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Hydrogeology of the Southern Dead Sea Basin

(the area of the evaporation ponds of the Dead Sea Works)

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Abstract

In this report we summarize the known information regarding the hydrogeology of the southern basin of the Dead Sea, near the area of the evaporation ponds of the Dead Sea Works. There are three main aquifers in the vicinity of the evaporation ponds: Kurnub Group Aquifer, Judea Group Aquifer, and The Coastal alluvial Aquifer. All of the aquifers are connected to some extent to each other. In several places the Judea and the alluvial aquifers actually constitute a continuous aquiferal system in which the levels and the salinity of the groundwater are similar. The connection between the deeper Kurnub aquifer and the alluvial aquifers occurs through faults. The general direction of the groundwater flow in the regional aquifers is to the northeast, towards the Dead Sea rift. The utilization of groundwater in this area is mainly by the Dead Sea Works and also by Mekorot, from all aquifers.

North of Mt. Sedom there are four main streams with wide Alluvium aquifers: Hemar (and Zohar), Boqeq, Parsa and Ye'elim. The alluvial aquifers in these streams consist of thick layers of highly permeable gravel and act as pathways for groundwater, channeling water from the Judea aquifer in the surrounding hills to the evaporation ponds. In these streams, an opposite flow of evaporation pond brine also occurs from the evaporation ponds into the aquifer. These two directions of flow create a brine-freshwater interface in which the freshwater overlies the brine. Freshwater pumping from the aquifers increases the brine flow from the evaporation ponds. In between the streams, the alluvium units consist mainly of impermeable marl with some thin layers of gravel to which groundwater flow is limited.

1. General Background

The aim of this report is to summarize the known information regarding the hydrogeology of the southern basin of the Dead Sea, near the area of the evaporation ponds (EP) of the Dead Sea Works (DSW). Many hydrological studies were conducted in this area, mostly for the DSW. We realize that some more information could exist in confidential reports which are not open to the public. Nevertheless, we think that most of the information is here and thus this report gives the state of the art knowledge of the hydrogeology of the EP area. This report describes the relationships of the different aquifers with the EP and less attention is given here to pumping regime of the aquifer and the utilization scheme, unless it has bearing to the relation with the EP. In addition to this report, we also prepare a GIS based map with all the boreholes that are available to us.

2. Hydrogeological description of the Dead Sea system

The Dead Sea (DS) lies in the central part of the Syrian-African Rift System. It is located in the lowest topographical-structural segment of the rift and serves as a drainage basis for all the hydrological systems in its vicinity; both surface and subsurface (Figure 1). The western catchment area of the DS is between the water divide on the mountainous backbone and the Dead Sea. Though there is a certain match between the subsurface and the surface water divide, they are not identical (Arad, 1964).

The EP hydrological system is located in the southern part of the DS basin and is separated from the DS by the Lisan diapir. Unlike the DS whose water drops at a rate of 1 m/yr, the EP level rises by about 20 cm/yr since the early 1980's due to pumping by the DSW (figure 2). Due to the negative water budget of the DS, and the consequent drop in water levels, the EP would already be a dry area. The pumping of DS water and its transportation to the southern part is keeping a lake in this area. The brine in the EP varies in its salinity and water composition according the season and DS pumping regime. In 1986, according to data from the Dead Sea Works, the salinity in the EP was 260,000 mgCl/L and the Cl/Br ratio –was 35, compared to 220 and 0.45 in the DS.

The area to the west of the evaporation ponds of the Dead Sea Works is divided into three morphological units whose general direction is north-south: the mountain heights in the west, the fault scarps in between, and the Dead Sea coastal strip in the east

(Figures 3 and 4). The fault scarps are a morphological manifestation of a series of north-south trending normal faults, and their planes dip steeply eastward. The vertical throw of every fault, which continues for several kilometers, reaches hundreds of meters. The step structures between the faults continue eastwards into the Dead Sea rift, where they are covered by rock units younger than those exposed by the faults and by alluvium. Along the faults, young alluvium rock units in the east are lined up against older units of the Kurnub and Judea groups in the west.

The total area of the Judea desert basin is more than 750 km^2 (Fink, 1994). The general direction of the groundwater flow in the regional aquifers is to the northeast, towards the Dead Sea rift. The region is characterized by a desert climate with a small amount of rain, from 100 mm/yr in the vicinity of the Dead Sea to larger amounts (500-600 mm/yr) with the approach to the Hebron mountain backbone in the west.

The sedimentary rocks that are exposed in the mountain area are from the Lower Cretaceous to the Upper Cretaceous periods. These rocks underwent processes of folding and faulting that produced a complex structure that influences the characteristics of the groundwater flow in the area (Burg et al., 2000). In the northeastern Negev, the Hazera and the Hatira anticlines are found, with large erosive cirques, Ha'Makhtesh Haqatan (Hazera) and Ha'Makhtesh Hagadol (Hatira) at their highest structural points (Figure 3). The southeastern sides of the anticlines are much steeper than their opposite ones. The axes of the anticlines extend in a general southwestern-northeastern direction and descend in a northeastern direction. The decisive influence of the fold structures of the northern Negev on the groundwater flow regime along the axes of the synclines are detailed below.

The salt diapir of Mount Sedom blocks the flow of the Judea Group groundwater eastward to the southern part of the evaporation ponds (Naor, 1987). The Ami'az Plain, the area between the Mount Sedom salt diapir in the east and the fault scarps in the west (Figure 4), is built of marl and clay units alternating with sand and pebble horizons of Pleistocene age, most of them of low hydraulic conductivity. The thickness of the Pleistocene section there reaches 1160 m (according to the Ami'az 1 oil drillhole located in the center of the plain) and thus is of great importance in determining the flow regime (Burg et al., 2000).

There are three main aquifers in the vicinity of the evaporation ponds: Kurnub Group Aquifer, Judea Group Aquifer, and the Coastal alluvial Aquifer. The Judea Group rocks are built of marine carbonates and have a lithostratigraphic continuity over long distances, which enable regional definition of its units over wide areas. On the other hand, the rocks of the Kurnub Group were formed in continental and coastal environments, and appear in widely variegated compositions and in less clear lithostratigraphic continuity. The local alluvium aquifers are built of alternations of different lacustrine and alluvial sediments, with no clear lithostratigraphic continuity. These aquifers are described in the following chapters.

3. The Kurnub Group Aquifer

3.1 Groundwater Flow at the Kurnub Aquifer

Because of the lack of exposed Lower Cretaceous Kurnub Group rocks in the western catchment basin of the Dead Sea, except for the complete sections in different compositions and thicknesses in the Hazera and Hatira “makhteshim” (erosion cirques), the information regarding the group's rocks relies on data from a number of oil and water wells of the Dead Sea Works, located between the Tamar area in the south and Rahaf in the north. A complete section of the group was encountered in Amiaz 1 borehole in the south and in Mezada 1 borehole in the north. This section in the Dead Sea area is 350-450 m thick and is built of clastic rocks (sandstone and clays) with a number of carbonate horizons. Northwards, the clastic horizons decrease and the carbonate section thickens (Arad, 1964). The change in lithology both in the vertical and horizontal dimensions enables dividing the aquifer to sub-aquifers, of which the hydraulic connections are not always clear. Issar et al. (1972) claimed that the recharge in central Sinai is the source of the water in the sandstone of the Kurnub Group aquifer and that the main recharge was during a rainier period than the present one, tens of thousands of years ago.

Naor et al. (1991) estimated the average annual recharge to the Lower Cretaceous sandstone as 4.5 MCM/yr which is replenished in its exposures in the Ramon, Hatira and Hazera erosion cirques. In their opinion, this water drains northeastwards, to the evaporation ponds and maybe even to the northern basin of the Dead Sea. Burg et al. (2000) estimated that the amount of replenishment to the aquifer in Sinai and in the northern Negev is around 3.4 MCM/yr.

The utilization of groundwater in this area is mainly by the Dead Sea Works. In 1990 the DSW produced around 13 MCM of water from the Kurnub Group (Naor et al., 1991), at the end of the 1990’s the amount reached about 17 MCM (Burg et al., 2000) and today reaches 25 MCM (Naor et al., 2009)

Because the natural recharge of the Kurnub aquifer is small and the production of groundwater is high it can be viewed as a one-time reserve. Nevertheless, large amounts of water can still be produced for tens of years because of their broad spatial extension and their thickness, the store is very large, and also because at the margins of the Dead Sea Rift the water levels are very shallow to artesian (Naor et al., 2009).

Arad and Michaeli (1964) noted that the connection between the accumulating volume of production from the aquifer and the continuous water level drop in the Kurnub Group aquifer boreholes of the Dead Sea Works proves that there is a depletion of the aquifer non-renewable storage.

Burg et al. (2000) showed that continuation of the production rate in 1998 for the next 20 years would not cause an additional drop in levels in all four well fields in the basin. The salinity in the Ami’az field is also expected to remain stable (up to 4000 mg/L Cl) because the production from the Kurnub aquifer is almost entirely at the expense of emptying a one-time storage with very little recharge of fresh water and also because of the relatively low hydraulic conductivity that characterizes this aquifer. Additional production from the aquifer will, however, cause a large level drop of tens of meters in levels and attaining a new balance will be slow. Ettinger and Langozki (1969) presented a contour map of hydraulic heads in the Kurnub Group similar to the water level map of the Judea Group.

3.2 The Chemical Composition of groundwater in the Kurnub Group

The water in the Kurnub Group is brackish (Table 1) and there is an increase in salinity from south to north (Burg et al., 2000). The lowest chloride concentrations are found in several of the Tamar wells (630-730 mg/L Cl), similar to the concentrations found in wells farther away from the rift. The concentrations are higher in the Admon wells (1500-2000 mg/L Cl), in the Amiaz and Ye'elim wells (several thousand mg/L Cl) and up to 19000 mg/L Cl in Rahaf 1.

The increase in salinity is usually characterized by a change in the Na/Cl, SO_4/Cl and Mg/Ca ion ratios. The first two ratios decrease with the increase in salinity and the third one increases. In the Rahaf 1 borehole these ion ratios approach their ratios in the Dead Sea water, implying a significant contribution of DS type brine. It should be noted that brine with DS type composition could either be DS (or EP) water itself, possibly with hydraulic connection to the saline water body, or remnant of ancient DS brine without any hydraulic connection to the present lakes. The composition of the water in the Tamar 3 borehole represents the low salinity water in the Kurnub Group (and the Judea Group) in which high Na/Cl and SO_4/Cl ratios and a low Mg/Ca ratio are found. Similar ratios were also found in the water in the Admon field. In the artesian Ye'elim 3 well, located some 18 km north of the Amiaz field, the chloride concentrations are around 3000 mg/L Cl while the ion ratios are identical to those in the Tamar wells that are located 25-30 km to the south. This fact is still not clear and requires further study. The water in the Kurnub Group has a characteristic isotope composition throughout the Negev and Sinai (Vengosh et al., 2007).

