THE SOURCE OF THE YARKON SPRINGS, ISRAEL

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ABSTRACT. Radiocarbon and tritium analyses are used to show that the accepted conceptual hydrological model of the Yarkon-Taninim aquifer is untenable. The conventional model would have the groundwater flow in the carbonate Judea Group aquifer from the Beer Sheva region in the south to discharge at the Yarkon springs. Moreover, the conventional model considers the Judea Group aquifer to be a single hydrological entity. However, analysis of the Yarkon springs and surrounding wells demonstrate that it is stratified into upper and lower aquifers.

The water in the deeper aquifer is fresher, cooler and younger compared to the water in the overlying aquifer. The deeper aquifer water type is identical in composition to the Ca-Mg-HCO_3 Judean Hills recharge water immediately to the east. It is this recharge water that is dominant at the Yarkon Springs. There appears to be no derived appreciable contribution of groundwater from the Beersheva region in the south. Thus the currently accepted hydrologic model is in need of serious revision. The present study introduces new and high quality groundwater resources to be target for exploitation.

INTRODUCTION

The Cretaceous Judea Group limestones and dolomites make up the Yarkon-Taninim aquifer that is currently accepted to extend as a hydrological unit from the Negev up to the Carmel Mountain. This covers a large proportion of Israel. The Judea Group contains high quality ground water in large abundance. As such the Yarkon-Taninim aquifer is one of the main reserves of fresh water in Israel. Due to its importance, many hydrological studies have been carried out on the groundwater and its flow patterns have been the topic of several computer models.

The currently accepted hydrological conceptual model of the Yarkon-Taninim aquifer was laid down by Mandel (1961). He considered that in the absence of other known discharge sites, the large Yarkon and Taninim springs are the outlets of the aquifer that is recharged in the Judean Hills. Later computer modeling (Baida et al. 1970) considered that the Beersheva region was hydrologically contiguous with the Yarkon area and this region was thus added to the model as an up-dip portion of the aquifer.

As the static water level in Beersheva portion of the aquifer is higher (25 m above sea level) than the Yarkon (16.5 m above sea level) and the Taninim (4–11 m above sea level) springs, the water flow is assumed to be in a dominant south to north direction (Figure 1). Along the path of the accepted flow, additional recharge that flows westwards down dip is prevented by the impermeable clays of the Saqiye Formation from discharging into the sea and diverted northwards, to discharge first at the Yarkon spring and then the underflow at Taninim spring. Moreover, this aquifer is not only considered to be laterally continuous but also vertically in the section as well. The Beersheva-Yarkon-Taninim aquiferal model is the accepted hydrological flow pattern that is used in the exploitation of this important resource.

No regional geochemical-geochronological study has been carried out to substantiate the groundwater flow directions, or indeed to verify if the aquifer is truly one continuous and homogeneous hydrologic unit as is assumed. It should be noted that several geohydrological arguments have been raised (Kronfeld et al. 1990; 1993; Mazor and Kroitoru 1990; Weinberger et al. 1994) that would challenge these assumptions.

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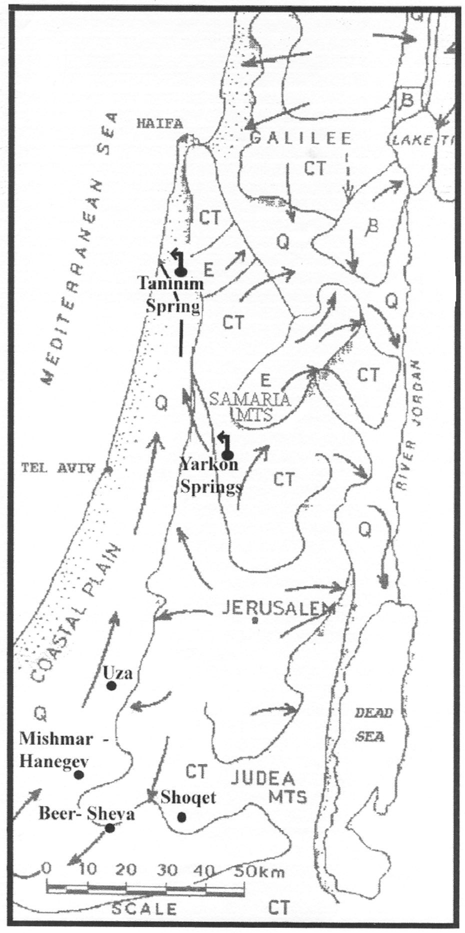

