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The effect of base level changes and geological structures on the location of the groundwater divide, as exhibited in the hydrological system between the Dead Sea and the Mediterranean Sea

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SUMMARY

The effects of base (sea or lake) level changes on the location and elevation of the groundwater divide were examined in the hydrological system between the Mediterranean Sea and the Dead Sea. Steady-state simulations were conducted with a 1-D analytical model and transient conditions were simulated using FEFLOW groundwater modeling software. Two hydrological scenarios were simulated: (a) a transition to a new steady-state, following the expected drop of 150 m of the Dead Sea level; and (b) the time of the precursor of the Dead Sea (Lisan Lake), some 20,000 years ago, when the lake level was about 250 m above the present-day Dead Sea level and the Mediterranean Sea level was 120 m below its present one. The results of the simulations show that the Dead Sea level drop has led to a progressive decline in the groundwater level up to several kilometers inland from the shoreline. The hydraulic gradient increases, and thus the discharge to the lake also increases at the expense of the storage, and also due to a small enlargement of the recharge zone by a ~600 m shift of the divide.

Broadly, the subsurface hydrological system is compartmentalized into several sections, separated by low permeability fold structures bounding the mountainous uplands. Most of the groundwater recharge occurs in the uplands. Given this geometry and the available water level measurements, analytical and numerical modeling results show that only changes in the Dead Sea level and recharge rate result in dramatic changes for the scenarios examined. Limited by the low permeability folds, the effects of the Dead Sea level on the groundwater level are most pronounced in the vicinity of the Judea Desert lowland. The folds also greatly limit migration of the groundwater divide associated with changes in the Dead Sea level. Transient simulations show a peak increase of ~30% in the Dead Sea groundwater flux in ~75 years, resulting from drainage of lowland aquifers. After more than 500 years the groundwater flux is expected to return to values no more than 4% higher than at the beginning of the simulation. This small net increase is consistent with the small shift in the groundwater divide.

Introduction

The effect of base level changes and the structural configuration on their related groundwater systems in the world is very important, particularly where both marine and nearby inland base levels below sea level were subjected to considerable current and young changes still within the hydrological memory. In such cases, consequent shifts in groundwater divides, as well as in groundwater flow gradients, depend strongly on the structural configuration in between. Examples for systems where base levels (sea level) have changed in the recent past (20,000 years ago) are the Imperial Valley, California (e.g., Loetz et al., 1975; Kafri, 1984), the Afar depression, East Africa (e.g., Fouillac et al., 1989) and the Qattara depression, Egypt (e.g., Thiele et al., 1970). In most cases, this subject was dealt with regarding changes in coastal aquifers as a result of variations in sea level due to climate changes since the last glacial period (e.g., Essaid, 1990). Other studies attempted to simulate the possible effect of global warming and the consequent sea level rise on coastal groundwater systems (e.g., Sherif and Singh, 1999; Oude Essink, 2001; Tyagi, 2005). A few studies discussed the effect of changes in lake levels on their adjoining groundwater systems. Among the examples is that of Mono Lake (e.g., Rogers and Driess, 1995).

The main objective of this study is to examine the response of the groundwater divide to both natural and man-made changes in the elevation of the base levels. This was studied in the groundwater system between the Mediterranean and the Dead Sea (DS) base levels. This system represents an example which underwent, and is still subject to, considerable base level changes, and is

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strongly controlled by the structural configuration. The effect of the geological structure on the water divide was elaborated on by simulations that assessed future and past groundwater levels, the discharge to the lake, as well as the location of the groundwater divide.

Hydrogeological background

The main geological structure in the study area is the anticlinorium of the Judea and Samaria mountains (Fig. 1), which by itself consists of a few NE–SW trending anticlines. The anticlinorium dips to the coastal plain of Israel. The same configuration prevails in the east where the structure dips in an undulating form toward the DS Rift. The western (Ramallah) monocline is underlain by a reverse fault, and its influence on the hydraulic conductivity and flow gradient has been analyzed previously (Yechieli et al., 2007).

The Judea Group Aquifer (JGA) discussed herein, which consists mainly of Cretaceous carbonate rocks, is the largest active aquifer in Israel. This aquifer, some 600–700 m thick, is recharged along the Judea and Samaria mountain crests of central Israel. It dips to the west towards the Mediterranean coastal plain and to the east toward the Jordan River-DS valley. On both sides, the aquifer is confined under a thick sequence of Upper Cretaceous and younger layers. At the bottom, it is confined by Lower Cretaceous layers (Qatana Fm.) (Fig. 1b). To the west, close to the Mediterranean coast, the JGA carbonate sequence passes laterally into the Talme Yafe Formation, of low permeability. This configuration, exhibited on a W–E directed cross-section between the Mediterranean Sea and the Dead Sea Rift (Fig. 1b), assumingly does not enable hydraulic connection of the aquifer to the sea and blocks seawater intrusion into the aquifer.

