Dynamic Groundwater Equilibrium during a Base Level Drop: The Dead Sea Case

Y. Kiro[1,2], *Y. Yechieli*[1], *V. Lyakhovsky*[1], *E. Shalev*[1] and *A. Starinsky*[2]
[1]Geological Survey of Israel, Jerusalem
[2]Institute of Earth Sciences, The Hebrew University of Jerusalem

The effect of sea level changes on groundwater and sea water intrusion is of great importance in relation to global sea level changes and water resources management. The Dead Sea's rapid level drop due to human influences makes it a suitable place for studying such effects in the phreatic aquifer in its vicinity. The absence of tides and waves isolates the effect of the base level drop and seasonal changes. Furthermore, the rapid drop (1 m/yr) allows detecting the effect of the level changes on the groundwater levels and the transition zone between the fresh and saline water in a relatively short period.

During the past few years the groundwater level and transition zone were monitored in the Dead Sea region. A groundwater level drop was detected in most boreholes in the region ranging from 20% to 100% of the Dead Sea level drop rate [*Yechieli, et al.*, 2007]. The groundwater level in the specific study area (Wadi Arugot) has been dropping at the same rate as the Dead Sea level [*Kiro*, 2006], keeping the hydraulic gradient constant (Figure 1).The transition zone's general trend is downward, but seasonal changes in the Dead Sea level cause an upward movement of the transition zone in the winter (Figure 2).

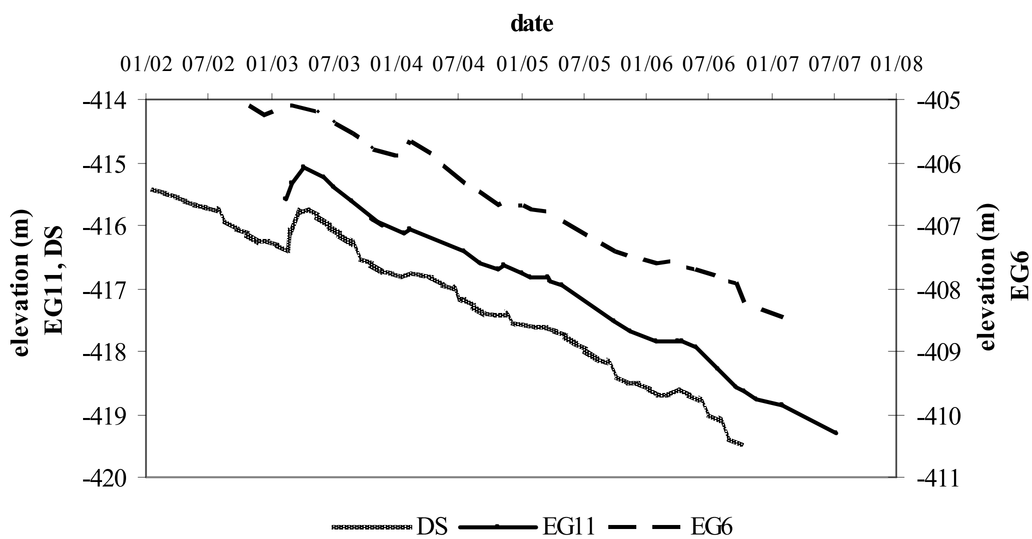

Figure 1. Groundwater levels measured in boreholes near the Dead Sea during recent years. EG11 is 100 meters from the shore and EG6 is 700 meters from the shore.

Theoretical analysis and simulations with the USGS SUTRA code [*Voss*, 1984] were done in order to understand the field data and define the parameters that effect the response rate of the groundwater system. The field data and the simulation show a difference between the groundwater level response and the transition zone response. Groundwater flow is defined by a diffusion equitation [*Bear*, 1979] and in general the time required to obtain equilibrium in a diffusion process is given by $t \propto L^2 / D$ [*Turcotte and Schubert*, 1982], where L[m] is a characteristic length and D[m^2/s] is the diffusion coefficient. The diffusion coefficient in a phreatic aquifer is n/T [*Bear*, 1979] where n is the porosity and T [m^2/s] is the transmissivity.

Therefore, the characteristic time of the groundwater level response should be proportional to the expression nL^2 / T.

