

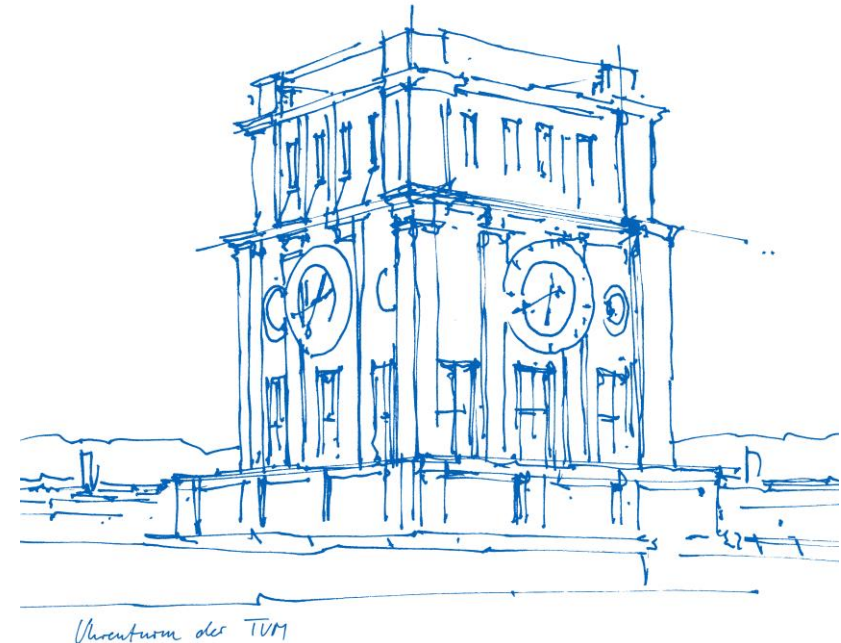
Comparison of optimization approaches for the well placement of groundwater heat pumps

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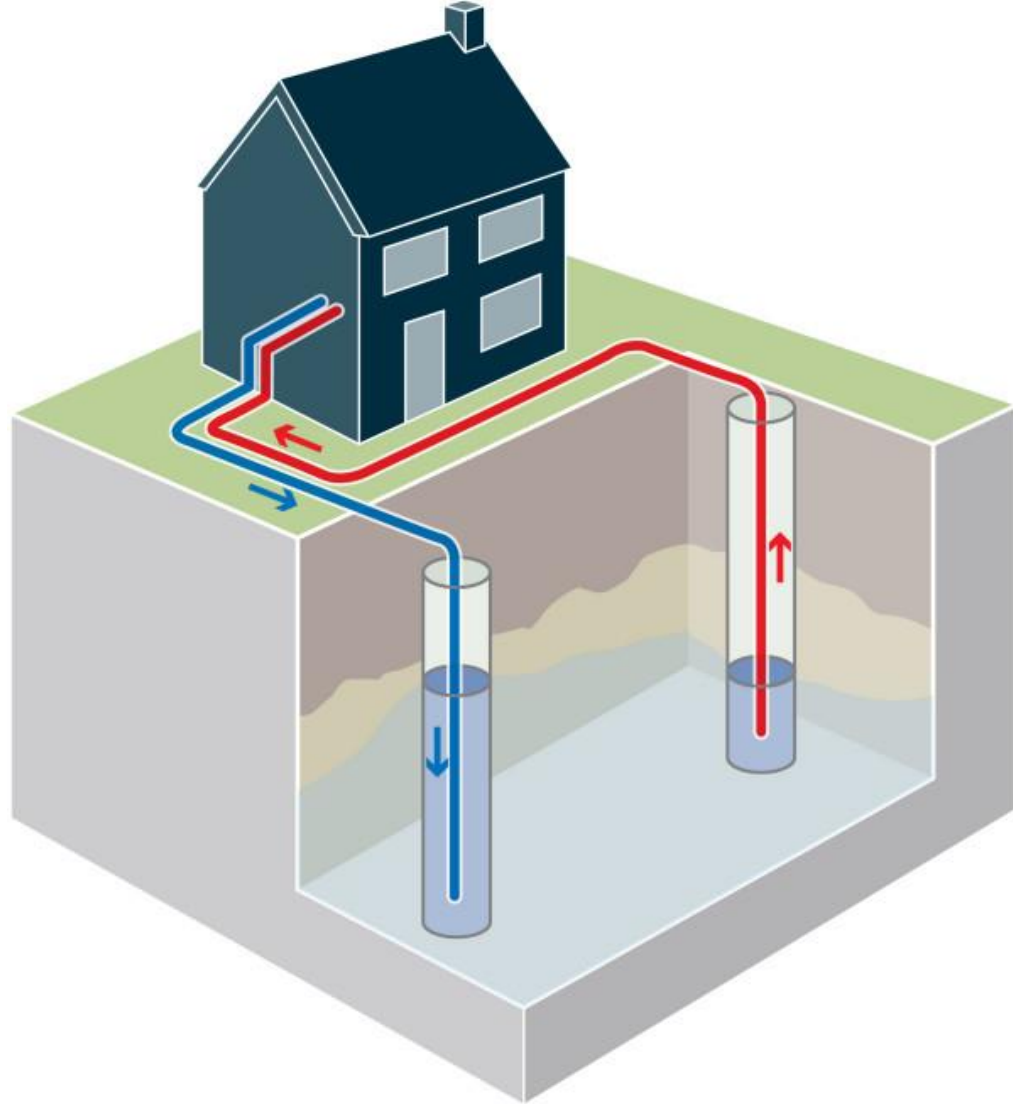
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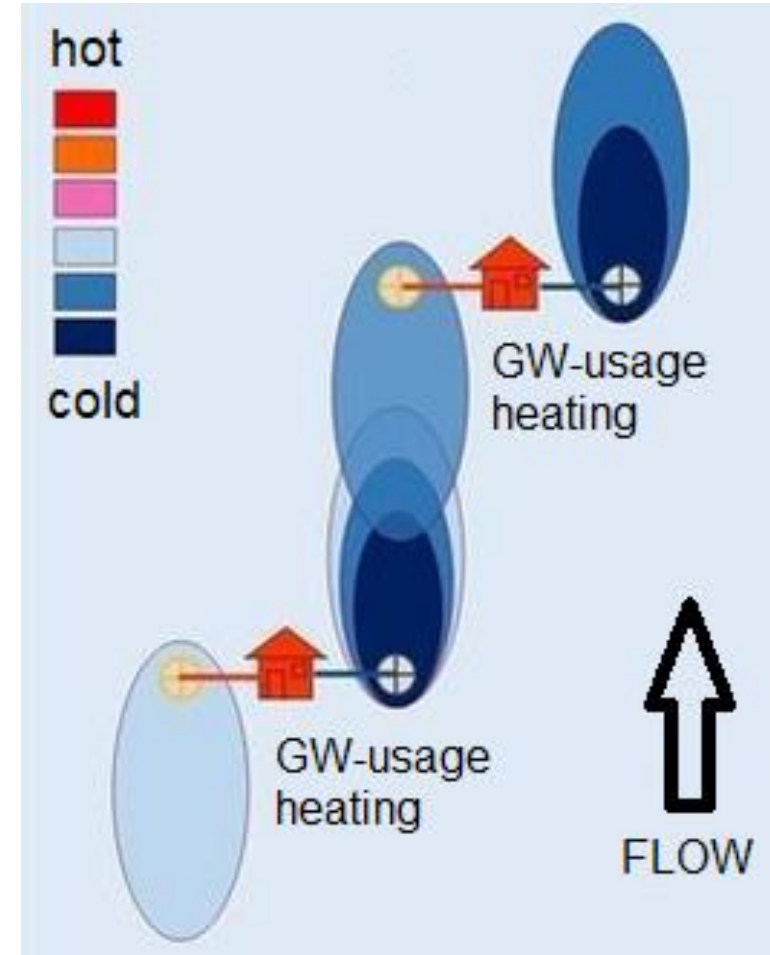
EGU 2023, Vienna



