Borehole Thermal Energy Storage in the Variably Saturated Zone

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Summary

In order to avoid harming groundwater resources while still maintaining a high volumetric heat capacity, we will investigate the feasibility of borehole thermal energy storage (BTES) in the variably saturated zone with irrigation for moisture management.

Motivation

Borehole Thermal Energy Storage (BTES) is among the cheapest types of sensible heat storage [1]. However, when installed in the saturated zone below the groundwater table, their operating temperature can be limited due to groundwater protection concerns.

To avoid negative effects on groundwater resources and limitiations of the maximum temperature, BTES can be installed in the variably saturated zone above the groundwater table, where no competing uses between heat storage and drinking water resources exists.

Operating a BTES in the variably saturated zone affects both soil temperature and soil moisture distribution. Especially at higher temperatures, soil drying decreases the specific heat capacity and the thermal conductivity of the surrounding soil, which decreases the storage capacity as well as the heat injection and extraction capabilities of the heat exchanger pipes [2,3].

Therefore, we investigate the feasibility of irrigation for enhancing the moisture of the surrounding soil and preventing soil drying. This seems promising especially in highly porous, low permeable soils, where induced water flows are small, and therefore water consumption and induced convective heat losses are manageable.

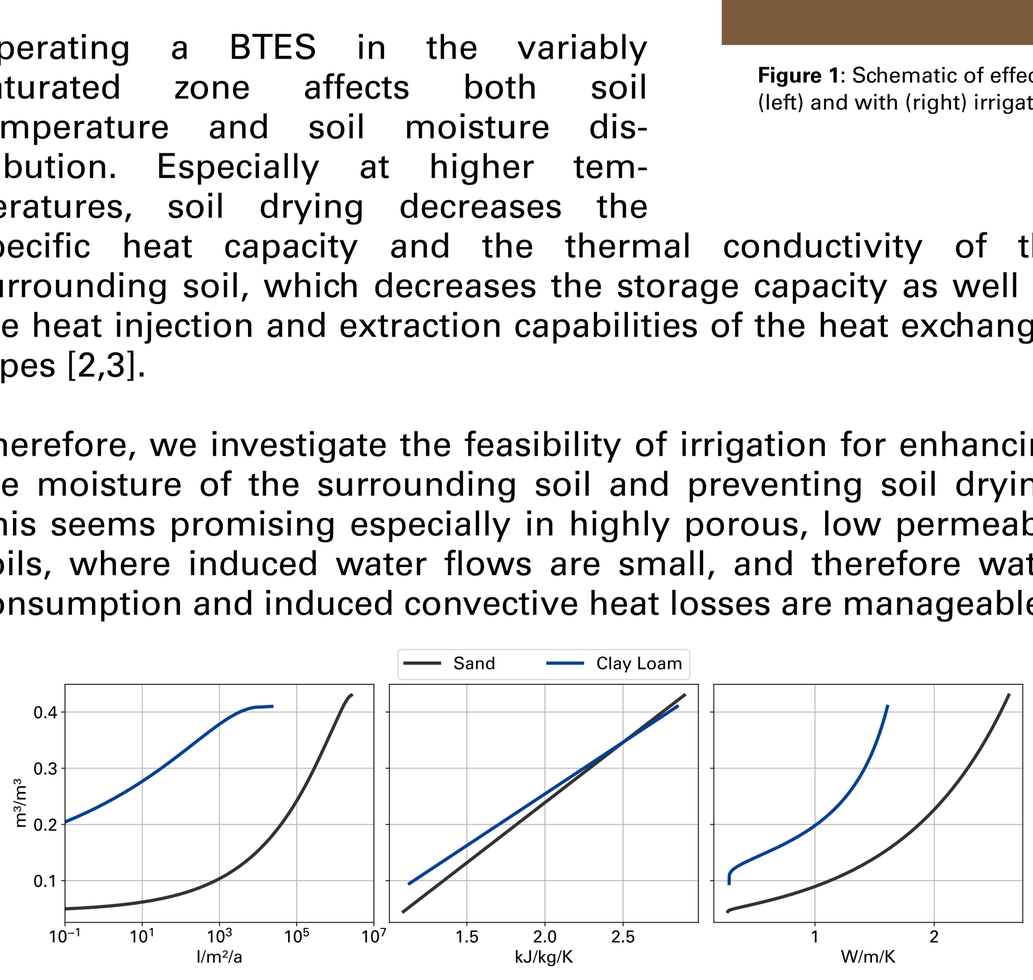

Figure 2: Dependence of hydraulic conductivity (left), volumetric heat capacity (middle), and thermal conductivity (right) on volumetric water saturation. Parameters from [4, 5, 6].

Modelling

In order to quantitatively predict changes in soil temperature and soil moisture, as well as the effects of irrigation on soil moisture and convective heat losses, a finite element model of coupled heat and moisture flow in the variably saturated zone will be implemented using Dumux [7]. The main focus of the modelling will be the use of temperature and moisture dependent parameters and constitutive functions.

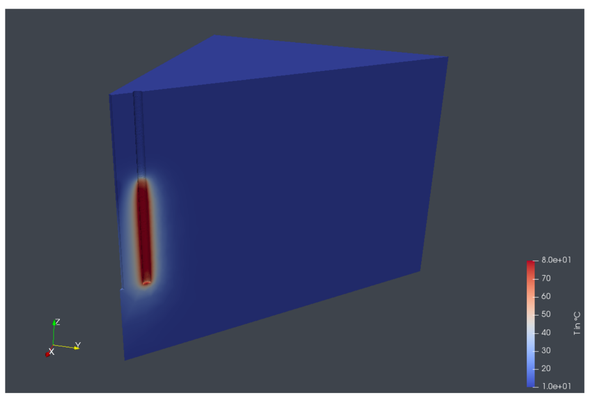

Figure 3: Model output of a coupled heat and moisture flow model in Dumux.

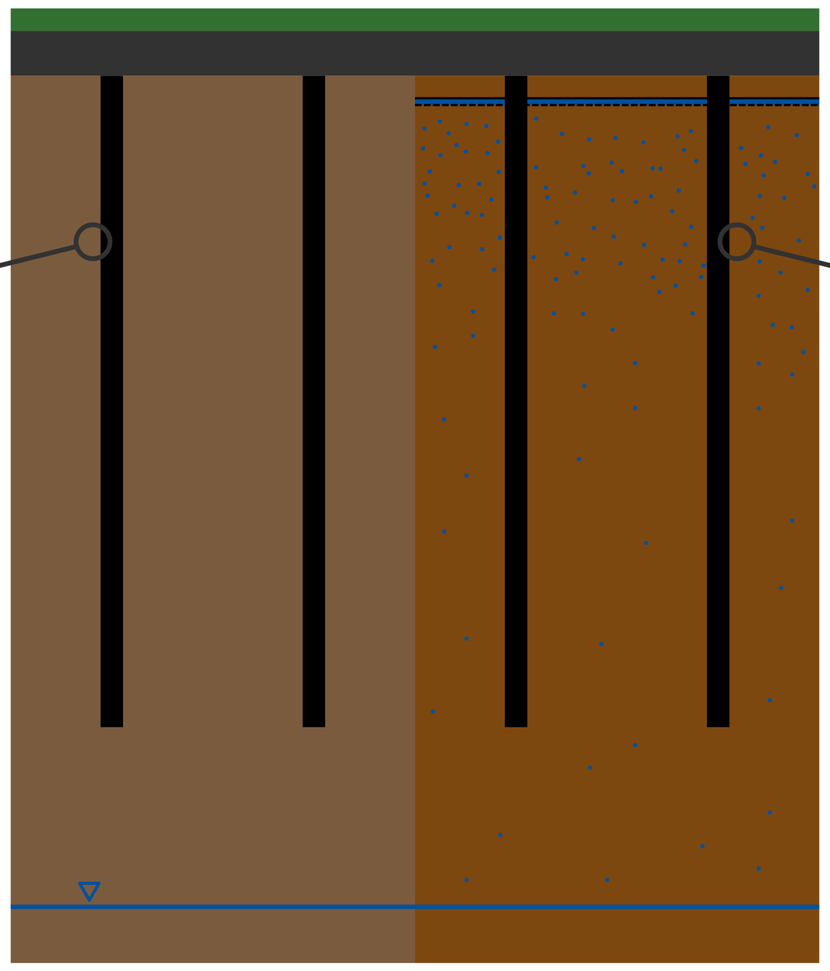

Figure 1: Schematic of effects of a BTES in the unsaturated zone without (left) and with (right) irrigation

Experiments

Several experiments on different scales shall be performed at VEGAS. Small scale experiments will be used to investigate the dependence of material properties on soil moisture and soil temperature, as well as to calibrate measurement devices (e.g. TDR probes).
A larger scale tank experiment (6m x 9m x 4m) under controlled thermal and hydraulic boundary conditions will be performed to evaluate the performance of the system and to check the validity of the numerical model.
Automated in situ measurements of moisture and temperature during the tank experiment will be conducted using TDR probes in a multiplexer setup controlled by a Raspberry Pi, and Pt100 temperature sensors, respectively.

Finally, we aim to evaluate the real world performance of a variably saturated BTES with irrigation in a pilot project.

Figure 4: VEGAS tank. The tank is currently empty, as thermal insulation with optional wall heating/ cooling was installed for better control over thermal boundary conditions.

References

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https://www.iws.uni-stuttgart.de/vegas/

VEGAS
Research Facility for Subsurface Remediation