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# Hydrogeological modeling and design optimization of BHE sites

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# Content

1. Motivation: Investigation of groundwater flow and subsurface heterogeneity influence on BHE operation

2. Approach: site modeling, parameter sensitivity analysis, design optimization, and software comparison

    - Hannover site: parameter sensitivity
    - Vechta site: field measurements, data analysis, modeling of groundwater flow and heat transport, parameter calibration, model-based prediction
    - Hamburg site: field measurements, data analysis, geological modeling of subsurface heterogeneity, modeling of groundwater flow and heat transport, parameter calibration, model prediction
    - Clustered BHE systems: design optimization

3. Outlook and next steps

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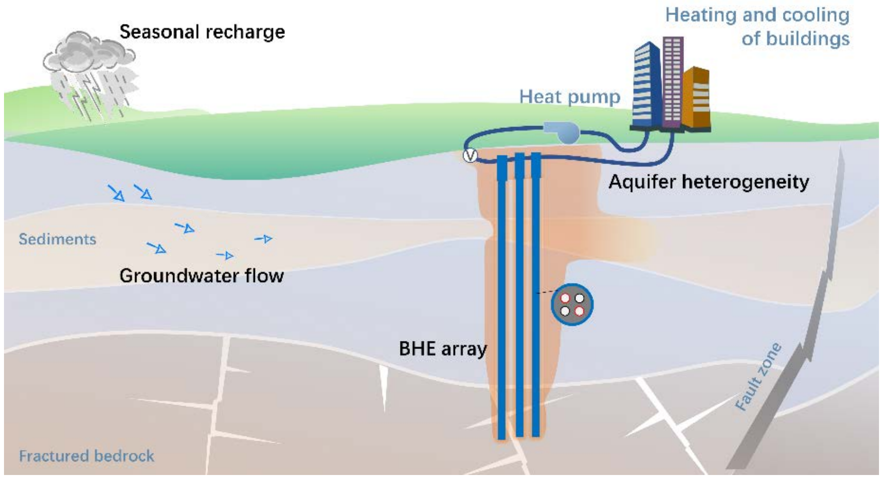
# 1. Motivation

- Investigation of groundwater flow and subsurface heterogeneity influence on BHE operation




- Subsurface is naturally heterogeneous
- Groundwater flow is accompanied by heat transfer processes
- Influence of these two factors can be site-dependent

## 2. Approach

- Schedule

| Site | Community | Hannover | Vechta | Hamburg |
|---|---|---|---|---|
| Objectives | BHE cluster design optimization | Parameter sensitivity | Effects of groundwater flow and heterogeneity (layers) | Effects of groundwater flow and heterogeneity (3D geological model) |
| Data collection | / | | | |
| Site modeling | | | | |
| Model calibration | / | / | | |
| Sensitivity analysis | / | | / | / |
| Supplementary monitoring | / | / | | |
| Optimal heat strategy | | | | |
| Regeneration energy | | | | |