Figure 1 The conceptual flow model of the Yarkon-Taninim aquifer as proposed by Mandel (1961) and Baida et al. (1970). The model would have water from the Beersheva region flow north to drain at the Yarkon and Taninim springs. The position of the wells in Table 3 are shown.

In order to validate the flow model, the water in the aquifer must show evidence of realistic chemical and age maturation. In simplest terms, the discharge must be older than the water immediately updip if we are indeed dealing with the same aquifer. Likewise, the discharge should be of the same or greater salinity and temperature, and be of the same or more mature stage of chemical maturation. While this may seem trivial, chemical anomalies have been encountered in local studies (Mercado 1980). The *deus ex machina* of cation exchange with clays have been intoned to explain local chemical deviations from what would normally be expected—if the aquifer were indeed one large flowing unit. This explanation may be employed, but with the proviso that it can also explain the isotopic, chemical, and temperature changes that are not affected by cation exchange processes.

A previous study of the Judea Group aquifer in the Beersheva region (Kronfeld et al. 1993) had already been carried out, in which the tritium δ^{13}C, radiocarbon, temperature and chemistry of the waters was measured. It was seen that there was a definite chemical maturation, rise in salinity, and temperature all of which corresponded to a decrease in the ^{14}C content of the water along the flow path for that specific region. Therefore, to test if these waters were indeed continuing northwards to drain at the Yarkon Springs, the same parameters were measured in the water at the Yarkon Spring. To further test homogeneity of the aquifer in stratigraphic profile, wells exploiting different stratigraphic horizons were sampled.

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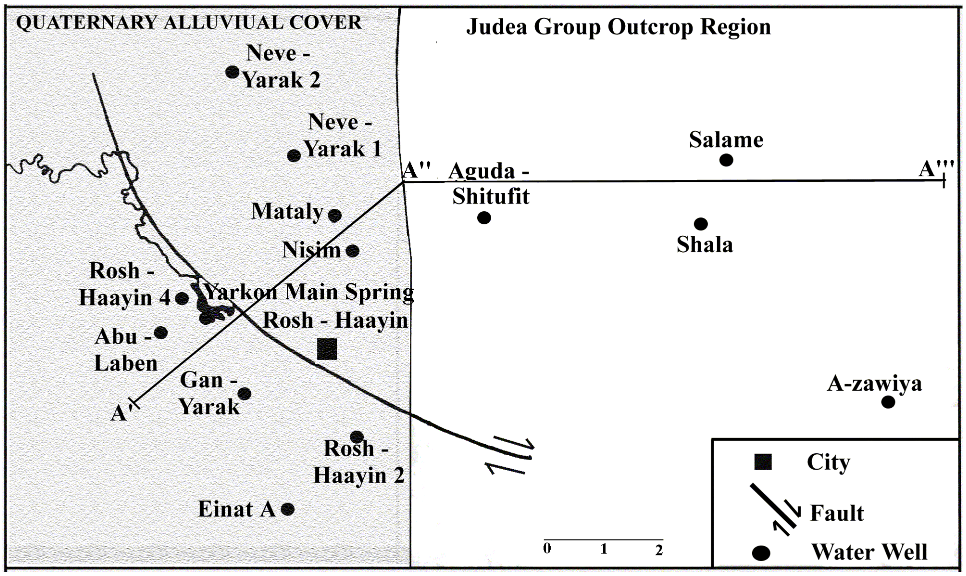

Figure 2 Sample locator map of the wells in the Yarkon spring region that were sampled

