

## Pilot Study for the Planning of a Seasonal Aquifer Thermal Energy Storage System (ATES)

### Project Description

As part of an energy transition pilot project on a North Sea island, the seasonal storage of thermal energy in an aquifer (Aquifer Thermal Energy Storage, ATES) is being investigated. Two shallow aquifers are being considered as potential storage horizons, and their groundwater flow dynamics are to be characterized in greater detail as part of the preliminary investigations.

Only two groundwater monitoring wells are available for hydrogeological investigation. Both aquifers encountered are under artesian conditions, resulting in groundwater overflow at the wellheads when the monitoring wells are open.

Long-term horizontal in-situ groundwater flow measurements are planned to determine flow direction and velocity and to identify potential tide-related changes in groundwater flow.

The results provide supplementary data for assessing the potential advective displacement and spatial migration of the thermal storage zone with the natural groundwater flow and for supporting the further planning and modelling of the ATES system. The project envisages the seasonal storage of thermal energy generated by a renewable energy system combining wind and solar energy with a biogas plant.

ATES systems can make an important contribution to the seasonal storage of renewable thermal energy and thus to the transition towards sustainable heat supply.

### Hydrogeological Setting

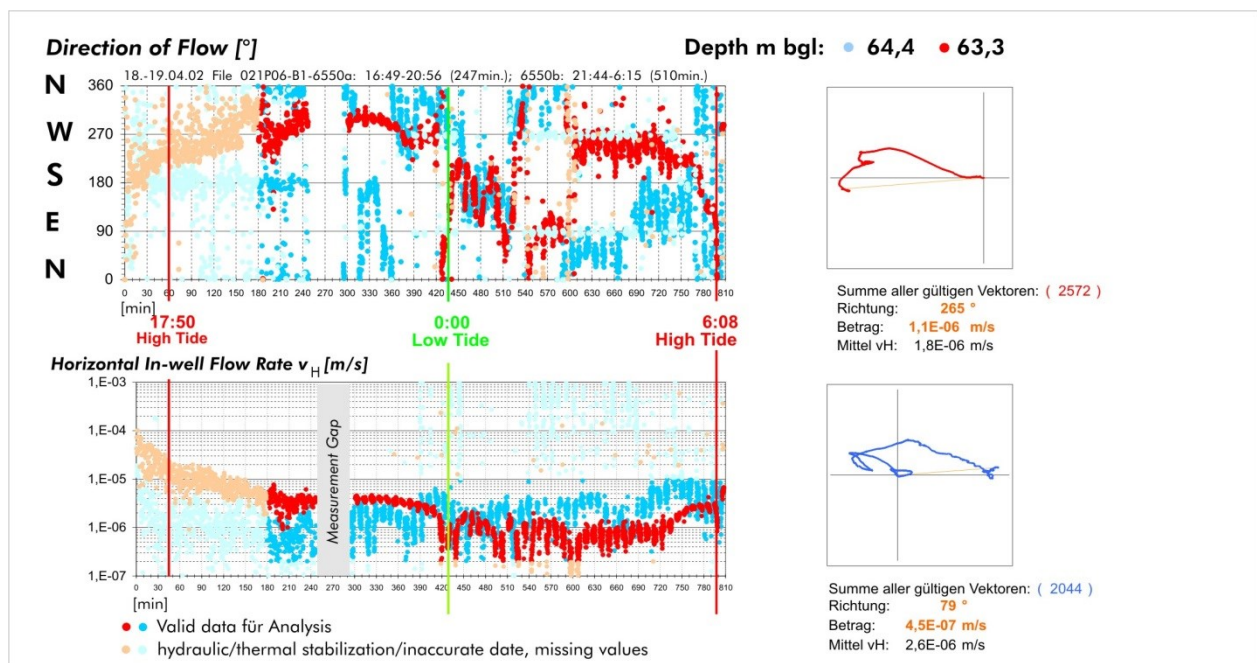
Confined artesian porous aquifers consisting of fine to coarse sand. The profiles comprise several sandy aquifer horizons separated by low-permeability layers of clayey marine deposits and clay several metres thick. Interbedded glacial till occurs locally.

