Combined ERT-TDEM measurements for delineating saline water intrusions from an estuarine river into the adjacent aquifer

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ABSTRACT

The present geophysical feasibility study is part of a general ongoing research project aiming at studying the relationships between seawater and groundwater via estuarine rivers. The specific objective of the study is to delineate the expected saline water intrusion from estuarine rivers into adjacent aquifers by means of high resolution and accurate geoelectric/geoelectromagnetic methods. To achieve this objective, combined high resolution electrical resistance tomography (ERT) and accurate time domain electromagnetic (TDEM) measurements were carried out at two sites along the lower part of the Alexander river. The sites were located within a distance of approximately 1.5 km from the coast.

The riverbed of the Alexander river as well as several other coastal rivers along the Mediterranean coast of Israel is below sea level; thus they are subjected to seawater penetration up to about several kilometers upstream. As a result, a stratified water column is developed with bottom water salinities reaching those of seawater. Similarly to the well known seawater intrusion into coastal aquifers, the saline water within the rivers may contribute to groundwater salinization. While seawater intrusion into coastal aquifers is well known, the potential salinization from estuarine rivers was hardly studied.

The geophysical measurements clearly showed saline water intrusion (resistivity of 1-2 ohm-m) from the Alexander River into the aquifer at the most upstream site (1.5 km from the coast). The resistivities at the two sites located closer to shoreline were significantly higher (>10 ohm-m). Thus, contrary to observations of seawater intrusion into coastal aquifers, the saline intrusion from coastal estuaries is more localized or patchy and seems to be site dependent. This may be attributed to heterogeneity in the hydraulic conductivity of the shallow aquifer along the river.

INTRODUCTION

An estuary is a semi-enclosed coastal body of water which has a free connection to the open sea and within which seawater is measurably diluted with fresh water derived from land drainage (Cameron and Pritchard, 1963). In the specific case of estuarine rivers, the penetration of saline seawater through the river channel may induce circulation through the aquifer driven by density-forced convection (Fig. 1). Though basic modeling and some discharge measurements are available (e.g. Smith and Turner, 2001; Werner and Lockington, 2006), actual measurements of the flow patterns in the sub-estuarine aquifer and of the rates involved were hardly done.

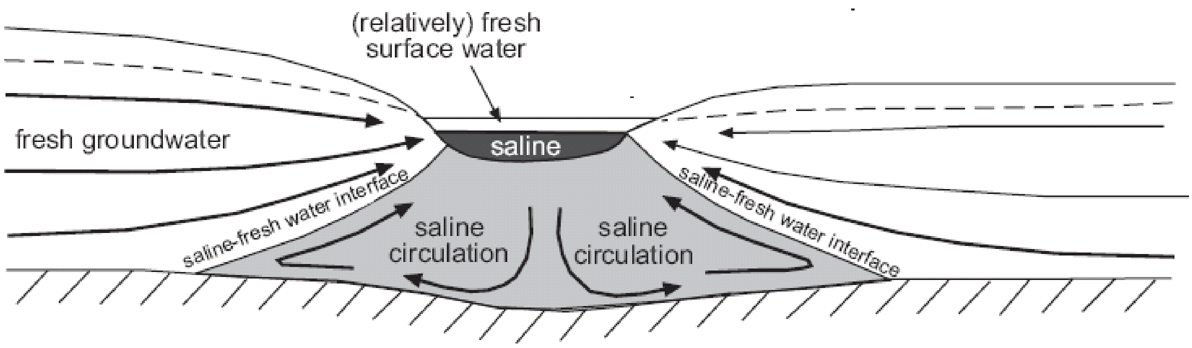

Figure 1. A schematic illustration of density-driven convection occur beneath and adjacent to a halo-stratified river during steady state condition (modified after Smith and Turner, 2001).

The Alexander river is one of the estuarine rivers that crosscut the Mediterranean coast of Israel. It is located 15 km south of Mt. Carmel (Fig. 2). Its drainage area is about 553 km^2 with a largest discharge record of 260 m^3/s and an average annual discharge of 9x10^6 m^3. The riverbed is lower than sea level up to 5.5 km upstream, while seawater intrusion is usually observed to about 4 km from the sea. Deep water within the river is usually saline, though its salinity is less than that of seawater, while surface water is almost fresh. The saline part of the river cuts through the coastal Quaternary granular (sands and calcaranites) phreatic aquifer. Adjacent to the river, groundwater levels are mostly higher than sea level.

METHODS

The electric resistance tomography (ERT) technique employs multi-electrode DC arrays to obtain 2-D resistivity distribution in the subsurface. Several profiles were run using standard on-land electrode arrays perpendicular to the river and one profile crossing the river by means of a special marine cable.

