MONITORING OF TIDAL AND SEASONAL INFLUENCES ON SALINE INTRUSION INTO A COASTAL AQUIFER IN NEW ZEALAND COMBINING DC RESISTIVITY TRAVERSING AND HYDROCHEMICAL TECHNIQUES

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Abstract

Increased private and commercial use of bore water on the Kapiti Coast in New Zealand has raised concerns about saline intrusion into the shallow aquifers of the area. Processes influencing the dynamic environment of the saline interface and mixing zone are not well understood and extensive field studies in different geological and hydrological settings are required to gain further insight. Te Horo Beach (NZ) is a small, fast developing community in the north of the Kapiti Coast District and therefore an ideal test bed for imaging saline intrusion processes related to seasonally changing freshwater abstraction rates. The shallow coastal aquifer that is exploited mainly by an increasing number of domestic shallow bores is made up of Holocene sands and gravels. Three repeat DC resistivity measurements carried out in 2014/2015 along a transect through the middle of the Te Horo Beach township have revealed an approximately 10 meter shift of the saline interface between winter and summer seasons. This shall be confirmed with a long-term, regular 5-weekly repeat DCR monitoring along this and two additional profiles which started in October 2015 with first results confirming the expected behaviour. Higher-resolution tidal DCR monitoring along the same profile revealed similar resistivity changes within a different time scale. Combined geoelectrical and hydrochemical measurements should lead towards a broader understanding of the processes tied to saline intrusion into a shallow coastal sand and gravel aquifer and provide a tool for future management of groundwater take in the area and similar aquifer environments around the world.

Approach

Repeat DC resistivity measurements along the S1 transect in the Te Horo Beach township (Figure 1) showed a distinctive difference of the position of the saline interface between results obtained from a wet winter (October 2014) and dry summer (May 2015) month measurement. This manifests as an approximately 10-meter shift of the saline interface towards the township during summer time. Decreased fresh water flow towards the coastal discharge point of the aquifer could explain the saline water intruding further inland during dry months. However, these spot measurements could be a pure coincidence and might be overprinted by aquifer recharge patterns. Hence, a long-term regular 5-week monitoring of the profile lines has been started in October 2015 in order to try and understand the processes influencing the saline interface position and extent as well as the shape of the mixing zone within a seasonal time frame. A 5 meter minimum electrode spacing has been proven to not be able to resolve any tidal influences and was hence used for the seasonal monitoring study. However, diurnal tide dynamics are regarded important to saline intrusion on a small time scale with possibly similar characteristics as the long-term seasonal cycle. A 2 meter minimum spacing tidal monitoring was therefore carried out along profile line S1 covering half a diurnal tidal cycle in order to find potential similarities of recurring events (tides, seasons) that influence saline intrusion into shallow coastal aquifers. As geophysical methods are always non-unique, it is intended to support the DC resistivity inversions with hydrochemical data obtained from 14 different private shallow wells spread over the Te Horo Beach township (green dots in Figure 1). Such an integrated analysis of different approaches to understand the complicated processes leading to saline intrusion aims to gain a better picture of these dynamics, which will be applicable to similar geological and hydrological settings around the world.

