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A Generic Workflow to Assess (Stimulated) Clastic Aquifer Potential

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ABSTRACT

Geothermal development in aquifer settings, targeted beforehand by oil and gas exploration, can benefit largely from putting subsurface information and models in a geothermal context. To this end we developed a generic resource and performance assessment methodology to designate prospective high permeable clastic aquifers and to assess the amount of potential geothermal energy. It is capable to build from a wealth of deep subsurface data from oil and gas exploration and production which is publicly and digitally available. The performance assessment results in potential maps giving an overview of the expected doublet power which can be retrieved on an economic basis and a potential indicator, which provides insight in subsurface suitability for specific applications. The workflow has been applied for the Netherlands and results are publicly accessible through the web-based portal ThermoGIS (www.thermogis.nl). ThermoGIS complements existing subsurface information systems available in the Netherlands, it supports the geothermal community in assessing the feasibility of a geothermal system at any location, and it provides a non-expert insight in the geothermal energy potential on a national and regional scale. Public access to relevant subsurface data has facilitated spectacular growth of low enthalpy geothermal projects for greenhouse heating and the number of issued licenses promises an even faster growth in the future. In the Netherlands hot water is extracted from permeable clastic aquifers of around 2000 m depth which have been explored for oil and gas production in the past.

Recently, we extended the workflow to assess the implications of hydraulic stimulation for low permeability clastic aquifers at deep depth-levels (>2000 m) where permeability deteriorates as a consequence of mechanical compaction and cementation. For the stimulation and well layout we adopt long horizontal well trajectories up to 2 km length with vertical fracs along the well bore. The implications on subsurface potential are significant as it unlocks considerable clastic aquifer potential. Our calculations indicate that hydraulic stimulation is capable of producing higher flow rates and power than without stimulation with a moderate increase in Levelized Costs of Energy (LCOE). In addition it extends the depth and spatial extent of the potential resource. The LCOE for the reservoir stimulation scenario can stay well below 12-13 Euro/GJ, depending on reservoir transmissivities which can be as low as 0.5 Darcymeter.

1. INTRODUCTION

Geothermal energy in the Netherlands has been growing rapidly over the last decade. Several low enthalpy geothermal projects have already been developed for greenhouse heating and the number of issued licenses promises an even faster growth in the future. In the Netherlands hot water is extracted from clastic aquifers of around 2000 m depth which have been explored for oil and gas production in the past. Geothermal development in the Netherlands benefits from a) extensive knowledge of the Dutch subsurface, b) public availability of data and models of the subsurface, c) excellent match between heat demand of greenhouses and subsurface potential. TNO facilitates geothermal development through putting subsurface information and models in a geothermal context (www.thermogis.nl).

The planned doublet systems produce from naturally permeable clastic aquifers. However, at increasing depth natural permeability in the clastic aquifers deteriorates as a result of mechanical compaction and chemical cementation of pores. Hydraulic stimulation allows to enhance the contact surface of the well with the reservoir and thus reduces the reservoir hydraulic resistivity. If natural permeability is virtually absent, hydraulic stimulation can also be used to create permeable pathways to connect injector and producer wells. Tensile fracking in non-critically stressed tectonic environments, which occur in large parts of the Netherlands, allows to perform hydraulic stimulation with a low level of seismicity. In this paper we analyze the performance of tensile hydraulic stimulation strategies, for geothermal systems at large depth (Figure 1; Pluymaekers et al., 2013).