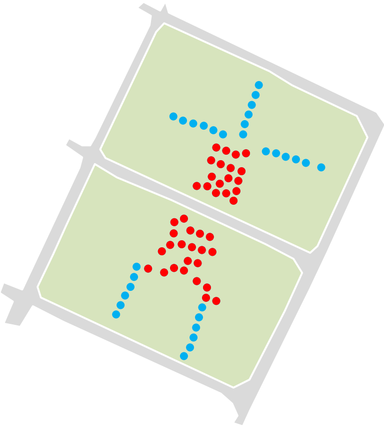
*Finished*

*In progress*

*Planned*

# 2.1 Hannover site (“virtual” site, parameter sensitivity)

- Site description



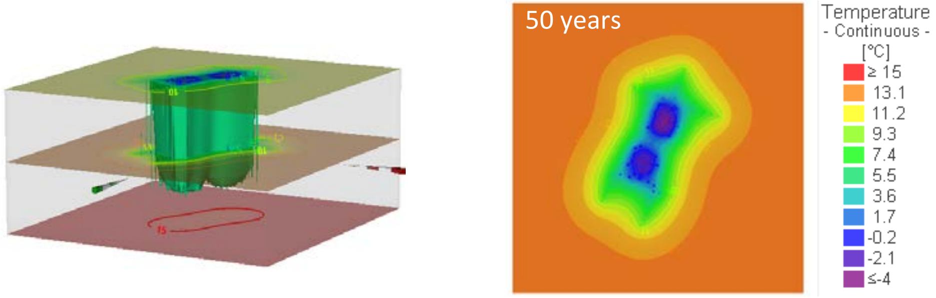

BHE without regeneration

BHE with regeneration

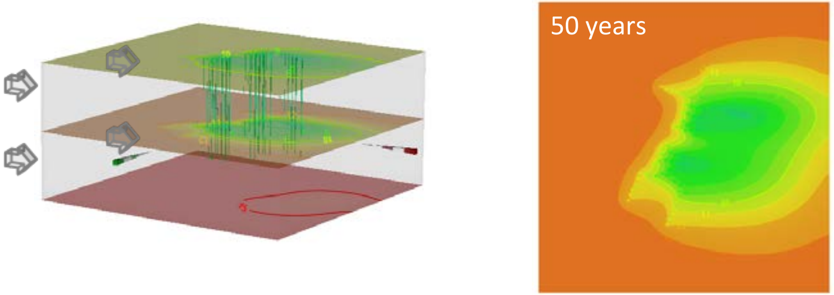
| Parameters | Values |
|---|---|
| Number of BHE (planned) | 70 (40 with regeneration) |
| BHE length | 150 m |
| Undisturbed temperature | 11.3 ºC |
| Thermal conductivity | 2.2 W/m/K |
| Darcy flux | / |
| Aquifer heterogeneity | / |
| Groundwater table depth | / |
| Rainfall | / |
| Heat transfer coefficient | / |

- Example of subsurface temperature field change considering groundwater flow

No groundwater flow



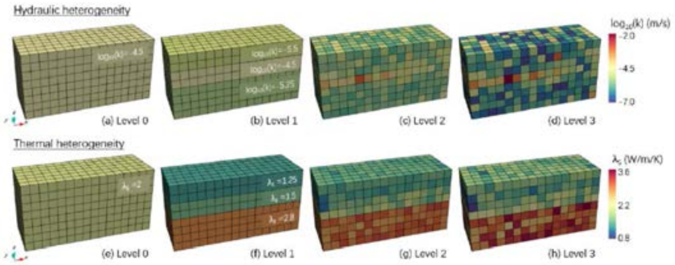

Darcy flux of $10^{-7}$ m/s



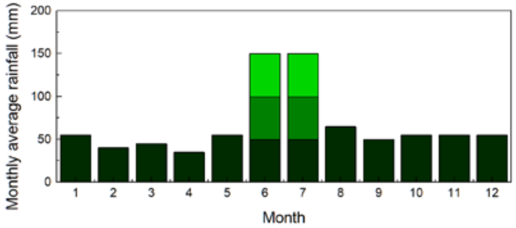
- Uncertain parameters

| No. | Parameter | Levels |
|---|---|---|
| a | Darcy flux in the aquifer ($m/s$) | [1e-8, 1e-7, 1e-6*, 1e-5] |
| b | Thermal conductivity of soil ($W/m/K$) | [1, 2*, 3, 4] |
| c | Depth of groundwater table ($m$) | [0*, 10, 25, 50] |
| d | Thermal heterogeneity degree | [0*, 1, 2, 3] |
| e | Hydraulic heterogeneity degree | [0*, 1, 2, 3] |
| f | Geothermal gradient (°C/$m$) | [-0.01, 0*, 0.01, 0.02] |
| g | Heat transfer coefficient on land surface ($W/m^2/K$) | [0*, 2, 4, 6] |
| h | Seasonal rainfall in June and July ($mm/month$) | [0*, 50, 100, 150] |

