The effects of sea tides on fresh-saline water interface fluctuations at coastal aquifers - preliminary results of field data and laboratory experiments

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ABSTRACT

This study deals with the effects of sea-tides on groundwater level and fresh-saline water interface (FSI) fluctuations, in order to understand the dynamics of the coastal groundwater system influenced by tide fluctuations.

Monitoring of groundwater levels and Electrical Conductivity (EC) in several observation boreholes at the coastal aquifer of Israel shows that sea-tide induces fluctuations of groundwater level with the same wave periodicity, but with decreasing amplitude as the groundwater pressure wave propagates inland. In a similar way, the interface between the fresh groundwater and the saline seawater fluctuates with the same periodicity as well.

Time series analysis of field data measured in observation boreholes located up to 70 meter from the shoreline, showed a dramatic time-lag between the fluctuations of the hydraulic heads and those of the salinity. While the response of groundwater level to sea-tide was relatively fast (around 1.5 hours), the response of the FSI was much slower (around 12 hours).

In order to understand this phenomenon we conducted a laboratory experiments in a two-dimensional flow tank, which enabling simulation of sea-tide and high-resolution monitoring in time and space of groundwater level and EC. Preliminary results from the laboratory experiments show the same phenomenon observed in the field, namely a significant time-lag between the fluctuations of the groundwater level and those of the FSI.

Both field data and the laboratory results indicate that the propagation of the pressure wave into the aquifer is much faster than the salinity changes. It seems that the sea-tide fluctuations induce a pressure wave that triggers much slower salinity advection.

INTRODUCTION

Understanding the processes and mechanisms taking place at the FSI at coastal aquifers has become an important issue for basic hydrology research and for water management as well. Many researchers dealt with the effect of sea-tide on the induced groundwater-table fluctuations in the vicinity of the shoreline (e.g. Ataie-Ashtiani et al. 1999; Nielsen 1990) and on the resulted fluctuations of the FSI by field monitoring (Kim et al. 2006, Levanon et al. 2013) or laboratory experiments (Kuan et al. 2012).

METHODS

Time series analysis- Field data

Groundwater and FSI fluctuations were measured in nine observation boreholes located up to 70 m from the shoreline at the coastal aquifer of Israel, and the Mediterranean Sea level was measured at the same time. These field data was analyzed using Cross-Correlation (CC) analysis, in order to determine the correlation and the time-lag between the different time series and to understand the dynamics of the coastal groundwater system influenced by tide fluctuations.

Laboratory experiments

The laboratory experiments were conducted in a two-dimensional rectangular flow tank, filled with granular material and saturated with water, simulating a homogenous and phreatic coastal aquifer (Fig. 1).

The flow tank is divided into three distinct chambers: a central flow chamber representing the aquifer, and two side chambers, which formed the boundary conditions during the experiment. The left chamber represents the seawater boundary and the right one represents the inland boundary of the regional fresh groundwater. At the back of the flow tank 168 electrodes were introduced in order to measure voltage in-situ and 6 piezometers in order to measure groundwater level along the cross-section. An engine, controlled by a computer, is connected to the outflow in the left boundary, enables changing the 'seawater' level in this boundary according to the experiment progression. The different water levels are controlled by a system of elevators, pipes and pumps.

The experiments included 2 water bodies: fresh water with density of 0.997 g cm^{-3}, and saline water, colored by red food color, with density of 1.028 g cm^{-3} similar to the density of the Mediterranean Sea.