4. The Judea Group Aquifer

4.1 Groundwater Flow at the Judea Aquifer

The limestone and dolomite rocks of the Judea Group constitute the main aquifer in this area, and are exposed in the structurally high areas close to the national water divide. On the slopes of the Judea Desert, mainly chalk and marl impermeable rocks of the Mount Scopus Group are exposed. In the channels of the main streams, rocks of the upper part of the Judea Group are exposed. Accordingly, the mountain heights are the main area of recharge whereas in the Judea Desert there is little recharge in the streams during floods. At the eastern end of the Judea Desert, at the fault scarp area, almost the entire section of the Judea Group rocks is exposed (Figures 3, 4).

The thickness of the Judea Group decreases gradually eastwards from 900 m at the mountain backbone to around 500-600 m in the fault scarp area, west of the Dead Sea in the En Gedi area and to around 300-400 m in the Sedom area (Druckman, 1985).

The recharge to the Judea aquifer in the entire northern Negev basin was estimated by Burg et al. (2000) to be 12.5 MCM/yr. in the 1990s. A similar amount is produced from the aquifer.

Intermediate chalky-marly layers found in the Judea Group section divide it into two sub-aquifers that drain separately to the Dead Sea rift. The sub-aquifer in the lower part of the Judea Group (Hevyon Formation) is confined to layers beneath the clay in the En Yorq'am Formation. The water level in the Hemar T/30 borehole is artesian and evidently its source is the water of the Kurnub aquifer that rose along the adjacent fault

(Burg et al., 2000). The large difference in levels and salinity between the two regional aquifers indicates there is a good hydrological separation between them (Fink, 1994; Burg et al., 2000; Naor et al., 2009).

In the western part of the Dead Sea western catchment basin, in the mountain backbone, the upper aquifer is unsaturated and the groundwater level is found within the section of the lower aquifer, in places, in its lower part. Further east the aquifer rocks descend, and in the upper aquifer there is a phreatic aquifer above the Moza Formation. The water flowing in this upper aquifer discharge as springs in the fault scarp area, such as En Arugot, En David and En Boqeq, retaining low salinity (Arad, 1964; Arad and Michaeli, 1964). The discharge measured at En Boqeq was about 36 m^3/hr (Eckstein and Rosenthal, 1965). The spring drains a perched horizon in the Zafit Formation that is disconnected from the lower regional sub-aquifer in the Hevyon Formation (Burg et al., 2000).

It has been claimed that, near the water divide, there are hydraulic connections between the Judea and Kurnub aquifers (Arad and Kafri, 1980) and farther east there is a separation between them and the hydrostatic pressures are higher in the lower, Kurnub aquifer. Other hydrologists, however, claim that there is no hydraulic connection between the aquifers (Issar et al., 1972).

According to Burg et al. (2000), the main geologic structures dictating the direction of the flow in the Judea Group aquifer (and to a lesser extent also in the Kurnub Group aquifer) are the Hazera anticline, which plunges to the northeast, and the faults of the western boundary of the Dead Sea rift (Figure 3). The Hazera anticline does not constitute a barrier to the groundwater flow in the Kurnub aquifer because that aquifer is immersed also in the axis of the anticline and therefore there is passage of water in the Kurnub Group from the Ef'e syncline eastward perpendicular to the axis. As opposed to this, for the Judea Group aquifer, the area of the anticline axis constitutes a hydrologic block up to latitude 057. From there northward, because of the plunge of the axis, passage of water eastward is possible also in the Judea aquifer.

On the basis of the chemical composition of the water, Burg et al. (2000) concluded the following about the flow regime in the two regional aquifers: Water reaching the Judea Group and the Kurnub Group aquifers at the Ami'az Plain area from the southwest and the west split into two flow components: one to the south in the direction of Zin stream and the Sedom playa; and the second to the north, towards the outlet of Hemar stream. There is a water divide between the Ami'az wells in the south and Hemar-Zohar wells in the north. The location of the water divide is determined by the effect of production in the different well fields.

Water flowing northward passes to the alluvial aquifer in the area around Hemar stream. The source of most of the water in the alluvial aquifer is from the regional aquifers (mainly from the Judea Group). This is clear from the lack of dependence of the oscillations in water levels of the alluvium aquifer due to flood events and also by the resemblance to the oxygen isotope composition in the water of the Hemar wells.

The levels in the Kurnub Group in the northern part are higher by about 60 m than the levels in the Judea Formation. This difference is larger than that in the southern part of the basin in the Negev, due to the large production in the Judea aquifer.

According to Burg et al. (2000) the eastern wells in the Hemar-Zohar field (Hemar 4, 5 and Zohar 4) are affected by the brines in the alluvium aquifer in the east and there is a clear relation between production rates and groundwater levels and the increase in salinity. In the western wells in this field (all of them in the Judea Group), which are situated at the opening of the path of flow southwards, the salinity is stable in time and reaches up to 1600 mg/L Cl. In the years prior to 2000, in which the production in the whole basin was nearly stable, there was a clear stabilization in the levels of most of the wells. Small drops in level occurred only in the Hemar-Zohar field at the edge of the northeastern basin (about 2 m/yr). Since the production in this field is smaller than the recharge, it can be assumed that stabilization of the levels is a matter of time. In that period, a state of hydrologic balance is achieved.

Burg et al. (2000) showed that if production from the Judea aquifer in 1998 continues for 20 years, it will cause a drop of a few meters in the levels in the southern Admon-Ami'az borehole fields and a drop of up to 40 m in the Hemar-Zohar field. In such a production regime, the salinity is expected to remain stable both in the Admon field (up to about 2000 mg/L Cl) and in the western part of the Hemar field (around 1500 mg/L Cl). A slow salinization trend is expected in the Ami'az field (up to 10,000 mg/L Cl) and in the eastern Hemar-Zohar boreholes. It should be noted that the forecast for the Hemar-Zohar area was given even though the model was not calibrated for this area. A forecast was also given for the case of an increase in production from the Judea Group aquifer, which has a relatively large recharge, and the hydraulic conductivity is far greater than that of the Kurnub Group. Attaining new hydrologic balance in this aquifer will be faster and the drop in levels is expected to be a few meters.

4.2 The Chemical Composition of groundwater in the Judea Group

The water in the Judea Group aquifer at the southern part is more saline than the water in the Kurnub Group (over 1000 mg/L Cl compared to 600-800 mg/L Cl). The situation of the water arriving from the west is reversed – the Judea Group water is less saline (560-580 mg/L Cl, according to intermediate pumping from the Ef'e 3 borehole during drilling) than the water in the Kurnub Group (1400-1700 mg/L Cl). This chemical information was used by Burg et al. (2000) in order to estimate the flow direction in the Judea and Kurnub groups.

Similar to the Kurnub Group, in the Judea Group there are also variations in salinity between the different wells (Table 2). In this aquifer, too, there is an increase in salinity from south to north, but here it is much sharper. The trend of increase in salinity manifests the growing influence of saline water bodies that are found in the margins of the rift (Burg et al., 2000). In the boreholes that are close to the Dead Sea, such as Ye'elim 2, Zohar 2, and others, interface conditions were found and there is a connection between the rate of the production and the level of salinity (Naor et al., 1991). The increase in salinity is accompanied by a change in the ion ratios, which approach those of the Dead Sea water. The part of the saline component in the mixture is 5-15% (Arad, 1993).

The water in the Judea Group has a 'heavier' isotope composition than that in the Kurnub Group and is similar to the composition of rainwater in the Negev (mostly heavier than $\delta^{18}O$= -5.5‰; Burg et al., 2000).

The age of the water reaching the Judea Group in the Dead Sea area, according to the concentration of ^{14}C and Tritium, is usually tens to hundreds of years (Yechieli et al., 1994; 1996), compared to the water in the Kurnub Group, which is more than 30,000 years (Yechieli, 1993). This data is mostly from the northern part of the DS region, since very little analysis was done in the southern basin.

5. The Coastal alluvial Aquifer

5.1 Groundwater Flow at the alluvial Aquifer

The coastal alluvial Aquifer near the EP extends from Mount Sedom in the south to Ye'elim stream in the north and from the fault scarps in the west to beneath the evaporation ponds. This aquifer is built mainly of clastic rocks that accumulated in alluvial systems that drain toward the center of the Dead Sea rift. The aquifer constitutes part of a Neogene-Quaternary section built of alternating gravel units (aquiferal) and clayey and silty layers (aquicludal). Also common in the section are units of gypsum and aragonite, and layers of halite that precipitated in a lacustrine environment. At the bottom of the EP, in the area east of the mouth of Parsa stream, beneath a 3-4 m layer of friable salt, there is a series of alternating salt and clay layers (Neev and Emery, 1967, 1995). The salt layers are relatively permeable (hydraulic conductivity of 0.001-0.005 cm/sec). A clear trend of thickening of the salt layer eastward toward the center of the basin at the expense of the clay was discerned. In the western part of the EP the salt layers are mixed with gravel and overlie a unit of alternating salt and clay (Israel Electric Corp. Ltd., 1991; Burg et al., 2000). The gravel layers constitute several sub-aquifers while the layers of clay constitute aquicludes separating between them (Michaeli and Harash, 1986; Yechieli, 1993). The different sub-aquifers contain different water bodies with different salinity, chemical compositions and hydraulic heads (Yechieli et al., 2004). The upper sub-aquifer seems to be connected hydraulically to the EP showing no drop in water levels and possibly a rise in level (Yehcieli et al. 2007). There is very little data regarding the behavior of the lower sub-aquifers with time. It is possible that the lower sub-aquifers (even next to the EP) are connected to the DS (10-20 km to the north) whose water level is about 30 meters above the EP.

Because of the large difference between the density of the fresh waters and the saline waters, the slope of the interface is very moderate (Yechieli, 2000) and the penetration distance of the waters of the Dead Sea and the evaporation ponds from the coastline westward is expected to be to large compared to the penetration of the Mediterranean Sea water to the coastal area. The unclear connection between the various sub-aquifers in the alluvium rock units and the DS (or EP) and the dynamics of the hydrological system along the coast make it difficult to determine the exact configuration between the different bodies of water (Yechieli et al., 2003a).

