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PERCOLATION OF DOMESTIC SEWAGE INTO A KARSTIC AQUIFER

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ABSTRACT

A hydro-ecological study has been carried out on the percolation of the Jerusalem sewage flow in the Soreq river. The mean infiltration rate in the mountainous Karstic aquifer, along 28 km stream flow, has decreased from 9cm/day in 1972 to 5 cm/day in 1979. The infiltration in the Soreq Valley downstream, where the river flows upon alluvial gravel beds overlying chalky-marl beds along 22 km, is unexpectedly high. The mean rate in 1978-79 was 9 cm/day, but most of the water percolated at a rate of 14 cm/day in a short segment of 4 km, which lies above a buried anticline.

INTRODUCTION

The purpose of the present research is to investigate the hydraulic and chemical relations between the wastewater flow in the river and the groundwater below. This paper is mainly based on ref. 4, which summarized the previous works.

Description of the area

The upper part of the investigated area is situated in the watershed of the Soreq river that flows westwards towards the Soreq Valley and the Mediterranean Sea. The river is deeply incised and meanders much within its valley. The area is composed of carbonatic rocks; limestones and dolomites with Karstic features. Intercalation of chalk and marl as well as patches of residual "terra-rossa" cover the entire area.

Rainfall regularly occurs during the winter months October-April, and amounts to an average of about 565 mm/year. Runoff occurs in the river only subsequently to significant rainfall events. Surface runoff in the Soreq Valley, 55 km downstream from Jerusalem, totals an average of 2.3 MCM/year which is about 1% of the rainfall upon the catchment area of 405 km^2. This is due to the high infiltration rate of the rainwater into the karstic calcareous outcrops.

Two active aquifers are found in this area:

a. The dolomites and limestones of Lower Cenomanian that crop-out in the vicinity of Jerusalem and form a regional aquifer (fig. 1), which is now being exploited by water wells at the rate of about 10 MCM/year. This aquifer is underlain by a layer of marls (Albian, Lower Cretaceous) and the water-level, rises up to 350-500 m above M.S.L., to a depth of 50 to 200 m. The water is of excellent quality (30-50 ppm chloride).

b. Limestones and dolomites of Turonian - upper Cenomanian age, which form a perched aquifer in the Judea Mountains, become an important aquifer in the Soreq Valley downstream, where these two aquifers get connected and combine into a main regional aquifer.

The lower part of the investigated area, the Soreq Valley, is a geological syncline composed of thin cobble alluvial river beds, pebbles and gravel intercalated with marl and overlying Senonian chalky-marl beds.

The two western outlets of the raw sewage system of Jerusalem, serving about 2/3 of the population, were constructed in 1962. The volume which drained into the Soreq river at the time of the present study (1979), was at a rate of 12 MCM/year. The river carries the sewage flow to a distance of about 50 km, to the coastal plain aquifer (fig. 1). The travel time of wastewater from the sewage outlet to the Soreq Valley, a distance of 36.5 km downstream, is 44 hrs (ref. 1). In order to minimize pollution of pumping wells upstream, a pipeline was constructed along a short segment of the Soreq river in 1969. Downstream in the Soreq Valley, about 40% of the total sewage volume is pumped out for irrigation.

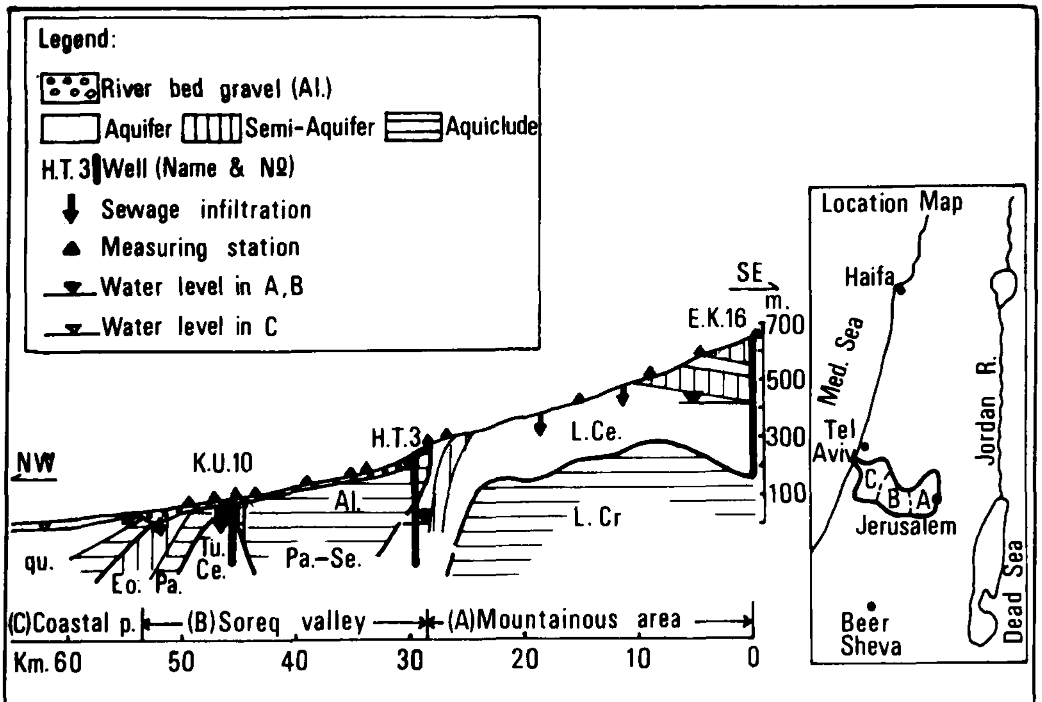

FIG. 1 HYDROGEOLOGICAL CROSS SECTION ALONG SOREQ RIVER

METHODS

Sewage flow data

The present work is based on five series of measurements carried out in the years 1972, 1973, 1976, 1978 and 1979. The series was composed of 1 to 3 months each of records, in 3 to 7 special hydrometric stations. The stations were of precalibrated hydraulic type. In the first 3 years they contained trapezoidal sharp crested weirs and in the last 2 they contained Parshal flumes.

The losses were determined by the differences in the flow between stations.

The daily water balance equation

The volume of sewage percolating into the aquifer is calculated by the following balance equation:

$Q_g = Q_\ell + S_p - ET - \Delta M$ (ref. 1)

where

Q_g - Daily ground water recharge. This value is determined from the balance equation.

Q_ℓ - Daily flow losses in the stream flow. This value is determined from the stream-flow difference between adjacent stations.

ET - Evapo-transpiration. This value is determined separately for the flowing water (Considered as equal to 0.7 of potential evaporation).

S_p - Discharge of small springs into the stream flow, obtained from direct measurement.

ΔM - Change in moisture content of the soil along the stream flow banks. Assuming saturation conditions this value is considered zero.

RESULTS

Since the beginning of the measurements the sewage discharge through the outlets had increased from 21,380 m^3/day in 1972 to 33,320 m^3/day in 1979 (table 1). Assuming that the measured discharges represent the sewage flow throughout the entire year, the annual increased volume would range from about 8 MCM to about 12 MCM respectively. Sewage losses in the mountainous region have decreased during the years. In the autumn of 1979 sewage losses reached 13% of the inlet discharge, namely 4440 m^3/day or 1.6 MCM/year appx. After reducing the evapotranspiration along 28 km of the stream flow, the annual infiltrated volume is appx. 1.25 MCM. In the Soreq Valley the daily sewage loss was of about 40% of the inlet discharge, namely 12080 m^3/day or 4.4 MCM/year appx. The annual infiltrated volume along 22 km. of the stream flow is 3.75 MCM appx.

Infiltration rate in the mountainous region has decreased from 9.4 cm/day in 1972 to 4.9 cm/day in 1979. The apparent reason is the accumulation of organic matter on the stream bed (ref. 5).

Multiple linear regression was performed between infiltration rate along 5 segments of the Soreq river and different hydraulic parameters (ref. 2). It was found that infiltration rate is directly affected by the fault ratio (which is defined as density of faults along a segment), and inversely affected by the slope along the river channel segments.

Another affecting factor is the lithology. Since the aquiferous segment is longer, infiltration rate increases. Thus in 1973 calculated infiltration rates ran from 3.1 to 11.1 cm/day with an average rate of 8.2 cm/day. The Soreq Valley is a syncline divided into 3 segments according to its geological structure. The upper one, along 5.5 km, is composed of a thick section of cobbles overlying Senonian chalk beds. The infiltration rate in 1973 went up to 17.2 cm/day. The middle segment along 12.5 km of the syncline axis, is composed of a thin alluvial cover overlying Paleocene marls and shale beds. The infiltration rate in 1978 was 4 cm/day and decreased to 2 cm/day in 1979. The lower segment along 4 km of the buried anticline is composed of a thin alluvial cover overlying thin Senonian chalk beds, over the Turon-Cenomanian Carbonatic aquifer. The infiltration rate in this section ran up to 14 cm/day. The average infiltration rate in the Soreq valley in 1978-9 was 9 cm/day.

TABLE 1

Results of sewage infiltration along the Soreq River

Parameters / Measur. Date & Dur.(days)	Station No.	Segment length (km)	Lithology description	Inlet dis.*	Losses dis.•	Infilt. dis.*	Infilt. rate cm/day
			MOUNTAINOUS REGION				
10/72(12)	(1+2)-3	32+8	l.s.+dol.+gr.	21.38	11.08	9.50	9.4
9/73(14)	1-2	9.5	ch.+dol.	17.20	1.10	0.73	3.1
"	2-3	5.7	dolomite	16.10	1.54	1.32	9.2
"	4-5	4.1	dolomite	6.52	1.30	1.14	11.1
"	(3+5)-6	13.0	l.s.+dol.	19.78	3.98	3.47	10.7
8-9/78(60)	(1+2)-3	28.0	l.s.+dol.	32.38	6.28	5.05	7.2
9-10/79(51)	(1+2)-3	28.0	l.s.+dol.	33.32	4.44	3.42	4.9
			SOREQ VALLEY				
9/73(14)	6-7	5.6	cob.on M.	15.80	2.84	2.41	17.2
10/76(10)	1-2	10.5	cob.on M.	15.70	2.30	1.57	2.8
10/76(10)	2-3	3.0	peb.on ch.+m.	12.35	3.48	3.11	5.4
8-9/78(30)	3-4	18.0	cob.on ch.+m.	26.55	3.13	1.82	4.0
8-9/78(30)	4-5	4.0	peb.on ch.	24.76	10.76	10.15	14.5
9-10/79(41)	3-4	18.0	cob.on ch.+m.	28.88	2.04	0.90	2.0
9-10/79(41)	4-5	4.0	peb.on ch.	28.40	10.04	9.48	13.5

Lithology Abbreviations: l.s. - Limestone; ch. - Chalk; cob. - Cobble; gr. - Gravel; dol. - Dolomite ; m. - Marl ; peb. - Pebble;

• $10^3 m^3$/day

Chemical Effects On Groundwater

The exploitation of the lower Cenomanian mountainous aquifer began in the fifties. In the following decade an increase in salinity of the groundwater was found in wells located near the sewage flow. It was probably due to the percolation of sewage into the wells. In several pumping wells the nitrate concentration increased rapidly until 1969, when a bypassing pipeline was constructed (e.g. 43 ppm in Ein Karem 12 in 1969). The pollution traces still exist in Ein Karem 6 (Table 2). In the confined aquifer in the Soreq Valley, the nitrate concentrations are negligible. During the last 20 years the choloride concentrations have increased persistently from 25 to 50 ppm in the mountainous aquifer upstream, and from 260 to 420 ppm in the Soreq Valley downstream. The following table shows the chemical composition and some ionic ratios in selected Cenomanian wells as compared to the sewage water.

