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Evaluation of heat and water flow in porosity permeable horizons

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Several strategies have been developed to explore the circulation of geofluids, which can yield heat transport over large spatial scales. Groundwater flow from recharge areas, where precipitation seeps downwards beneath the ground surface and reaches the saturated zone, to discharge areas, where subsurface water is discharged to streams, lakes, ponds or swamps, forms an additional mechanism of heat transfer to pure conduction, which is generally assumed for the underground thermal regime. In this paper we discuss and apply two different analytical models of heat and water flow, both valid for steady-state thermal conditions and for uniform, isotropic, homogeneous, and saturated porous media.

By combining conductive and groundwater advective heat transfer, a first model assumes heat and water flow in vertical direction and neglects thermal gradient along the horizontal. The thermal field is influenced only by the flow of water parallel to the thermal gradient, whereas perpendicular water flow if any has no effect. Because most layers are sloping and because surface topographic relief usually exists across the aquifer, usually isotherms are not horizontal. Hence, we applied a second model for heat and water flow, neither purely horizontal nor purely vertical. In the governing equation of heat conduction-advection we take account of the horizontal flow of heat and water. The flow rate is assumed to be constant and sufficient small that thermal equilibrium is maintained between the water and the rock matrix.

Examples of application are given for a set of boreholes drilled for geothermal exploration. Hydrothermal parameters (vertical and horizontal components of the Darcy velocity and the Péclet number) are determined by matching temperature and thermal gradient versus depth data with the two models. Thermal information is completed by a set of thermal conductivity measurements carried out on core samples recovered during drillings. The analysed underground temperatures contain a discernible climatic signal, explainable with an increase of ground surface temperature over the past few decades. This could have caused a positive shift in the temperature–depth data. Thus, temperature data used in this study were preliminarily treated for such a climatic noise.

Our approach assumes that water volumetric heat capacity and bulk thermal conductivity of the porosity permeable horizons are constant along the section of the borehole where groundwater movement occurs. Under natural conditions, this is not always the case, and curvatures in temperature profiles can be also explained by variation of such parameters. However, for the investigated boreholes, thermal conductivity measurements show a variation not larger than ten per cent about the average, thus excluding that distortion in temperature-depth curves is due to lithological change. This implies an uncertainty on the hydrothermal parameters of the same order of magnitude. Moreover, the temperature and pressure dependence of thermal parameters can be neglected, as the investigated depth range is relatively shallow.