The alluvial hydrogeological system in the western catchment basin of the Dead Sea is connected to the regional aquifer of the Judea Group, and to a lesser extent, to the Kurnub Group aquifer found below it. There is evidence that in several places, such as in the Hemar area, that the Judea and the alluvial aquifers actually constitute a continuous aquiferal system in which the levels of the groundwater are similar (Naor et al., 1987; Shalev et al., 2005). There is insufficient evidence to estimate the possibility of a hydrologic connection between the Kurnub aquifer and the alluvial aquifer.

Fink (1994) estimated the direct recharge from rain on all the Kurnub and Judea Group exposures and the alluvium units in the Judea Desert basin to be 3-5 MCM/year, assuming a recharge factor of 10-15%. He estimated that there was another component of recharge from floodwaters in the stream channels amounting to ~0.5 MCM/yr. Likewise, based on chloride concentrations in groundwater, he estimated that there was an addition of EP water of around 6% to the balance of groundwater flowing in the alluvial aquifer in the segment between Mount Sedom and Nahal Ye'elim. This amounts to around 0.26 MCM/yr.

A similar estimate of the amount of groundwater flowing from the Judea Group aquifer eastward to the alluvium units only in the outlet area of Hemar Wadi was around 4 MCM/yr (Burg et al., 2000). This was estimated according to the width of the flow (around 2 km), the hydraulic gradient in the boreholes (22‰) and the average transmissivity of 250 m^2/day. In their opinion, a large part of this flow drained to the EP. This was based on quantitative balances carried out by engineers of the Dead Sea Works in the years before 1999, which calculated the inflow of groundwater at a rate of 2.5-3 MCM/yr and the rest of the flow drains northward to the Nahal Zeelim and northern Dead Sea.

It seems that the estimates of the amount of flow in the alluvial aquifer that were made in the 1980s (Michaeli and Harash, 1986; Naor et al., 1987), were based on an exaggerated thickness that was related to the layers conducting the water and perhaps also too high hydraulic conductivity values (Fink, 1994). Hence, the amount of water draining in this area to the EP according to these studies is to a large extent exaggerated.

Due to the increase in the EP levels in the last 30 years, there is also an increase in groundwater level in their vicinity which may damage the infrastructure of the hotels. The first attempt to solve this problem was by several large diameter pumping wells which did not succeed because of the large penetration of EP brine toward the pumping station. Another attempt is being implemented in the last 5 years, whereby many small discharge well were drilled, pumping enough water to lower the water level near the hotels without drawing the EP brine.

5.2 Hydraulic Tests of the Alluvium Aquifer

The pumping rates from the alluvial aquifer range from 70 to 80 m^3/hr. The equivalent specific discharge is in the range of 4-7.5 m^3/hr. Transmissivity values extend over a wide range of 550-2300 m^2/day (Fink, 1994). The values of the specific discharge and transmissivity seem somewhat high for the associated steep water table gradients of 13-24‰. Fink (1994) argued that this anomaly is a result of incorrect interpretation of the pumping tests. An inflow of brine water from the open water body of EP or its underlying brine-saturated strata results in smaller well drawdowns. Interpretation of a pumping test under such conditions, without taking into consideration the contributing boundary, provides higher, erroneous transmissivity values.

Pumping interference tests in the Arugot Wadi show that the hydraulic conductivity of the alluvial section is in the order of magnitude of 100 m/day and transmissivity of 1500 m2/day (Wolman et al., 2003). Similar values were estimated in the En Boqeq area.

5.3 The Chemical Composition of groundwater in the alluvial aquifer

The alluvial aquifer contains waters of different types that have a wide range of salinities, from relatively fresh to that of the Dead Sea. Table 3 presents the chemical composition of several representative water sources.

Saline water is found in boreholes in all of the area west of the EP. It appears that there is an interface relation between the saline water and the fresher groundwater (Michaeli and Harash, 1987), but the actual conditions are not clear. The range of salinities and compositions of the saline waters are very large. Some of the water is similar in composition to Dead Sea water and some is different. The typical temperature in the borehole waters is around 26^{o}C.

Hame Zohar is a group of saline springs that emerged in the 1960's close to the southern Dead Sea coast (today – the evaporation ponds), along a coastal strip about 100 m long (Mazor et al., 1969). Close to this place, there were sub-marine springs called Aharoni Springs, which emerged from the Dead Sea floor in 1965. In several boreholes saline water containing H_2S was found. In the Hame Zohar 2 borehole (148 m deep), water with a concentration of 140 gr/L Cl was found. Also found in the borehole was an upper water horizon with a chloride concentration of 30 gr/L. A borehole drilled in its vicinity into layers of the Kurnub Group to a depth of 553 m, was initially artesian (pressure of 10 atmospheres), but over the years the pressure dropped and the salinity decreased from 91 to 41 gr/Cl/L. The chemical composition was similar to that of the Dead Sea, the temperature was 38^o C and the discharge was around 400

m^3/hr. In the Tapuah borehole (46 m deep), in the same area, very saline and H_2S rich water at a temperature of 38^o C was found.

6. Main Areas of Interest

The hydraulic conductivity of the alluvial aquifer in the stream channels is evidently higher than that outside the stream and therefore the stream constitutes subsurface drain. The groundwater flows from the surrounding hills in the Judea aquifer to the drain (stream channel) and from there to the delta and to the evaporation ponds. Burg et al. (2000) suggested that it is possible that there is a rise in groundwater in faults that raises the level in the area. In addition, the width of the strip of exposures of the alluvial aquifer changes between 2 km in the area around the streams to several tens of meters in between the streams. North of Mt. Sedom there are four main streams with wide Alluvium aquifers: Hemar (and Zohar), Boqeq, Parsa and Ye'elim. A detail description of the Alluvium aquifers in these streams is provided below.

6.1. The Hemar and Zohar Alluvial fans

The unique structural situation in the area of Nahal Hemar enables drainage of the groundwater in the Judea Group aquifer eastwards, via the alluvial aquifer, to the EP. In addition, there is surface flow in the streams, some of which may recharge directly the alluvial aquifer. In the western part of the alluvial fan of Hemar stream, the alluvial aquifer, which is built of coarse clastic material, directly overlies Judea Group rocks at a depth of several tens of meters from the surface and there is no separation between them (Naor et al., 1987; Shalev et al., 2005). Maps of groundwater levels Hemar and Zohar streams (Figures 5, 6) show similar levels in both aquifers and a direct hydrologic connection between the two. Hence, the two aquifers can generally be regarded as one hydrogeological unit. A lack of match between changes in the levels in the alluvial aquifer and flood events in the streams led to the conclusion that there is no significant recharge to the aquifer and it is not fed by flood waters to a large extent. Therefore, the main water source is lateral groundwater flow from the regional aquifers, mainly from the Judea Group aquifer. Supporting this conclusion is the data on the isotope composition of the oxygen in the aquifer water, which is different from that in the floodwaters, and also the irregular levels in the Nahal Hemar 3 borehole imply a rise in water from depth along the faults (Burg et al., 2000).

Three production wells, located along the main stream (Nahal Hemar 3, 4, 5) produce groundwater from the alluvial aquifer. Three more wells (Nahal Zohar 4 and Nahal Hemar 1, 2) produce from the Judea Group aquifer at the head of the streams. The total annual production from the Hemar and Zohar boreholes from the alluvial and Judea Group aquifers between 2000 and 2008 was about 2.1 MCM/yr, compared to an average annual production of around 3.1 MCM/yr in the 1990s (Naor et al., 2009).

The water levels in the boreholes in the alluvial aquifer which dropped by 5 to 15 m since the beginning of the 1990s, have nearly stabilized in the last years. According to the differences in the water levels in the Hemar boreholes, there is a sharp gradient from south to north and from west to east, implying lower hydraulic conductivity in this aquifer than that in the Judea Group (Naor et al., 2009).

Michaeli and Harash (1986) estimated that the amount of water in the alluvial aquifer draining the area north of the Nahal Zohar mouth to EP is 7 MCM/yr. Naor et al. (1987) calculated the flow from the west along ~3 km in a section of Nahal Hemar-Nahal Zohar and got a value of ~15 MCM/yr. The amount of groundwater that drains through this area according to later estimates is much smaller. Thus, this value is still questionable. Shalev et al. (2005a) estimated the flow to the evaporation ponds as follows: The hydraulic conductivity in the alluvium section in the area is on the order of 100 m/day and the width of the Nahal Hemar delta is around 2 km. Assuming the flow occurs in the upper meter of the section across the entire delta, the amount of water entering the evaporating ponds daily is thus 400 m^3 (1.5 MCM/yr). This calculation constitutes only a rough estimate of the volume.

According to Shalev et al. (2005a) and Naor et al. (2009), the level of the groundwater in the wells pumping from the alluvial aquifer dropped by more than 10 m in 1990. The level in the Nahal Hemar 4 and Nahal Hemar 5 boreholes dropped by about 20 m until 1999, causing an increase in salinity of the water in these wells. Thus, the pumping in these boreholes was decreased and the level rose by about 10 m, but the increase in salinity of the boreholes continued. The water level in the Nahal Hemar 3 borehole is the highest and its salinity is the lowest. The Nahal Zohar 4 borehole produced from the upper sub-aquifer of the Judea Group about half the amount of the total water in the Hemar-Zohar boreholes until 1995. Despite the pumping in it until 1995, the salinity in that borehole did not change. Since 1995 no change was made in the pumping, yet the salinity rose. Evidently, the brine flowed slowly (during 5 years) in the direction of the borehole and as a result of the continuous pumping, from 1995 the pumping drew a mixture of brine and fresh water. Today the levels in the Nahal Hemar 5-14 boreholes are less than a meter higher than the evaporation pond level (EP). The dynamic level in the boreholes at the time of pumping is 30 m lower than the static level, much below the level of the pond. In addition to the pumping, a continuous level rise of the evaporation pond water (about 20cm/yr) increases the hydraulic head of the pond's brine and pushes it westward in the aquifer.

Figures 7 and 8 present the changes in water level and chloride concentration in 1988-2008 in the Hemar and Zohar boreholes that penetrate the alluvial aquifer. In these years there was an increase in salinity in all the boreholes. The most rapid salinization occurred in the most eastern borehole, Nahal Hemar 4, in which the water level is the lowest. The concentration rose from about 5000 mgCl/L at the beginning of the 1990s to 40,000 mgCl/L in the year 2008.