Groundwater heat pumps (GWHPs)



Typical GWHP (adapted from [1])



Negative interaction between systems [2]

Optimization of the GWHP well placement

Maximizing potential (extracted heat) and/or efficiency of GWHP systems while meeting regulatory and technical conditions

Analytical approach [3]

- Linear advective heat transport model (LAHM)
- Mixed-integer linear programming (MILP)

Optimization

Analytic formulas

Optimization

PDEs

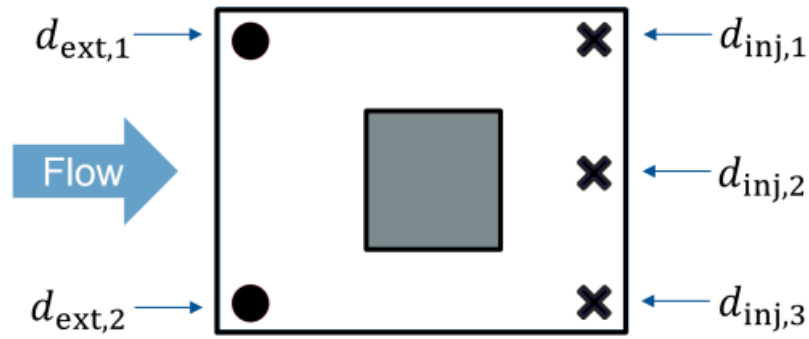
PDE-based approach [4]

- FEM numerical simulation model in Firedrake [5]
- Gradient-based optimization using adjoints

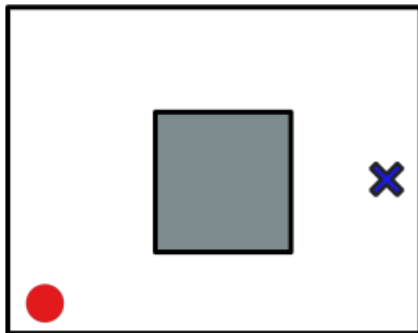
[3] Halilovic, S., Böttcher, F., Zosseder, K., & Hamacher, T. *Optimizing the Spatial Arrangement of Groundwater Heat Pumps and Their Well Locations*. Available at SSRN 4325803. <https://dx.doi.org/10.2139/ssrn.4325803>

[4] Halilovic, S., Böttcher, F., Kramer, S. C., Piggott, M. D., Zosseder, K., & Hamacher, T. (2022). *Well layout optimization for groundwater heat pump systems using the adjoint approach*. *Energy Conversion and Management*, 268, 116033. <https://doi.org/10.1016/j.enconman.2022.116033>

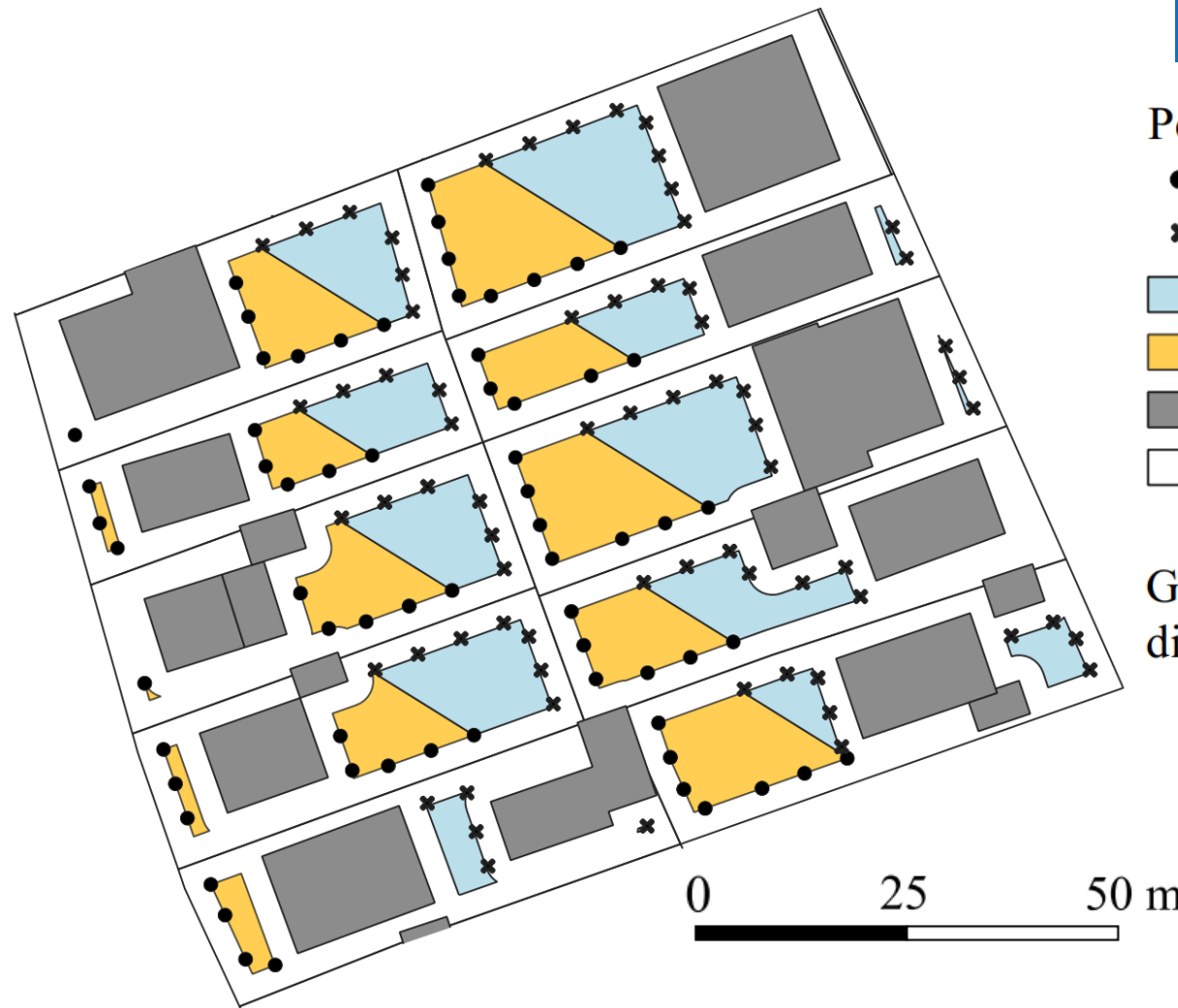
Analytical approach – Well placement (selection)