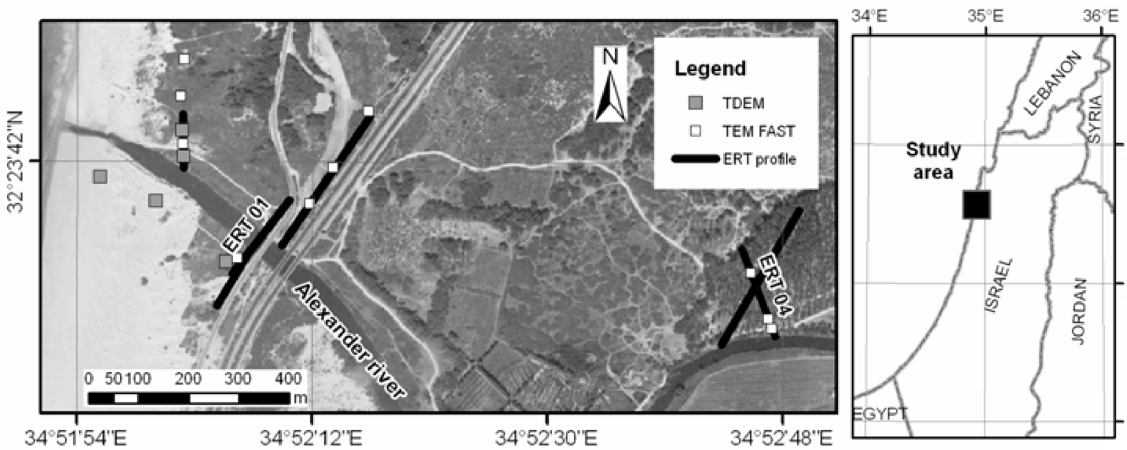

Figure 2. Location map of the study area.

Although ERT provides excellent lateral resolution, in many cases it is not accurate enough in detecting the depth to fresh-saline water interface as compared to time domain electromagnetic (TDEM) method (Goldman *et al*. 1991). In order to take advantage of both techniques, the combined ERT-TDEM measurements were used for characterization salinity (conductivity) of groundwater adjacent to the river. Two different TDEM systems were used in the survey depending on the expected depth to the target. The Geonics EM67 system was used for depths exceeding roughly 10 m, while the high resolution TEM-fast system was applied for shallower depths.

RESULTS

The TDEM measurements carried out with the Geonics EM67 system at the western part of the river, close to the shoreline, did not identify any saline water down to at least 20 m below the river bed. Below this depth, the TDEM results exhibit a typical distribution of resistivities (salinities) in coastal aquifers including fresh-seawater interface and diffusion zone. The ERT measurements at this site also did not show a significant saline water intrusion from the river into the aquifer (fig 3a). The interpreted resistivities are much higher than those typical for saline aquifers (< 3-5 ohm-m), except for a few small spots at both banks of the river. At the eastern site, located at a distance of about 1.5 km from the shoreline, the ERT profiles 3 & 4 (Fig. 3B) clearly showed saline water intrusion (resistivities of 1-2 ohm-m) from the river into the aquifer. The intrusion has lateral dimensions of at least 50 m. Taking into account the diffusion zone, the overall dimensions of the intrusion extend to approximately 100 m. The accompanying TEM-fast measurements led to similar results.

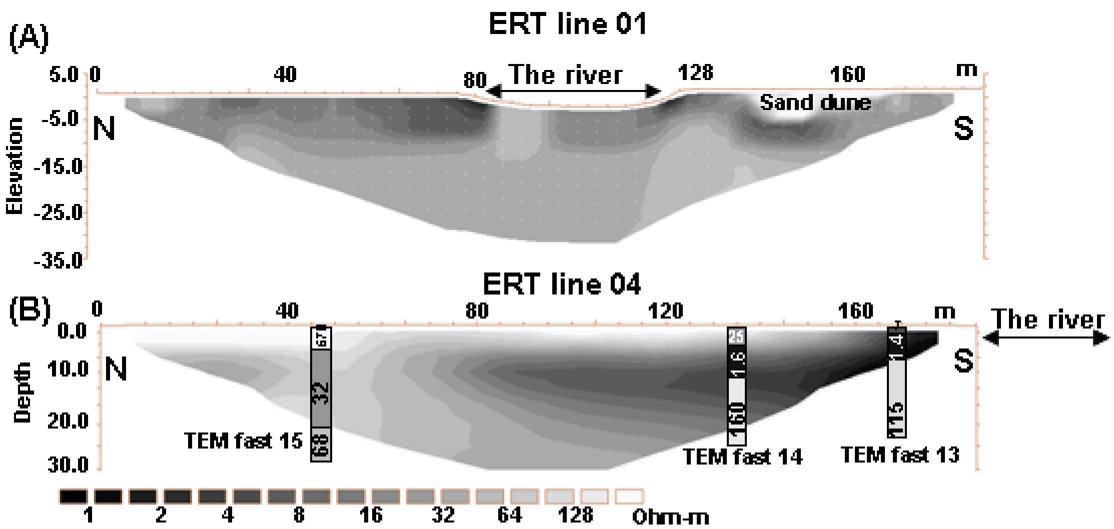

Figure 3. The geophysical results from the Alexander river. (A) is from the western site (~400 m from the shoreline) and (B) is from the eastern site (~1.5 km from the shoreline).

CONCLUSIONS

The geophysical results show the effect of salinization of groundwater by the intrusion of saline water from the Alexander river. Higher salinity was found at the eastern site (upstream) than at the western site (downstream). Most likely this is the result of a local heterogeneity in hydraulic properties caused by the river sediments. Unlike relatively homogeneous seawater intruded part of the coastal aquifer, the saline intrusion from the Alexander river seem to be site dependent.

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