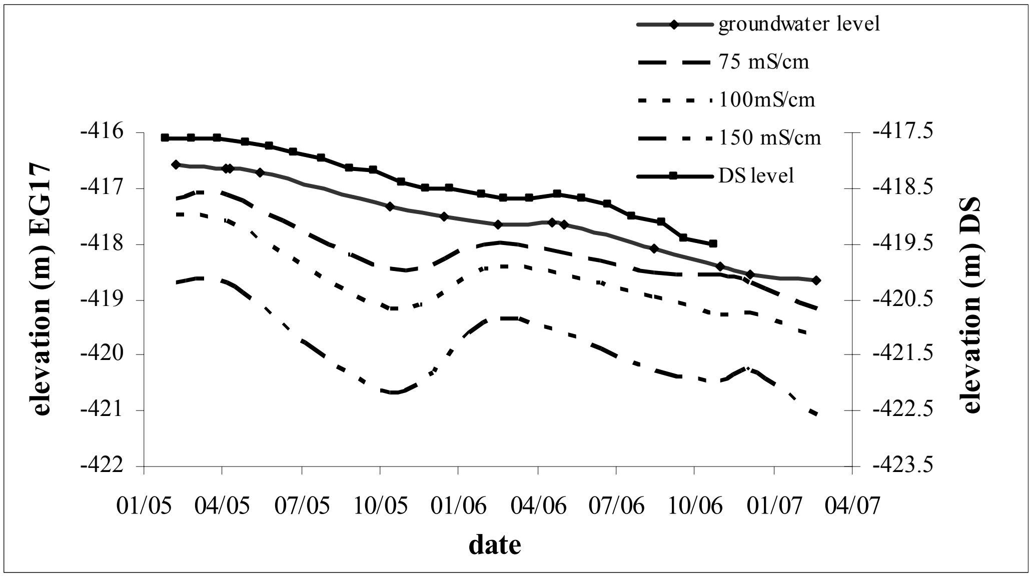

Figure 2. The transition zone between the fresh and saline water in a borehole located 200 ??? m from the Dead Sea shore (values are of electrical conductivity which represent salinity up to about half of that of the Dead Sea) . The transition zone moves downward during the Dead Sea level drop. Seasonal rises in the Dead Sea level cause an upward movement of the transition zone.

The transition zone response rate, however, is a function of the density gradient in a density-dependent flow [*Voss*, 1999]. Since the flow is almost lateral, there is a significant influence of the transition zone slope, which depends on the hydraulic gradient. Therefore, the transition zone response is a function of the groundwater level response and the hydraulic gradient.

According to these principles, we defined two characteristic times using simulations, analyzing the response of both the groundwater level and the transition zone to an instantaneous drop of a base level. These characteristic times are useful for understanding the equilibrium state of groundwater in the entire Dead Sea region and can be used with some modification in other system elsewhere.

The difference between the groundwater level characteristic time and the transition zone characteristic time creates different types of responses of the groundwater system:

- *Fast response of both the groundwater level and the transition zone* - both groundwater level and transition zone are close to equilibrium with the lake level.
- *Slow response of the groundwater and fast response of the transition zone*. The transition zone is always in equilibrium with the groundwater level. This response occurs in a relatively large hydraulic gradient.
- *Fast response of the groundwater level and slow response of the transition zone.* The transition zone becomes wider with time and is not in equilibrium with the groundwater level as occurs in the study area.

The second stage was to examine the response of the groundwater system to a continuous lake level drop represents the situation in the Dead Sea. Theoretically, a continuous lake level drop could be approximated as a sum of discrete instantaneous lake level drops. In this case, the discharge increases gradually until it reaches a constant value, and a new dynamic equilibrium is attained (Figure 3). At this point, the groundwater level drops but the hydraulic gradient remains constant, as we see at some sites in the Dead Sea region. According to the simulations, the saline water initially flows toward the lake, but after a period of time the saline water circulation tends to return (as occurs in steady-state).

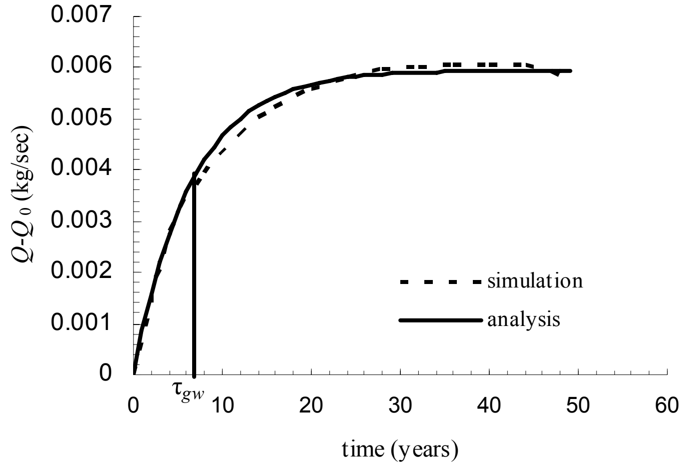

Figure 3. Discharge to the lake during a lake level drop. The discharge attains a constant value after a certain period of time.

The vertical movement of the transition zone that results from the lake level drop causes a widening of the transition zone due to the vertical effect of the longitudinal dispersivity. Hence, the bathymetry affects the thickness of the transition zone during the drop of the lake level. A high boundary slope will cause a thicker transition zone.

The response rate of the groundwater around the Dead Sea can be useful for parameter estimation, which can be achieved by calculating the characteristic times. On the other hand, calculating the characteristic times in a given location can give a good estimation of the equilibrium state in that location.

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Contact Information: Y. Kiro, Institute of Earth Sciences, Givat Ram Campus, The Hebrew University, Jerusalem, 91904, Israel, Phone: +972-2-6584053, Email: yael.kiro@mail.huji.ac.il