Potential well locations [3]



Selected well locations [3]



Definition of potential well locations [3]

Potential well location

● extraction

✕ injection

□ Down-gradient part

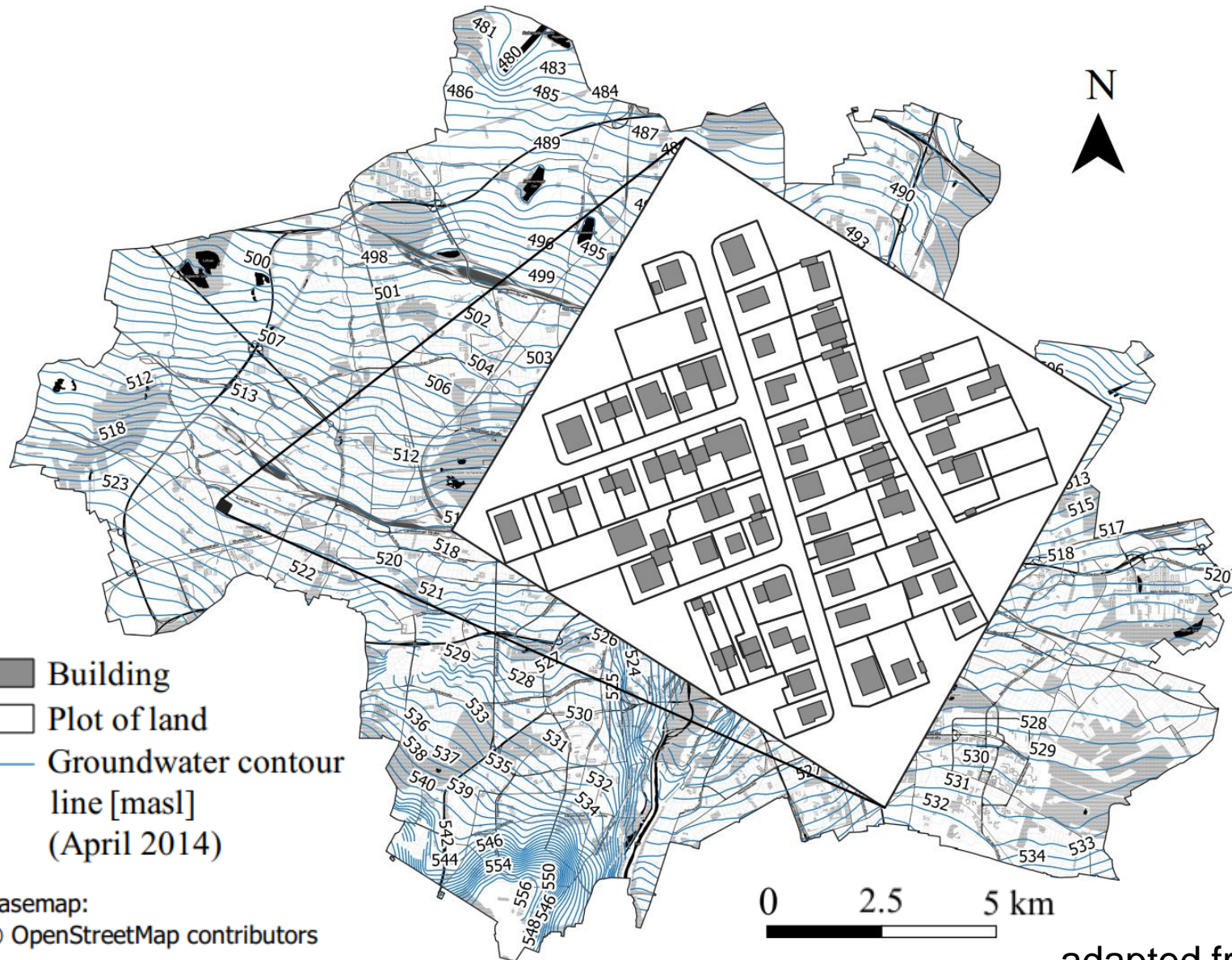
□ Up-gradient part

■ Building

□ Plot of land

Groundwater flow direction

Analytical approach – Case study