* represents the value set in the base case




Four degrees of heterogeneity




Histogram of the monthly average rainfall

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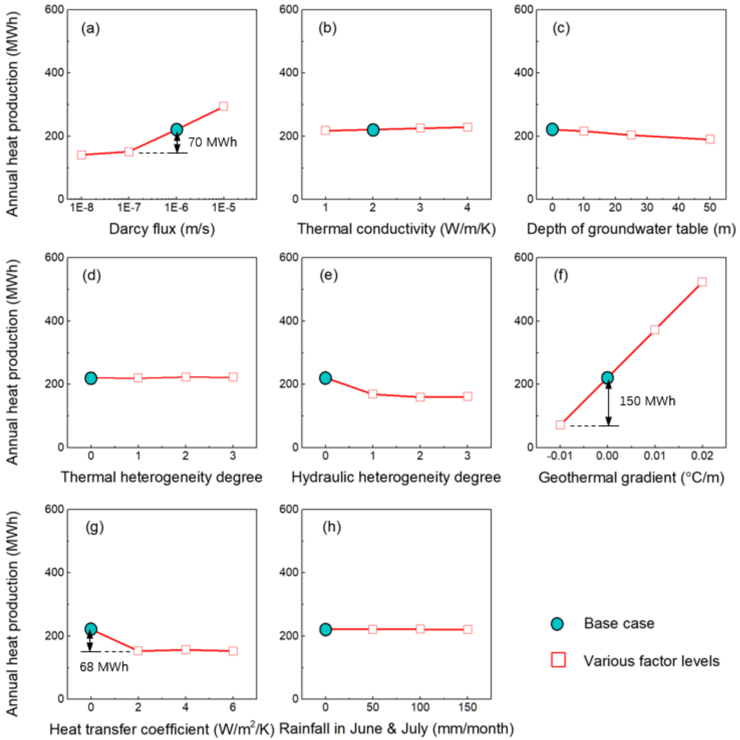
- Sensitivity of the annual heat production with respect to the eight factors

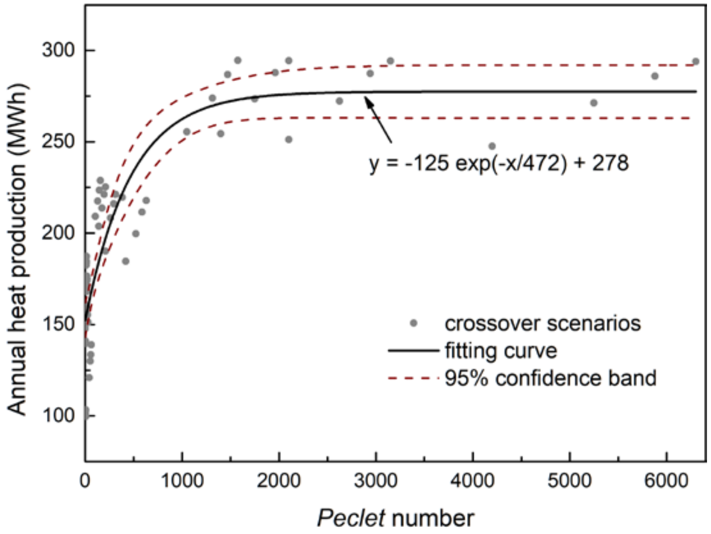



- Geothermal gradient
- Darcy flux
- Heat transfer coefficient on ground surface
- Hydraulic heterogeneity
- Depth of groundwater table

- Uncertainty of annual heat production based on *Peclet number*

$$Peclet\ number = \sum_{1}^{n} \frac{\rho_w c_w v_D (L - h_w)}{\lambda_s}$$

| | |
|---|---|
| $v_D$ | Darcy flux |
| $h_w$ | Groundwater table |
| $\lambda_s$ | Thermal conductivity |




ca. 153 MWh

## 2.2 Example of a housing community (BHE cluster design optimization)

*Design of clustered individual BHE systems (Witte and Boots, 2022)*

Difficulties for designers, law-makers, and regulators:

1) how to guide individuals to install BHEs?

