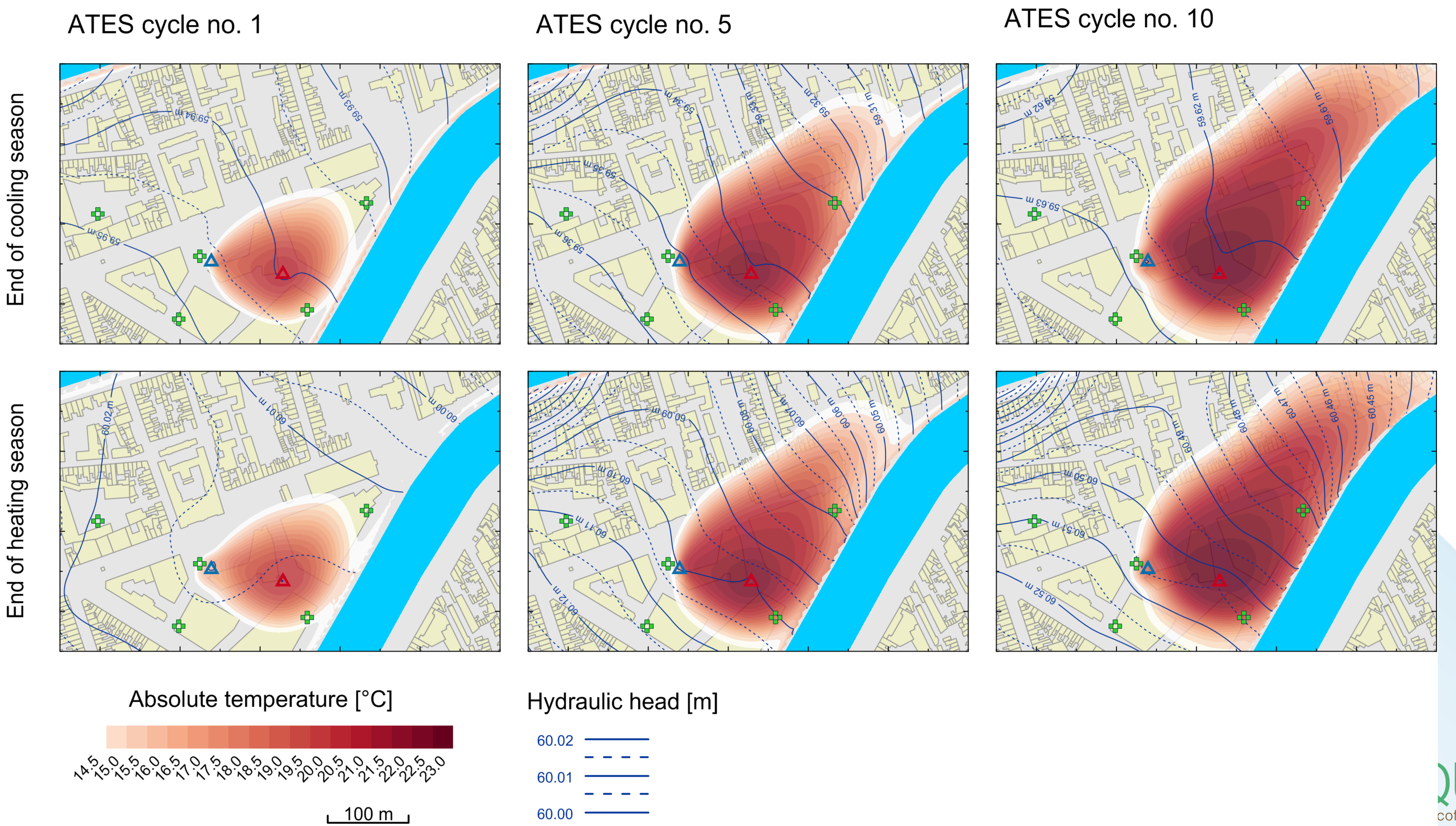
- Short-circuit during the cooling season.
- Meuse temperature: no impact on ATES system operational temperature.
- Thermal plume intercepted at O3 and O4 after a couple of cycles.