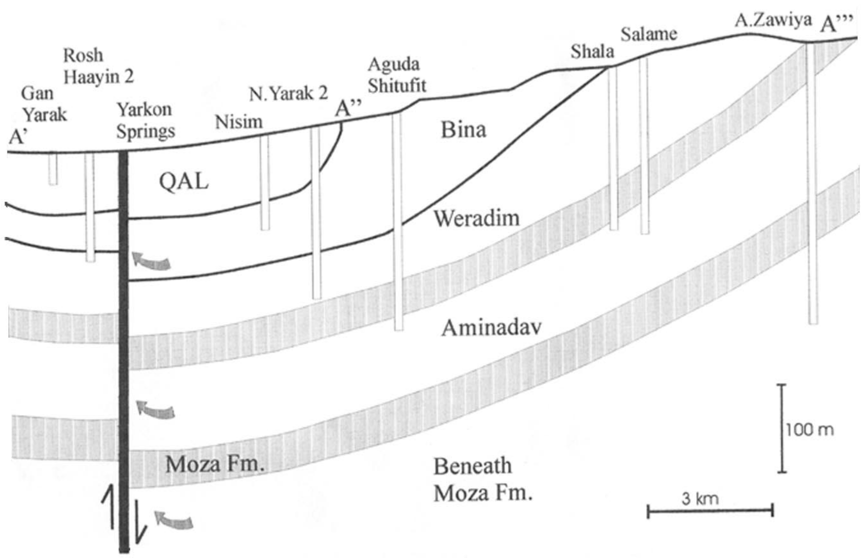

Figure 3 Hydrogeological section showing the different hydrological units that are exploited by the water wells in the study area. The accepted hydrologic conceptual model does not consider that the Judea Group aquifer is divided into independent aquiferal units. It is the deeper formations that have been found by present study to be the major contributors to the Yarkon Springs. They are significantly younger, cooler, and contain lower salt contents than the water in the upper aquifer. It is the latter that has been, until now, considered to represent the Judea Group (Yarkon-Taninim) aquifer.

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SAMPLING AND RESULTS

Tritium, $\delta^{13}C$, ^{14}C, temperature, and water chemistry were measured at the Yarkon springs and from representative surrounding water wells that exploit specific stratigraphic horizons in the Judea group (Figures 2 and 3). The temperature and pH was measured in the field. The chemical analyses were performed at the laboratory of the Hydrological Service in Jerusalem. The tritium and ^{14}C analyses (by scintillation counting) were performed at Radiocarbon Laboratory of the Weizmann Institute. In addition, the Uza-1 well, representing the northernmost extension of groundwater flow from the Beersheva region, was also measured to serve as a comparative representative of this portion of the aquifer.

Table 1 Chemistry of the Rosh Haayin Region Well Water (mg/L)

Sample	Year of analysis	Depth (m)	Temp °C	pH	Ca	Na	K	Mg	HCO_3	SO_4	Cl
A-Zwaiye	1995	285	22.1	7.24	76	20	3	26	234	4	36
A. Shitufit	1995	227	23.3	7.4	87	42	11.7	32	295	15	73
Hevrat Maataly	1995	116	23.9	7.56	99	139	4	45	420	50	270
Salame	1995	172	22.4	7.6	77	22	2	31	295	4	38
K.Einat A	1995	70			85	125	7	40	300	38	228
Shala	1995	160	22.5	7.35	79	20	1	36	325	4	40
Abu Laben	1995	90	24.8	7.2	82	114	5	40	320	43	180
Nissim	1995	100	23.3	7.37	95	135	5	42	298	45	264
Newe Yarak-1	1995	174.5	25.2	7.23	74	100	5	38	317	40	186
Newe Yarak-2	1995	180	24.7	7.35	73	67	4	34	335	26	116
Gan-Yarak	1995	28.3	24.4	7.2	99	137	6	45	342	50	280
Rosh Haayin	1975	118.5	25.1	7.13	69	103	3	33	296	38	177
	1995	103.5	24.7	7.36	93	125	5	45	421	43	214

Table 2 Carbon isotopes and tritium in the Yarkon springs and surrounding water wells