6.2 The En Boqeq Region

In the En Boqeq borehole, in the Boqeq Wadi, water was found in three horizons. The water in the upper horizon (the Ghareb Formation rocks) was similar in composition to the water in En Noit. The lower horizon was in rocks of Turonian age. In a pumping test a transmissivity value of 290 m^2/day was found and the level was at an altitude of -372.7 (Eckstein and Rosenthal, 1965). After pumping 62 hours, the pumped water was similar in composition to the Dead Sea water, but of lower salinity (chloride concentration, 31 gr/L compared to 220). Between Nahal Boqeq 1 borehole and En Noit there is a steep hydraulic gradient, due to the existence of a fault that caused the water coming from the west to rise along it and to emerge at En Noit, higher by ~30m than the water level in the borehole. Some of the water, however, continued to flow horizontally from the borehole area toward the drainage basin of the DS (Eckstein and Rosenthal, 1965).

According to Naor and Granit (2009), there are three different water bodies in the area, one of which is good brackish water which is found in the regional aquifers to the west of the fault scarp. Based on information in the boreholes in the Nahal Boqeq area and on the chemical composition of the water, including that from several new boreholes that were drilled in the framework of their study, they reached the following conclusions:

1. Brine water bodies and evaporation EP waters in the alluvial aquifer prevent the good, brackish water from reaching the evaporation ponds.

2. Lens of fresh water in the alluvial strip is floating on saline water (around 0.4 MCM/yr). Most of it was pumped in the SMET boreholes near the hotels, but a small amount of this water could reach the EP (0.1-0.15 MCM/yr).

3. It is vital to catch the En Boqeq water in order to reduce the flow next to the ponds (Naor and Granit, 2009).

An interesting case is that of En Noit spring in the Nahal Boqeq region that emerged at the intersection of two longitudinal faults (Eckstein and Rosenthal, 1965). The water of the spring was hot and its discharge was 4-8 m^3/hr (Eckstein, 1975). According to the travertine sediments around the spring, its discharge in the past may have been larger. The spring has been dry in the past years following the general drop of the groundwater level. A representative composition of the En Noit water is presented in Table 3. The isotopic composition of the spring water is similar to that of the water in the Kurnub Group (Gat et al., 1969). A high concentration of Radon was found in the En Noit water. It seems that the source of the radioactive Radon is in the Ghareb shales and phosphate of the Mishash Formation through which the water passed (Eckstein and Rosenthal, 1965).

6.3 The Parsa-Ye'elim Area

The Judea Group aquifer in the area around the Parsa-Ye'elim stream is characterized by high salinities that represent brine water. In the research borehole T.C.-1, which was drilled on the mountain height, water was found west of the Ye'elim boreholes with a chloride concentration of about 550 mg/L (Bar, 1982). Hence a marked increase in salinity of the Judea Group aquifer occurred close to the faults of the rift margins (Burg et al., 2000) near the DS.

Data on the groundwater in the Judea Group aquifer in the area of Parsa stream is found in the "pumped storage" research tunnel project. Several boreholes were drilled in the tunnel's floors and pumping tests were carried out in them. There is a groundwater horizon in the Hevyon rocks beneath the tunnel (Guttman, 1986). At a distance of 723 m from its entrance, the tunnel penetrated this horizon and water burst at a high discharge. The salinity of the water was around 600 mgCl/L and the composition of the water was similar to the water of En Boqeq flowing from the Zafit Member. The gradient of the groundwater horizon was 2.5%. Interference flow tests between observation boreholes indicate that the transmissivity was 100-200/day and the storativity was 3%. The observation boreholes that penetrated below the tunnel show an interface at a distance of 470 m from the tunnel entrance, and a gradual salinity increase with depth in every borehole. Boreholes east of the research tunnel portal showed a gradient of 4-5% normal to the coast in the alluvial sediments. According to that, and using an estimate of the hydraulic conductivity value (k) smaller than 1, a flow of less than 50 m^3/day/km was obtained along the coast. According to Arazi (2007), the fact that the level in the tunnel rose by only 1 m since 1985 while the level in the EP rose by 4 m during this time, indicates a lack of a direct hydraulic connection between them. Increasing the gradient in the tunnel as it approaches the open faults to its east could indicate the existence of drainage northward to the Dead Sea. The level of EP of 391 m.b.s.l (2007) is in general perched on impermeable layers and not connected to the main hydrological system. Water of low salinity (up to 30,000 mgCl/L) penetrates the EP both along the coast and through breaks in its bottom. There is evidence of leakage from it northward, mainly through the Ye'elim fan, to the base of the drainage of the Dead Sea that is lower by 30 m.

Shalev et al. (2005a) proposed a conceptual 3-D hydrological model for the area between the Parsa stream in the south and the Ye'elim stream in the north (Figure 9). Since most of the area of the EP is found on impermeable layers (salt and clay) limiting the groundwater flow, it can generally be assumed that the connection of the EP to the regional hydrological system is only partial. Close to the fault scarps, around the stream channels, the alluvial aquifer is built of a series of gravel layers and sand and is continuous. At some distance from the faults, layers of clay separate between the gravel layers and the aquifer is divided into several sub aquifers. In places between the alluvium fans, the alluvial aquifer may almost disappear. In these places the northward flow is possible mainly in the Judea Group, but also in layers of the alluvium in the immediate proximity, along the boundary faults of the rift. The estimated regional hydraulic gradient is southwest to northeast, and therefore flow of the groundwater is in the direction of the northern basin of the Dead Sea in the regional aquifers and in the alluvial aquifer. In the alluvial aquifer and along the faults of the rift there is a possible mixing of all the types of the following water: from the EP, from the Kurnub Group and water from the Judea Group. To the north of the EP there is a swampy area to which brines drain from the EP and possibly also from leakage of DS water from the feeder channel (a channel that transports DS brine from the pumping station in the northern DS basin). This water has had a red hue in the last decade as a result of iron oxidation or algae. The source of the iron oxidation could be from Kurnub Group groundwater, which has a relatively high concentration of iron that oxidizes on the surface, but the water may be from another shallow source. The area is also characterized by "sand volcanos", which form due to a rise of groundwater onto the surface, creating sediment heaps. The source of this groundwater may also be groundwater that bypasses the EP and eventually drains to the northern basin. The water originating in the Judea and Kurnub groups may reach the surface through the alluvial aquifer as a result of their high heads. An interesting case is that of the drainage in the Ye'elim 1 borehole. At the time of the drilling, when the borehole penetrated only the Judea Group, the measured static level was -387.73 and the salinity was 28,000 mgCl/L. At the end of the drilling in 1976, when the borehole penetrated the Kurnub Group, an artesian head of around 10 atmospheres was measured (altitude of -255) and the salinity was 2,240 mgCl/L. In April 1977 the measured artesian head was only 0.5-1.0 atmospheres and in July 1977 the level dropped below the surface. In 1986 the level was at a depth of 34.2 m, similar to the original level of the Judea Group, and salinity was 81,600 mgCl/L. The reason for the drop in the level is a large hole that formed in the pipe at the level of the Judea Group a short time after the drilling was completed, causing the Kurnub Group water to flow into the Judea Group. The increase in salinity could be a result of penetration of brines following a drop of the water levels. In an examination using a current gauge, Burg et al. (2000) found that the flow from the Kurnub Group aquifer to the Judea Group aquifer was at a rate of 75-80 m^3/yr However, following additional examination, they changed their estimation to be at least 3 MCM/yr (Burg et al., 2000). They suggested closing up the borehole in order to stop the leak of the groundwater from the Kurnub Group, which is liable to cause damage to the northern embankment of the evaporation pond.

The sinkholes forming in the Ye'elim area are apparently connected to the processes of salt dissolution (Yechieli et al., 2004). The salt dissolution rate depends on the groundwater salinity and on the speed of the flow. The Kurnub Group aquifer contains water with low salinity while the Judea Group aquifer in this area contains water with higher salinity (Burg et al., 2000). Therefore the potential for dissolution and creating sinkholes is greater in the Kurnub Group water which is quite fresh even near the DS.

7. The hydraulic connection between the groundwater system and the EP

Studies showed that solutions from the evaporation ponds of the Dead Sea Works infiltrate into the surrounding aquifer (Yechieli, 1993) and that fresh groundwater infiltrates into the ponds (Michaeli and Harash, 1986; Bar-Yosef, 1991; Naor et al., 1991). In some areas, the mountain rock units, including those of the Kurnub Group, reach close to the Dead Sea. The rocks of the Judea Group are, in places, in direct contact with the lake's water. It seems that there is a hydrological connection with the lake also in areas where the alluvium units separate between these rocks and the lake water (Naor et al., 1987).

The evidence for penetration of the EP water into the aquifer (specifically penetration of the EP brine, and not just a contribution of the DS type brine) include:

a) Very low Na/Cl ratio (0.10), much lower than any DS brine (DS itself is 0.25).
b) At several places near the EP, high Tritium brines were found. This is different from most other brines in the sub-surface that have low Tritium values implying ages greater than 50 years. The age in this case means the time of penetration of the saline lake water into the subsurface and disconnection from the atmosphere (this is when the clock started to work). Thus, relative high Tritium values are evidence for relatively recent penetration (~20-30 years) (Yechieli et al., 1994).

8. Monitoring Plan

We suggest that monitoring water levels in existing boreholes (~50 boreholes) will take place four times a year. Continuous level measurements with automatic transducers and data loggers should be installed in ten representative boreholes.

Electrical conductivity profiles and general chemical analysis of water samples should be monitored twice a year in selected boreholes. In addition, all pumping data should be documented.