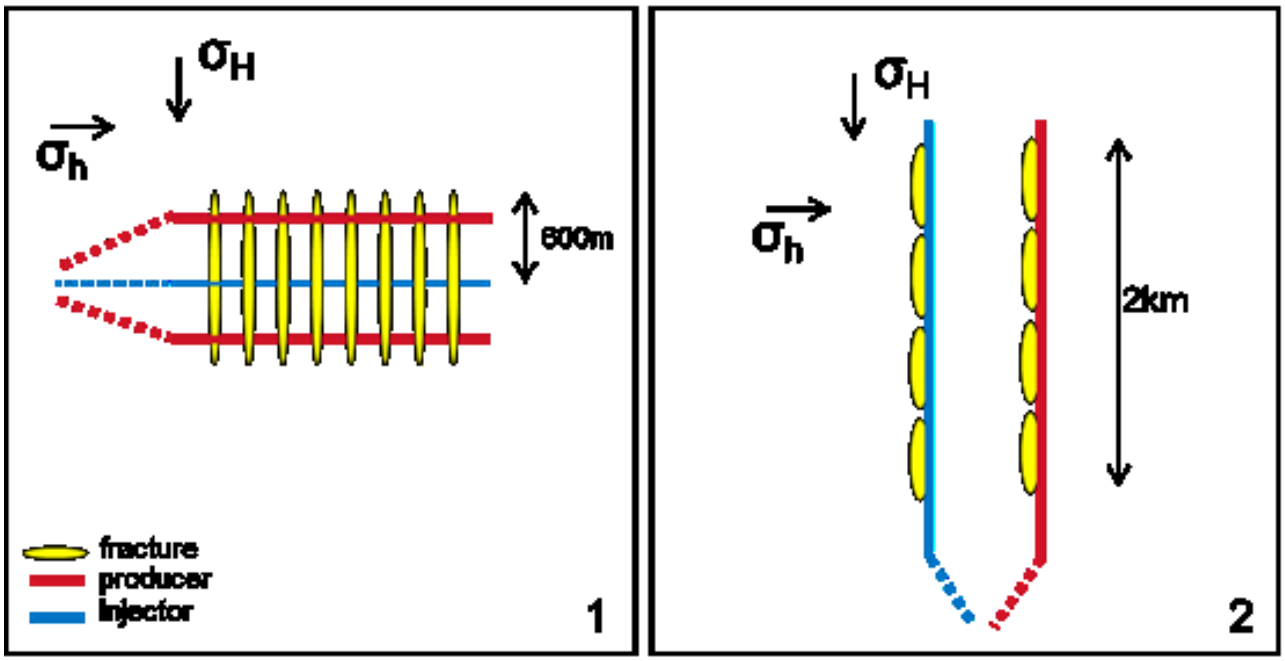


Figure 1: Schematic layout of subvertical fractures (top view) relative to wells. Scenario 1 (left) marked by fractures perpendicular to the well bore. Scenario 2 (right) marked by fractures oriented parallel to the fracture well (after Pluymaekers et al., 2013).

2. METHODOLOGY

Pluymaekers et al. (2013) proposed two stimulation scenarios for deep subsurface stimulation involving tensile fracking. In this paper we focus on the implications of scenario 2 for hydraulic stimulation in a Dutch context for low permeability clastic aquifers at a depth of 2000 to 4000 m. The transmissivity of these aquifers has been mapped in the framework of the Dutch subsurface information system on geothermal energy in the Netherlands (Pluymaekers et al., 2012; Kramers et al., 2012; www.thermogis.nl). We show that the implications on subsurface potential are significant as it unlocks considerable clastic aquifer potential.