Temperature distribution in the aquifer



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Conclusion

Highly productive aquifer suitable for ATES application

but the imbalance between stored warm and cold water has to be monitored in the future.

Is the thermal plume an issue?

- Heat island effect linked to the thermal insulation of the building.

  → Cooling efficiency likely affected by the T° rise.

  → Increase inter-well distance to avoid short-circuiting.
- Simulation performed with ATES running in continuous mode.

  → Office building, working days.
- Overdesign: 100% efficient system simulated.
- Pooling/sharing the excess stored heat for old buildings in the district.

Is the model reliable?

- Calibrated model, but data scarcity.
- Uncertainty analysis needed.
- Long-term simulations to be run (25-30 years).

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Thank you for your attention

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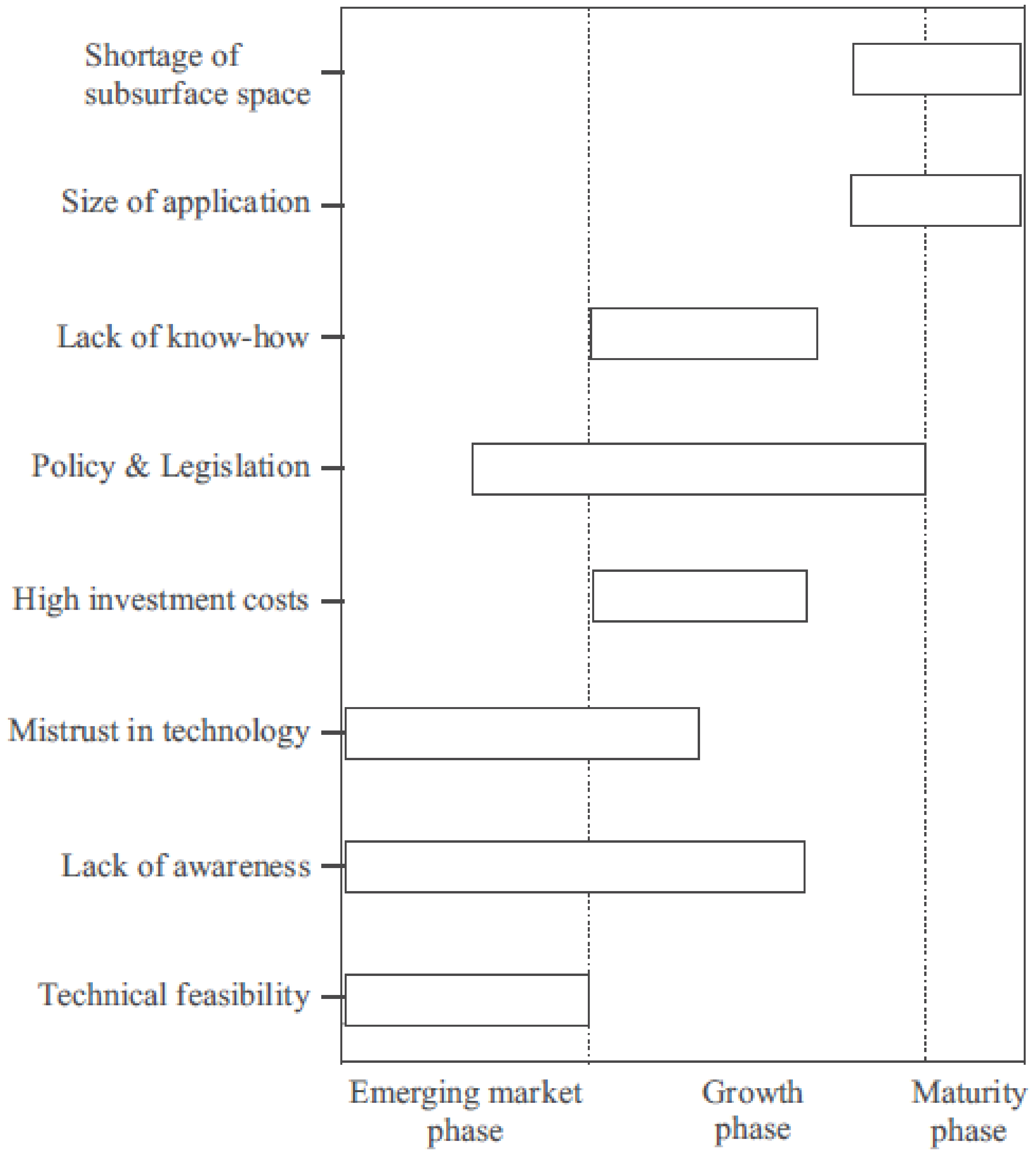
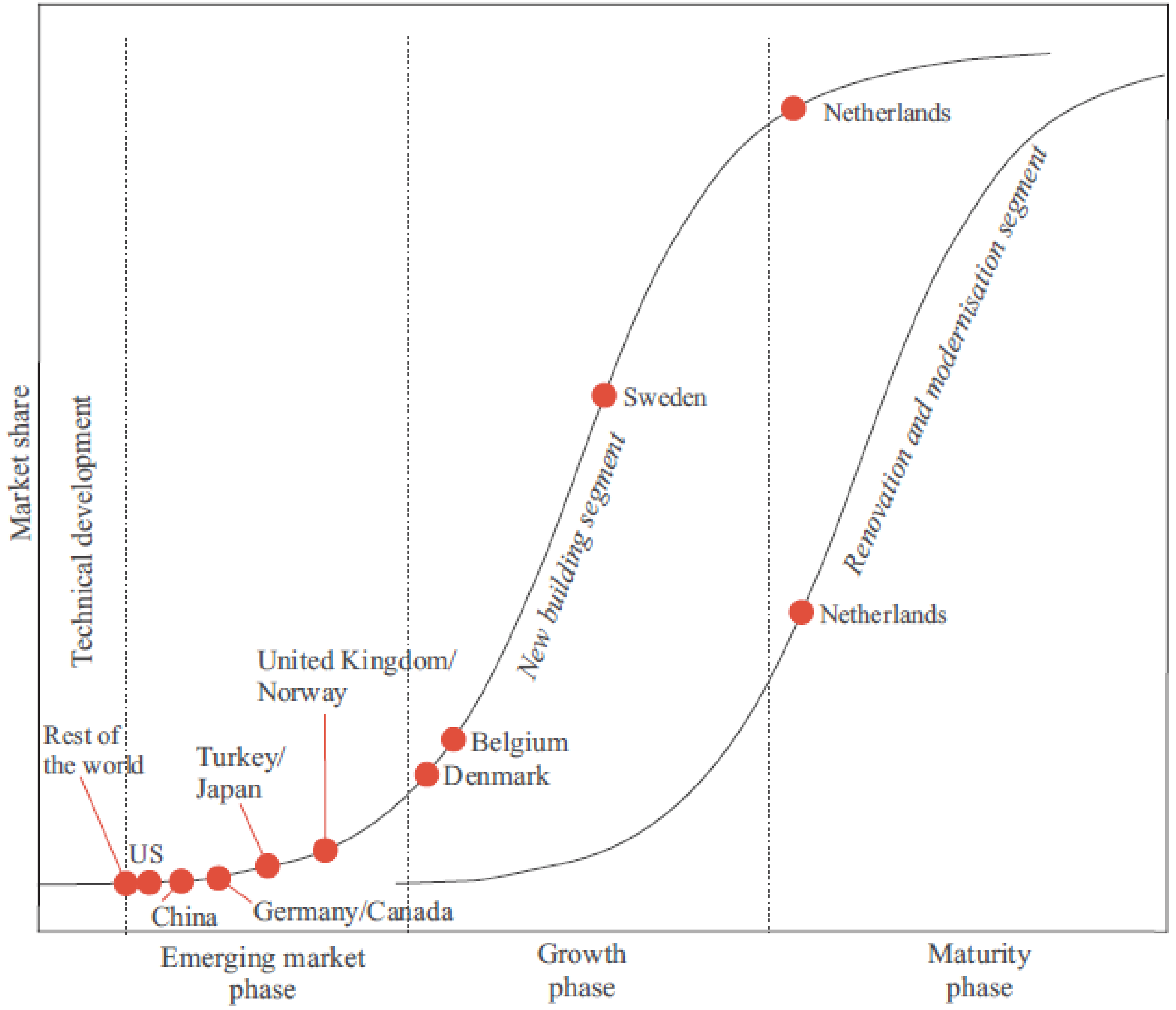
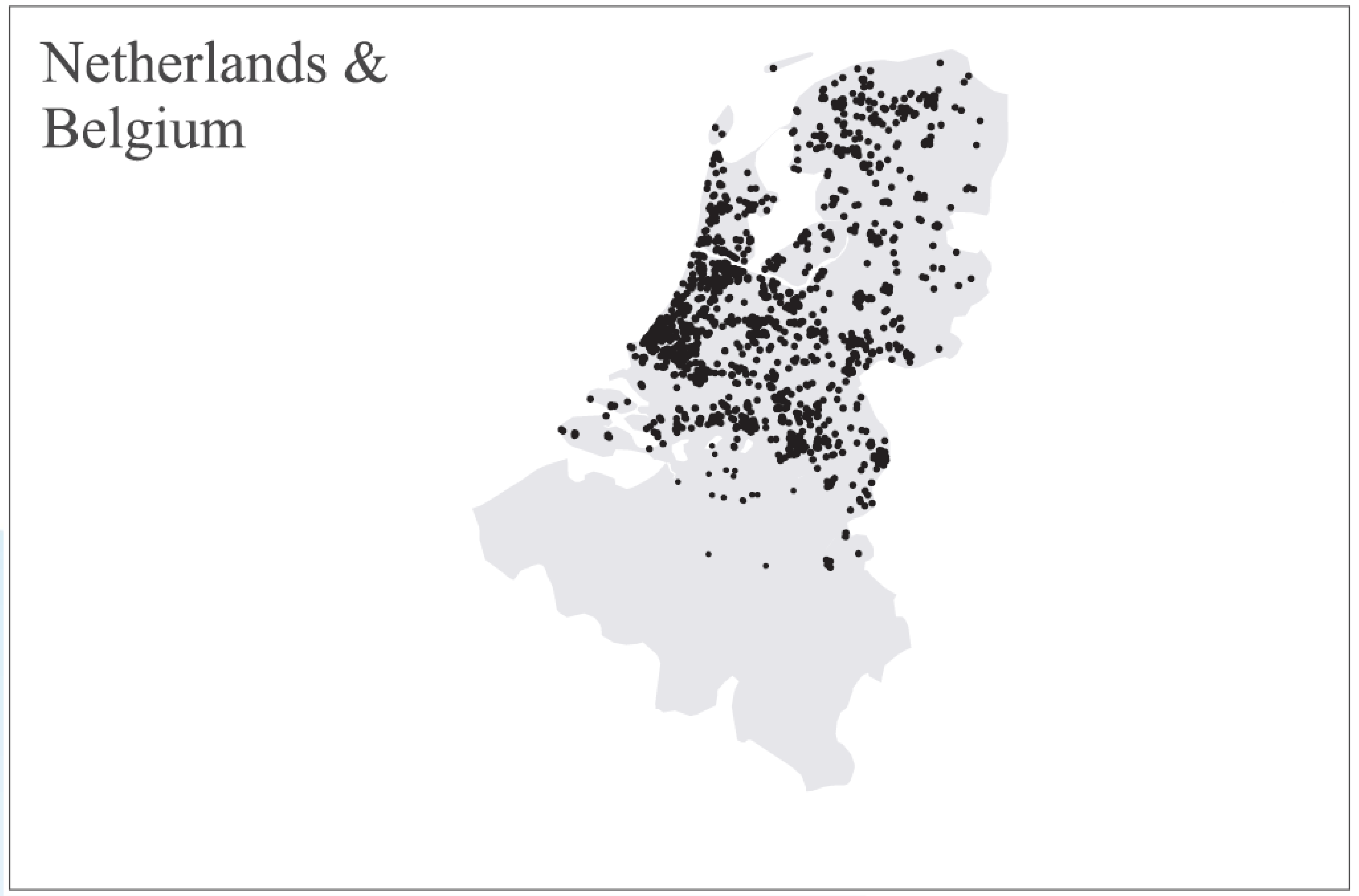
What about Belgium?