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10. Figures

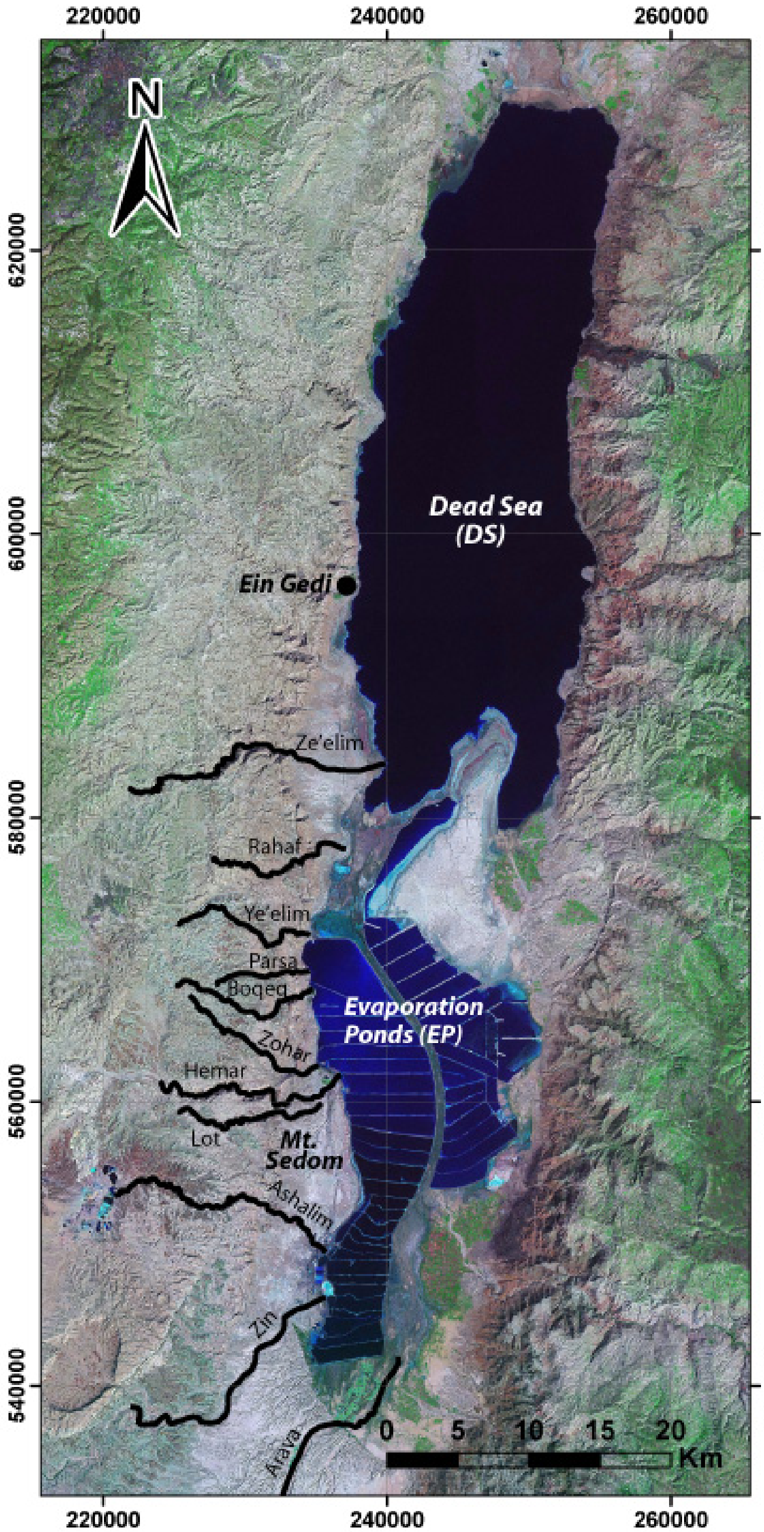


Figure 1: Location map, including the main streams at the southern basin.

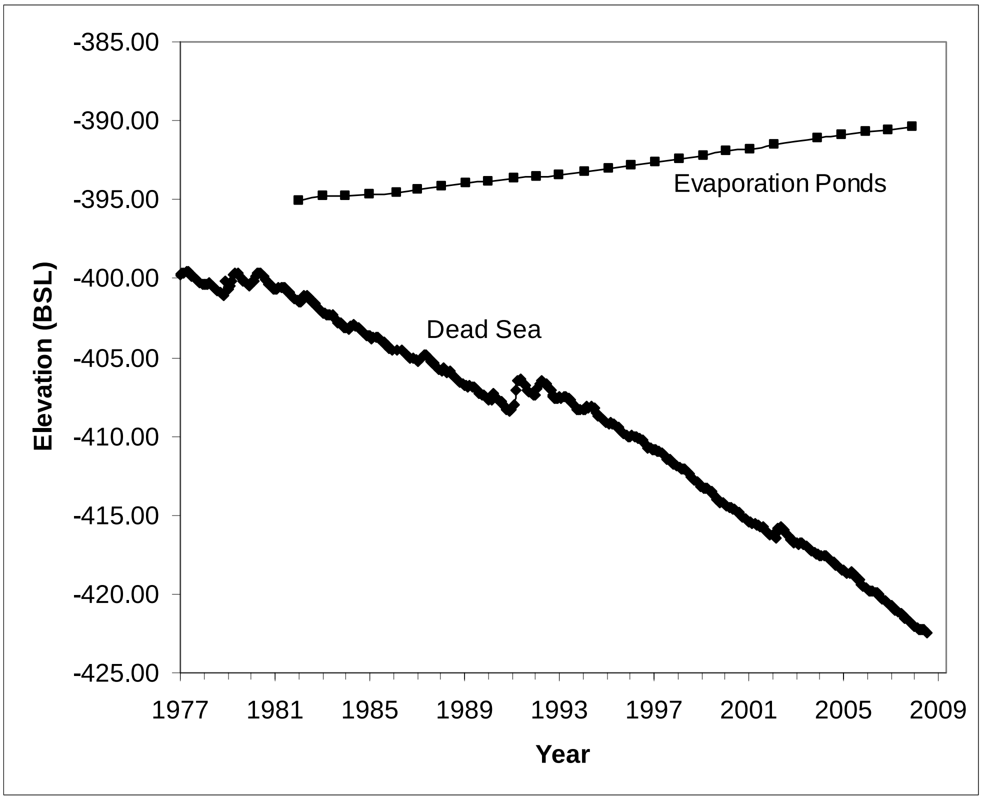


Figure 2: Evaporation pond and Dead Sea levels.

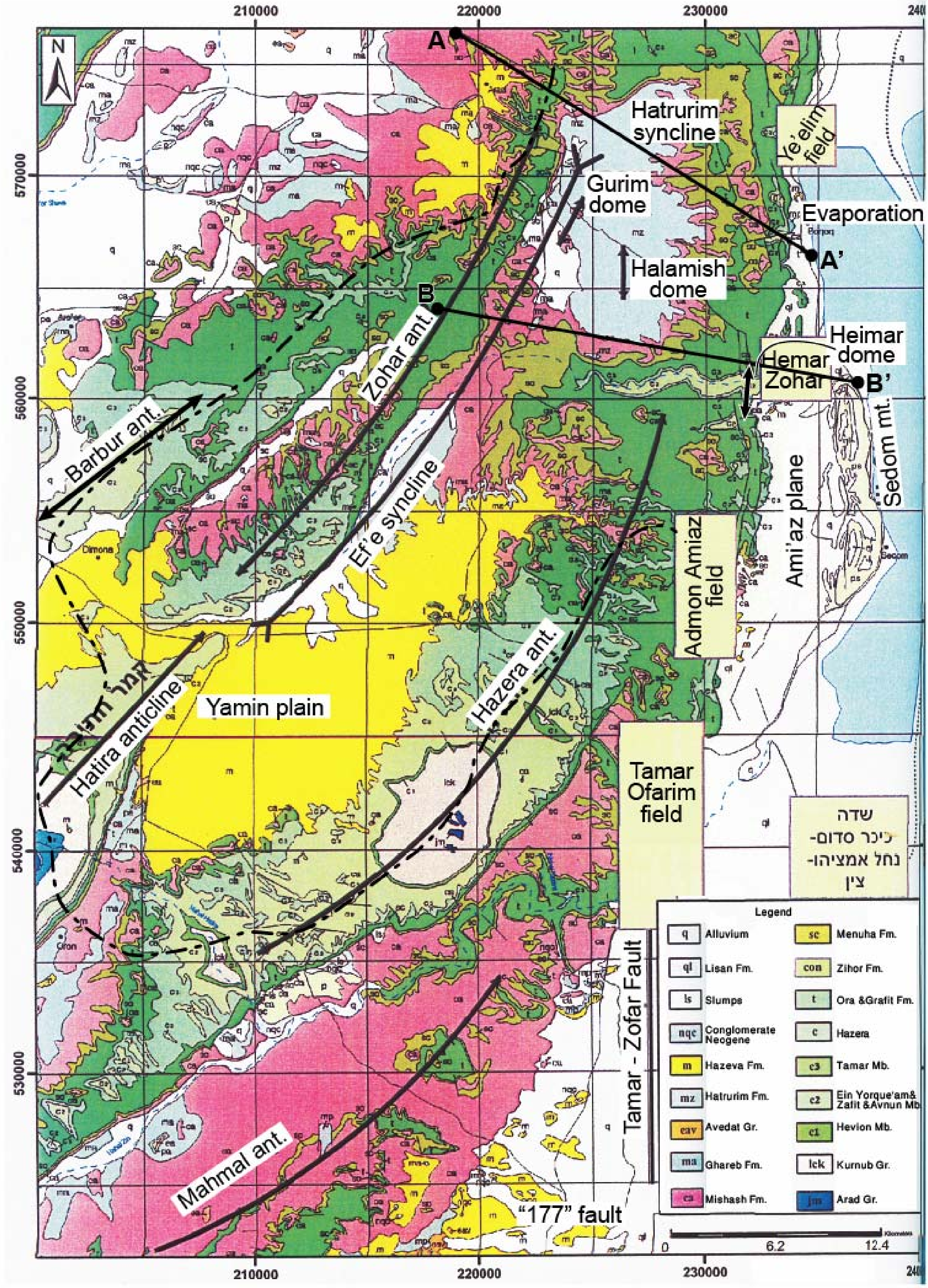


Figure 3: Geological map of the southern basin of the Dead Sea and southern Judea desert.