### Purpose of Investigation

- Initial characterization of groundwater flow dynamics in two confined artesian aquifers
- Identification of tide-related changes in groundwater flow direction and velocity
- Data basis for assessing potential advective displacement of the thermal storage zone
- Provision of directly measured groundwater flow data for groundwater flow and ATES modelling
- Hydrogeological data basis for the further planning of the aquifer thermal energy storage system

### Investigation Results

Long-term horizontal in-situ groundwater flow measurements in two groundwater monitoring wells provided initial depth- and time-resolved information on groundwater flow dynamics and the influence of the tidal cycle at depths of up to 64 m, supplementing the existing hydrogeological data. During the monitored tidal cycles, flow velocities ranging from approximately 2 to 60 cm/day were measured within the monitoring wells. Considering the hydraulic conditions within and around the



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wells, Darcy velocities in the aquifer of less than 2 cm/day can be derived from these measurements. The long-term measurements revealed distinct temporal changes in both groundwater flow direction and velocity associated with the tidal cycle. On average, slightly higher flow velocities were observed during rising tide and lower velocities during falling tide. The results therefore demonstrate tide-influenced, time-variable groundwater flow within the investigated aquifers and provide important input data for assessing potential advective displacement of the thermal storage zone.

### Technical Challenges

Due to the confined artesian conditions, groundwater discharged at the ground surface when the monitoring wells were open. To establish defined hydraulic conditions during the flow measurements and prevent vertical flow within the monitoring wells caused by artesian overflow, the solid casing section above the screened interval had to be sealed using a packer. Stopping the previously existing groundwater overflow initially altered the hydraulic and thermal conditions within the monitoring wells. An extended stabilization period was therefore required before the actual flow measurements could begin, allowing sufficient hydraulic and thermal re-equilibration.

### Customer Benefits

- Depth- and time-resolved information on groundwater flow dynamics within the potential storage horizons
- Identification of tide-related changes in groundwater flow direction and velocity
- Data basis for assessing advective displacement of the thermal storage zone
- Provision of directly measured groundwater flow data for groundwater flow and ATES modelling
- Supplementary data basis for the further planning and dimensioning of the seasonal aquifer thermal energy storage system
- Assessment of monitoring well construction and condition

### Client

Municipal Island Administration

### Project Location

North Sea island

### Scope of Investigation

- 2 monitoring wells / 5 inch

- Investigation depths: 30–64 m

### Project Duration

5 days

021P06

## Groundwater Flow Investigation in Flooded Borehole-Intersected Mine Workings

### Project Description

To investigate groundwater flow conditions within flooded mine workings with regard to potential geothermal utilization and hydraulic interactions with the connected groundwater system, several boreholes were drilled into the mine gallery system and completed as groundwater monitoring wells. The screened sections were positioned within the intersected mine galleries. Horizontal in-situ groundwater flow measurements were carried out at several vertical positions across the intersected gallery profiles to characterize flow direction and velocity within the mine gallery system and to provide directly measured data for further hydrogeological assessment.

### Hydrogeological Setting

Free-flowing mine galleries within limestone and dolomite formations, accessed by boreholes with screened sections positioned within the intersected galleries

