Using Fiber-Optic Distributed Temperature Sensing to Assess Groundwater-Lake Exchange in an Acid Mine Lake in Eastern Germany

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Abstract
Groundwater flow through contaminated mine sites is a major concern in many parts of the world. In this study, a variety of instrumentation was used to locate and quantify groundwater inflows into an acid lake in Eastern Germany. While previously installed piezometers and spring meter wells identified several points of groundwater inflows into the lake, such techniques are spatially biased to the point of installation. To address this limitation, a fiber optic distributed temperature sensing (DTS) system was deployed across the lake bottom and in vertical transects to confirm anomalies in the diurnal temperature wave. This technology provides the opportunity to measure temperature in very high spatial and temporal resolution along the entire span of a cable. A 1000 meter cable was deployed spatially along the sediment-water interface to identify spatially scattered areas of groundwater inflow, while two high resolution profilers which return temperature readings every 24 vertical and one were installed vertically near standing water. This methodology was capable of detecting the diurnal temperature cycle across the lake bottom, which shows significant vertical fluxes in the lake. Ongoing analysis of the data is expected to identify areas in which there are anomalies in the diurnal temperature cycle at the lake bottom, such anomalies may indicate groundwater inflow into the lake. These areas will be used to locate future piezometer and spring meter installations.

Methods
Fiber-Optic Distributed Temperature Sensing (DTS)
Fiber-optic distributed temperature sensing (DTS) relies on the scattering of light in a glass fiber to measure temperatures at very high spatial and temporal resolutions along a fiber optic cable. This technology has the ability to resolve the Royer-Lansac algorithm of the Rayleigh scattered components (the temperature independent) and temperature-dependent anti-Stokes signals) and the two-way travel times from the instrument to the point of reflection and back are used to determine the temperature and the location of the point of scattering. Spatial resolutions up to every 2 meters and temporal resolution as fine as 15 seconds can be achieved with this technology.

Using Temperature as a Groundwater Tracer
The high heat capacity of water makes temperature an excellent tool for examining the interactions between groundwater and surface water. Groundwater and surface water have distinct thermal signatures. While surface water shows a high-amplitude temperature cycle (in both annual and diurnal cycling), groundwater tends to be more constant and exhibits damped-temperature cycles on a daily and seasonal basis. These differences can be used to identify and quantify regions of groundwater-surface water interactions.

Results and Discussion
The fiber used in the vertical profilers was not robust enough to stand up to the rigors of the field. The laterally deployed cable returned two days worth of data, presented below. However, peak temperature measurements were affected by an unknown source of interference. As a result, the data presented below will require further investigation.

The daily amplitude of the temperature signal (calculated as the difference between the maximum and minimum daily mean temperatures at the lake bottom) is shown below for the length of the cable. Daily amplitude is affected by the depth of water and exposure to sunlight, as well as the potential influence of groundwater fluxes. Areas with localized groundwater inflows will have reduced amplitude when compared to other points of similar depth. Three amplitude phenomena are highlighted on the plots below.

Background
Lake 77 is an acid mine lake in Eastern Germany where previous studies have found strong influences of groundwater inflows on biogeochemical processes at the lake-groundwater interface. In this study, we:
1. Deploy a fiber-optic DTS cable laterally along the lake bottom and vertically in the lake substrate to continuously measure temperatures in these areas
2. Use anomalies in the diurnal temperature wave at the sediment-water interface to identify likely points of groundwater inflow to the lake

Field Deployment
Three fiber optic cables were deployed at the study site – one laterally along the sediment-water interface, and two vertical profilers. The lateral deployment utilized a loose-tube cable with teflon strength members and protective insulation, while the vertical deployments relied on delicate tight-buffered fibers encased in PVC insulation.

Conclusions
Fiber optic DTS is a feasible technology for use in identifying spatially-scattered temperature anomalies that may be associated with groundwater inflows into a lake.

Additional measurement methods will likely be required to quantify fluxes between surface waters and groundwaters

References

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Lake 77, with the study area indicated by the gold box.