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Research papers

Using hydrogeophysical methods to assess the feasibility of lake bank filtration

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ABSTRACT

Lake Tissø is the fourth largest lake in Denmark with sufficient, continuous surface water input making lake bank filtration an optimal surface water extraction method provided that there are suitable shallow aquifers with a good hydraulic connection to the lake. The shallow subsurface under the lake was mapped by five waterborne Electrical Resistivity Tomography (ERT) and eight Ground Penetrating Radar (GPR) surveys to locate potentially suitable aquifers. Distributed Temperature Sensing (DTS) was used for the general characterisation of the hydraulic connection between the lake and aquifer. The waterborne ERT surveys showed several zones of coarser material along the shore extending up to five meters depth below the lake surface, while on-land ERT surveys confirmed that these zones extend to the lakeshore with similar thickness. Both waterborne ERT and GPR profiles agreed that at a selected field site the highest possibility of coarse sediments is 60–140 m from the lakeshore. Lakebed temperatures measured in December 2016, May and June 2017 all indicated potential groundwater discharge to the lake at approximately 135 m from the shoreline supporting the results of geophysical surveys showing coarser sediments in that area. A 2D numerical flow model of the area with a geological setup based on geophysical information and slugtest data, also showed upward groundwater discharge peaks at 60 and 140 m from the shoreline confirming the findings of the field surveys. Thus, this study shows that the combination of waterborne ERT and GPR surveys with DTS measurements is a fast and efficient way to assess the feasibility of lake bank filtration in these settings. This approach of combined hydrogeophysical methods is robust and has a potential to site lake bank filtration areas not only next to large rivers where coarse sediments are found in abundance, but even in different sedimentary environments where suitable layers for lake bank filtration are more difficult to identify.

1. Introduction

The growing population of the world necessitates a more conscious water management with emphasis on both the quality and quantity of water supplies. Bank filtration is an increasingly used method to meet the demands for both drinking water and industrial process water (Ray, 2008; Ghodeif et al., 2016; Pholkern et al., 2015). During bank filtration the surface water is extracted through a pumping well located adjacent to the surface water body (Schubert, 2002), thus the extracted water undergoes physical, chemical and biological filtering while flowing from the surface water body, through the aquifer to the pumping well (Hiscock and Grischek, 2002; Holzbecher, 2006). This natural filtration and potential attenuation of pollutants may considerably reduce water treatment costs compared to other extraction methods. On the other hand water quality in bank filtration wells can be periodically vulnerable due to sudden changes in the hydraulic conditions such as flooding with shorter travel times of surface water to the pumping well (Wett et al., 2002). Water extraction by bank filtration is only sustainable if the surface water supplies are replenished continuously, and thus most extraction sites are bordering large rivers or in some cases also lakes (Massmann et al., 2008). Furthermore, it is also required that the surface water bodies are in good hydraulic connection to shallow aquifers.

Geophysical measurements are traditionally used to map structures of subsurface materials also under surface water bodies. Electrical resistivity measurements survey the resistivity distribution of the subsurface, which in turn is related to hydrological properties such as porosity, water content and pore fluid conductivity. These surveys can be carried out in a waterborne setup where the electrodes can be directly fixed to the bottom of the surface water body, towed behind a

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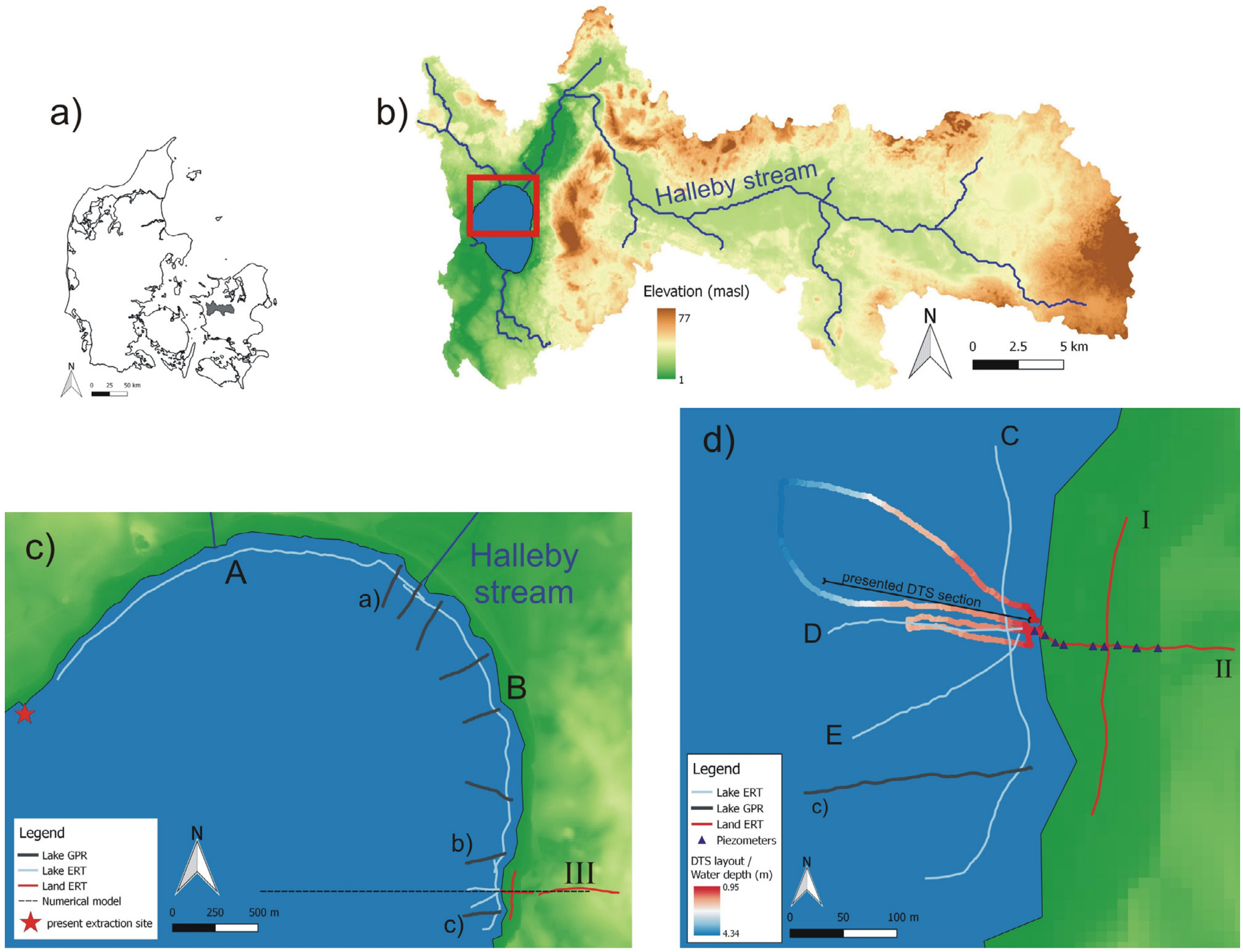