### Purpose of Investigation

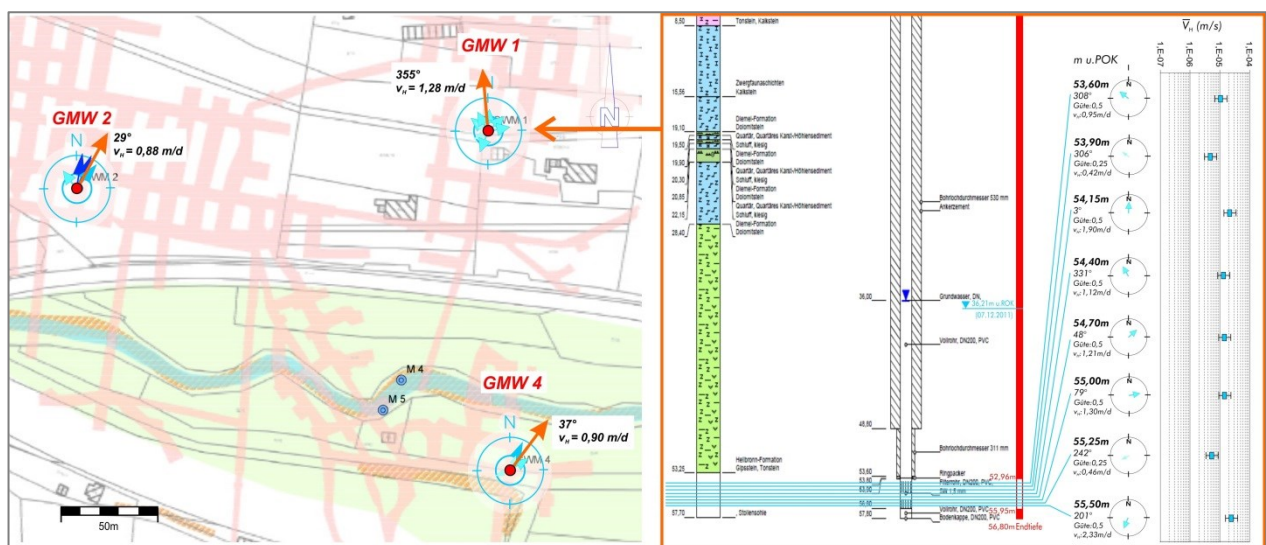
- Investigation of groundwater flow conditions within the flooded mine gallery system
- Provision of hydraulic data for assessing the potential for geothermal utilization
- Assessment of hydraulic interactions with the connected groundwater system
- Data basis for risk assessment with particular regard to drinking water protection
- Provision of directly measured flow data for groundwater flow modelling

### Investigation Results

Horizontal in-situ groundwater flow measurements were carried out at several vertical positions across the gallery profiles intersected by the boreholes. In all four investigated monitoring wells, the measurements indicated a prevailing northward flow, with mean flow velocities ranging from approximately 0.5 to 1.5 m/day. However, the vertically resolved measurements showed that flow conditions were not uniform across the individual gallery profiles. Local deviations in flow direction were observed, including partially counter-directional flow near the gallery floor. Due to the low flow velocities and the considerable hydraulic degrees of freedom within the free-flowing galleries, the measurements showed a time-variable, transient flow pattern over the individual measurement periods of one to two hours. By evaluating and balancing the measured flow vectors over time, the prevailing flow directions and characteristic flow velocities could nevertheless be reliably determined. The results therefore demonstrate both an overall prevailing flow within the mine gallery system and local as well as temporal variations in flow conditions across the individual gallery profiles.

### Hydrogeological Challenge

The considerable hydraulic degrees of freedom within the free-flowing mine galleries, combined with low flow velocities, result in spatially and temporally variable flow conditions. Individual measurements therefore represent only snapshots of the actual flow situation. Extended measurement periods and time-integrated evaluation of the measured flow vectors made it possible to distinguish short-



## Groundwater Flow Investigation in Flooded Borehole-Intersected Mine Workings

term variations from the prevailing flow pattern and to reliably determine characteristic flow directions and velocities.

### **Customer Benefits**

- Direct determination of the prevailing flow direction and velocity within the mine gallery system
- Vertically resolved characterization of flow conditions across the gallery profiles
- Identification and analysis of local and partially counter-directional flow
- Characterization of time-variable flow behaviour over extended measurement periods
- Hydraulic data basis for assessing potential geothermal utilization
- Provision of directly measured flow data for groundwater flow modelling
- Verification of monitoring well construction and condition

### **Client**

Public-Sector Authority

### **Services**

- Monitoring well camera inspections
- Horizontal groundwater flow measurements
- Data analysis and project documentation

### **Scope of Work**

4 monitoring wells / 5–8" diameter  
Measurement depths: 28–55 m

### **Location**

Baden-Württemberg, Germany

### **Duration of Field Work**

4 days

011P139