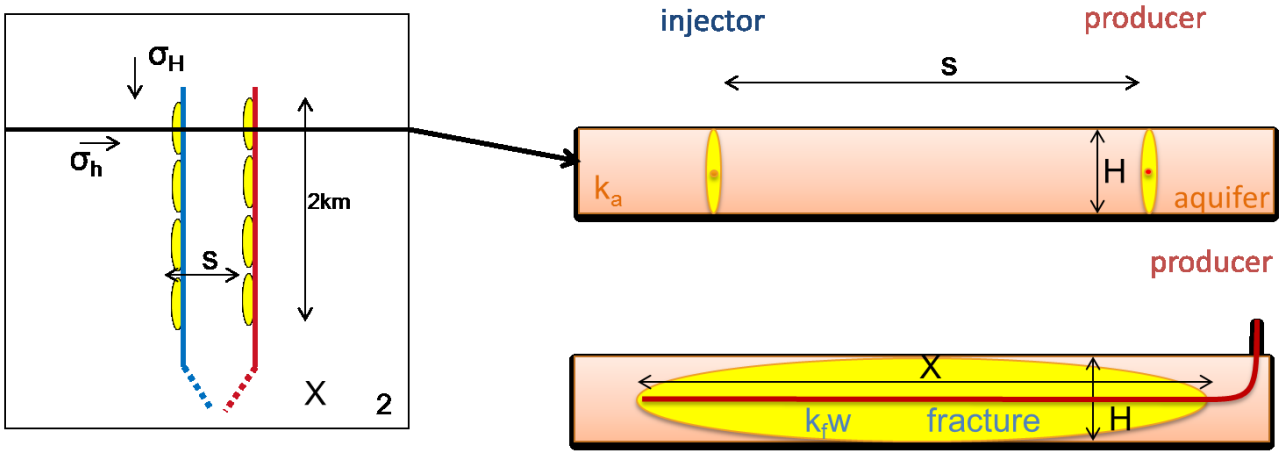


Figure 2: Schematic layout of subvertical fractures (top view) relative parallel to the fracture well for scenario 2. The fracs, shown in yellow provide an excellent hydraulic connectivity with the low permeable reservoir in between the injection and production well separated by a distance s.

The fracking scenario (Figure 2) relies on the natural permeability of the reservoir, and adopts multiple fractures parallel to the well bore to increase the contact surface between well and the low permeable formation. Within the 2D model the fractures have been modeled as line sources and sinks of 2 km length and 500 m apart (Figures 1, 2). The horizontal well segments have been chosen more close to each other, as proposed in Pluymaekers et al. (2013; Figure 3), as for the clastic aquifers the flow rates in most cases would be slightly lower than proposed in Pluymaekers et al. (2013). The increase in relative pressure at the fracture wall to drive a flow rate Q in the aquifer to the midway point of the injector and producer well is estimated as follows based on the transmissivity k_a [m^2] of the aquifer:

$$P_{res} = Q\frac{1}{2}\frac{\mu}{k_a HX}s \tag{1}$$

where μ is the viscosity [Pa s] of injected or produced water at the injection and production well respectively, s is horizontal distance between the wells [500 m], and H is thickness [m] of the aquifer. The resulting P_{res} [Pa] has been corrected to obtain well head pressures at reservoir level with the following well index factor:

$$P_{well} - P_{res} = Q\ \frac{1}{6}\frac{\mu}{k_f wX}0.5H \tag{2}$$

where μ is fluid viscosity [Pa s], k_f is fracture permeability [m^2], and w is fracture aperture [m]. It is assumed that the fracture extends vertically over the thickness of the reservoir, and X is the length [m] of the horizontal well section. We adopt $k_f w$ = 500mDm, based on Pluymaekers et al. (2013). P_{well} [Pa] is typically just a few bars higher than the reservoir pressures.