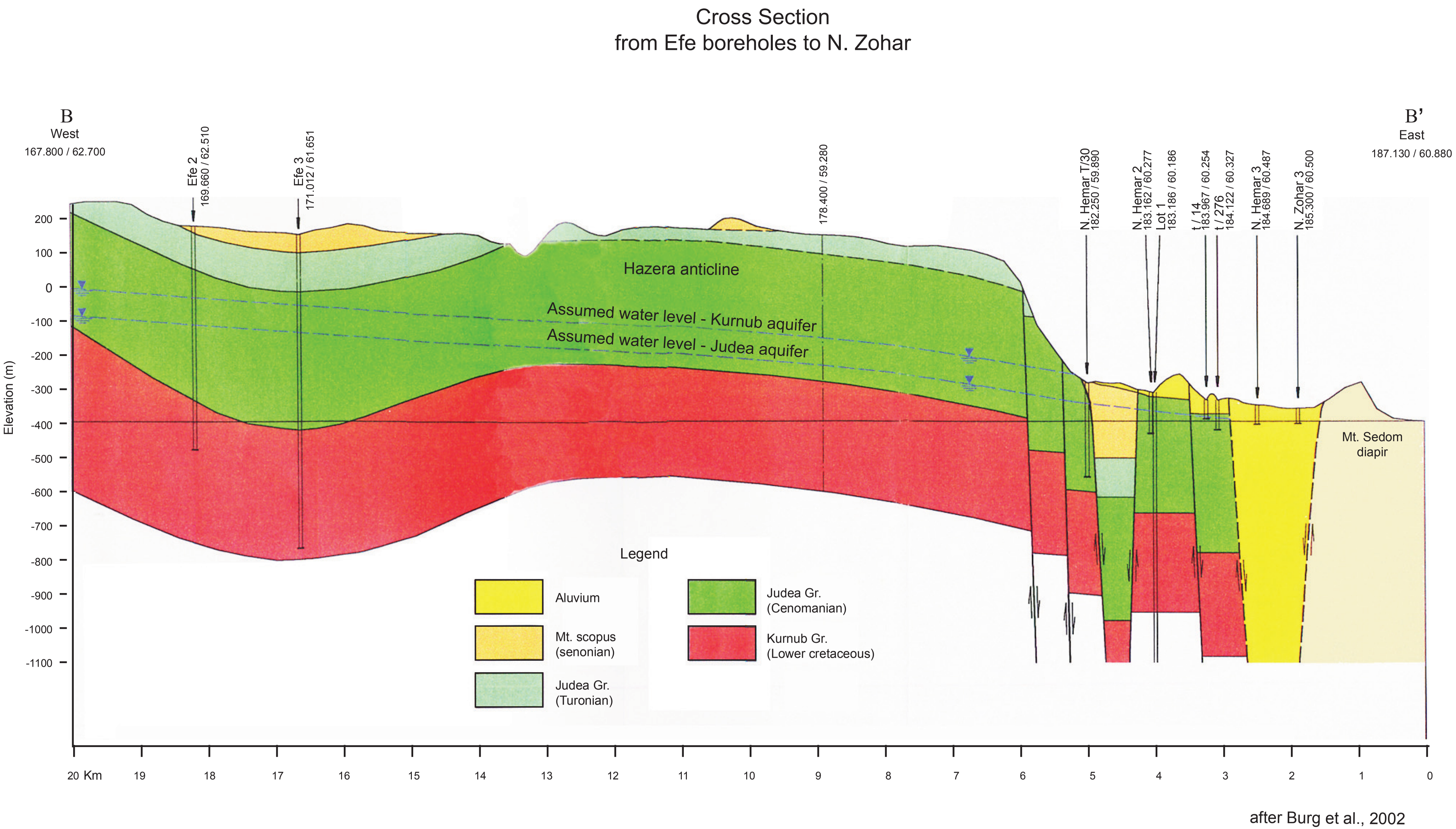


Figure 4: Geological cross section B-B' (see location in figure 3)

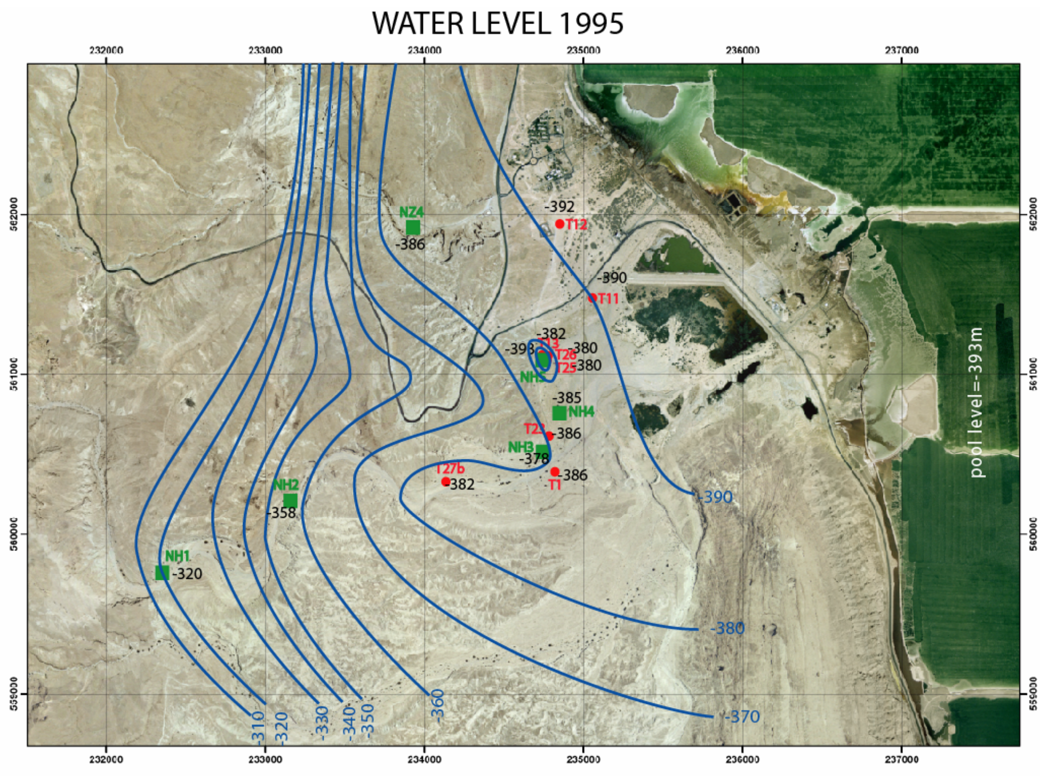


Figure 5: Groundwater levels of the Judea and Alluvial aquifers at the Hemar-Zohar area at 1995

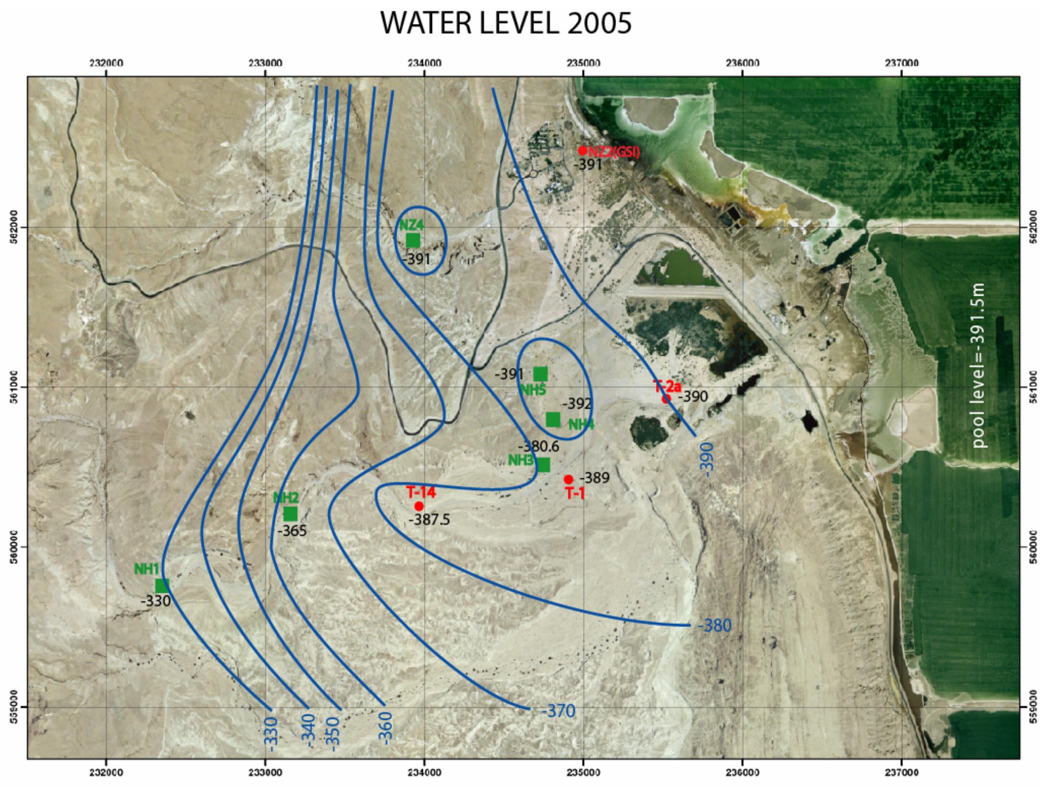


Figure 6: Groundwater levels of the Judea and Alluvial aquifers at the Hemar-Zohar area at 2005

