Informing groundwater model hydrostratigraphy with airborne time-domain electromagnetic data and borehole logs - DTU Orbit (09/01/2019)

Informing groundwater model hydrostratigraphy with airborne time-domain electromagnetic data and borehole logs

Hydrological models of groundwater systems and integrated hydrological systems are commonly used tools to manage groundwater resources and support decision making. The models are utilized to quantitatively support management of water supply from well fields; perform dewatering calculations for construction sites; quantify groundwater contamination in time and space; estimate ecological impacts of anthropogenic or climatic stresses; characterize salt-water intrusion phenomena, etc. Applications can be at scales from tens to thousands of square kilometers. The reliability of numerical groundwater models is closely related to the quality and amount of hydrological and geological data available to inform the modeling process. This is particularly true for lithological and geological data required to map the 3-D distribution of aquifer materials, which is also called the hydrostratigraphy. A major challenge for groundwater modelers is that the hydrostratigraphy, which is one of the most critical parameterizations of groundwater models, is based on properties for which direct information is inherently difficult to obtain. The uncertainty resulting from this is non-trivial to estimate and thus rarely quantifiable.

Airborne time-domain electromagnetic (AEM) data obtained using novel methods of data acquisition and processing are attractive because the resulting electrical resistivity models of the subsurface can be obtained at a lateral resolution unmet by geological data while covering areas of hundreds of square kilometers. Application of geophysical data in hydrology however is challenged by the necessary petrophysical translation of the measured physical property into a hydrological property. The PhD study investigated an approach to incorporate structural information contained in large AEM data sets directly into the groundwater modeling process. The work focuses on reproducibility and objectivity, which is typically lacking in traditional interpretations of AEM and lithological information, and the approaches presented in this thesis are to a large extent automatic. An approach that integrates EM data and borehole lithological information directly into groundwater models is proposed. The approach builds on a clay-fraction inversion which is a spatially variable translation of resistivity values from EM data into clay-fraction values using borehole lithological information. Hydrostratigraphical units are obtained through a k-means cluster analysis of the principal components of resistivity and clay-fraction values. Under the assumption that the units have uniform hydrological properties, the units constitute the hydrostratigraphy for a groundwater model. Only aquifer structures are obtained from geophysical and lithological data, while the estimation of the hydrological properties of the units is inversely derived from the groundwater model and hydrological data.

A synthetic analysis was performed to investigate the principles underlying the clustering approach using three petrophysical relationships between electrical conductivity and hydraulic conductivity. Aquifer structures obtained from clustering on electrical conductivity and clay fraction resulted in mismatch with the true pumping well capture isochrones of 8 to 13 percent. Results for clustering only on electrical conductivity were not stable. The approach was first tested for the 156 km2 large integrated hydrological model of the Danish case study Norsminde. The hydrological performance in terms of fit to the transient hydraulic head observations and stream discharge observations results in root mean square errors of 2.0 m and -0.79 m, and mean errors of 0.28 m3s-1 and -0.011 m3s-1 for head and discharge respectively. Benchmarking against comparable Danish models reported in scientific papers confirmed good hydrological performance.

The automatic hydrostratigraphical modeling approach was extended to quantify of the uncertainty of groundwater model predictions. An ensemble of equally likely hydrostratigraphical models was simulated at locations with no data to parameterize the entire model domain, using indicator variograms. The method was applied to the 46 km2 groundwater model of the Danish site Kasted. Hydrological performance of 75 realizations in terms of fit to steady-state hydraulic head observations and base-flow estimates correspond to root mean square errors around 5.5 m and mean errors of -0.2 m, and percentage errors around 0 to -4 respectively. Differences in local scale connectivity/dis-connectivity of aquifer materials resulted in a probabilistic well catchment area. Results indicate 85% probability that the well catchment area extends beyond the real catchment area determined from a manually developed deterministic geology.

The applications to Norsminde and Kasted sites, combined with the theoretical insight gained from the synthetic analysis, show promising results for direct integration of AEM data into the groundwater modeling process using cluster analysis. Because the presented methods are reproducible and time saving due to being highly automatized, the methods potentially have commercial value.

General information
State: Published
Organisations: Department of Environmental Engineering, Water Resources Engineering, Niels Bohr Institute
Contributors: Marker, P. A., Bauer-Gottwein, P., Mosegaard, K.
Number of pages: 69
Publication date: 2016

Publication Information
Place of publication: Kgs. Lyngby
Publisher: Technical University of Denmark, DTU Environment
Original language: English
Electronic versions: