25-29th September 2016
43rd IAH congress
Montpellier, France
CORUM CONFERENCE CENTER
Abstract n°2584

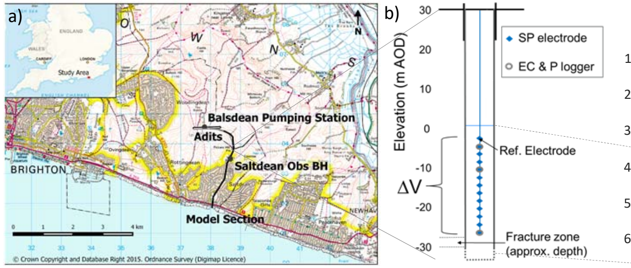
Self-Potentials: A Novel (and Cheap) Way to Predict Seawater Intrusion?

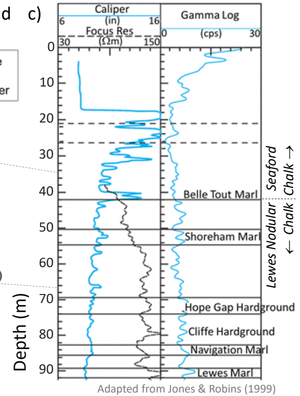
MT Graham(1)*, DJ MacAllister(2), MD Jackson(3), A Ijioma(3), J Vinogradov(4) & AP Butler(1)
*Email: m.graham14@imperial.ac.uk

Seawater intrusion threatens many coastal abstraction bores; this risk is heightened by increasing populations and climatic variability. Established techniques are costly and often fail to predict the timing of intrusion events. Self-potentials (SPs) were measured in a coastal groundwater borehole near Brighton that is regularly impacted by seawater intrusion. A consistent vertical SP gradient is observed, which reduces several days prior to breakthrough. Previous models have failed to replicate either phenomenon. We present the results from a model that correctly matches the initial SP gradient for the first time, giving a valuable insight into some of the key controls on the observed precursor signal. This represents an important step in the use of SP as a predictive tool for seawater intrusion.

Background SPs are voltages caused by gradients in pressure, solute concentration, redox potential and temperature[1,2]. They have been used mainly for mineral & hydrocarbon exploration[3], but detection and advanced warning of seawater intrusion is a possible new application[4]. SP equipment is cheaper than traditional monitoring approaches and is more practical to install.

Data Collection Conducted since 2013 at Saltdean, near Brighton, England

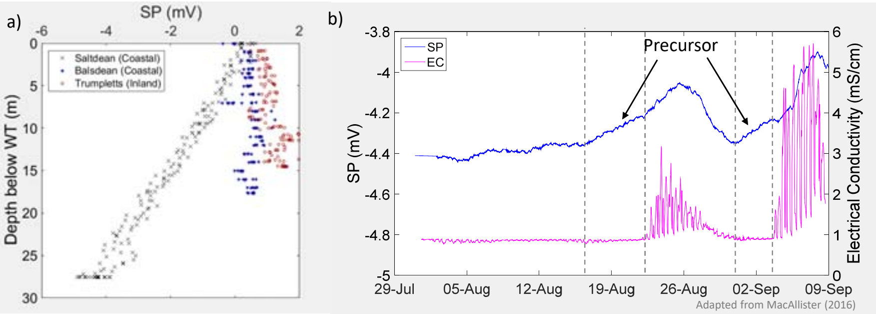




Adapted from Jones & Robins (1999)

Fig.1 An SP array (b) was placed in the Saltdean Obs BH (a), which has been subject to regular seawater intrusion. The borehole intersects the Seaford Chalk and the Lewes Nodular Chalk. A nearby geophysical log[5] (c) highlights the presence of laterally extensive marls and hardgrounds.

Field Data To date, models[4] have failed to explain the phenomena in Fig.2, first reported by MacAllister (2016)



Adapted from MacAllister (2016)

Fig.2 a) A consistent vertical SP gradient was observed in the Saltdean Obs BH, which was absent at a nearby coastal BH not subject to saline intrusion (Balsdean) and at an inland BH (Trumpletts) b) The vertical SP gradient at Saltdean reduces by 0.1-0.2 mV about 1 week before each intrusion event.

Self-Potentials and Seawater Intrusion

When rock pores are large, the *diffusion potential* (V_d) dominates and voltage **decreases** with decreasing salinity.

In small pores, the *exclusion potential* (V_e) dominates and voltage **increases** with decreasing salinity.

These give the combined exclusion-diffusion potential (V_{ed}).

Exclusion efficiency (η) = $(V_{ed}-V_d)/(V_e-V_d)$; V_{ed} = zero if $\eta \approx 0.2$.