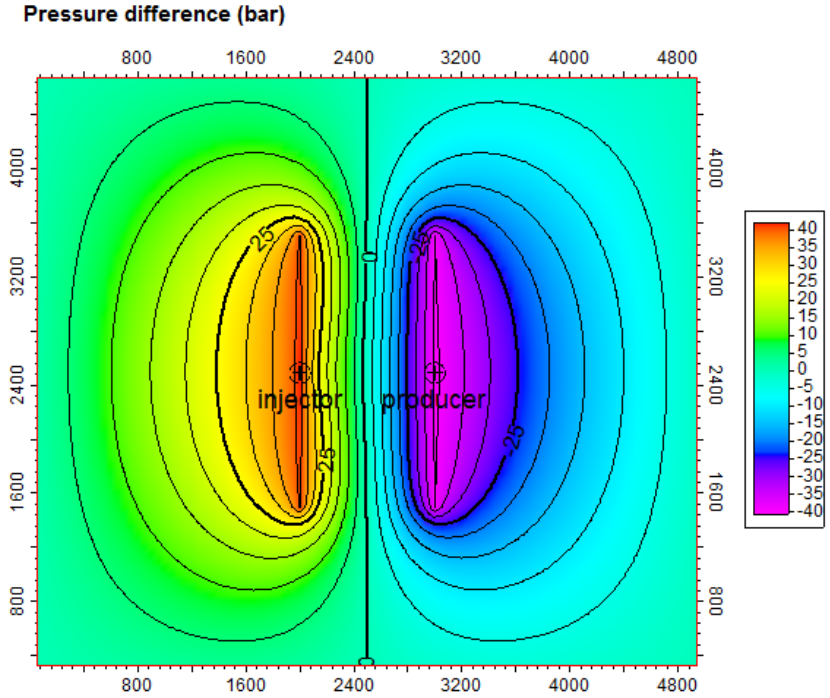


Figure 3: Map view pattern of the cell pressures and temperatures at 30 years of operation for a flow rate of 100l/s (after Pluymaekers et al., 2013).

3. RESULTS FOR GEOTHERMAL POTENTIAL

We evaluated the implications of scenario 2 for hydraulic stimulation in a Dutch context for low permeability clastic aquifers at a depth of 2000 to 4000 m, whose transmissivity has been mapped in the framework of the Dutch subsurface information system on geothermal energy in the Netherlands (Pluymaekers et al., 2012; Kramers et al., 2012; www.thermogis.nl). To this end we selected the Rotliegendes aquifer (Figure 4). It is marked by variable transmissivity, in large part related to a decrease of porosity and permeability with burial depth.

The levelized Costs of Energy (LCOE) have been calculated based on a techno-economic performance assessment (cf Van Wees et al., 2012) with a target coefficient of performance (COP) of 15 for the water loop. In the cost evaluation we take into account additional costs for the horizontal well trajectory and the costs for stimulation as 2 million Euro / 500m of horizontal well section.

Figure 3 shows the results in terms of predicted power and LCOE in map view for the Rotliegendes aquifer comparing the default potential and stimulated potential for P50 interpretations of $k_a H$ (cf Pluymaekers et al., 2012).

The implications on subsurface potential are significant as it unlocks clastic aquifer potential. Our calculations indicate that hydraulic stimulation is capable of producing higher flow rates and power than without stimulation with a moderate increase in LCOE and extending the potential resource in depth and spatial extent. The LCOE for the reservoir stimulation scenario can stay well below 12-13 Euro/GJ, depending on natural permeabilities which need to be in excess of 0.5 Darcymeter.