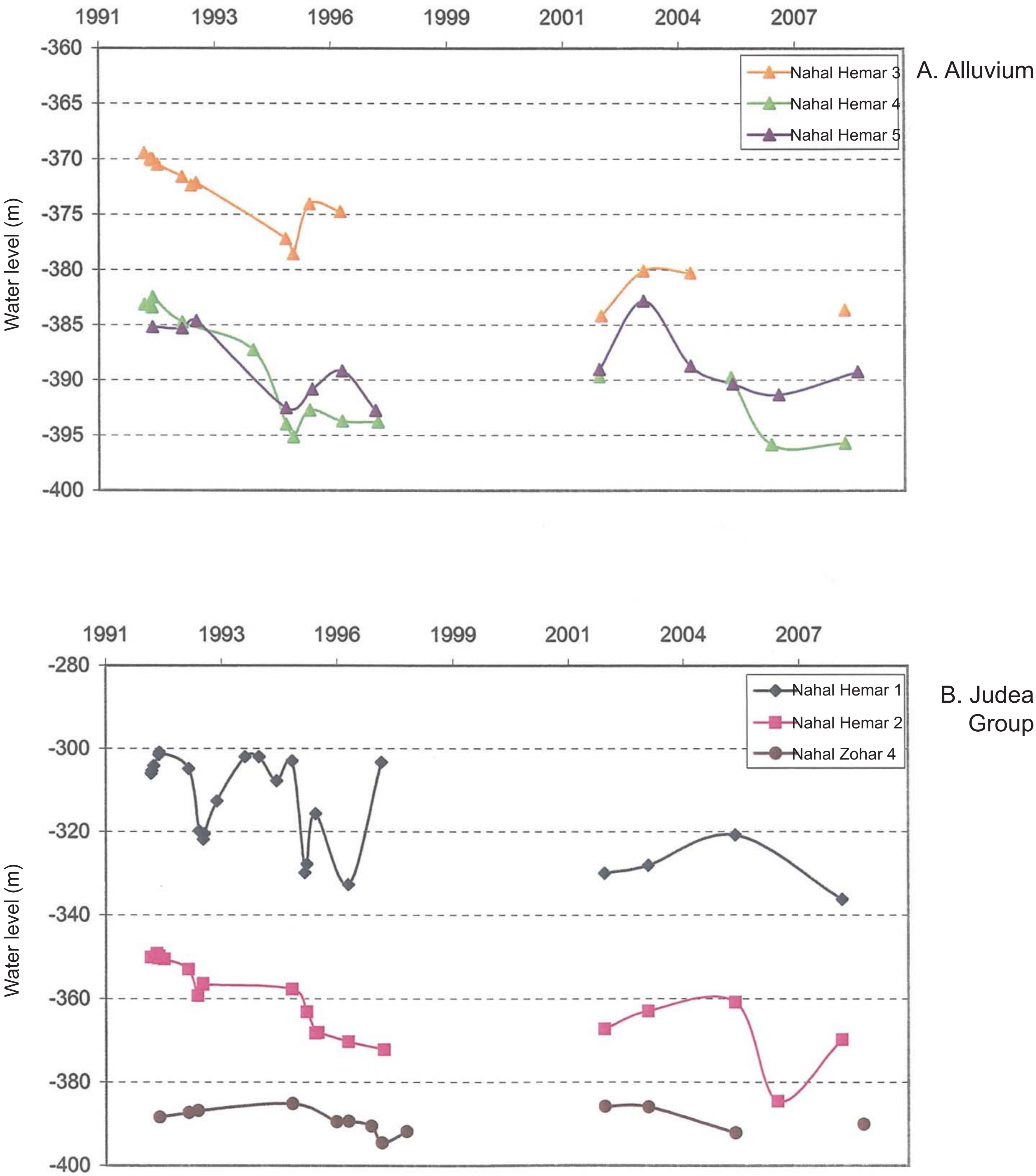
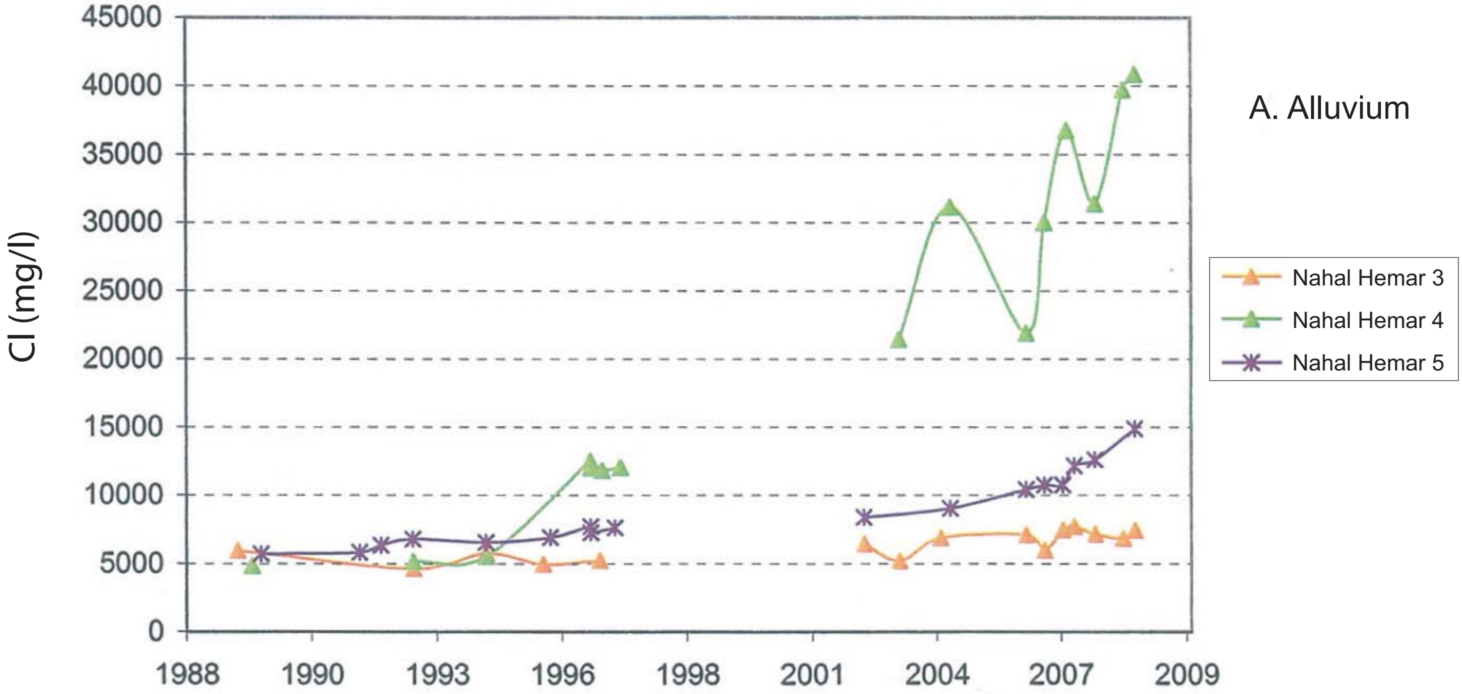


Figure 7: Groundwater levels at wells pumping from the A) Alluvial aquifer and B) Judea aquifer