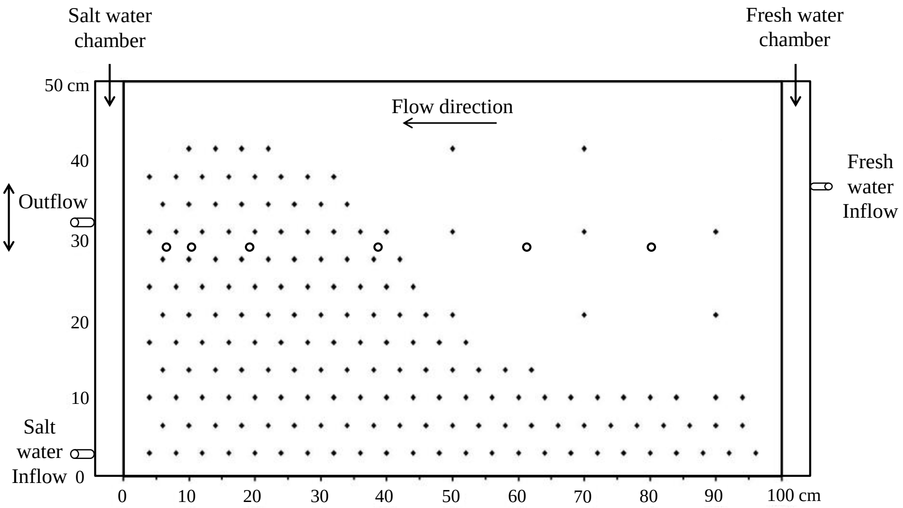

Figure 1. A schematic figure of the laboratory system. The black dots represent the location of the electrodes and the circles represent the location of the piezometers.

In the first stage of the experiment the porous medium was saturated with fresh water and the hydraulic gradient was the average hydraulic gradient between high and low tide. Then, the red saline water was inserted into the left chamber and penetrated into the porous medium creating FSI. After getting a static equilibration of the FSI the second stage of the experiment started, when the outflow and the saline water level in the left boundary fluctuated by the engine to create 'tide-like' fluctuations.

Tidal amplitude in the experiment was 2 cm (the hydraulic gradient was 1-3%), and the time difference between two high tides was half an hour.

RESULTS

Both groundwater level and the FSI, which were measured in the coastal aquifer, were influenced by sea-tide and fluctuated at the same periodicity as sea-tide periodicity (Levanon et al. 2013). The CC analysis produced unexpected results, namely a time-lag of about 10 hours between the head and salinity oscillations, both measured at the same borehole located 70 m from shoreline. While the response of groundwater level to sea-tide was relatively fast (around 1.5 hours), the response of the FSI was much slower (around 12 hours).

Preliminary results from the laboratory experiments showed the same phenomenon as observed in the field. While the induced 'sea-tide' wavelength in the laboratory was 30 minutes (compared to 12 hours in the field) and its amplitude was 2 cm (compared to 10-40 cm in the field), the results of the laboratory experiments showed a significance time lag between groundwater level and FSI fluctuations (Fig. 2).

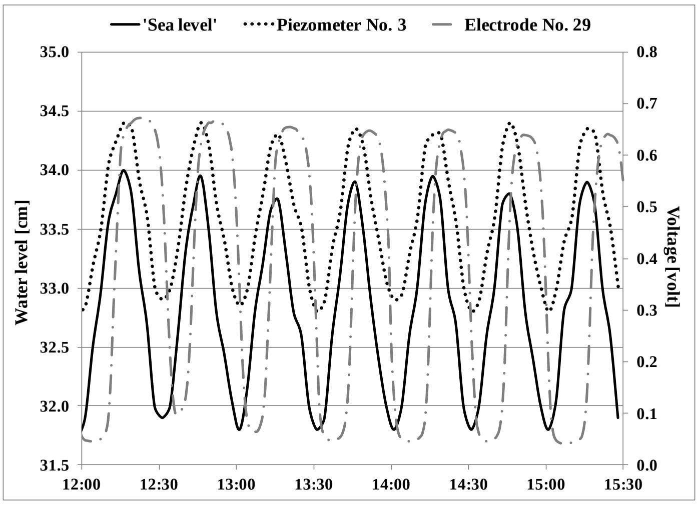

Figure 2. Preliminary results from the laboratory experiment. The groundwater level (dotted line) reacts immediately to 'sea level' fluctuations (solid line), while the FSI (grey dashed line) has a significance time-lag.

DISCUSSIONS AND CONCLUSIONS

Groundwater monitoring at the coastal aquifer of Israel indicates a significance time lag between groundwater level and the FSI fluctuations caused by sea-tide. This phenomenon was also observed in the preliminary laboratory experiments, despite the different scales (time and dimensions) between the field and the laboratory. It seems that the sea-tide fluctuations induce a relatively fast pressure wave which causes groundwater level oscillations, and later triggers much slower salinity advection which influences the FSI.

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