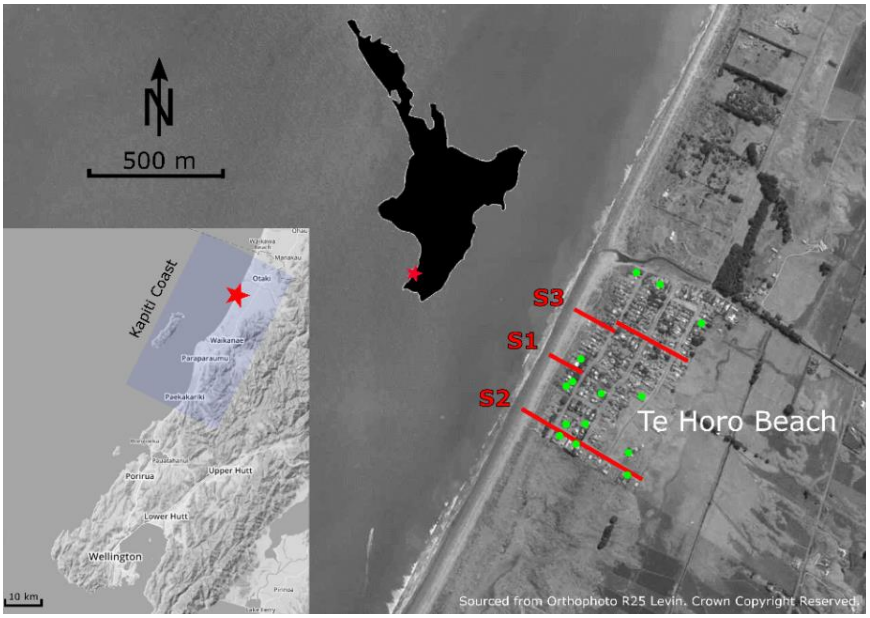

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Figure 1: Map of the study area Te Horo Beach (NZ). Red lines mark the three DC resistivity profiles. Green dots indicate the locations of the private bores that are used for taking water samples for the hydrochemical analyses.

Results

In Figure 2 inversion results for three measurements conducted along profile S1 between October 2014 and October 2015 are shown. Considering local geology from shallow bores drilled within the township, blue colours are associated with saltwater saturated sands. The saline interface is not a sharp boundary, but is characterised by the transition from low to medium resistivity values at the western part of the profile. Very high values at the top of the profile are interpreted as unsaturated to semi-saturated sands. The transition to green colours at around 5 meters depth marks the water table. This lower resistive part between 5 and 10 meters depth is interpreted as groundwater saturated sandy gravels with higher resistivity deeper parts representing fine to medium sands with some gravel content. With decreasing precipitation rates from late winter (October) to early autumn (May), a decrease of resistivity within the lower aquifer parts is observed, while the less resistive middle layer shows a small increase in resistivity. This goes with a shift of the interface position of almost 10 meters landwards which is reversed with the onset of the wetter winter season. A shorter (78 meters length), but more highly resolved part of the S1 transect measured at high and low tide during the same diurnal cycle is imaged in Figure 3. It is assumed that a high tide state is comparable with drier summer months and low tide being the equivalent to wetter winter months. The difference is that the freshwater pressure over a diurnal tide cycle does not change significantly. Hence, saline mixing is rather caused by an increased pressure from the seaward side (i.e. wave run-up).