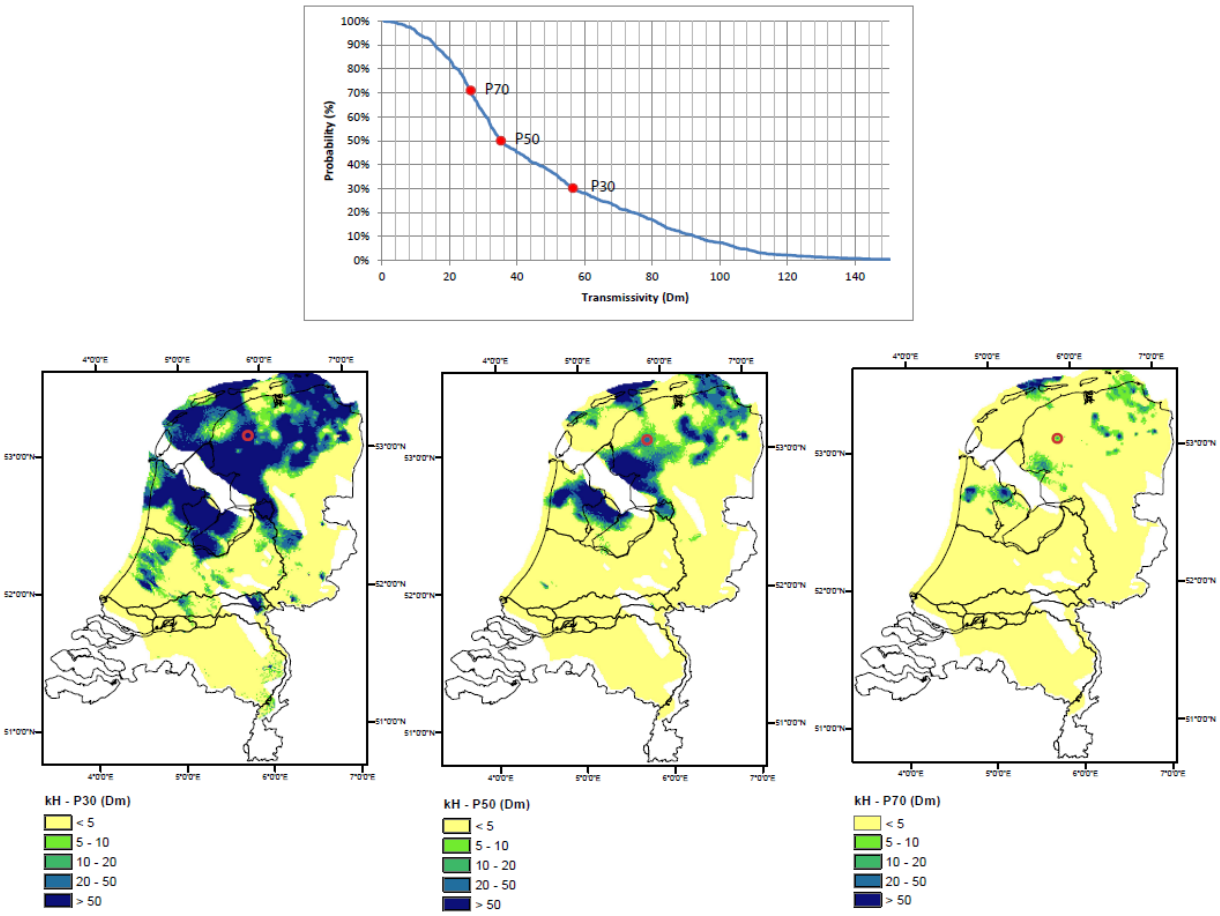


Figure 4: Probability distribution of the transmissivity of the Rotliegend aquifer, expressed in P30 (left) P50 (middle) and P70 (right) maps. The expectation curve (above) based Monte Carlo sampling is shown for a specific location (red circle on maps)