In recent lab tests **η = 0.01-0.12 for Chalk** (V_d dominant)

A single **shale** sample gave **η = 0.23-0.25** (V_e dominant)

2D Model Parameterisation

A hydrodynamic (SUTRA) & geoelectric (in-house) model simulates the transect in Fig.1a as follows:

- K_{CHALK} = 1000 m/d; K_{MARL} = 200 m/d; $K_{HARDGROUND}$ = 40 m/d
- Strata dip at 5° towards the coast (based on local BH stratigraphy)
- Front sharpened within the chalk and marl units to reduce unwanted dispersion (post-processing)
- Elevated salinity applied in the unsaturated zone, based on data from similar coastal locations[6]
- $\eta_{SEAFORD\ CHALK}=0.12$; $\eta_{LEWES\ CHALK}=0.09$ (below Cliffe HG), 0 (above Cliffe HG); $\eta_{MARLS,\ HARDGROUNDS}=0.24$

We solve:

$$j = -\sigma_s \nabla V_{ed} + \sigma_s C_{ed} \nabla \ln(C)$$

where j is current; C is ionic strength; σ_s is chalk conductivity; C_{ed} is a coupling coefficient related to η.

Model Results and Discussion

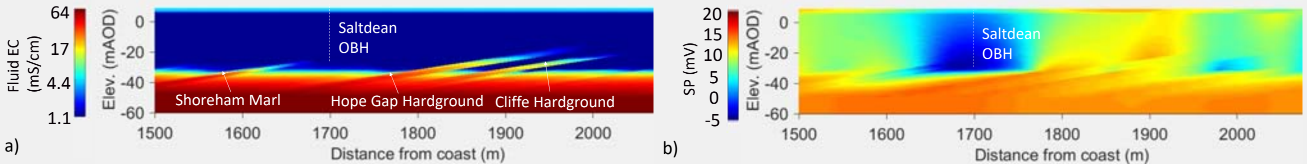


Fig.3 a) Modelled salinity near the Saltdean OBH, showing highly saline marls and hardgrounds and b) Resultant distribution of SP

The model results (Fig.3) replicate the observed SP gradient in the Saltdean Obs BH, as shown by the best-fit line in Fig.4. To demonstrate the sensitivity of this result to several controlling parameters, we also present the results for the following scenarios:

1. Constant η=0.04 throughout the chalk ('SP1')
2. No additional salinity in the unsaturated zone ('SP2')
3. Hardgrounds & marls assigned the same η as the surrounding chalk ('SP3')
4. No compression of the front in the chalk and marl units ('EC4' and 'SP4')

It appears that strong local heterogeneity is required to produce the observed SP gradient. Previous model runs also suggest that dipping strata are needed for areas of high salinity and η to extend above the near-horizontal front within the chalk and facilitate the flow of electric current through fresh groundwater.

As few datasets exist on the above controlling parameters, it is uncertain how widespread such gradients are and whether they are a prerequisite for the precursor seen in Fig. 2b.

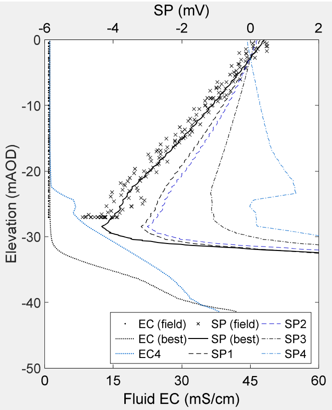


Fig.4 Model fit and parameter sensitivity

Further Work

Further work is required in the following areas:

1. Lab measurement of η for marls and hardgrounds, to confirm whether they are dominated by exclusion
2. Transient SP modelling of the period leading up to intrusion
3. SP measurement and modelling of intrusion in additional boreholes to assess a) whether the phenomena in Fig.2 are specific to the Saltdean Obs BH and b) how the technique may be applied to other aquifers.

(1) Dept. of Civil & Environmental Engineering, Imperial College London
(2) Dept. Civil & Environmental Engineering, University of Strathclyde
(3) Dept. of Earth Science & Engineering, Imperial College London
(4) School of Engineering, Kings College, University of Aberdeen

Refs
1. Revil, A., 1999. Ionic diffusivity, electrical conductivity, membrane and thermoelectric potentials in colloids and granular porous media: A unified model. Jour. of Coll. & Interface Sci., 212(2): p. 503-522.
2. Jouniaux, L., et al., 2009. Review of self-potential methods in hydrogeophysics. Comptes Rendus Geosci. 341(10-11): p. 928-936.
3. Jackson, M.D., 2015. Tools and Techniques: Self-Potential Methods, in Treatise on Geophysics, G. Schubert, (ed.), p. 261-293.
4. MacAllister, D., 2016. Monitoring seawater intrusion into the fractured UK chalk aquifer using measurements of self-potential (SP). PhD Thesis, ESE Dept., ICL. p. 258 pp.
5. Jones, H.K. & Robins, N.S. (eds) 1999. The Chalk aquifer of the South Downs. Hydrogeol. Report Series, BGS.
6. BGS, 2016. Chloride porewater profiles. Dataset provided in email by BGS, 18 May 2016.
7. Westermann-Clark, G.B. & Christoforou, C.C., 1986. The Exclusion-Diffusion Potential in Charged Porous Membranes. Jour. of Electroanal. Chem., 198(2): p. 19.
8. Jackson, M.D., et al., 2012. Spontaneous Potentials in Hydrocarbon Reservoirs During Waterflooding: Application to Water-Front Monitoring. SPE JOURNAL, 2012. 17: p. 53-69.