The aquifer is replenished along the mountain crests where a groundwater divide is formed between the western and eastern drainage basins. The groundwater flows from the recharge zone to the Mediterranean coastal plain in the western portion of the aquifer. Due to the overlying confining layers and the assumed blockage of flow to the west by the Talme Yafe aquiclude, the aquifer has apparently no connection to the sea. Thus, most of its past natural drainage was through the large Yarqon and Taninim springs and at present most is pumped through water supply wells and the rest is through the Taninim spring, north of the study area (Fig. 1a).

To the east, groundwater flows toward the Dead Sea Rift (DSR) base level. Parts of the flow emerge along the flow path as springs. Most of the flow down-gradient seems to be blocked along the Rift margins by the impervious graben fill and as a result emerges in several specific locations, which are also structurally controlled, through the large springs of Zuqim, Qane and Samar (e.g., Guttman, 1998; Laronne and Gvirtzman, 2005).

The groundwater system in Israel is, at present as well as in the past, controlled by two base levels, namely the Mediterranean in

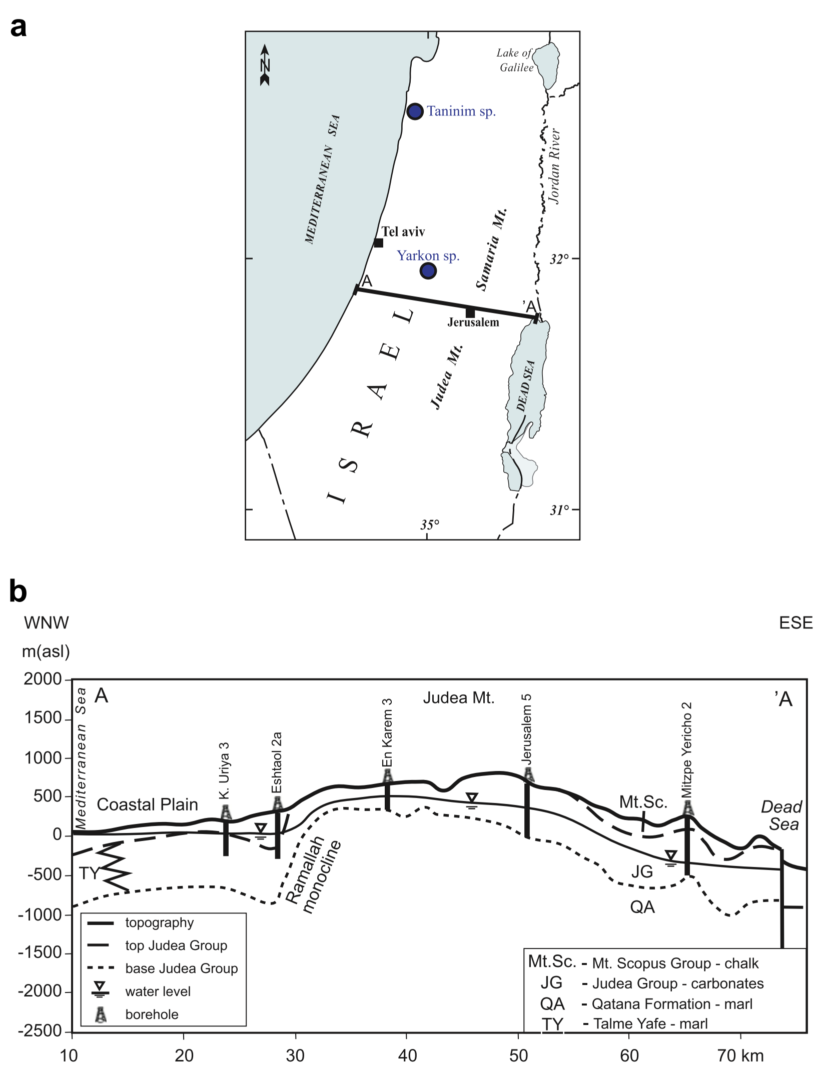

Fig. 1. (a) Location map of cross-section (A–A'); (b) simplified hydrogeological cross-section from the Mediterranean Sea to the Dead Sea.