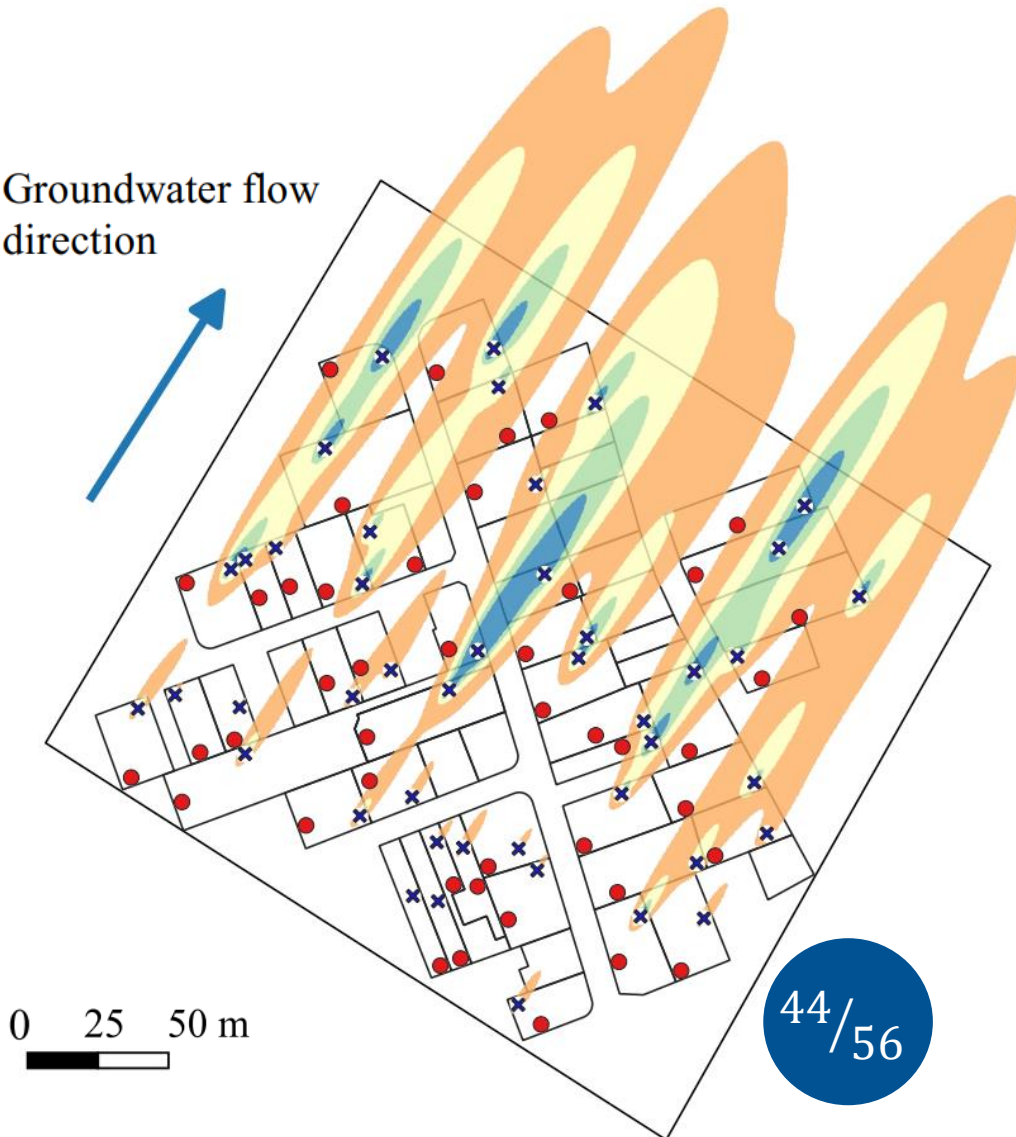
Optimization problem

- 56 plots of land (potential GWHP systems)
- Heating demand estimated using UrbanHeatPro [6]
- Place GWHPs and their wells
 - extracted heat maximized
 - regulations are satisfied

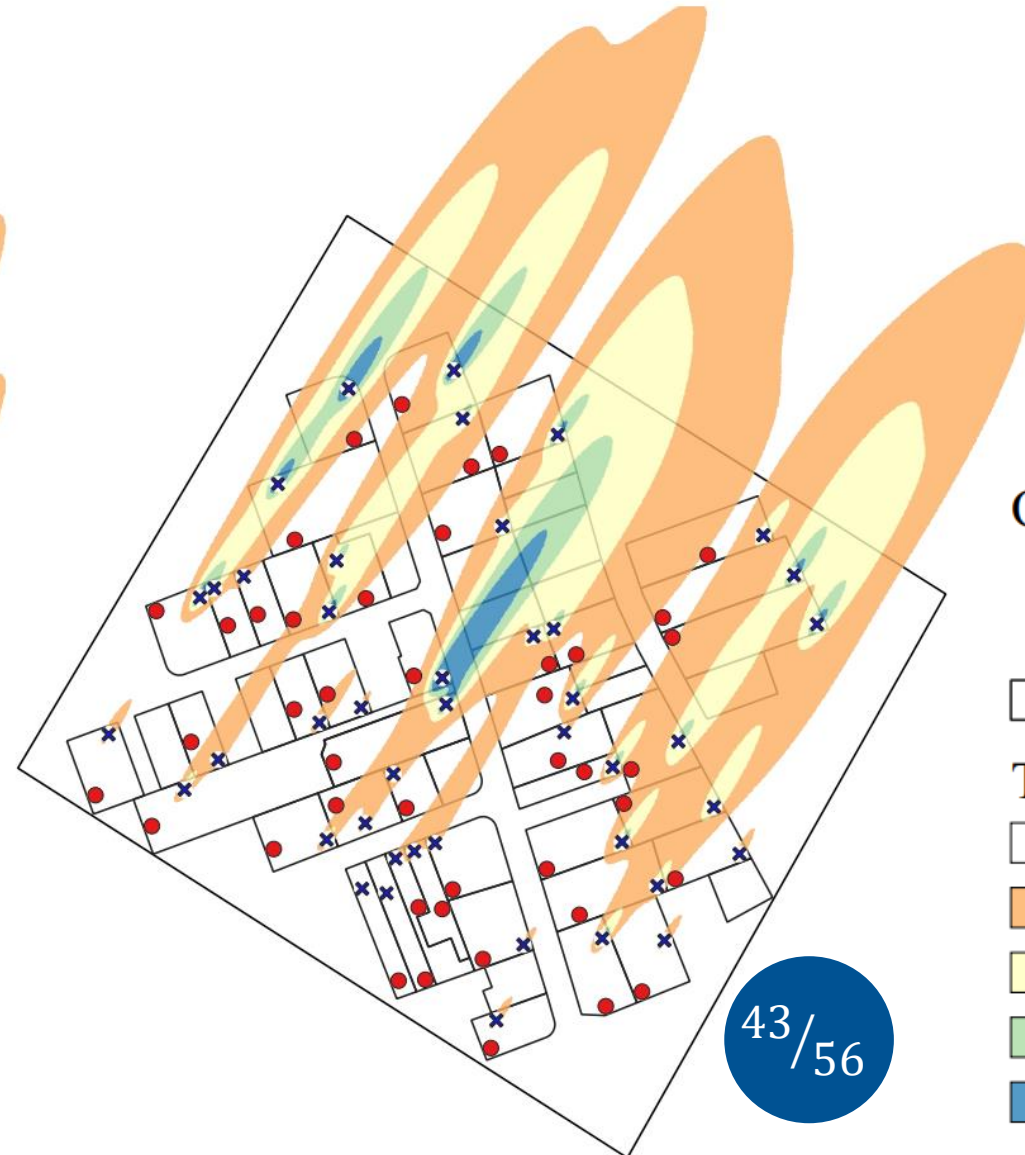
adapted from [3]