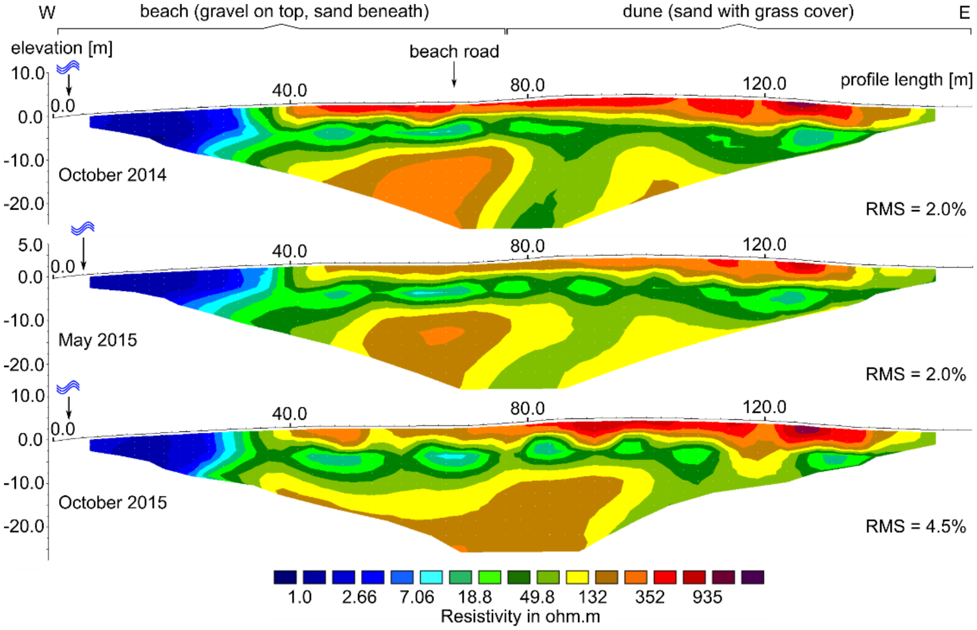

Figure 2: DC resistivity models for the S1 transect measured with a 5-meter initial spacing in October 2014, May and October 2015. Repeat measurements show a seasonal change with a shifting saline interface position and a changing resistivity distribution within the coastal aquifer.

Similar behaviour on a smaller time scale can be observed from the tidal monitoring measurements, with an increase of resistivity in the more resistive zones and a decrease in lower resistive parts with reducing tidal level. As a possible explanation for the observed contradictory behaviour in lower and higher resistive parts it is thought that differences in hydraulic conductivity and/or permeability are responsible for a varying reaction time needed to adjust to saline intrusion. Therefore, a time lag is observed for the assumingly lower hydraulically conductive, less resistive zone between 5 and 10 meters depth, while the higher resistive deeper part of the aquifer likely has a higher hydraulic conductivity and hence, reacts almost immediately to changes in saline water content.

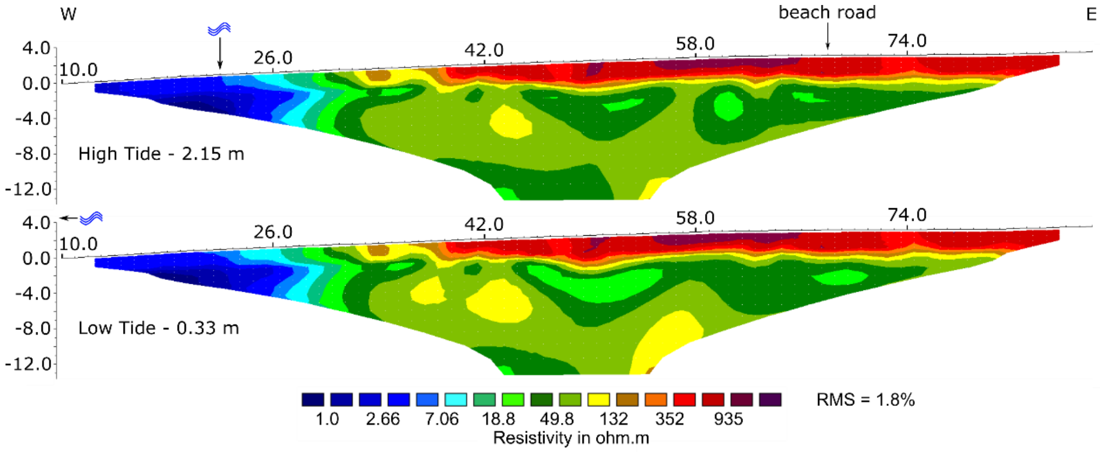

Figure 3: Time-lapse DC resistivity models for the S1 transect (2-meter initial electrode spacing) tidal monitoring in November 2015. Shown are the results for the high and low tide measurements. A change in resistivity distribution within the aquifer is apparent and indicates a time shift.