Sample	^{14}C PMC	$\delta^{13}C$ ‰ (PDB)	Tritium TU	Temp °C
Yarkon Springs				
Main spring (June 1992)	74.1 ± 0.5	–11.4	4.8 ± 0.9	22
Main spring (Oct 1992)	66.4 ± 0.7	–11.9	1.8 ± 0.5	22
Judea Group Groundwater[a]				
Water wells				
Bina and Weradmin formations				
Gan Yarak (1995)	44.7 ± 0.3	–11.9	2.0 ± 1.9	24.2
Newe Yarak-2 (1995)	45.1 ± 0.3	–10.4	0.4 ± 0.2	24.7
Rosh Haayin-2[b]		—	0	—
Nisim (1995)		—	2.7 ± 0.2	23.3
Amminadav formation				
Aguda Shitufit (1995)	62.8 ± 0.4	–11.3	3.2 ± 0.2	23.3
Shala (1995)	74.7 ± 0.4	–11.9	4.7 ± 0.2	22.5
Salame (1995)	—	—	4.8 ± 0.2	22.4
Beneath Moza formation aquiclude				
A-Zawiya (1995)	67.5 ± 0.5	–12.0	5.0 ± 0.2	22.1

[a]According to stratigraphic units
[b]Analysis from Mazor and Kroitoru (1992)

Table 3 Comparison of the carbon isotopes, tritium, temperature chlorinity in the Beersheva Region

Sample	^{14}C PMC	$\delta^{13}C$ ‰ (PDB)	Tritium TU	Temp °C	Cl^- mg/L
Uza-1 (1997)	8.5 ± 0.2	−10.7	0 ± 0.2	—	345
Mishmar HaNegev2[a]	14.3 ± 0.3	−9.9	0 ± 0.2	31	266
Beersheva-6[a]	25.9 ± 0.	−10.2	0.2 ± 0.1	29	258
Shoqet-[a]1	64.2 ± 0.4	−11.0	0.8 ± 0.1	25.5	103

[a]Analysis from Kronfield et al. 1993

The results of the chemical analyses are presented in Table 1. The results of the tritium, $\delta^{13}C$, ^{14}C, and temperature analyses of the Yarkon Springs and nearby wells are presented in Table 2. The tritium, $\delta^{13}C$ and ^{14}C for the Uza-1 well, are presented in Table 3, in addition to previously published data from representative wells (see Figure 1).

DISCUSSION

In the Beersheva region, all of the wells exploit water from the Bina Formation. The chemical and isotopic parameters change in a manner that is consistent with changes expected along a flow path. The recharge, as represented by springs in the Judean and Hebron Hills (Kronfeld et al. 1993), are fresh (chloride content in the range of 30–70 mg/L). It is a Ca-Mg-HCO_3 type water, which is to be expected in an aquifer of limestone and dolomite. The $\delta^{13}C$ is approximately −13% as would be expected in an area having a C_3 plant cover (Vogel et al. 1986). The initial temperature of the recharge can be taken as 18–19 °C. Water of this initial signature then enters the aquifer and flows in the down direction of the wells of Shoqet, Beersheva, Mishmar HaNegev and onto the Uza-1 well. Along this flow path there are rises in the temperature (to >31 °C) and chlorinity (to over 345 ppm Cl).

The chemical composition changes primarily due to the addition of Na and Cl and subordinate amounts of SO_4. Concomitantly there is a continuous decrease in the ^{14}C activity from approximately 64 to 8.5 pMC over this same interval. Tritium is absent except in the wells near to the recharge. From the south until the Uza-1 well, the chemistry, the age, and the temperature within the aquifer has changed in a manner consistent with the conceptual model of Baida et al. (1970) for the Beersheva portion of the aquifer.