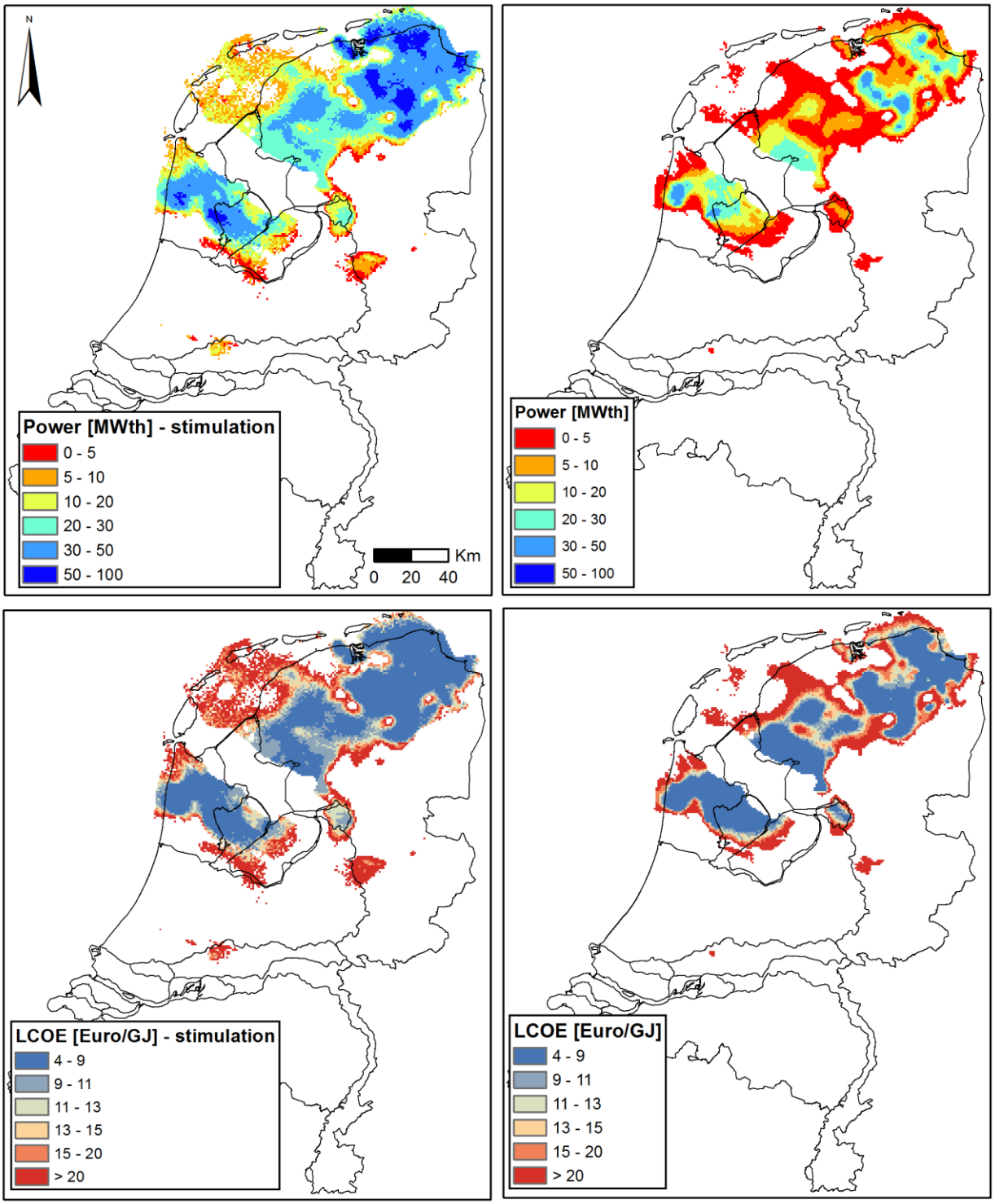


Figure 5: Map view pattern of predicted power [MWth] and LCOE [Euro/GJ] without (left) and with hydraulic stimulation (right) for the P50 scenario.

4. CONCLUSIONS

We evaluated the implications for hydraulic stimulation in a Dutch context for low permeability clastic aquifers at a depth of 2000 to 4000 m, whose transmissivity has been mapped in the framework of the Dutch subsurface information system on geothermal energy in the Netherlands (Pluymaekers et al., 2012; Kramers et al., 2012; www.thermogis.nl).

The implications on subsurface potential are significant as it unlocks considerable clastic aquifer potential. Our calculations indicate that hydraulic stimulation is capable of producing higher flow rates and power than without stimulation with moderate increase in LCOE and extending the resource in depth and spatial extent. The LCOE for the reservoir stimulation scenario can stay well below 12-13 Euro/GJ, depending on natural permeabilities which need to be in excess of 0.5 Darcymeter.

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