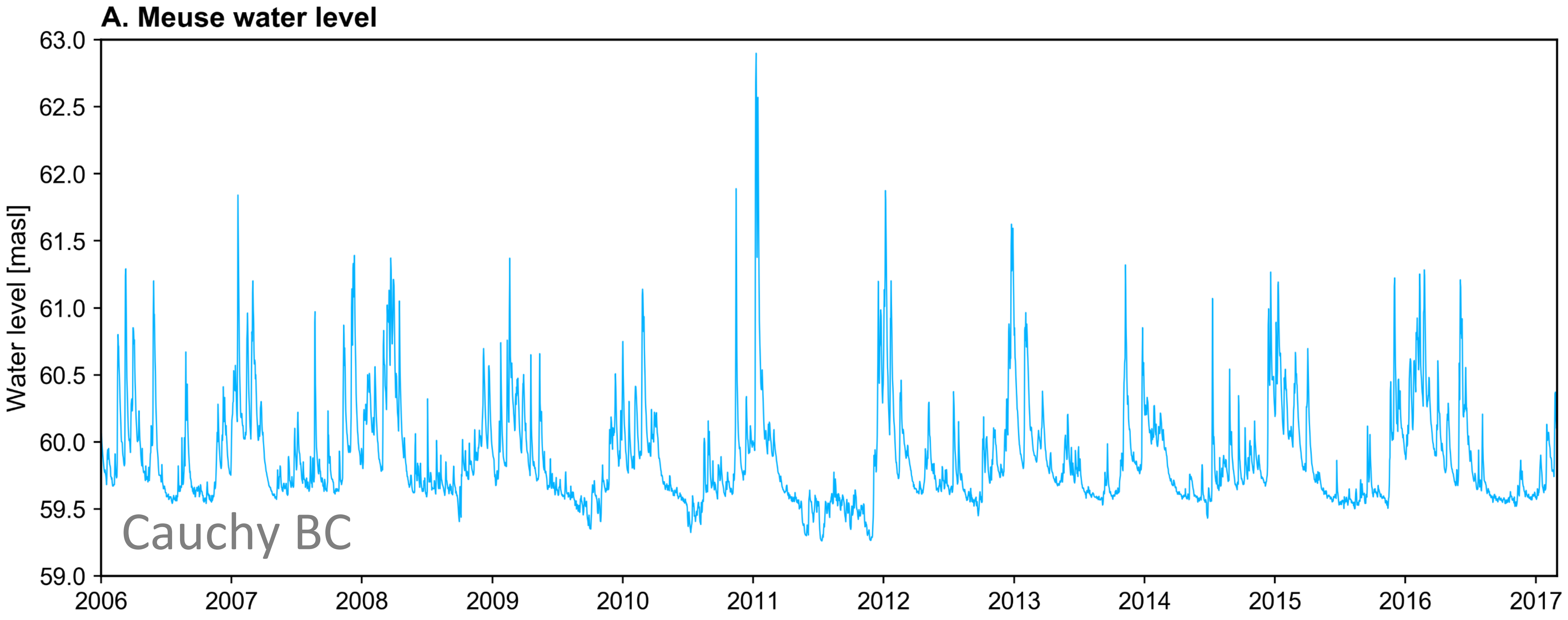


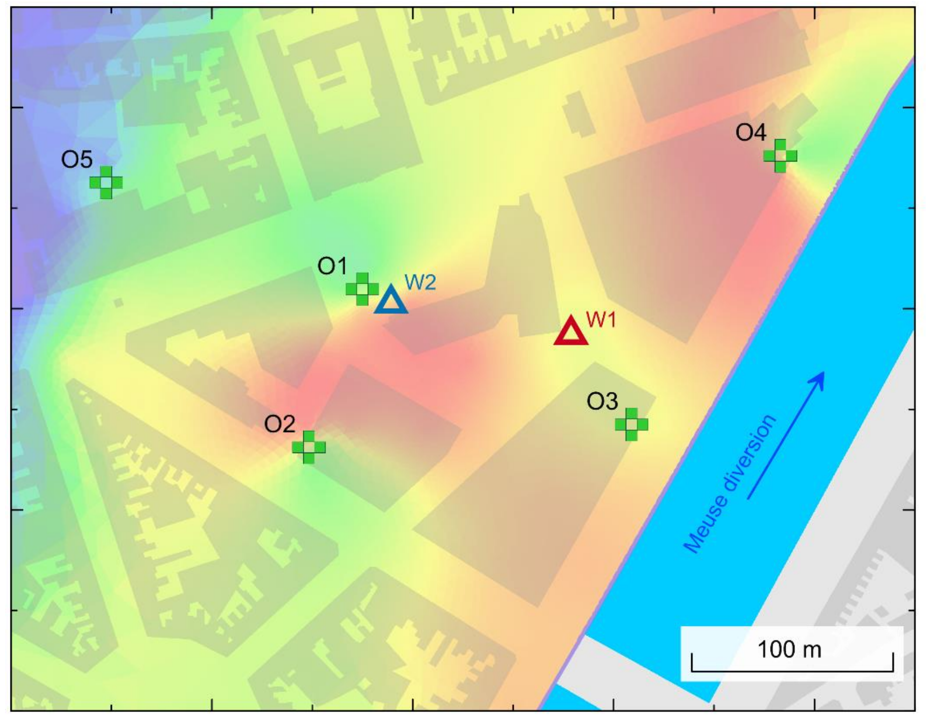


