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ASPECTS OF GROUNDWATER SALINIZATION IN FILIATRA LIMESTONES

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ABSTRACT

The Filiatra limestones can be separated into two hydrological units. The northern aquifer has sodium-calcium, chloride-bicarbonate type of waters that recharge the thin coarse grained aquifers of the neogene sediments, whereas the thick marls create an impermeable barrier for the sea water to intrude eastwards. Chloride ion concentration increases southward due to salinization. The southern karst aquifer, which dips into the Ionian Sea, has sodium chloride type waters. Chemical analysis data of its waters for over a decade indicate mixing between fresh karst water and intruding sea water inland.

INTRODUCTION

Salt, brackish and fresh water are miscible liquids. They are completely soluble in each other. The mixing of groundwater bodies with different chemical composition is brought about by two physical processes. The first is diffusion which results from the thermal motion of molecules and ions and the second is hydrodynamic dispersion that is caused by flow through a network of interconnected channels.

In theory an abrupt interference between fresh and salt water is not possible due to the phenomenon of hydrodynamic dispersion and diffusion which create a transition or mixing zone where the chlorine content gradually changes from that of salt water via brackish to fresh water. Besides the two processes mentioned above, differences of specific density of the groundwaters in salt-fresh water cases play an important role.

In the case of a small transition zone there is an abrupt interface between fresh and salt water (Bruggeman 1991), as in the case of the Filiatra limestone aquifer. This implies that changes in the hydrological regime due mainly to human activities (e.g. overabstraction by pumping), will result in the change of the equilibrium of the interface with a very thin transition zone. Such is the case of the limestone aquifers in southern and eastern Peloponnesus; an area of relatively low precipitation and overabstraction due to pumping. Both factors are considered to be the main cause of this change of equilibrium. The late drought which hit southern Greece in the late 80's and early 90's, impaired this regime by increasing the salinization of the nearshore karst aquifers.

Water from nine boreholes sunk into the western flamnk of the elongated

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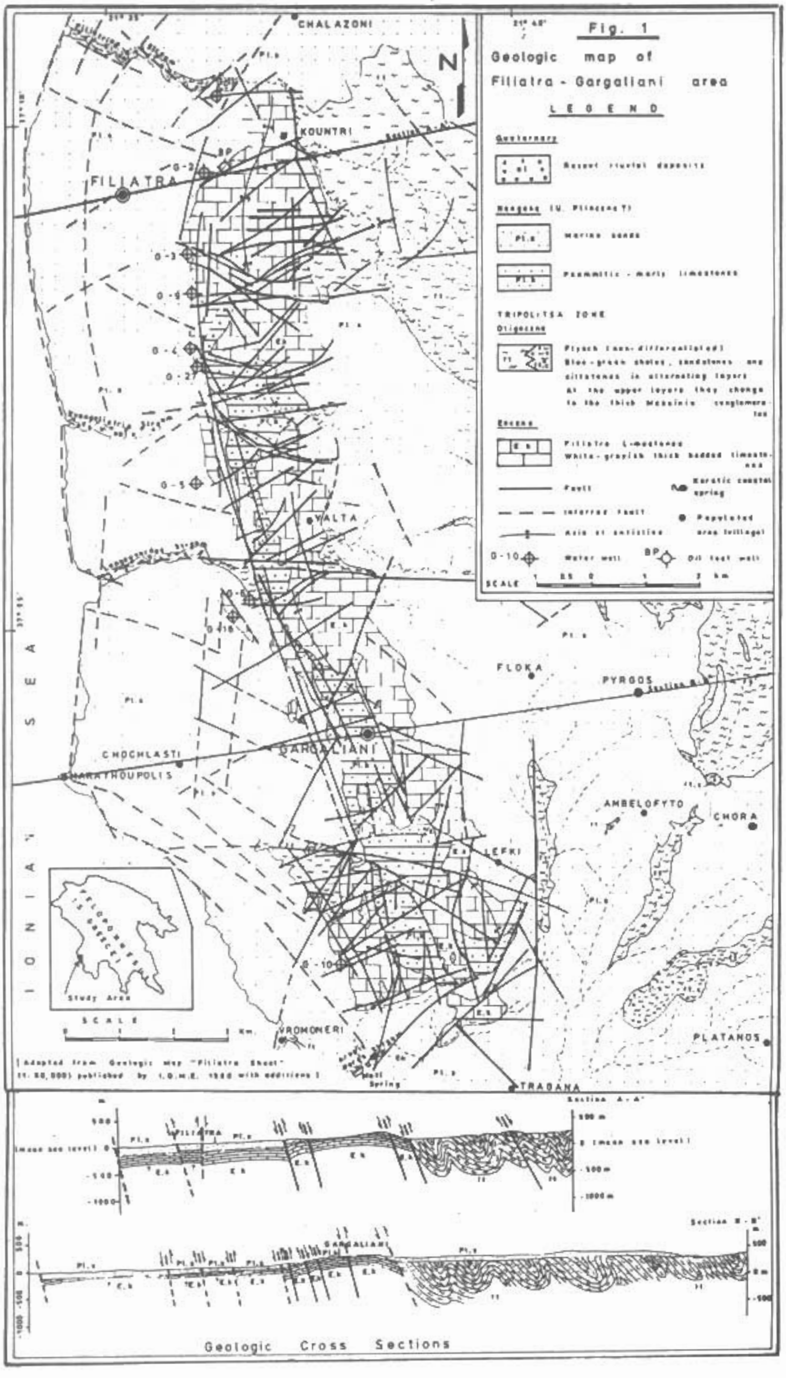


Fig. 1: Geologic map of Fiiatra - Gargaliani area

Filiatra Eocene limestone aquifer, in a north south direction, together with the Mati Gargaliani nearshore karstic spring, lying on the southwesternmost edge of these limestones, were sampled for chemical analysis for the period 1981-1992 at the laboratories of the Ministry of Agriculture and I.G.M.E., in Athens. Chemical analysis included Ca^{++}, Mg^{++}, Na^{+}, K^{+} cations, and Cl^{-}, $SO_4^{=}$, HCO_3^{-}, $CO_3^{=}$ anions, as well as pH and Electrical Conductivity measurements.

SPECIFIC ASPECTS OF GROUNDWATER FLOW IN FILIATRA LIMESTONES

The Filiatra Eocene faulted and folded limestones, dolomitic limestones and dolomites (B.P. 1971) forming a horst-anticline, are generally permeable by fissuring and solution processes. They represent an important pattern in the study of a series of phenomena connected with sea water intrusion in the western flanks of this extensively faulted anticline, plunging south (Figure 1).

These limestones comprise a separate hydrogeologic unit which does not receive any lateral recharge from the thick impermeable shales of the flysch formation outcroping east of it (Figure 1). The lateral recharge from the weak phreatic zone of both thin marine sands (Pl.s) and psammitic marly limestones (Pl.k), outcroping in the east and overlying the impermeable flysch clay schists, is negligible. Thus the only recharge of the Filiatra limestones is by direct precipitation. They also receive some additional recharge from the runoff waters of the four stream channels (Figure 2) flowing westwards and cutting across these limestones, on their way to the Ionian Sea (Tavitian et al 1993).

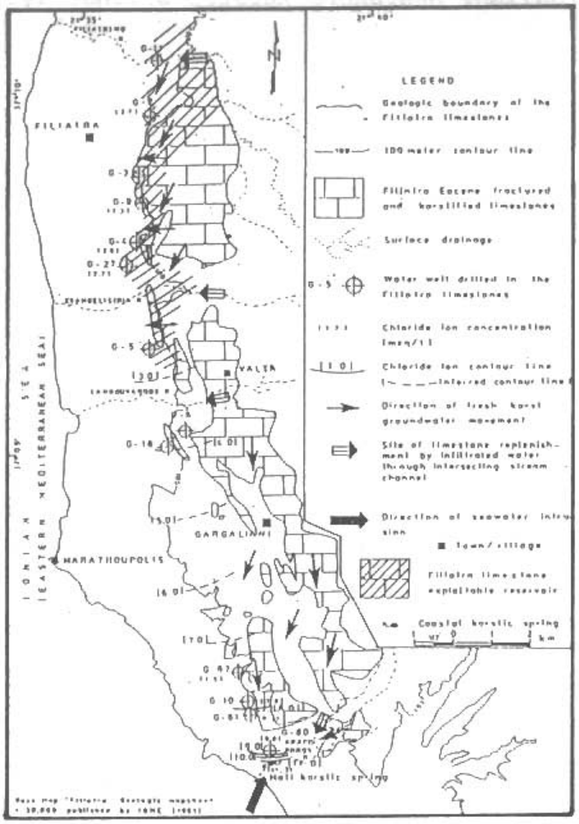
The Filiatra limestones are found to be divided into two hydrologically separate blocks (Sabatakakis & Makris 1993) by a strike-slip fault north of Gargaliani, disconnecting the karst channels. Thus they are seen to have two different directions of groundwater flow: one is to the west (partly recharging the thin neogene coarse-grain aquiferes) and the other to the south (partly recharging Mati spring).

According to the morphologic quantitative analysis of these limestones, their mean elevation is 175 meters and the mean annual precipitation at this elevation is 850 mm (Kantas & Tiniakos 1985. Their total outcroping surface area (including the overlying thin calcarenites) is 40 km^2. Hence the total amount of rainwater falling on their surface is $34x10^6$ m^3/yr. This is almost equally divided between the northern and the southern Filiatra limestone aquifers.

The infiltration coefficient in such karstified limestones in Greece, as estimated, ranges between 45 and 50% (Marinos 1975, Soulios 1985 and Tavitian 1990). Thus taking the average 47.5%, the total amount of precipitation water infiltrating into these limestones as calculated is $15.4x10^6$ m^3/yr. Moreover, the northern aquifer receives an additional amount of $3.1x10^6$ m^3/yr through the channels of the three streams cutting across the Filiatra limestones, whereas the southern aquifer receives only $0.2x10^6$ m^3/yr as natural recharge through the Arapis Poros stream channel (Tavitian et al 1993).

Thus the northern aquifer has a total of $10.8x10^6$ m^3 as annual recharge, whereas the southern aquifer only $7.9x10^6$ m^3. Part of the water of the former is abstracted through pumping while the remaining ($9x10^6$ m^3) recharges the neogene aquifers. On the other hand some of the infiltrated water in the southern aquifer is drained through the Mati nearshore karstic spring ($1x10^6$ m^3; including surface flow and groundwater flow), some is used for

Fig. 2a:Hydrogeologic map of the Filiatra limestone .



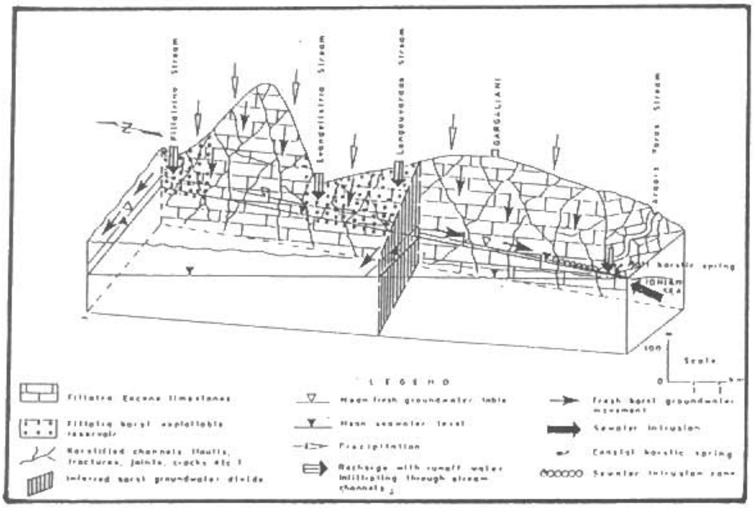


Fig. 2b: Hydrogeologic block diagram of the karstified Filiatra limestones.

agricultural and domestic purposes ($1.5x10^6$), while the remaining $5.4x10^6$, recharges the southern part of the neogene aquifers.

Figure 3(a) represents the mechanism of discharge of the brackish water of

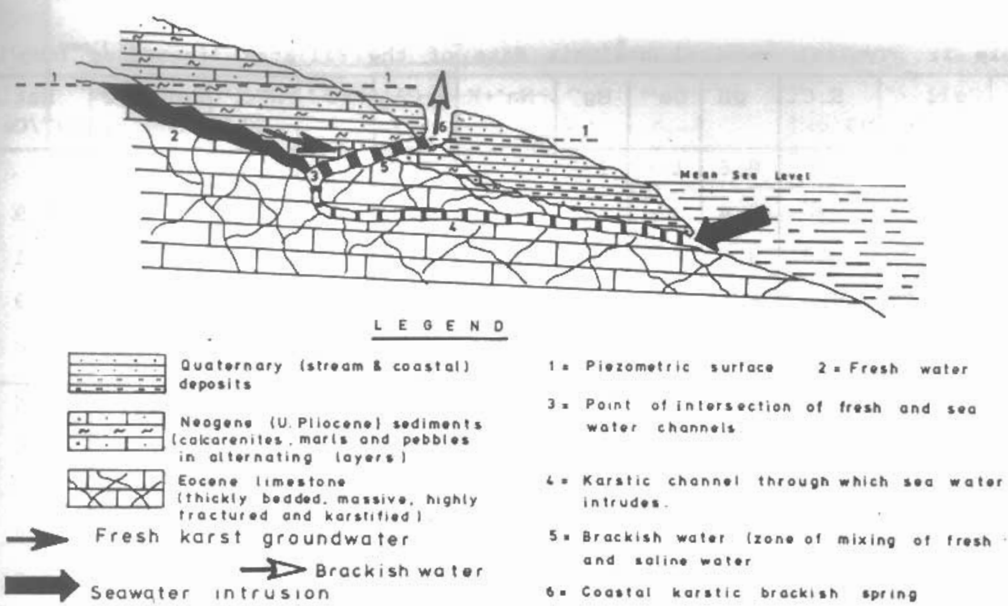


Fig. 3a: Schematic geological section showing the mechanism of discharge of the Mati - Gargaliani karstic coastal spring.

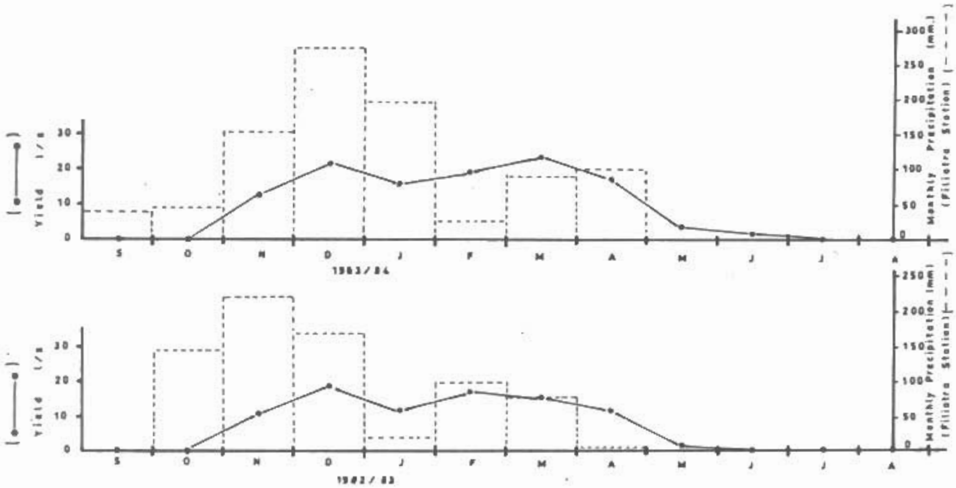


Fig. 3b: Hydrograph of Mati - Gargaliani karstic coastal spring for the hydrologic years 1982/83, 1983/84.

of Mati spring using Bogli's (1980) model for coastal karstic springs, while Figure 3(b) gives two hydrographs of the same spring for the years 1982/83 and 1983/84 comparing the yield with the precipitation of the Fi-liatra station. The discharge measurements were not taken at the spring's outlet, as this is impossible due to the fact that there is only a vertical karst hollow near the shore through which water flows to the sea. Hence the overflow discharge is measured at the coast. However a considerable amount of water moves underground, as groundwater flow, which is not measured. The estimated average total discharge is in the order of $1x10^6$ m^3/yr. This is a typical Mediterranean

Table 1: Typical chemical analysis data of the Filiatra limestones (meq/l)

	Well Number	E.C. μS/cm)	pH	Ca^{++}	Mg^{++}	$Na^{+}+K$	Cl^{-}	$SO_4^{=}$	HCO_3^{-} $CO_3^{=}$	Revelle Coeff.	Ratio Mg^{++}/Ca^{++}
Northern aquifer	G - 2	660	8.6	1.8	2.2	2.4	3.5	0.77	1.2		
	G - 9	590	8.4	2.0	1.8	2.1	2.3	0.7	2.9	0.79	0.9
	G - 4	700	8.6	1.5	3.1	2.4	2.8	0.4	3.8	0.74	2.1
	G - 27	680	8.5	1.5	2.9	2.4	2.7	0.5	3.6	0.75	1.9
	G - 5	660	8.4	1.5	2.7	2.4	2.6	0.5	3.5	0.74	1.8
Southern aquifer	G - 82	1240	7.5	4.9	3.1	7.2	7.6	1.0	5.7	1.7	0.6
	G - 10	1550	7.9	5.0	3.0	7.1	7.6	1.7	5.8	1.3	0.6
	G - 81	1525	8.1	5.4	3.4	7.3	8.3	1.2	6.6	1.3	0.5
	G - 80	1320	7.6	4.6	3.7	8.1	8.9	1.4	6.1	1.5	0.8
	Mati	1860	8.0	5.2	3.8	9.8	10.9	1.9	6.0	1.8	0.7

type perennial karstic spring in a region with seasonal rainfall issuing through a well-defined outlet.

HYDROCHEMICAL CLASSIFICATION AND SALINIZATION

For purposes of determining the geochemical properties of the water of Filiatra limestone aquifer, i.e. chemical type, salinity, chloride ion content, and extent of sea water intrusion, complete chemical analyses were made of water samples taken from selected wells and Mati spring. Table 1 lists the data of such a typical analysis.

Using a Stiff diagram method to define individual patterns of chemical character (Figure 4) it is observed that there are two distinct groups of water : Group A includes waters from wells G-2, G-9, G-4, G-27 and G-5 which belong to the northern aquifer (Figure 2 a & b). They have lower Na and Cl concentrations. On the other hand Group B waters which have a higher Na and Cl concentrations belong to the wells G-82, G-10, G-81, G-80 and Ma-ti spring.

Chloride ion concentration definitely increases in a southward directi-on. This is also indicated by the isochlor lines of the Filiatra limestone aquifer (Figure 2a). This is attributed to sea water intrusion from the southwestern part of this aquifer (Mati spring area (Figure 2a). A three percent sea water contamination of a limestone aquifer water such as well G-10 produces a chemical pattern similar in character to that of the near-shore Mati spring. From the data of all chemical analyses the percentage concentration of the cations and anions was plotted on trilinear (Piper) diagrams (Figure 5).

In reference to the northern Filiatra aquifer (Figure 5 a-e) the groundwaters are predominantly sodium-calcium, chloride-bicarbonate type (chlorides 80-90 ppm); whereas the southern aquifer (Figure 5 f-j) has sodium chloride type waters (chlorides 280-350 ppm).

Overdevelopment of coastal karst aquifers, such as the southern Filiatra aquifer, can greatly decrease the freshwater head and bring conditions that are favorable for migration of salt water inland. The actual migrati-on of the salt-water front, however, is relatively slow, as it represents actual movement of water in the system under ion energy gradients with high resistance.

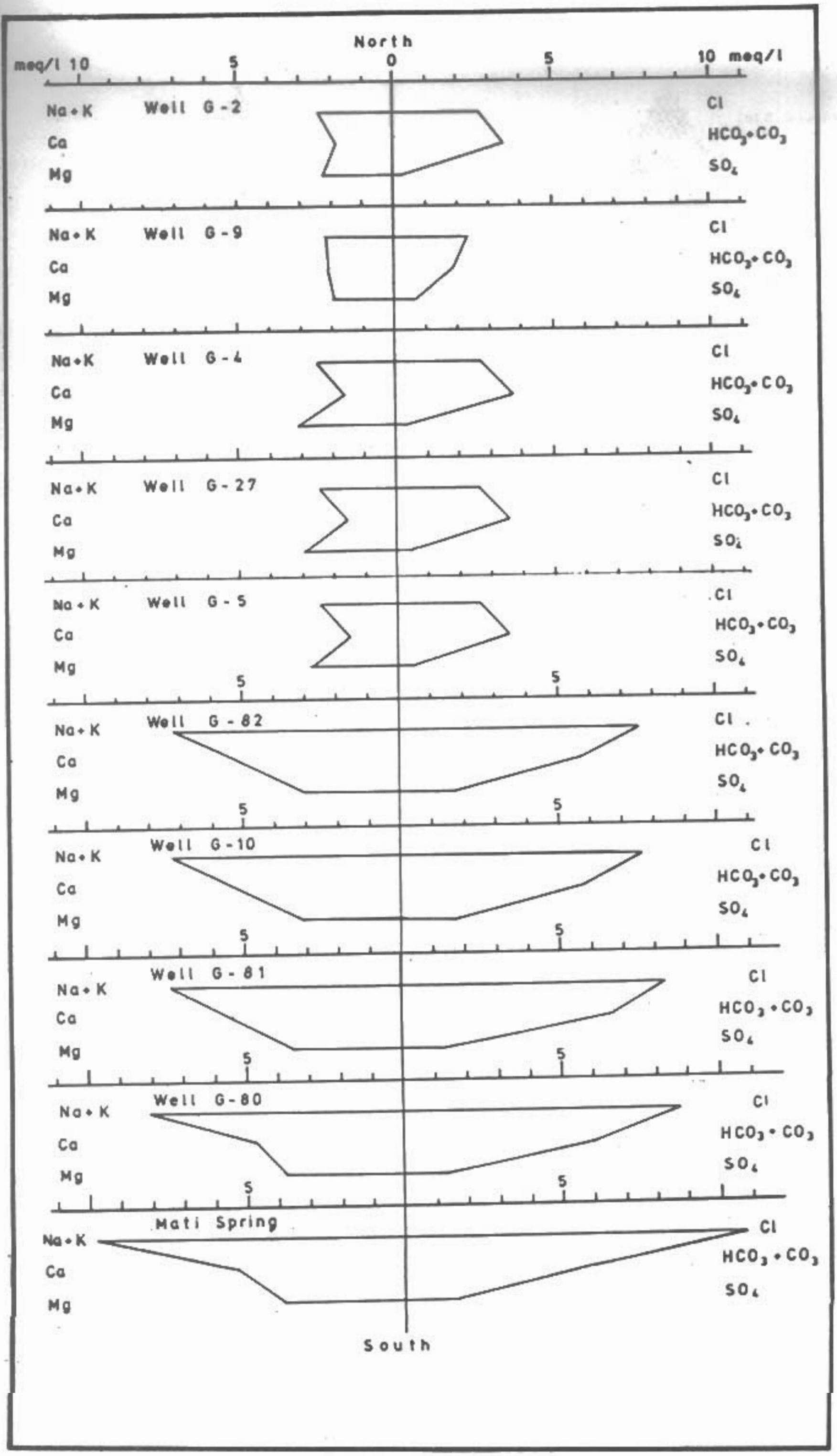


Fig. 4: Stiff diagramms showing the water patterns of the Filiatra limestones.