In order to get a better understanding of seasonal saline intrusion effects and DC resistivity images, hydrochemical measurements are carried out parallel to the geoelectrical measurements. First results along the extended S2 profile (Figure 4) show a good correlation between the measured bulk resistivity and that calculated from the measured fluid resistivity using a formation factor of around 2.75 as estimated by Wilson et al. (2006). This suggests a possible link between saltwater associated element concentrations measured in the groundwater and the resistivity distribution observed along the geoelectrical profile lines. It is however, crucial to know the exact well/screen depths in order to get an improved image of the subsurface. Therefore, gaining additional subsurface information is one of the major side tasks of this study.

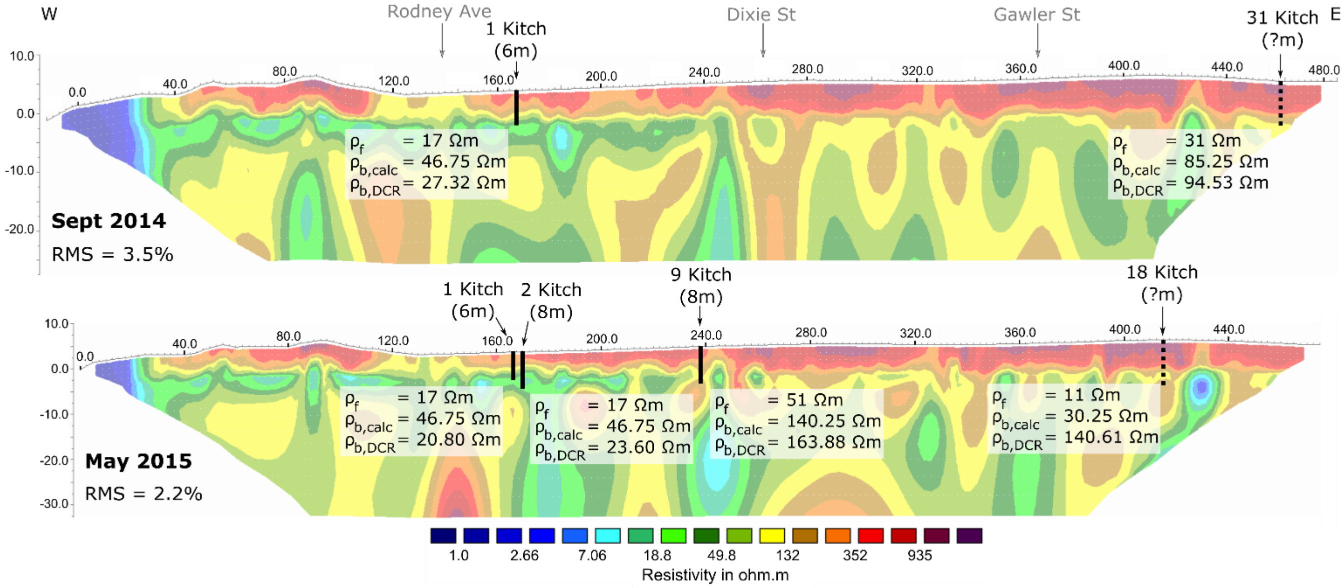

Figure 4: DC resistivity data collected along profile S2 in September 2014 and May 2015. Indicated are wells from which groundwater has been sampled and analysed. Some of the well depths are unknown or approximated. Bore '18 Kitch' is located about 60 meters north of the DCR profile line.

Conclusions

Repeated DC resistivity measurements in a seasonal and tidal time frame have shown similar behaviour in terms of resistivity changes resulting from saline water content in the shallow coastal aquifer. Additional hydrochemical data is able to confirm the bulk resistivity of the shallow part of the resistivity models and can further be used to identify and characterise saline intrusion. Even though it is difficult to get an accurate correlation between DC resistivity images and hydrochemical data, a combined analysis of different approaches will ultimately lead to a better understanding of saline intrusion problems at the study location and in similar hydrogeological settings.

References

Wilson S.R., Ingham M. and McConchie J.A. [2006] The applicability of earth resistivity methods for saline interface definition. *Journal of Hydrology*, **316**, 301-312.