ABSTRACT

Seawater intrusion is a serious threat to many coastal abstraction boreholes; this risk is heightened by increased climatic variability and rising populations, leading to higher demand. Existing hydrochemistry or geophysical techniques often fail to predict the timing of intrusion events. Self-potentials (SPs) measured within a groundwater borehole in the Upper Chalk of England show a characteristic increase in advance of saline breakthrough. We mimic this precursor signal for the first time using a combined hydrodynamic and geoelectric model and investigate its sensitivity to variations in aquifer heterogeneity at a range of scales. The results suggest that a clear precursor signal is likely to occur in systems where there is a relatively sharp saline front. This has the potential to improve groundwater management in systems of this type, by facilitating the optimisation of pumping regimes during at-risk periods.

DATA COLLECTION

• SP BH array (Fig. 1) installed in the Upper Chalk near Brighton, 1.7 km from England’s south coast (Fig.2)
• BH has suffered historically from seawater intrusion, largely via a fracture zone logged near its base (Jones and Robins, 1999).
• Electrical potentials recorded every 5 minutes since July 2013.
• Several intrusion events during late summer/autumn of 2013 and 2014.

SALINE PRECURSOR

• Smoothed SP data from the deepest electrode show an increase in voltage (0.1-0.2 mV) 1 week before each intrusion event (Fig. 3).
• Smaller precursors seen at shallower depths (MacAllister, In Prep.).
• Lab testing of Upper Chalk cores suggests only the diffusion potential ($U_{Diff}$) can account for the magnitude of this precursor (MacAllister, In Prep.).

NUMERICAL MODELLING

• Combined hydrodynamic & geoelectric model set up to mimic the observed precursor in the chalk, where groundwater flow and saline transport are heavily influenced by heterogeneity.
• Model discrete fracture zone (e.g. Jones and Robins, 1999) to assess precursor sensitivity to large-scale heterogeneity.

Model Scenarios

1) A relatively dispersed front, bisected by a fracture zone, as shown in Fig. 4 (FD);
2) A relatively dispersed front within a homogenous aquifer: bulk aquifer properties from Fig. 4 are applied throughout the model domain (HD);
3) A sharp front bisected by a fracture zone. Original salinity distribution at each depth in Fig.4 compressed into a 37.5 m transect around the mean isoline (FS);
4) A sharp front within a homogenous aquifer (HS).

Hydrodynamic Model

• A small-scale 2D model of a coastal aquifer was developed in SUTRA (Fig. 4).
• Once a stable saline wedge had formed (Fig. 5), water table elevation halved each day to simulate intrusion over a period of 4.4 days.
• Tidal motion ignored in order to mimic the smoothed SP signal shown in Fig. 3.

Geoelectric Model

• We attempt to solve the following equation (e.g. Jackson (2015)):
$$j = -\sigma \nabla U_{ED} + \sigma C_{ED} V \ln(C)$$

where $j$ is current (A), $C$ is ionic strength (M), $\sigma$ is the saturated conductivity (Sm$^{-1}$) and $U_{ED}$ is the diffusion coupling coefficient.
• We set $j = 0$ at all model boundaries and assume conservation of charge throughout the model domain, giving $V \cdot j = 0$.
• Combining $V \cdot j = 0$ with Eqn. 1, we get the trivial solution $\partial j/\partial x = \partial j/\partial y = 0$ which precludes presence of a precursor.
• Iterative solution of $AU_{ED} = B$ is trivial for large $\Delta x, \Delta y$ if there is no reasonable initial estimate $U_{ED}$.
• To reduce computational expense in 2D, we use a 1D model of the saline front to generate a non-trivial solution for $U_{ED}$ at small $\Delta x, \Delta y$ and derive an approximate relationship between $U_{ED}$ and C. This is used to provide an initial guess $U_{ED}$ at each time step.

Results and Conclusions

SP and salinity results for the obs points (Fig. 5) are shown in Fig. 6. We conclude that:
• The discrete fracture zone has little effect on the simulated SP signal.
• The model mimics the shape and magnitude of the observed precursors in HS & FS.
• For the dispersed scenarios, there is a measurable potential difference, but this does not change substantially before saline breakthrough.
• The precursor is highly sensitive to the dispersion of the saline front.

Implications and Further Work

SP may be a powerful tool for predicting saline intrusion and this work represents an important first step in understanding its application to a variety of aquifers. As data on front dispersion are rarely available, other methods are needed to characterise precursor signals a priori. Further modelling will assess links between SP power spectra before breakthrough and the existence of a precursor.

REFERENCES