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GROUNDWATER RECHARGE AND WATER QUALITY OF THE NEARSHORE YALOVA LIMESTONE CONGLOMERATE AQUIFER IN SW PELOPONNESUS

Από τον

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ABSTRACT
The Yalova nearshore aquifer composed of fractured Trifylia flysch conglomerates (mainly of limestone pebbles exhibiting solution features) is recharged laterally by some 7x10^6 m^3/yr of fresh groundwater. Part of this water is pumped for irrigation purposes whereas the rest is lost as subsurface outflow to the sea. Analysis of chemical data of groundwater samples for a period of ten years from five boreholes show a calcium-bicarbonate type of water in the north changing to calcium-sodium-chloride in the south due to seawater intrusion. As the demand for groundwater is increasing, a management plan must be enacted to protect the reservoir resources from uncontrolled pumping.

INTRODUCTION

The highly faulted and folded Trifylia flysch conglomerates of limestone pebbles in southwestern Peloponnesus, with a total area of nealy 100 km^2 and elevations ranging from over 1200m (Aegaleon Mountain) in the north down to sea level in the south (Yalova), can be subdivided into two distinct aquifers, approximately north and south of Chora (Figure 1). They exibit double porosity features due to pseudo-karstic solution activity.

Eight overflow mountain springs discharge the groundwaters of the elongated northern half of these conglomerates, while in the southern half part the groundwaters are discharged from two overflow springs and the remaining recharge the coastal Yalova aquifer (Tavitian & Tiniakos 1994). The latter has a total area of some 10 km^2 with elevations generally a few meters above sea level stretching north and east of Navarino Bay (Southern Ionian Sea) (Figure 1). The confined Yalova aquifer has been tapped (until 1990) by five test wells (Y-22, Y-28, Y-23, Y-24, Y-25) drilled by the Land Reclamation Survey of the Ministry of Agriculture (Figure 2). Studying the lithostratigraphic columns of all five wells it can be inferred that the aquifer is greatly affected by several normal faults and thus it is encountered at different depths. Water samples from these five wells were collected for the period 1981-1990 and were analyzed for; pH, electrical conductivity as well as Ca^{++}, Na^{+}, K^{+}, Mg^{++} cations and Cl^{-}, $SO_4^{=}$, HCO_3^{-}, $CO_3^{=}$ anions at the laboratotory of the Ministry of Agriculture in Athens to determine the water quality and the water type of this aquifer.

* The rocks outcroping in the study area belong to the Tripolitsa Zone and range in age from Eocene to Quaternary (see Geologic Map, Figure)
**.Min. of Agric., Land Recl. Surv., 92 P. Pigadion Str., 264-41 Patras.

EOCENE: Consists of thick bedded, neritic limestones (Ek) outcroping in the Western part of the geologic map. There are over 250 metres thick.
OLIGOCENE: Flysch ; outcrops in the eastern part of the map (Figure 1) and consists of :

GEOLOGIC SETTING

a.Regular rhythmic alternations of mudstones, siltstones and sandstones (ft): Thickness nearly 2,500 meters.Thick massive conglomerates (ftc); thickness nearly 1,000 meters. They are composed of well rounded pebbles and cobbles of limestone composition derived mainly from Pindos zone and less Tripolitsa zone rocks. Their matrix is medium to coarse grained quartzitic sand. They exhibit distinct solution (pseudo-karstic) features.UPPER PLIOCENE:
a.Mainly bluish-green marls and fine sands deposited in a shallow sea-lagoonal environment. Thickness nearly 150 meters.
b.Marly limestones, deposited in a shallow marine environment, rich in fossils; outcroping near Gargaliani. Thickness 10 meters.

QUATERNARY: Recent deposits include:
a.Mainly silts in marshy areas of thickness nearly 10 meters (SW part of the map).
b.Fluvial deposits in the stream channels, thickness nearly 10 meters (W part of the map).
c.Alluvial deposits; mainly clay, silts, sand and pebbles thickness nearly 10 meters (SW part of the map.
d.Talus cones (outcroping mainly in the N part of the map) of weathered material derived from the adjacent sandstone and conglomerate hills of the flysch; thickness nearly 50 meters.
e.Hard calcarenites composed of silt and sand particles, (outcroping near the coastline); Approximate thickness 10 meters.

GEOMORPHOLOGY
The area is composed of the following morphological units:
a.The Aegaleon Mountain range (highest part 1200 meters) trending NNW-SSE and following the direction of the main thrust fault. It is composed entirely of the over 3,500 meters thick flysch rocks of Oligocene age.
b.The Gargaliani Hills (highest part 370 meters) trending parallel to the Aegaleon Mountain. They are composed of the thick bedded, highly karstified Eocene limestones.
c.The Chora Plain (elevation 250 meters) lying between the two former features. It is composed of thin Upper Pliocene fine grained sediments overlying the flysch rocks.
d.The Filiatra Plain (elevation 50 meters) lying west of the Gargaliani Hills. It is composed of thin Upper Pliocene fine grained sediments overlying the flysch rocks.
e.The Yalova Coastal Plain (elevation below 10 meters) a marshy area composed of silts, lying SW of the map underlain by the flysch rocks (Figure 1).
f.The Eleofyton Hills (elevation 280 meters) lying east of the Yalova Plain. They are composed of the flysch conglomerates.

GROUNDWATER FLOW AND RECHARGE
The Aegaleon Mountain can be considered as an isolated hydrogeological unit seperated from the limestones of the Pindus Zone, in its east, by the mudstones and

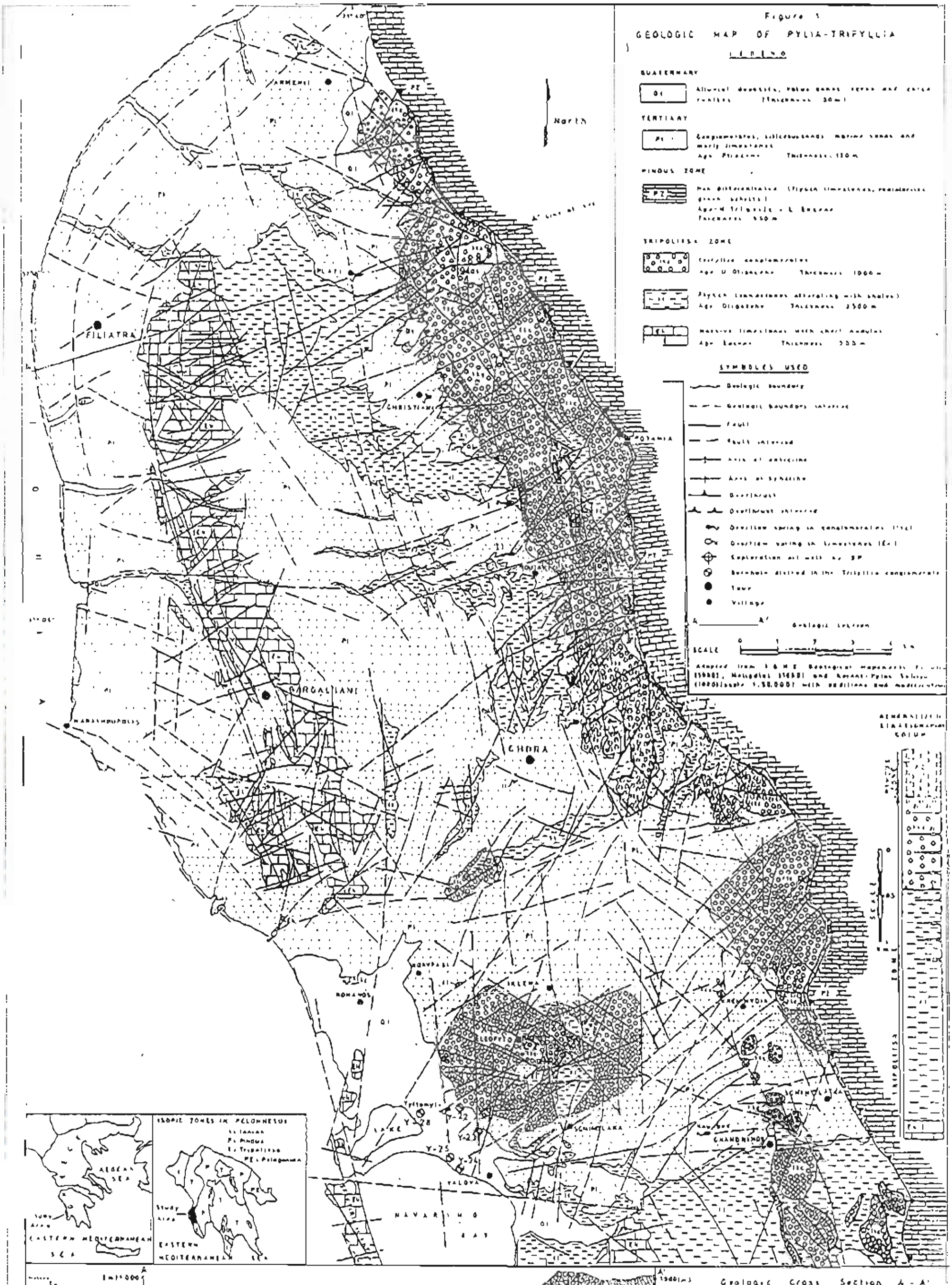
Figure 1
GEOLOGIC MAP OF PYLIA-TRIFYLLIA
SYMBOLES USED
North
FILIATRA
GARGALIANI
CHORA
CHRISTIANI
PLATI
ROMANOS
SCHINOLAKA
YALOVA
LAKE
N A V A R I N O B A Y
AEGEAN SEA
EASTERN MEDITERRANEAN SEA
Geologic Cross Section A - A'

Figure 2: LITHOLOGIC SECTIONS OF THE FIVE PUMP TESTED WELLS IN THE CONGLOMERATES

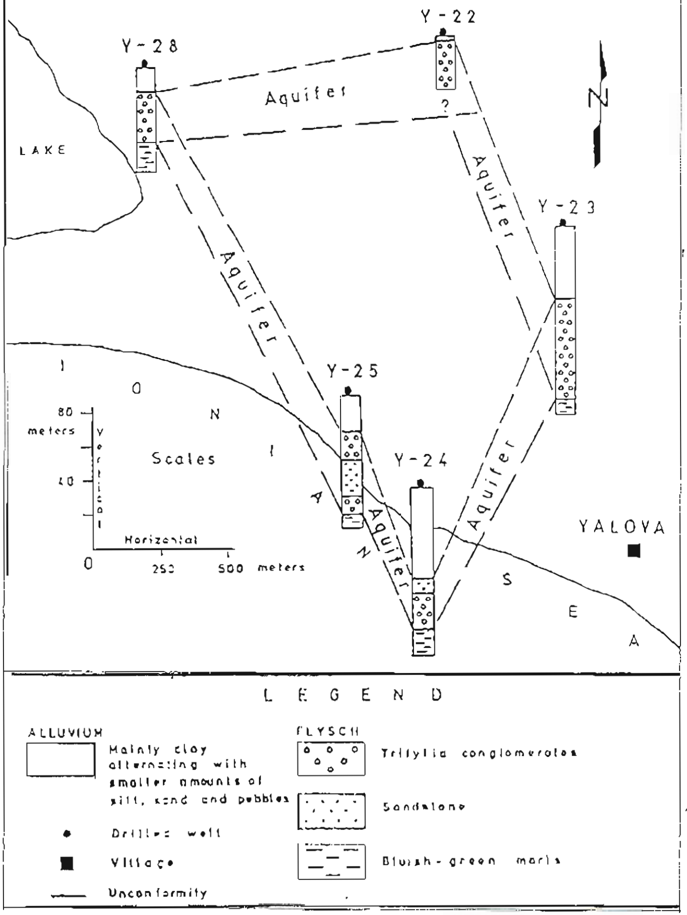

TABLE 1

Subregional water budget (average year) of the Trifylia flysch conglomerates (x 10^6 m^3/yr)

Region	Area (km^2)	Average Rainfall (m)	Gross Rainfall	Evapotanspiration	Rainfall Percolation	Spring Discharge	Pumping (up to 1990)	Subsurf Outflow to the sea	Surface Runoff
NORTH	46	1.2	55	27.5	11	11	–	–	16.5
SOUTH	56	0.8	45	31.5	9	2	3	4	4.5
TOTAL	102	0.98	100	59	20	13	3	4	21

shales of the Tripolitsa flysch outcroping north, east and west of it thus receiving no latteral groundwater recharge (Tavitian and Tiniakos 1994).

The high percentage of the carbonate pebbles in connection with the dense network of the intersecting faults and joints, facilitates the solution of these conglomerates by the infiltrating rainwater. Thus the groundwaters are collected and retained mainly in the secondary solution openings of the conglomerates and less in the sand matrix.

The equation relating precipitation Y (mm) and altitude X (meters) in this region is;

$Y = 0.615X + 650$

Table 1 presents the water budget of these conglomerates (northern and southern sub-areas) for an average year with pumping data till 1990. These conglomerates have an overall area of 102 km^2 and can be divided into two sub-regions.

The northern which includes all the recharge basins of the eight overflow springs (Plati, Potamia, Christiani, Mouzaki I, Mouzaki II, Chora) (Kantas & Tiniakos 1985) discharging all their waters within this sub-region (from Armenii in the north till Chora in the South) comprising an area of 46 km^2 whereas the highest peak reaches an elevation of 1250 meters. The average annual rainfall as calculated by using the data of six stations (Ministry of Agriculture) in the area for a period of 16 years (1975-1991) is 1.2 meters. The gross rainfall on this area is in the order of $55x10^6$ m^3/yr out of which $27.5x10^6$ m^3/yr is lost to evapotranspiration, $11x10^6$ m^3/yr percolates into the flysch conglomerates (which later is totally discharged by the eight overflow springs) (Kantas & Tiniakos 1988), and finally $16.5x10^6$ m^3/yr is directed into the river channels as surface runoff (Tavitian et al 1993).

The southern sub-region (stretching from Chora in the northeast to Yalova in the southwest) has a total area of 56 km^2 with its highest peak reaching 720 meters. This includes the area lying between the two villages Iklena and Kremmydia (south of Chora) where the Upper Pliocene outcroping marine sands (Pl) are thin and overly the Upper Oligocene flysch conglomerates. The two overflow springs Kubes (north of Kremmydia - east of Chandrinos) and Tyflomyti (north of Yalova) discharge, as calculated, part ($2x10^6$ m^3/yr) of the groundwater of these conglomerates. Of the remaining, $3x10^6$ m^3/yr is pumped by five wells (Y-22, Y-23, Y-24, Y-25, Y-28) sunk in the Yalova (flysch conglomerate) confined aquifer and used for irrigation, whereas $4x10^6$ m^3/yr is lost, through the same aquifer, as subsurfase outflow to the (Ionian) sea.

WATER QUALITY

A general relationship between mineral composition of a natural water and that of the bedrock solid minerarls with which the water has been in contact for a certain period of time is certainly to be expected. This relationship may be comparatively simple and uncomplicated, as in the case of an aquifer receiving direct recharge by rainfall and eventually from which water is discharged without contacting any other aquifer or other water, as in the case of these conglomerate groundwaters, except for the amount of $7x10^6$ m^3/yr that recharges the confined Yalova coastal aquifer.

The consolidated resistate sediments, such as these flysch limestone conglomerates, contain cementing material deposited on the pebble surfaces and within the fracture openings and bedding planes. This cementing material is usually deposited from water that has passed through the rock at some past time and can be redissolved. The cementing material in this case deposited from water, is mainly calcium carbonate (in solution as well as in sand size particles) which is one of the most common cementing materials together with silica.

Fresh groundwaters, like these conglomerate waters, are generally undersaturated in all but a few minerals. It is thus likely justified to assume that, as in this case, dissolution from the aquifer is the dominant process. Disregarding the minor mineral content of rainwater, it is here assumed that the major constituents were picked up by dissolution from the Trifylia limestone conglomerates.

All of the Aegaleon Mountain springwaters have Na^+ and Cl^- concentrations very similar to those in rainwater, indicating little interaction in the soil zone or rock, and probably implying very rapid recharge/pipe-conduit flow (Tavitian and Tiniakos 1994). Water analyses data in Table 2 of groundwater samples from the five wells in the Yalova aquifer represent water from a limestone area. The predominance of calcium and bicarbonate ions in these groundwaters is obvious.

Electrical conductivity values vary between 1150 and 780 μS/cm, indicating waters of medium to slightly high salinity. All pH values are seen to be slightly alkaline (in fact they vary between 7.4 and 7.8). In most natural waters, as in this case, the alkalinity is practically all produced by dissolved carbonate and bicarbonate ions. Alkalinity below a pH value of 8.2, as in the case of these groundwater samples, is a measure of bicarbonate ions (Davis and De Wiest 1966). Alkalinity values of these groundwaters vary between 15.1 and 41.6.

As groundwater percolates downward and latterally in this limestone conglomerate aquifer, it is loaded with alkali ions and the carbonic acid is thus totally neutralized. This causes an increase in the values of pH and alkalinity. The dominant anion HCO_3^-, in this case, identifies the large geochemical group to which these groundwaters belong. The principal material in limestones and dolomites are carbonates, chiefly of calcium. The solution of calcium carbonate, with some magnesium carbonate, is therefore the primary action when waters containing carbon dioxide attack the mineral matter in the limestones and dolomites. The amount of carbonates that can be dissolved largely depends upon the carbon dioxide content of the groundwater and the calcium and magnesium carbonate content of the rocks (Hem 1970).

Percolating groundwater continues to dissolve calcium and magnesium carbonate until the carbon dioxide content of the groundwater is exhausted. Thereafter the carbonate hardness of the groundwater tends to remain constant. The total hardness as $CaCO_3$ of these groundwater samples varies only by small amount from well to well (from 245 to 450 ppm) indicating that they exhausted their capacity to take calcium bicarbonate into solution after a relatively short distance of travel underground from the recharge area.

Figure 3 is a hydrochemical map of three parameters of this aquifer for the year 1990: 3A is the Electrical Conductivity Map, 3B the Isochlore Contour Map and 3C the Hardness Map. All three maps show that the corresponding values increase gradually to the south (i.e. to the direction of groundwater flow). Hence the groundwaters pick up more ions on their way to the sea thus increasing the amount of dissolved salts in them. This has an obvious impact on their quality.

The Revelle (1941) coefficients [ratio of $(Cl^-)/(HCO_3^- + CO_3^{=})$] the groundwaters of wells Y-22, Y-28 and Y-23 (1981) are low, they range between 0.3-0.2 indicating no mixing with seawater whereas those of Y-23 (1990), Y-24 and Y-25 are higher, ranging between 0.7-1.0 indicating slight mixing with seawater (Simpson 1946).

An interesting case is that of well Y-23. The chloride ion concentration of this well in 1981 (no pumping) was 65 ppm which increased up to 115 ppm in 1990 due tc overpumping. As a consequence the percent seawater content increase was doubled (0.25% to 0.50%) during that period.

The chloride ion concentration in the groundwaters of wells Y-22 and Y-28 is 60 and 70 ppm respectively while their seawater content is 0.3% implying no mixing with seawater. On the other hand the chloride ion concentration for the wells Y-25 and Y-

TABLE 2

Typical chemical analysis data of the coastal Yalova aquifer (meq/l)

Well No	E.C.	pH	Ca^{++}	Mg^{++}	Na^{+} + K^{+}	Cl^{-}	$SO_4^{=}$	HCO_3^{-} + $CO_3^{=}$	Revelle Coef.	Ratio $\frac{Ca+Mg}{Na+K}$	SAR	Class	Alkalinity	Hardness (ppm) Total	Temp	Perm	Ca	Mg
Y-22	780	7.4	7.1	1.9	1.6	1.7	1.8	7.1	0.2	5.6	0.7	C_3S_1	15.1	245	150	95	140	105
Y-23 (1981)	890	7.7	2.8	1.5	2.0	1.9	2.0	5.7	0.3	2.1	1.0	C_3S_1	20.8	380	285	95	305	75
Y-23 (1990)	910	7.6	2.8	2.1	3.5	3.2	2.2	3.0	1.0	1.4	2.2	C_3S_1	41.6	440	315	125	360	80
Y-24	1150	7.5	6.2	2.6	3.6	4.3	2.3	5.8	0.7	2.4	1.7	C_3S_1	29.0	440	290	150	310	130
Y-25	950	7.8	4.8	1.7	2.5	3.6	0.8	4.6	0.8	2.6	1.6	C_3S_1	31.3	450	355	95	355	105
Y-28	880	7.5	7.2	1.6	1.5	2.0	2.0	6.3	0.3	5.9	0.7	C_3S_1	14.5	330	220	110	255	75

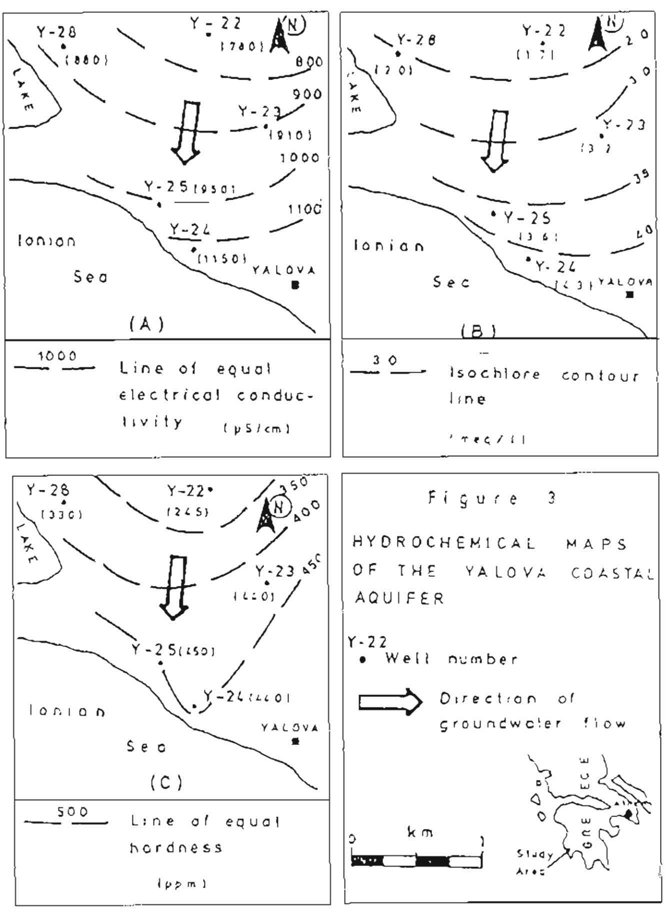

Figure 3

HYDROCHEMICAL MAPS OF THE YALOVA COASTAL AQUIFER

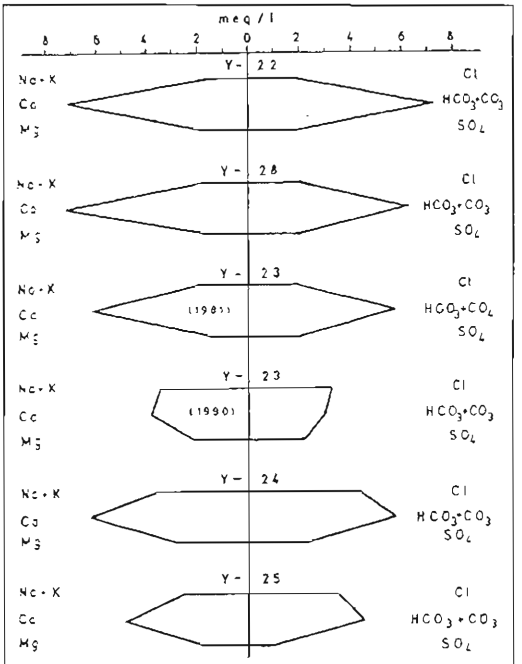

Figure 4

Stiff diagrams showing the water patterns of the Yalova coastal aquifer.

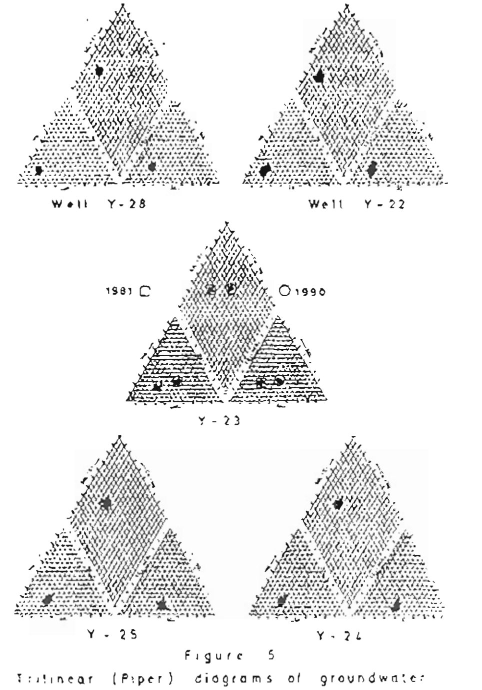

Figure 5

Trilinear (Piper) diagrams of groundwater samples from the Yalova aquifer (1981-1990)

24 is 130 and 150 ppm, while the percent seawater content is 0.55 and 0.65 respectively, implying some mixing.
The (Ca+Mg)/(Na+K) ratios of the two upstream wells (Y-22 and Y-28) are 5.6 and 5.9 respectively whereas those of the other wells (Y-23, Y-24 and Y-25) closer to the shore, are much lower (ranging between 1.4 and 2.6). This is in agreement with the fact that the first two are closer to the recharge area whereas in the case of the downstream wells there is an increase in the alkali metals resulting from ion exhange between fresh and seawater (Mandel and Shiftan 1981). In particular this ratio in the case of well Y-23 was decreased even more, from 2.1 to 1.4, by human activities due to overpumping (Table 2).
The sodium adsorbtion ratio values (SAR) of the non-affected portion of this aquifer (wells Y-22 and Y-28) are 0.7 indicating waters of low sodium (alkali) hazard with medium conductivity whereas the SAR values of the affected portion range between 1.7 and 2.2 indicating waters of low sodium hazard with slightly high conductivity. This implies that they can be used for irrigating well drained farmlands.
Using a Stiff (1951) diagram method (Figure 4) to define individual patterns of chemical character, it can be observed that there are two groups of water type (fresh and slightly saline) describing all the groundwater samples obtained from the five boreholes. Here too, in the case of well Y-23 the change from one group (1981 - fresh) to the other group (1990 - slighly saline) is quite obvious.
In Figure 5 the percent composition of the principal cations and anions have been plotted on trilinear graphs (Piper 1953). The groundwaters can be classified again into two groups: one, calcium-bicarbonate type waters with low salinity values; wells Y-22, Y-28, Y-23 (1981) and the other, calcium-sodium-chloride type of waters with moderate to slightly high salinity values; wells Y-23 (1991), Y-24, Y-25 due to mixing with small amounts of seawater due to overabstraction.
Groundwater compositions in the coastal Yalova aquifer are controlled principally by rock-water interactions in shallow zones inland where advective groundwater flow is occuring, as well as by fresh-saline water interactions (mixing) near the coast.
The geographical distribution of hydrochemical types in the coastal Yalova aquifer is heterogenous. At least two hydrochemical types can be determined from major ion concentrations, reflecting degree of rock-water interaction and marine influence. Water quality during short term test-pumping can be of a radically different character to that during continuous pumping especially in drought periods (dry years).

CONCLUSIONS AND MANAGEMENT

1.The 10 km^2 coastal fractured Yalova aquifer, composed of limestone conglomerates exibiting distinct solution features, lies nearly 30 meters below mean sea level. It is supplied latterally by some seven million cubic meters per year of fresh water from the Manglavas conglomerate hills which are the southern extension of the Aegaleon Mountain.
2.The Yalova aquifer can be subdivided into two parts according to its groundwater quality. The northern which has calcium-bicarbonate (fresh) type of water, and the southern which has calcium-sodium-chloride (slightly saline) type of water.
3.Due to increasing irrigation water demands in 1990 the amount of pumped water from this aquifer was in the order of three million cubic meters. As a result the water quality of the well Y-23 lying in the central part of the aquifer was influenced by seawater intrusion from the Gulf of Navarino (in the southern Ionian Sea) by changing it from calcium-bicarbonate type to calcium-sodium-chloride type.
4.A management plan for the development, use and protection of the reservoir resources must be enacted to safeguard current and future agriculture investment

while still maintaning irrigation viability. To achieve this the following practical remedial measures can be implemented:

a. the enforcement of available water legislation by controlling well drilling,
b. the careful control of groundwater withdrawals (not exceeding two million cubic meters annually) in order to make them strictly compatible with the safe rate of groundwater recharge,
c. the introduction of more efficient irrigation systems (e.g. drip irrigation) to reduce evaporative losses, and finally
d. the cultivation of crops with reduced water demands.

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