However, water of the type evolving in the Beersheva region is not found to discharge in the Yarkon Springs. Moreover, there is a marked difference in the groundwater from the various stratigraphic horizons. Indeed, it is the deepest wells that are the youngest, coolest and freshest. It is found that A-Zawiya, the deepest well (285 m), yields the coldest (22.1 °C) and the sweetest water (3 mg/L Cl) of Ca-Mg-HCO_3 type. This is chemically the least mature. It is exactly the type of water found in the springs of the Judean Hills recharge region to the east. This well is also the richest in tritium and ^{14}C. Kroitoru (1987) has demonstrated, using mass balance considerations, that the initial ^{14}C content of the Judea Group is approximately 62 ± 3 pMC. From this initial value, the ^{14}C decays away as a function of age. Values greater than this, such as 75 pMC seen in the Shala well, may represent the effect of the atmospheric nuclear weapon tests that greatly increased the ^{14}C in the precipitation. This reached a peak during the early 1960s. The three wells from the Aminadav Formation are very similar to the deeper A-Zawiya well. The shallower wells, pumping from the Bina and Weradim Formations are however, not only more saline, more chemically mature, and older, they are also warmer. The simple parameter of groundwater temperature is all too often overlooked in studying the hydrol-

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ogy of the aquifer. Groundwater should increase in temperature as in flows from higher to lower elevations. The increase should be approximately between 1.8 and 3 °C/100 m. This assumes of course that the water attains thermal equilibrium with the surrounding aquifer. The fact that the deeper water is colder indicates that the water is flowing rapidly. It has not thermally equilibrated with the ambient temperature of its surroundings. This is consistent with its very young age and its chemical composition. Thus we have indications of a very rapid flow, through what must presumably be a well-developed karstic system. The water in the upper sub-aquifer is flowing much slower. It has chemically interacted with the surrounding host rocks. As it has become older, it has picked up salts, and has achieved thermal equilibrium with its surroundings.

Since the 1940s, it was noted that the various springs of "Ras El-Ain" (the Yarkon Springs) exhibited very heterogeneous chemical compositions. The Yarkon Springs is a complex of many different outlets, of varying sizes and salinities (ranging from much less than 100 to over 200 mg/L Cl). The springs themselves issue forth along a fault line through alluvial cover overlying the upper portions of the Judea Group (Figure 3). It is the artesian water, recharged in the Judean Hills to the east that dominantly contributes to the spring discharge. The heterogeneity of the various small springs can be explained by mixing in various proportions along the fault zone of the fresh young ascending water with the saltier water found in the overlying phreatic upper sub-aquifer (Bina and Weradim Formations).

It is seen that the Yarkon Springs cannot be draining the Beersheva portion of the aquifer. Moreover, in the region of the Yarkon Springs, it is evident that the Judea Group is comprised of several distinct sub-aquifers. There is no connection between the upper and lower aquifers except along the fault zone. Moreover, freshwater is encountered at depth where salty water (in excess of 7800 mg/L Cl^-) has been encountered in the same deep stratigraphic interval in the Kiryat Gat-1 well immediately north of the Uza-1 well, again reinforcing the concept that water from the Beersheva region does not flow northwards to drain at the Yarkon Springs.

CONCLUSION

The conceptual model of the Yarkon-Taninim springs was established primarily upon the small difference in water levels between the two supposed outlets of the mountain aquifer (with the explicit assumption that they were from the same aquiferal stratigraphic horizons), a situation that pumping has since disturbed, so that today measurements can not be used to reconfirm the flow model. However, as the original measurement of the pieziometric level of the Yarkon Springs is not related solely to the upper sub-aquifer alone but is influenced by upwelling of a deeper sub-aquifer, there is no hydraulic underpinning for the hydrologic conceptual model put forth by Mandel (1961). Therefore the initial conceptual model could not have been correct for it measured and compared two different aquiferial horizons. In the region of the Yarkon Springs several independent sub-aquifers exist. The deepest of which contain the highest quality water. This deep-water resource has not been targeted for exploitation. Until now it has only been chance, and not through directed hydrologic planning, that it has been exploited; this water has been assumed to be part of one water body. If so, it was considered more economical to exploit this single water body by drilling shallow wells. The present study demonstrates that there is more than a single water resource to be exploited.

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