**maximize** the total heat extraction

**control** environment impacts

2) how to design the BHE system for individuals?

maintain long-term efficiency

**limit impacts from neighbors**

■ Optimization issue


A total of 58 building lots

- Objective:

  maximize total net specific heat extraction (NSHE)

- Constraints:

  1) thermal impacts to the environment < 6 °C

  2) thermal impacts from neighbors < 1.5 °C

  3) NSHE for individual varies in [10, 120] kWh/m/y

- Optimization issue


A total of 58 building lots

Constraints:

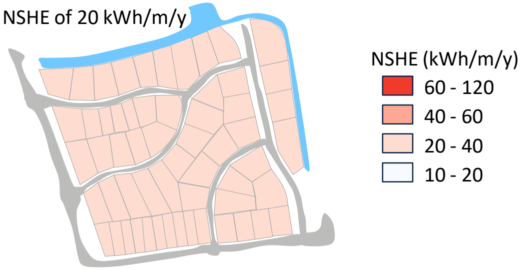
1) $\Delta T_{env} < 6$ °C

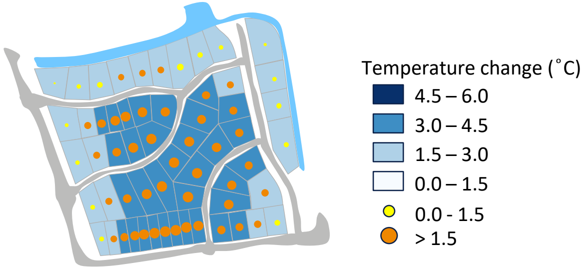
2) $\Delta T_{nei} < 1.5$ °C

3) $NSHE_{ind} \in [10, 120]$ kWh/m/y

**Initial case**

uniform NSHE of 20 kWh/m/y




Ball size represents the thermal impacts from neighbors

## Optimization issue


A total of 58 building lots

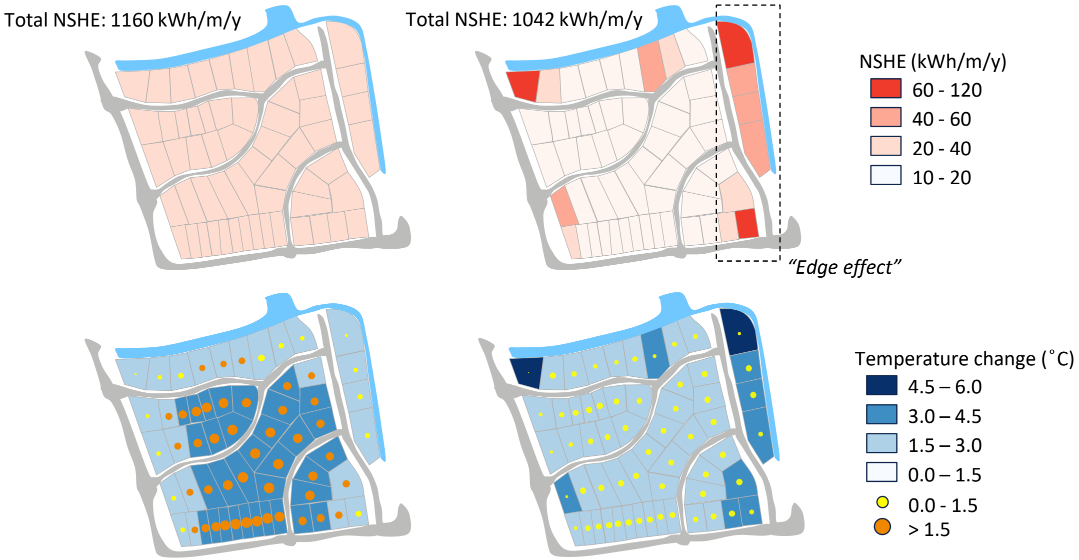
Constraints:

1) $\Delta T_{env} < 6\ ^{\circ}C$

2) $\Delta T_{nei} < 1.5\ ^{\circ}C$

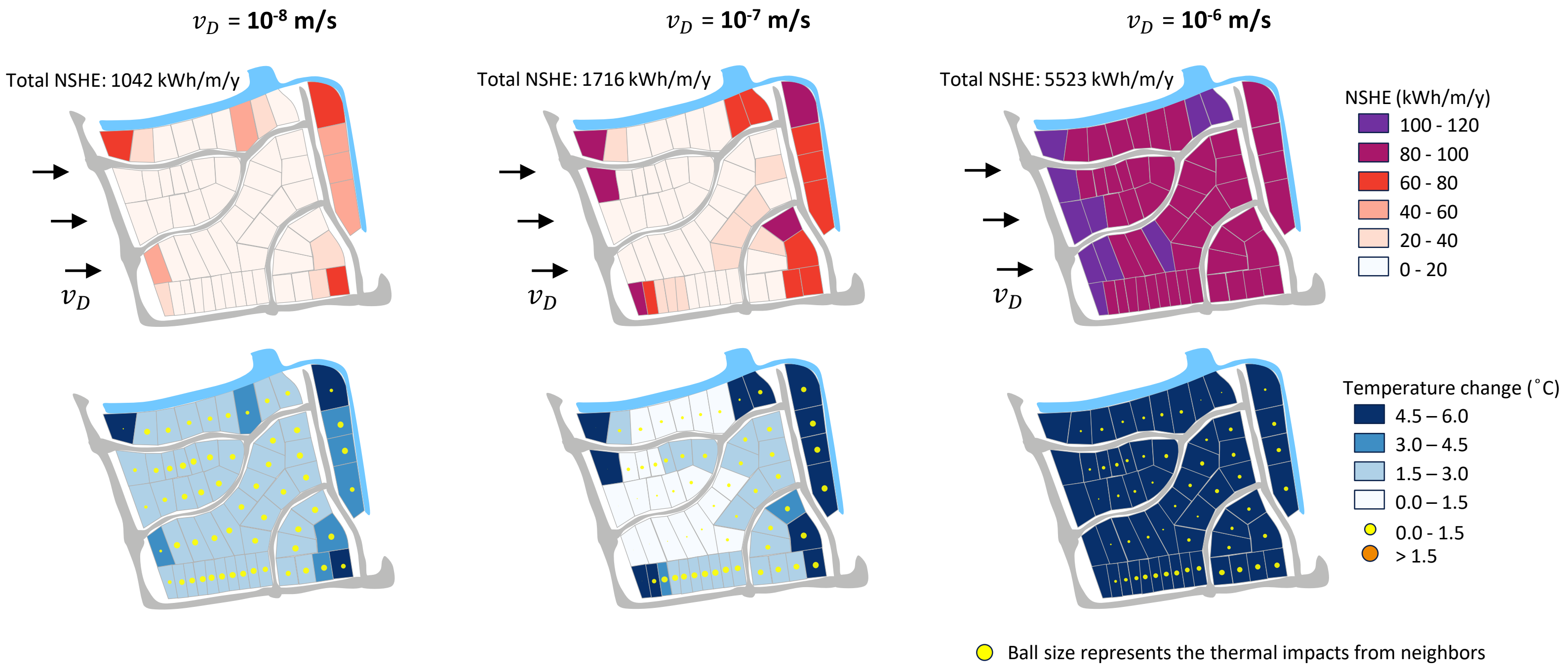
3) $NSHE_{ind} \in [10, 120]$ kWh/m/y

**Before opt.** **After opt.**




Ball size represents the thermal impacts from neighbors

- Considering GW flow



# 3. Outlook and next steps

- Consider regeneration energy in site modeling and design optimization
- Quantify the uncertainty of BHE array performance caused by aquifer heterogeneity and groundwater flow
- Assess the influence of groundwater flow and subsurface heterogeneity at existing sites, such as Hamburg and Vechta sites
- Compare simulation outcomes with results from TRNSYS simulations for real sites

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