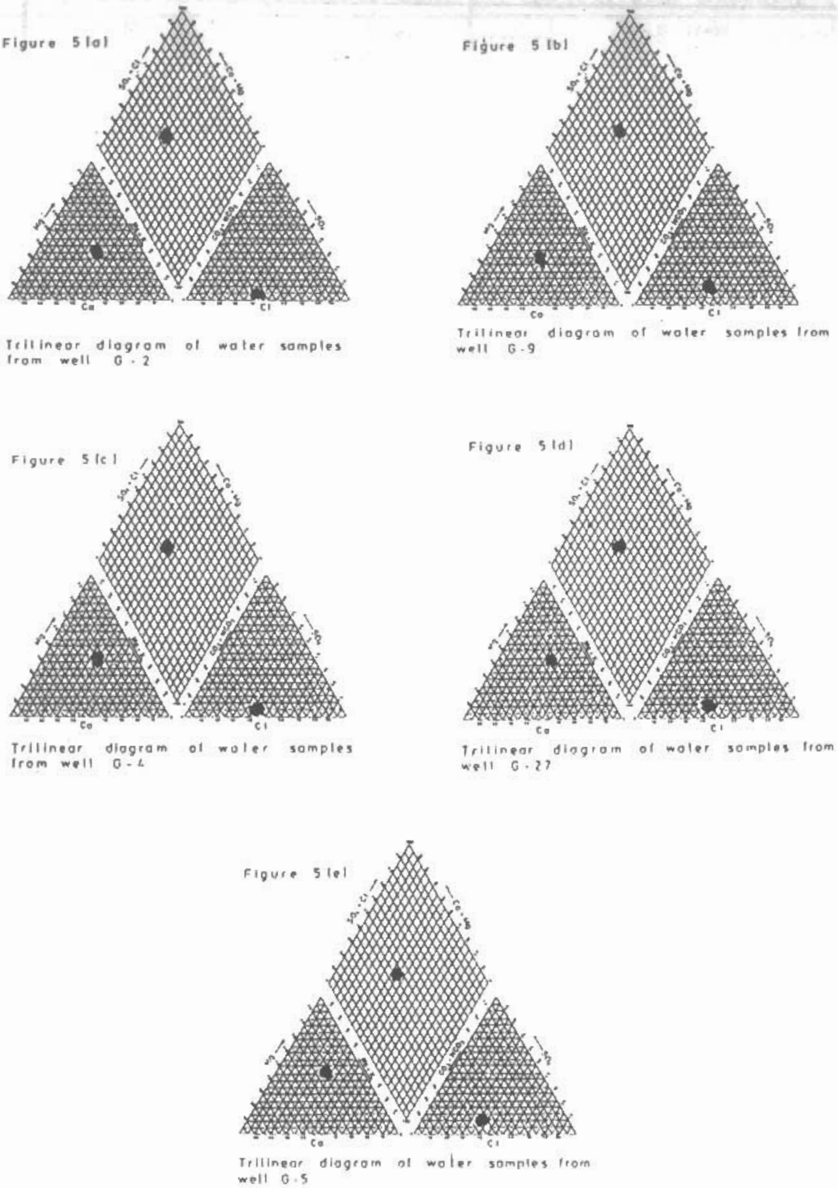
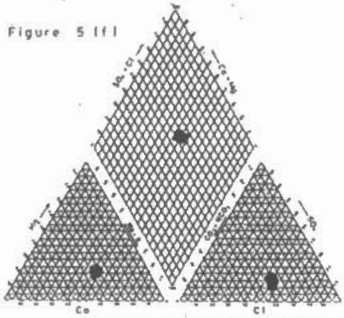


Fig. 5(a - e): Trilinear (Piper) diagrams of groundwater samples from the northern (freshwater) half of Filiatra limestone aquifer.