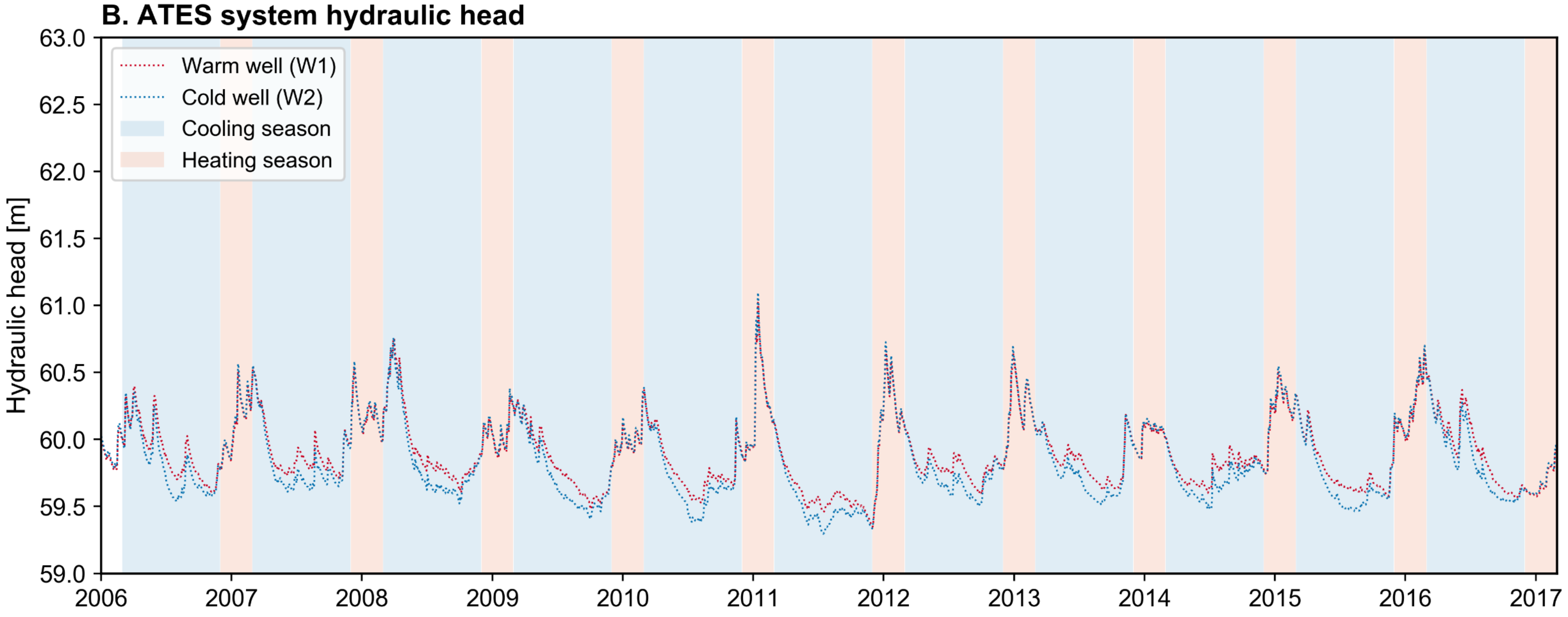


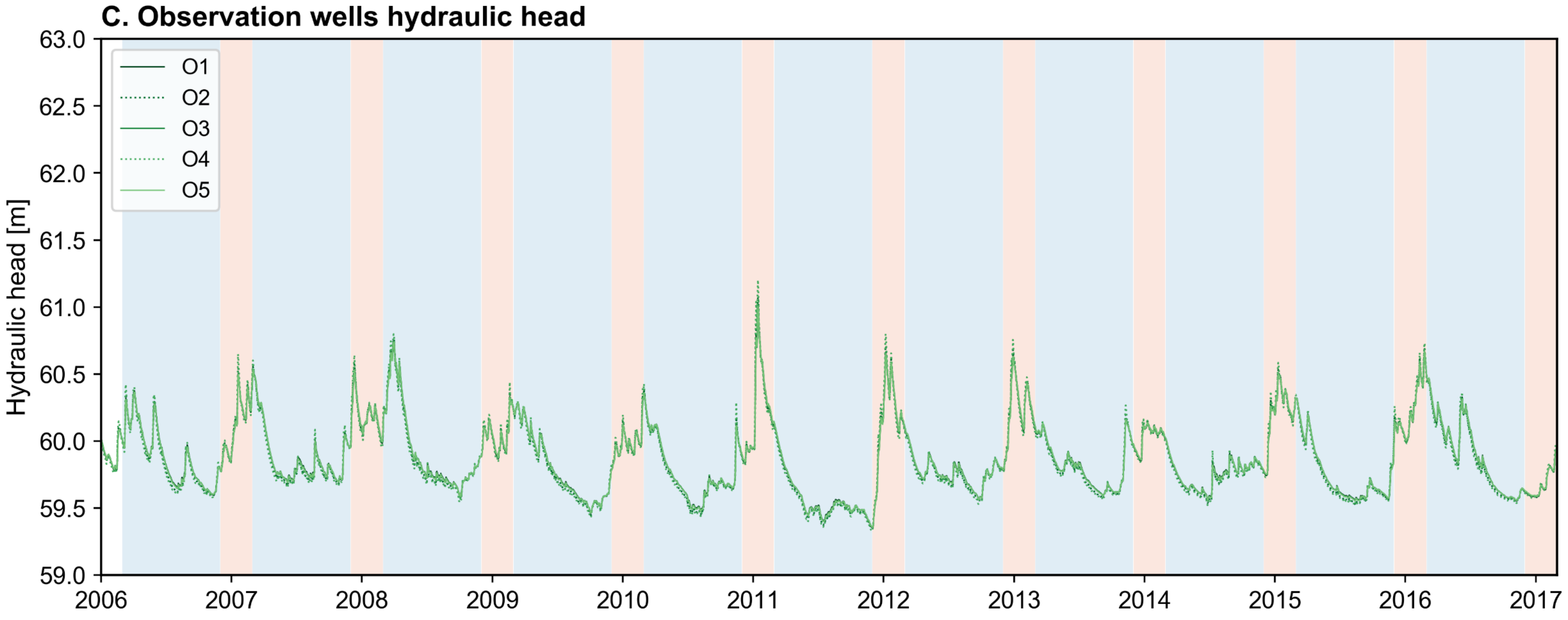
Fleuchaus et al., 2018 (Renew. Sustain. Energy Rev. 94)