Analytical approach – Results

Groundwater flow direction



Steady case [3]



Dynamic case (end of February) [3]

Optimal well layout

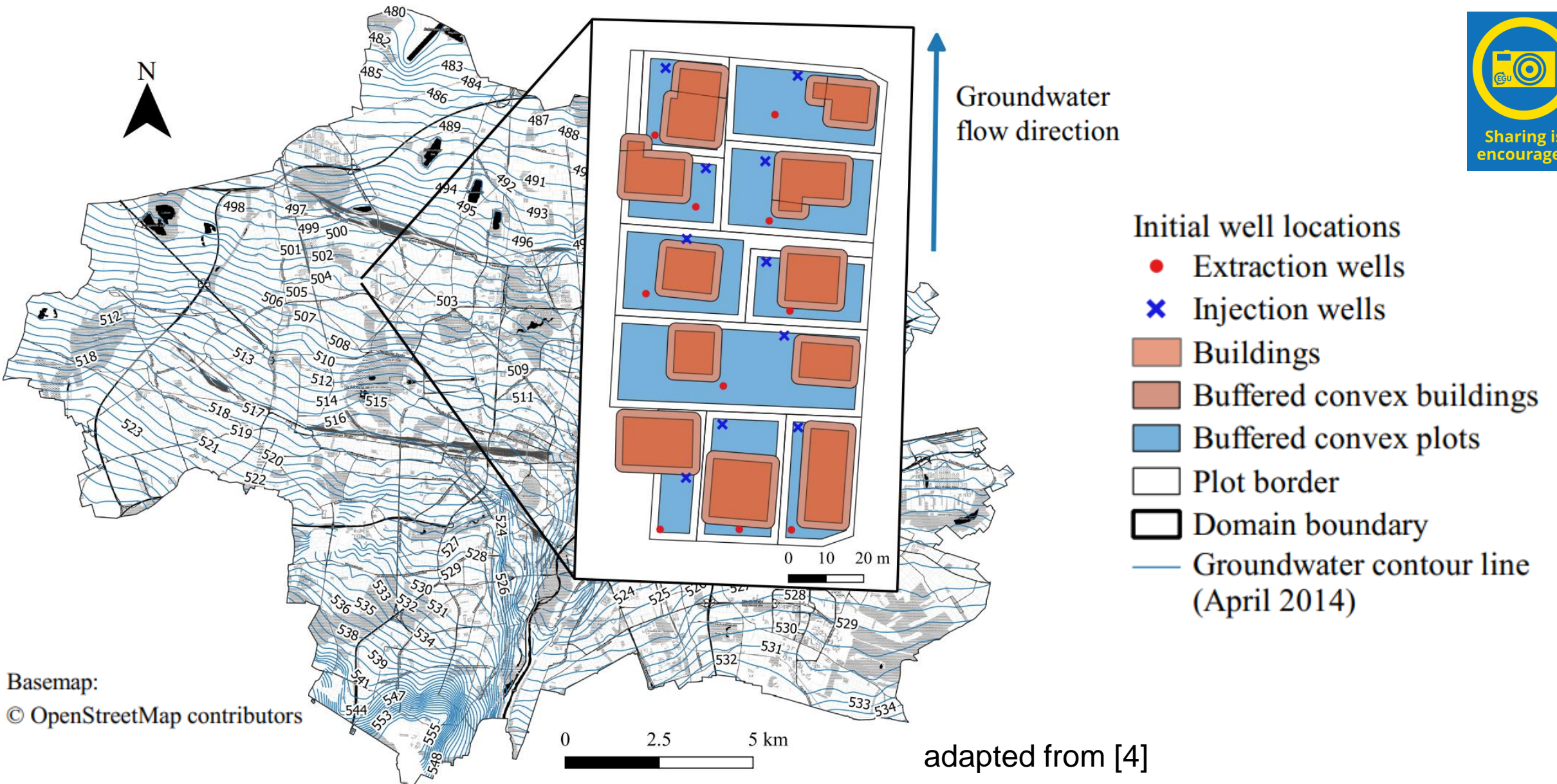
- extraction
- × injection

□ Plot of land

Thermal plumes [°C]

- ≤ 1
- 1 - 2
- 2 - 3
- 3 - 4
- > 4

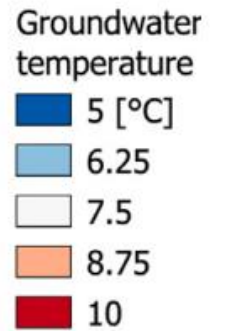
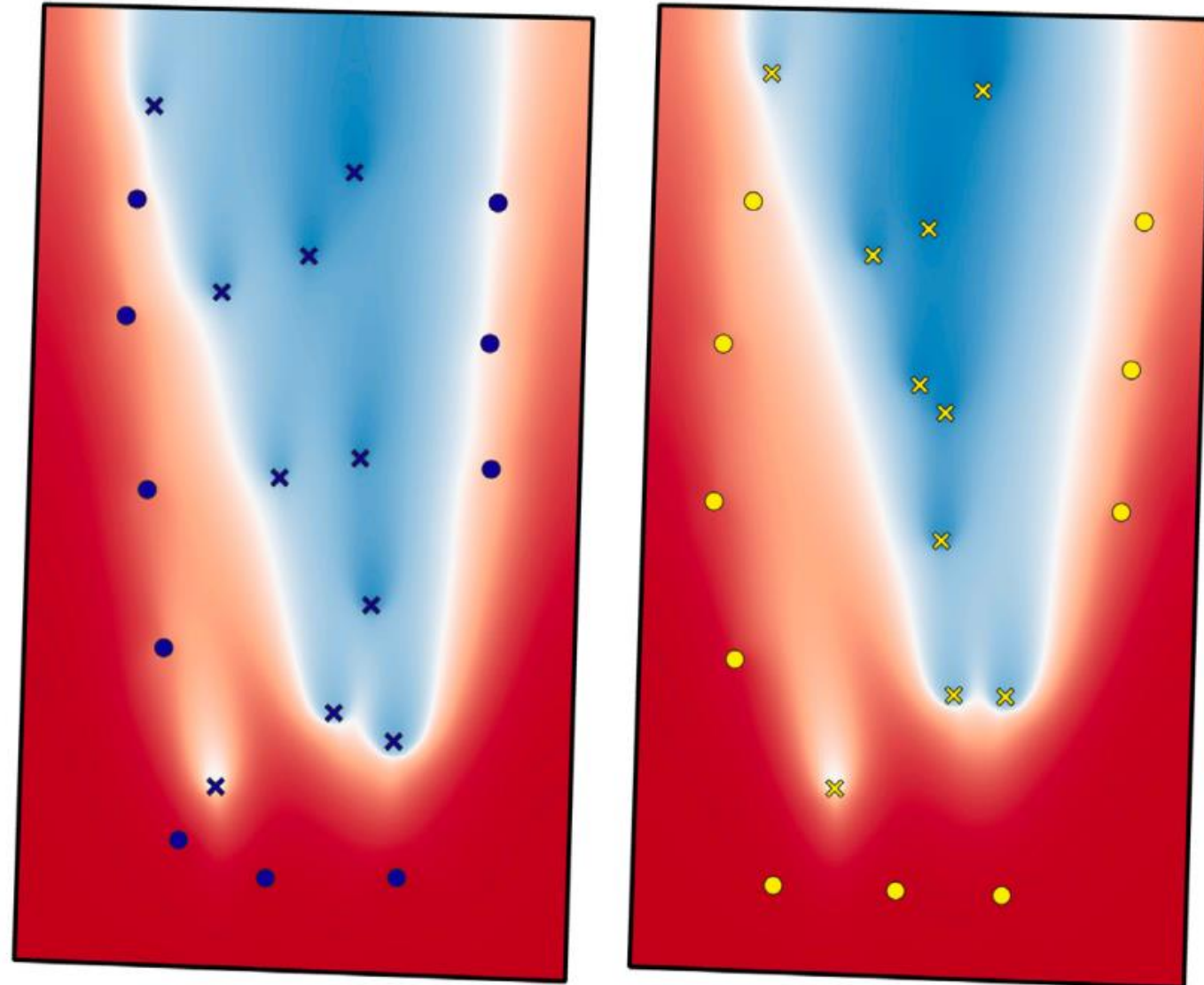
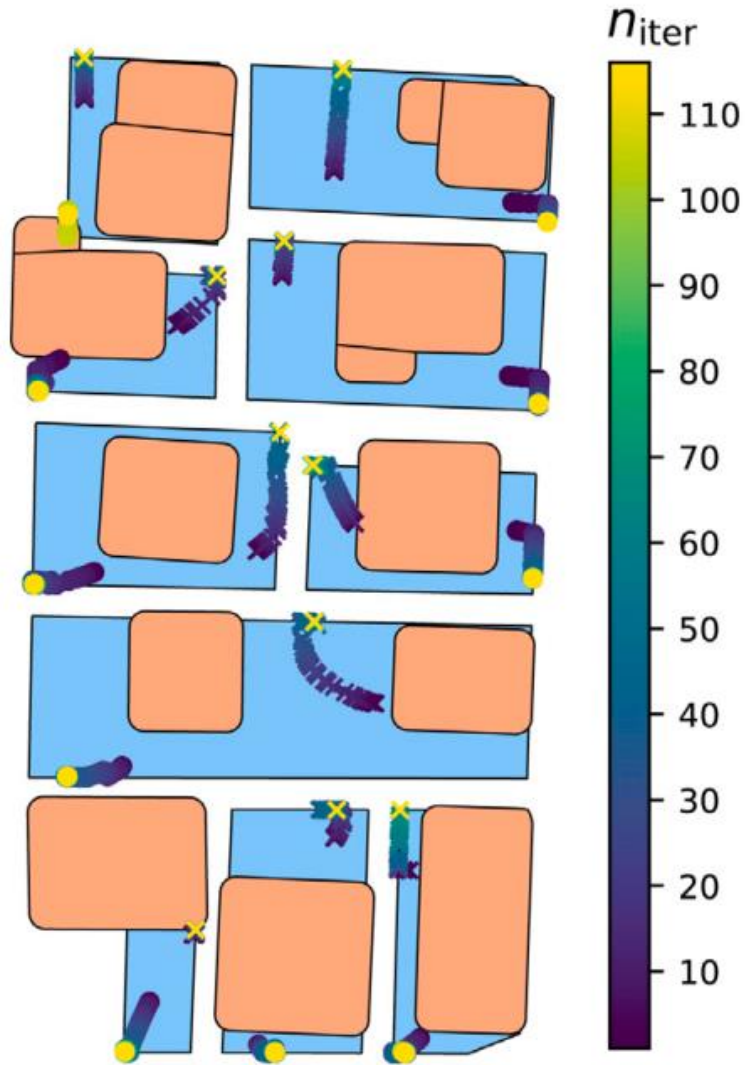
PDE-based approach – Case study



Basemap:
© OpenStreetMap contributors

adapted from [4]

PDE-based approach – Results



Well positions during optimization [4]

Initial and final GW temperature fields and well layouts [4]



	Approach	
	Analytical	PDE-based
Computational cost	+	-
Detailed GW simulation model	-	+
Applications	Analysis of geothermal potential	Detailed planning of GWHP systems

Comparison of the optimization approaches

Outlook

- Improving the approaches
- Combined (hybrid) approach
- Introduction of the approaches into practice (urban planning)

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- [1] British Geological Survey. *Ground source heat pump: Open loop GeoReport*, https://shop.bgs.ac.uk/Shop/Product/GRC_C108
- [2] Zosseder, K., et al. (2022). *Schlussbericht zum Verbundprojekt GEO-KW (Final report of the GEO-KW project)*. Lehrstuhl Hydrogeologie; Lehrstuhl Erneuerbare und Nachhaltige Energiesysteme. <https://doi.org/10.14459/2022md1692003>
- [3] Halilovic, S., Böttcher, F., Zosseder, K., & Hamacher, T. *Optimizing the Spatial Arrangement of Groundwater Heat Pumps and Their Well Locations*. Available at SSRN 4325803. <https://dx.doi.org/10.2139/ssrn.4325803>
- [4] Halilovic, S., Böttcher, F., Kramer, S. C., Piggott, M. D., Zosseder, K., & Hamacher, T. (2022). *Well layout optimization for groundwater heat pump systems using the adjoint approach*. *Energy Conversion and Management*, 268, 116033. <https://doi.org/10.1016/j.enconman.2022.116033>
- [5] Rathgeber F, Ham DA, Mitchell L, Lange M, Luporini F, Mcrae ATT, Bercea G-T, Markall GR, Kelly PHJ. Firedrake. *ACM Trans Math Software* 2017;43(3):1–27. <http://dx.doi.org/10.1145/2998441>
- [6] A. Molar-Cruz, UrbanHeatPro, <https://github.com/tum-ens/UrbanHeatPro>, 2020.