The Revelle coefficients (Table 1) of the northern aquifer are just below unity whereas those of the southern aquifer are just above it. This implies more sea water intrusion into the southern aquifer.

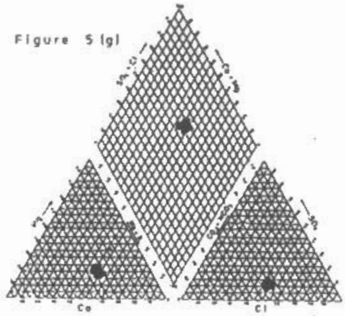
Pumping inland will reduce the head of the fresh water, and because head changes are transmitted rapidly through the karst system, the flow of fresh water seaward (Mati spring area) will be decreased. The head may decline enough to stop entirely the seaward flow of fresh water past the

Figure 5 (f)



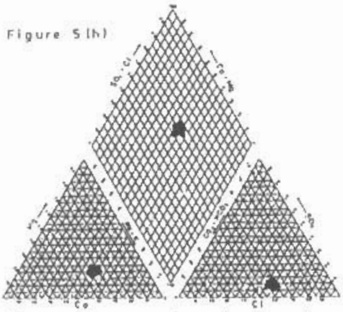
Trilinear diagram of water samples from well G-82

Figure 5 (g)



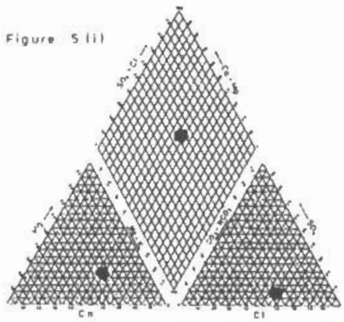
Trilinear diagram of water samples from well G-10

Figure 5 (h)



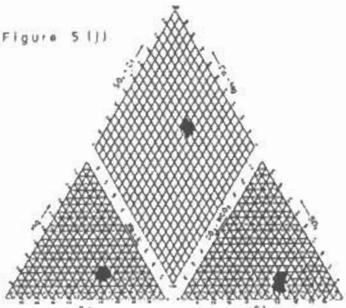
Trilinear diagram of water samples from well G-81

Figure 5 (i)



Trilinear diagram of water samples from well G-80

Figure 5 (j)



Trilinear diagram of water samples from Mali Gargaliani karstic spring

Fig. 5(f - j): Trilinear (Piper) diagrams of groundwater samples from the southern (brackish water) half of Filiatra limestone aquifer.

interface. With the decreased fresh-water flow, the system will be unstable, and salt water will invade the aquifer. The salt-water front will move inland (Wells G-82, G-10, G-81 & G-80 of the southern aquifer) to the point where the reduced fresh-water head is again sufficient to produce a balan-cing seaward movement of freshwater past the interface.

Salt-water intrusion into highly developed aquifers is a serious pro-blem in many nearshore karst aquifers (e.g. southern Filiatra aquifer), where salt water can be drawn into an aquifer when hydraulic heads are altered.

The recognition of incipient stages of salt-water intrusion, is of eminent importance so that steps can be taken to correct the deteriorating situation.

CONCLUSIONS

1. The Filiatra limestone aquifer can be divided into two parts according to its two different water types.

2. The northern aquifer has predominantly sodium-calcium, chloride-bicarbonate type of waters, indicating slight salinization. This is equivalent to nearly 1% contamination with sea-water.

3. The southern aquifer due to the lesser amounts of replenishment water (nearly 2/3 of the northern) in connection with its greater sinking rate, experiences more sea-water intrusion (nearly 3% contamination). Its water is of sodium-chloride type. Mati spring discharges brackish water.

4. Sea water intrusion takes place mainly from the coast of the Mati spring (southern aquifer)

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