TABLE 2

Chemical composition of groundwater in the Soreq watershed

Water group	Judea Mount.		Foot-hills	Soreq Valley		
Well + No. distance from sewage outlet (km)	E.K. 16 upstream	E.K. 6 upstream	H.T. 3 30	K.U. 10 43 (3 from Soreq R.)	Ay. 2 43 (12 from Soreq R.)	Sewage 5 50
Date / parameters mg/ℓ	6/1972	8/1976	5/1976	8/1975	7/1974	12/1978
calcium	55	58	65	83	144	114
magnesium	23	24	35	40	23	
sodium	13	18	81	202	207	236
potassium	1.3	1.6	4.7	6.5	4.7	21
chloride	31	42	121	343	355	366
sulfate	12	12	53	83	91	83
bicarbonate	244	246	329	295	323	512
phosphate	0	0.04	0	0	0	16
boron	0	0.02	0	0	0.35	0.66
org. nitrogen	0	0	0	0	0	85
ammonium	0	0 02	0.04	0.4	0.5	61
nitrate	12.3	20.6	2.6	2.7	0	85
Depth of W.L(m)	206	51	200	122	80	Surface
pH	7.4	7.4	7.4	7.1	7.3	8.0
Cond.μmho/cm	502	545	940	1670	1670	2030
deter.mg/ℓ	0.02	0	0.06	0	0	2.2
			Representative ion ratios			
$rHCO_3/C\ell$	4.59	3.44	1.58	0.50	0.53	0.82
$rNa/C\ell$	0.67	0.65	1.04	0.91	0.90	1.00
rNa+K/Ca+Mg	0.13	0.16	0.59	1.20	1.20	1.44
rNa/K	17.1	19.1	29.3	52.9	75.0	19.1

From the table above two groups of waters are discerned: the fresh groundwater in the Judea Mountains and the contaminated waters downstream in the Soreq Valley, with an intermediate group found in the foothills (Hartuv 3). The first group is of the bicarbonatic type, whereas the second is of the sodium-chloride type. Evidently the chemical composition and the ionic ratios change from the recharge area downstream. On the macro-chemical composition scale there is no significant difference between the groundwater in the Soreq Valley and the sewage water. Both waters are characterized by ion ratios typical to groundwaters in other mountainous aquifers in their downstream segments. However, closer inspection reveal a higher sodium, potassium and bicarbonate contents in the sewage water, in addition to the typical pollution indicators, such as high values of organic nitrogen, ammonium, nitrate, phosphate, detergents, etc. Therefore, in this particular case, the chloride, sulfate and bicarbonate concentrations are not valuable indicators of sewage water percolation into the aquifer downstream.

CONCLUSIONS AND DISCUSSION

Considerable amounts of sewage water infiltrate along the Soreq river stream. According to the measurements in 1979 the annual infiltration volume which percolated into the mountainous karstic aquifer is 1.25 MCM appx. The infiltration rate in this region has decreased from 9.4 cm/day in 1972 to 4.9 cm/day in 1979. In the Soreq Valley the annual infiltration is 3.75 MCM appx. Most of the sewage water percolates through the thin Senonian cover into the Turonian-Cenomanian confined aquifer along a short segment, above the anticline axis. According to the geological structure the range of the infiltration rate in the valley varies from 2 to 17 cm/day. In the last 2 years the average rate was steady, namely about 9 cm/day. It was found that the infiltration rates are directly affected by the lithological structure and the fault ratio, but are inversely affected by the slope. Self purification process along the sewage stream is still taking place (ref. 3). Organic nitrogen compounds and ammonia in the sewage water are transformed into nitrate during the percolation process (ref. 1). Therefore, the nitrate ion is proved to be a suitable indicator for groundwater pollution by sewage, whereas other pollutants seem to be less suitable. Although significant nitrate concentrations have been found in most of the water wells in the Judea Mountains, negligible concentrations were measured in the Soreq Valley.

The total volume of sewage water which has percolated into the aquifer during the last decades is very large (5 MCM in 1979 appx.). So far it has not been identified in the regional aquifer by the standard macro-chemical methods, but subtle micro-chemical methods may be more successful.

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