Analytical approach – Results

(a) Steady case

(b) Dynamic case

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Groundwater flow direction

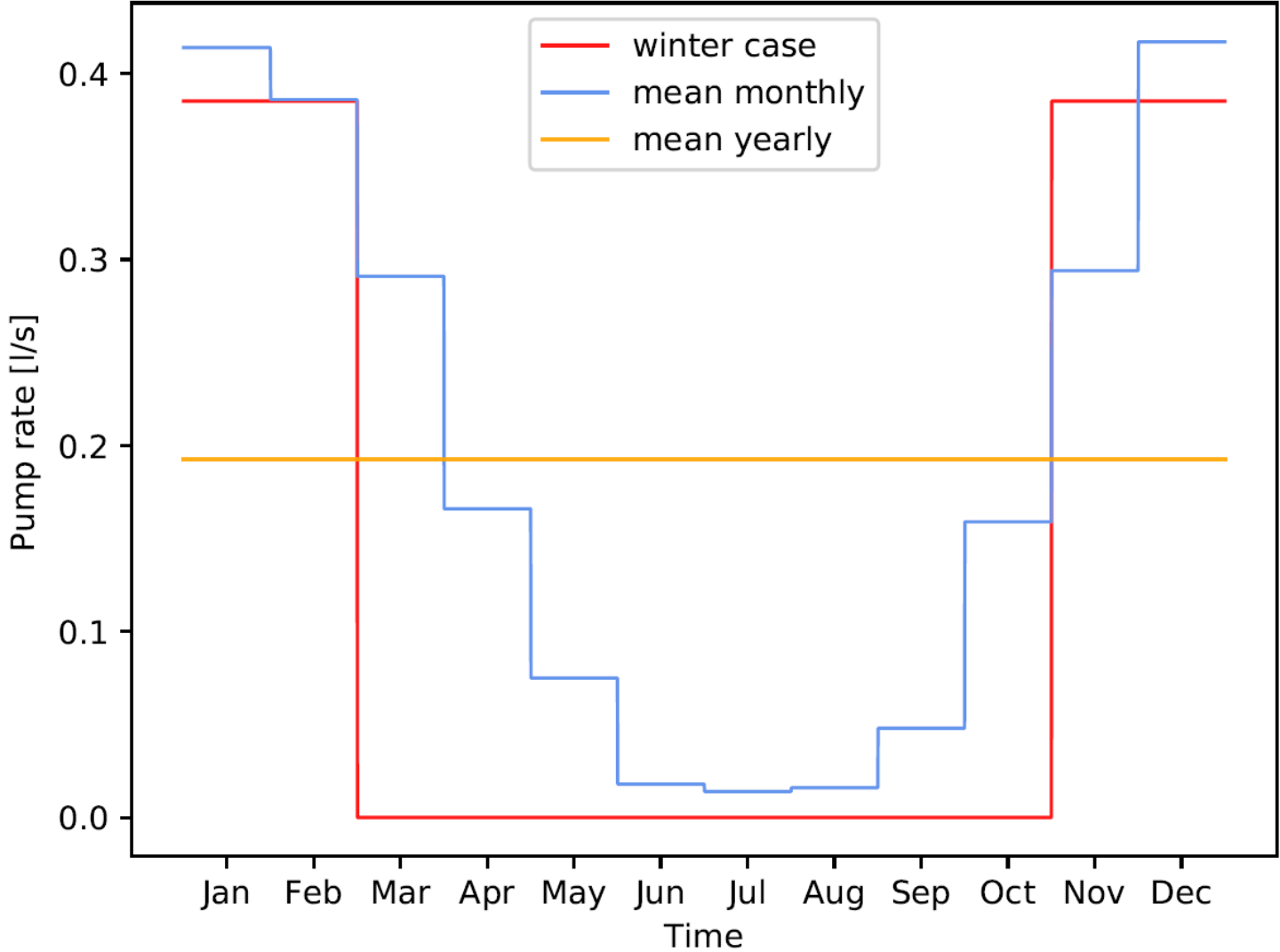
0 25 50 m

Optimal well layout

- extraction
- × injection
- Building
- Plot of land

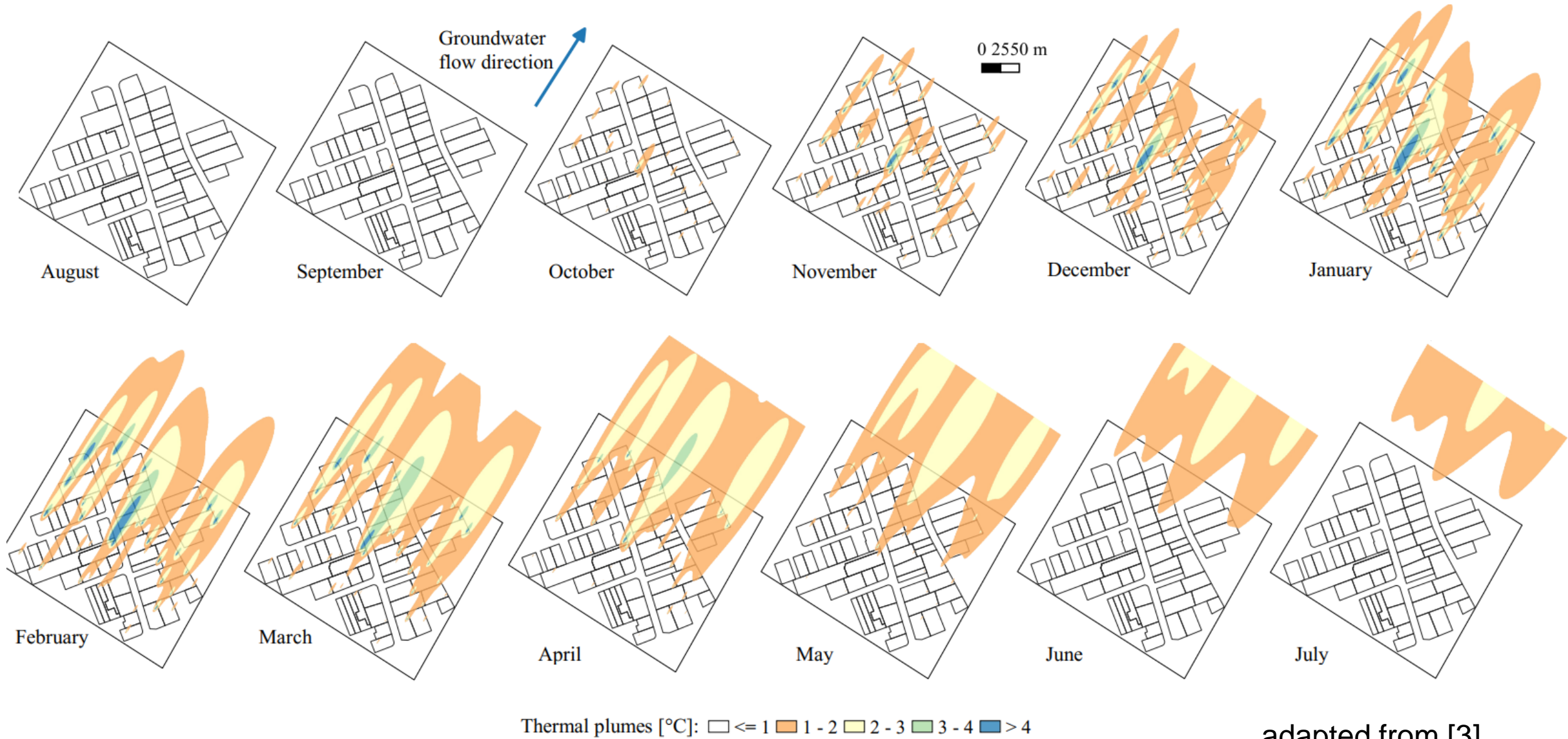