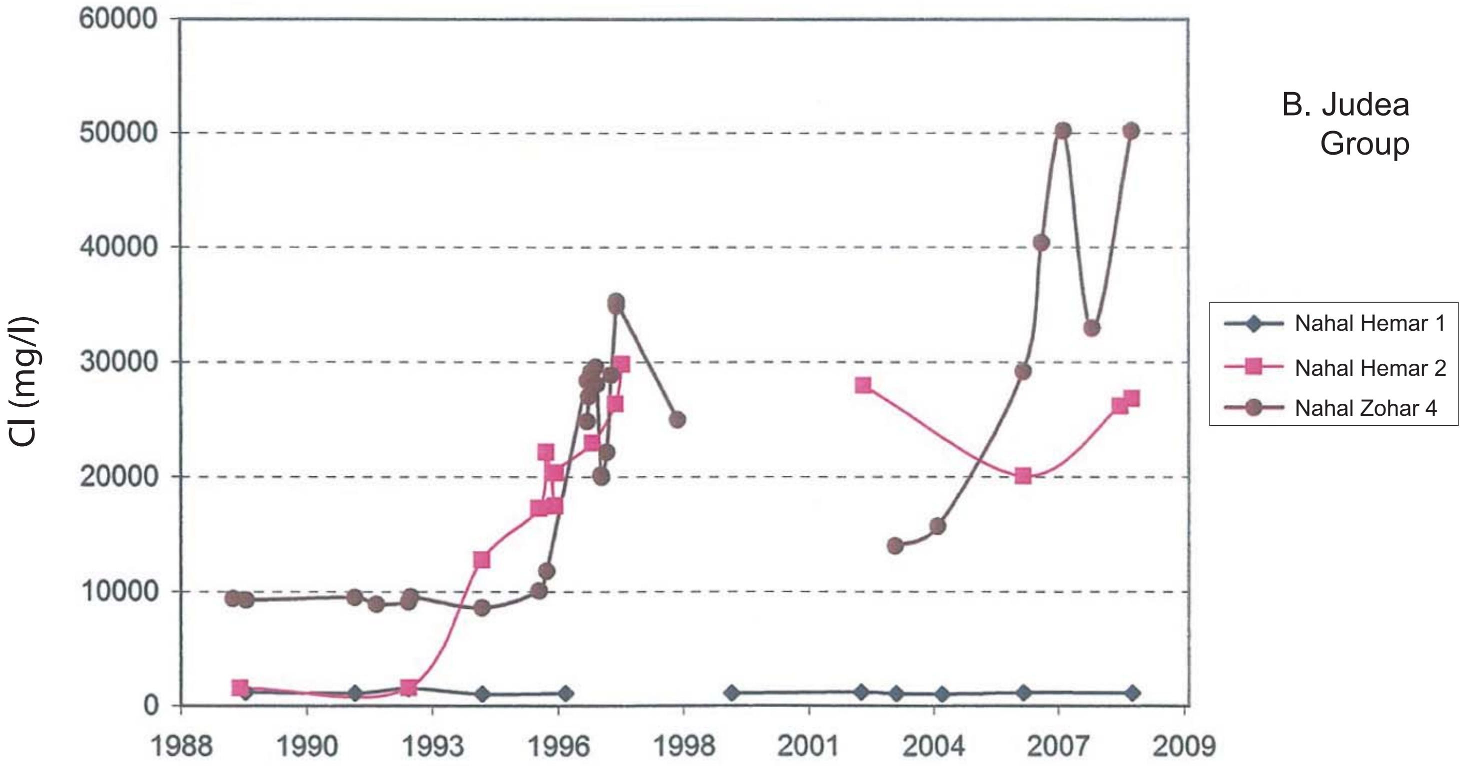


Figure 8: Chloride concetration at the A) Alluvial aquifer and B) Judea aquifer

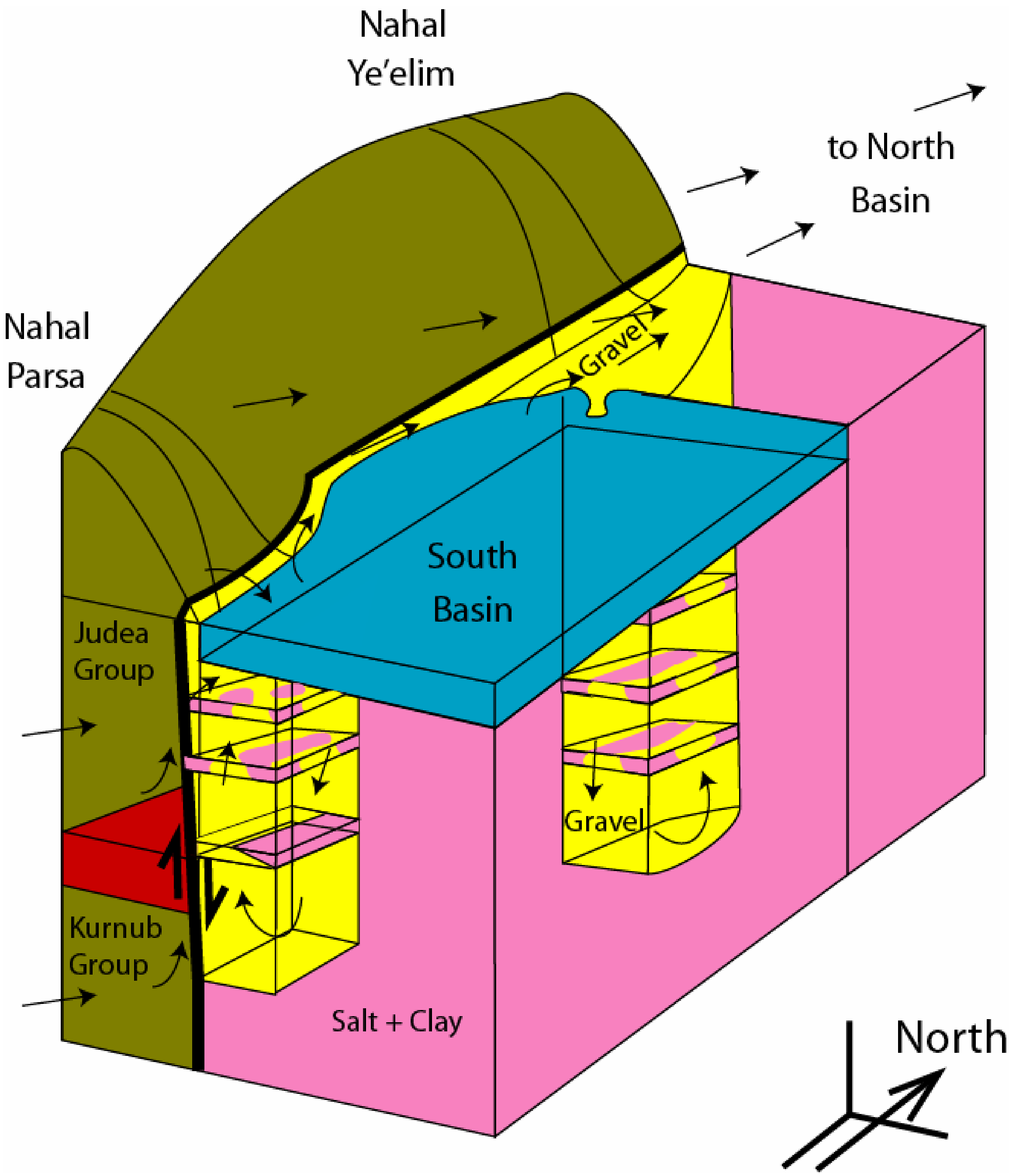


Figure 9: A conceptual 3-D hydrological model for the area between Parsa and Ye'elim streams

11. Tables

Table 1: Chemisrty of water from the Kurnub aquifer

	Date	HCO3	SO4	Cl	K	Na	Mg	Ca
E. Ofarim 6	26/11/1998	290	430	660	20	390	70	190
E. Ofarim 6	08/10/2008	293	392	731	97	375	97	195
E. Ofarim 7	19/05/1998	317	384	692	15.6	370	79	178
E. Ofarim 7	08/10/2008	305	464	710	27	368	95	203
E. Ofarim 8	22/06/2000	281	538	594	23	352	75	216
E. Ofarim 8	08/10/2008	317	532	710	35	380	92	206
Tamar 3a	28/11/1978	317	546	838	31	564	63	194
Tamar 3a	08/10/2008	353	877	2209	39	993	241	439
Tamar 6	28/11/1962	293	784	1303	51	858	90	245
Tamar 6	27/10/2004	-	317	1409	63	895	105	245
Tamar 8	22/09/1980	330	872	753	52	530	78	292
Tamar 8	29/11/2007	318	600	763	8	419	89	224
Tamar 9	01/04/1977	219	385	395	19	618	59	132
Tamar 9	29/11/2007	321	408	614	4	444	72	154
Tamar 11	29/03/1983	262	856	728	29	495	74	285
Tamar 11	21/12/2008	353	545	1099	43	519	111	300
Admon 2a	27/10/2002	360	699	1838	51	1124	56	333
Admon 2a	15/03/2007	366	719	1798	66	1119	103	260
Admon 5	05/08/1980	264	1085	1140.6	54.9	963	94	364
Admon 5	08/10/2008	244	798	2693	66	1435	142	382
Amiaz 7	23/01/1989	293	1340	2470	62.4	1112	167.4	780
Ye'elim 1	01/01/1977	250	2058	3050	45	1177	120	746
Ye'elim 1	08/07/2004	149	1528	74257	2439	12787	14862	6422
Ye'elim 3	12/06/2002	280	2051	2265	74	1419	156	658
Ye'elim 3	27/01/2003	298	1706	2260	47	1350	56	810
*Admon 4	18/04/1982	342	637	1029	41	630	91	210
*Admon 4	29/01/1986	344	642	1185	39	756	89	225
*Admon 4a	31/12/1997	329	833	1207	51	775	94	225
*Admon 4a	08/10/2008	353	649	1594	47	941	100	241
*Amiaz 5	09/04/1980	181.5	1588	1686	57.6	845	156	630
*Amiaz 5	25/02/1986	258	1027	8496	219	3310	690	1200
Dead Sea	1980	-	450	224900	7650	40100	44000	17200

* Also screened in the Judea aquifer.

Table 2: Chemisrty of water from the Judea aquifer

Drill	Date	HCO3	SO4	Cl	K	Na	Mg	Ca
E. Ofarim 16	22/05/2001	334	400	855	38.5	420	94	205
E. Ofarim 16	08/10/2008	158	583	1117	55	522	121	216
Tamar 5	25/11/1962	280	407	627	30	398	65	150
Tamar 5	09/01/1986	193	383	650	16	398	67	125
Tamar 5a	20/06/1995	335	631	1154	27.3	550	145	309
Tamar 5a	08/10/2008	341	619	1559	23	718	162	379
Tamar 7	07/03/1961	274	776	1485	81	816	153	248
Tamar 7	21/12/2008	377	544	2693	70	1111	235	427
Tamar 10	12/07/1980	294	541	1024	32	629	100	218
Tamar 10	08/10/2008	329	519	1110	23	646	104	237
Tamar 12	19/10/1983	317	656	1981	63	903	213	330
Tamar 12	08/10/2008	146	917	2251	35	1041	260	355
Zorim 1	13/10/1980	378	779	1260	59	717	100	264
Zorim 1	08/10/2008	219	599	1506	43	810	125	261
Admon 6	26/11/1997	305	1181	3357	98	1635	310	510
Admon 6	08/10/2008	277	1542	9822	185	3705	925	1338
Amiaz 4	30/04/1979	281	1323	5627	101	2361	346	1140
Amiaz 4	25/02/1986	280	1339	4183	90	1840	261	945
Amiaz 6	21/12/1988	244	500	7987	222	3151	603	920
N. Heimar 1	30/10/2002	320	385	1216	35	662	97	211
N. Heimar 1	08/10/2008	232	611	1170	31	689	110	174
N. Heimar 2	20/11/2002	366	775	28039	601	9806	2969	2426
N. Heimar 2	08/10/2008	154	776	26926	550	9236	2939	2473
N. zohar 4	01/01/1993	244	881	9577	248	3500	950	962
N. zohar 4	08/10/2008	124	699	50283	1108	12076	7757	4400
Ye'elim 2	26/07/1979	190	900	65300	1180	14200	11110	5400
Ye'elim 2	08/10/2008	187	1136	69909	1988	10750	13408	5587
Ye'elim 4	30/10/2002	205	651	48163	1331	9244	9225	3621
Ye'elim 4	08/10/2008	176	640	34542	942	6847	5971	2649
Rahaf 1	1993	-	1134	19363	557	6360	2468	1250
E. Bokek	1962	-	338	524	10	301	60	133
E. Bokek	1993	-	430	516	-	320	70	127
E. Nuit	1975	-	1687	2018	559	1212	130	606
Dead Sea	1980	-	450	224900	7650	40100	44000	17200

Table 3: Chemisrty of water from the Alluvium aquifer

Drill	Date	HCO3	SO4	Cl	K	Na	Mg	Ca
N. Zin 5	23/11/1962	280	609	1456	57	725	162	246
N. Zin 5	01/11/1986	297	543	1149	43	600	130	215
N. Zin 5a	19/04/1994	299	580	1065	39	552	136.8	216
N. Zin 5a	23/10/1997	260	658	1090	40	540	150	240
N. Zin 7	25/01/1978	280	375	2243	35.5	963	193	294
N. Zin 7	08/10/2008	194	697	4592	163	1687	538	478
N. Zin 9	17/01/2006	273	585	23551	1305	5296	3726	2083
N. Zin 9	08/10/2008	298	479	18931	1328	4816	2853	1605
N. Amazyahu 1	12/07/1995	240	442	5670	50	1730	430	1130
N. Amazyahu 1	08/10/2008	219	462	5122	39	1565	478	955
N. Amazyahu 2	03/04/1995	210	330	1750	20	580	170	420
N. Amazyahu 2	08/10/2008	134	384	1702	12	570	192	320
N. Amazyahu 3	12/09/1995	260	604	1840	70	820	210	250
N. Amazyahu 3	08/10/2008	232	460	1500	43	726	169	208
K. Sdom 4	24/04/1995	96	529	10508	133	3717	836	1410
K. Sdom 4	08/10/2008	193	434	11284	135	3746	995	1732
K. Sdom 5	05/07/1989	207	402	1857	31.3	664.7	234	370
K. Sdom 5	08/10/2008	219	419	1855	27	700	217	339
K. Sdom 6	25/05/1995	160	335	2370	40	820	230	340
K. Sdom 6	08/10/2008	194	422	3748	58	1317	417	506
K. Sdom 7	31/12/1998	220	390	3294	59	1265	334	420
K. Sdom 7	08/10/2008	219	391	1779	217	696	217	289
K. Sdom 9	23/10/1995	240	343	1500	30	530	160	280
K. Sdom 9	08/10/2008	146	480	1575	20	600	184	272
N. Heimar 3	29/10/2002	290	1206	6544	197	2738	504	952
N. Heimar 3	08/10/2008	290	1269	7564	198	3077	794	838
N. Heimar 4	10/08/2003	250	906	21494	358	7749	2315	1611
N. Heimar 4	30/10/2002	233	794	40901	629	14592	4249	2679
N. Heimar 5	30/10/2002	254	1357	8490	236	3419	864	879
N. Heimar 5	08/10/2008	240	1513	14995	323	5829	1509	1415
E. Hakikar	1975	-	629	756	18	360	130	186
E. Momila	1975	-	58	255530	14720	14390	45650	48010
Hamei Zohar (drill)	1975	-	830	139500	3640	22200	26000	14000
Hamei Zohar (spring)	1975	-	678	35510	825	8595	5830	3600
T/3	1986	-	1490	182000	1940	74300	19500	6500
T/9a	1986	-	710	152000	5000	34300	31600	12800
Tapoach	1992	-	480	211000	4810	44000	36000	14300
Dead Sea	1980	-	450	224900	7650	40100	44000	17200