Simulated hydraulic head







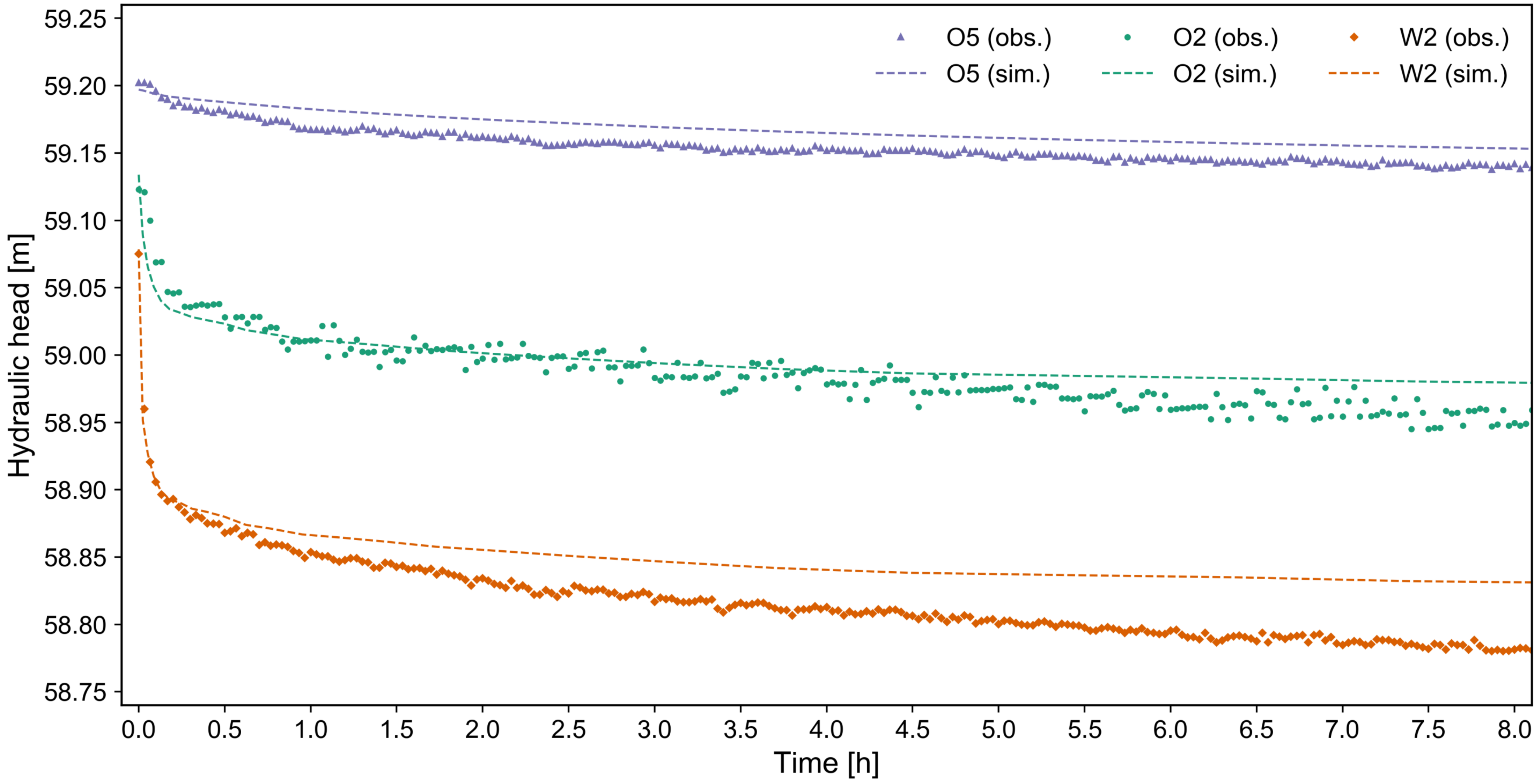


- Meuse water level: seasonnaly dependent, controlled flow through locks located upstream.
- Major influence on groundwater head in the aquifer.

Groundwater flow calibration

- Calibration under steady state conditions:
  - No active pumping well.
  - Low residuals calculated.
  - But, very low local hydraulic gradient.
- Validation under transient conditions:
  - 50 m³/h at W2.
  - Drawdown at piezometers: ok.

	Observed head (m)	Simulated head (m)	Residual (m)
O1	59.21	59.21	0.00
O2	59.21	59.22	0.01
O3	59.19	59.18	-0.01
O4	59.18	59.16	-0.02
O5	59.24	59.23	-0.01



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