Optimal well layouts (adapted from [3])

Analytical approach



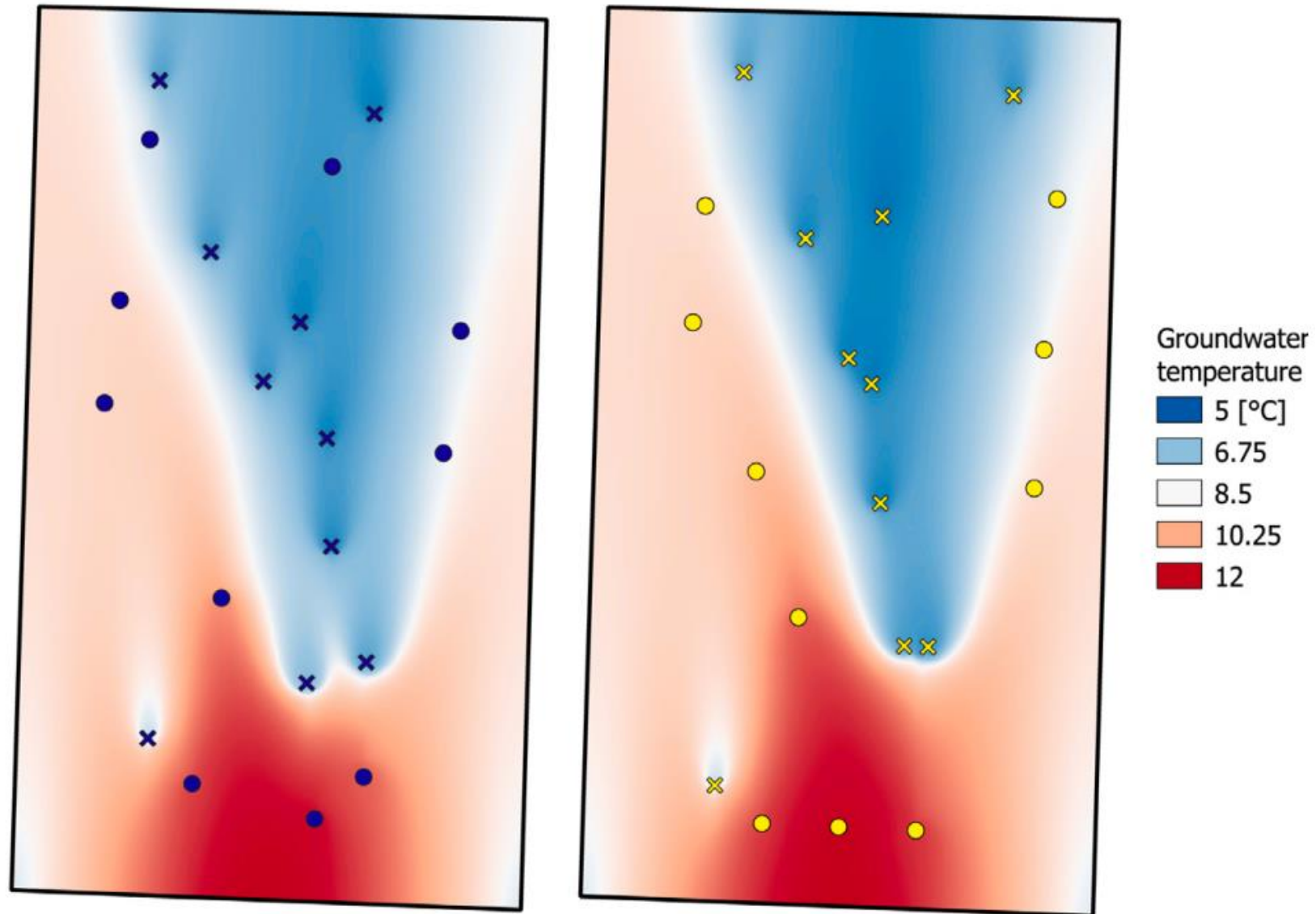
Optimization scenarios (cases) [3]

Analytical approach – Results (dynamic case)



adapted from [3]

PDE-based approach – Results (scenario 2)



Initial and final GW temperature fields and well layouts [4]