Fig. 1. The location of Lake Tissø in Denmark (a) and the topographical catchment of the lake (b). The location of the large-scale hydrogeophysical surveys and the 2D model domain (c), and the geophysical surveys and DTS layout at the test site (d). The depth of the deployed fiber optic cable from the water surface was measured on 30 March 2017, at the highest lake stage during the surveys. Lake GPR surveys are identified with small letters, lake ERT surveys with capital letters and on-land ERT surveys with roman numbers.

boat at the bottom or arranged as a streamer cable floating at the water surface (Loke and Lane, 2004). These surveys have been used to map sediment properties under surface water bodies (Loke and Lane, 2004; Crook et al., 2008), finding fault zones under rivers (Kwon et al., 2005) and underwater geological controls (Krantz et al., 2004) or to study the geological evolution of sediment sequences (Colombero et al., 2014). Ground Penetrating Radar (GPR) measurements use high frequency electromagnetic signals to find differences in dielectric properties of the subsurface and thus locate boundaries. These measurements are also used over open water to detect sedimentary changes or to estimate bathymetry and water volumes (Conant et al., 2004; Lin et al., 2009; Sambuelli and Bava, 2012; Kidmose et al., 2011). In a similar manner, these waterborne geophysical methods can be used to detect coarser material zones beneath surface water bodies to optimize the placing of bank filtration wells.

Groundwater discharge to surface water bodies indicates a natural good hydraulic connection to the underlying aquifer. Traditionally, groundwater discharge is mapped and quantified by point-scale measurements, frequently by seepage meters (Rosenberry et al., 2010; Kidmose et al., 2011) and vertical sediment temperature profiles (Schmidt et al., 2007; Jensen and Engesgaard, 2011) or in streams on a larger-scale by differential gauging (Briggs et al., 2012; Poulsen et al., 2015). Recently Distributed Temperature Sensing (DTS) has been increasingly used to detect groundwater discharge over larger areas at the bottom of surface waters (Lowry et al., 2007; Krause et al., 2012; Sebok et al., 2013) or to study infiltration rates at managed aquifer recharge sites (Vogt et al., 2010; Becker et al., 2013; Mawer et al., 2016).

The DTS method relies on the natural difference between the relatively stable groundwater temperature and the seasonally variable surface water temperature where discharging groundwater will influence the temperature distribution at the Sediment-Water Interface (SWI). The slight alteration in the SWI temperature distribution can be detected by a fibre optic sensor cable deployed at the SWI and thus indirectly infer the spatial distribution of groundwater discharge to surface water bodies. As of yet, DTS has mostly been used in shallow surface waters and most frequently in stream environments. The deployments of Briggs et al. (2012) in a stream occasionally deeper than 1.4 m, Slater et al. (2010) in a river with water depths ranging between 2 and 18 m and Selker et al. (2006) in Lake Geneva comprise the deepest reported deployments. Still, DTS studies in lakes (Blume et al.,2013; Sebok et al., 2013) are less common. Due to generally much smaller and slower currents in lakes compared to streams, sediment temperatures at the lakebed are more sensitive to physical processes, e.g. solar radiation (Neilson et al., 2010; Sebok et al., 2013), thermal stratification (Wilhelm and Adrian, 2008), wind and wave action (Churchill and Kerfoot, 2007), than temperatures at the bed of streams. Therefore, temperatures at the lakebed are influenced by many other processes and conditions in addition to thermal influences due to discharging groundwater. So far waterborne geophysical measurements and DTS were rarely applied simultaneously even though studies show