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IMPLICATIONS OF EXPECTED CLIMATIC CHANGES ON THE ISLAND OF RHODES

HYDROLOGY AND WATER RESOURCES OF THE ISLAND OF RHODES

by

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2.3. HYDROLOGY AND WATER RESOURCES OF THE ISLAND OF RHODES

1. Introduction

In the last few years the need of rational management of the aqueus potential and of new water resources exploration in Rhodes island has become necessary because of:

- the continuous growth of island's permanent population,
- the huge development of tourism, and
- the continuous increase in water needs per habitant.

The problem of water supply has become particularly acute during the last two years which has been characterised as dry. According to 1987 estimates the total annual consumption in water has risen to 30 Mm3. It should be noted that a great part of the total water quantity (approx. 67% to 70%) is consumed mainly for water-supply and irrigation purposes at the northern part of the island, where development and economic activities are most intensive (triangle between Rhodes city - Fanes - Kolimpia).

The use of the total annual water consumption is 17 Mm3 for water-supply and 13 Mm3/year for irrigation. Part of the consumption is also used to cover the needs of nearby islands which belong to its district i.e. Simi and Halki.

Rhodes island exhibits important hydrogeological peculiarities due to the complex structure of its geological formations. Studies realised are not sufficient for a conclusion about ground water trapping possibilities from aquifers and about surface water exploitation.

Today the island's water resources exploitation is carried out mainly through boreholes and wells, from a dam at Apollakia (8 Mm3 water capacity) and from the island's main springs.

Drilling has been intense recently particularly in the island's hydrological basins at the northern part. The lack of management of water resourses and the continuous unbalanced development of water needs may create important water supply risks in the future. Already, especially in certain coastal areas, ground water is brackish due to intensive pumping. Moreover, significant drop in aquifer static level has been observed (even below sea-level) associated with important borehole yield drop.

2. Hydrological conditions

2.1. Surface runoff

At the whole island 51 hydrologic basins can be distinguished (fig. 1). The main watershed divides it into two parts, the western part and the eastern part where the greater and more developed basins exist. The largest water quantities runoff occur from western sector of the northern part (Kilakos, Drossos, 1989).

The surface runoff is affected mainly by torrents which do not flow permanently throughout the year. Big torrents however flow for longer periods during rainy years and exhibit significant flood yield (table I). There is however a severe lack in monitoring the island's torrent yields and only at northern part there is a relatively systematic measurements of torrent yields. Therefore, the annual surface runoff estimations derive mainly indirectly by comparing similar hydrological basins.

According to Iakovidis (1988), the surface runoff coefficient for the whole island is 10.5% of the mean annual precipitation which is 710 mm, which means a total annual water runoff is 105 Mm3. The surface runoff coefficient for Apolakia dam is 11.5% of the mean annual precipitation (583 mm) or 3.2 Mm3 water runoff annually. The mean surface runoff of island's northern part in particular, for last decade, is in the order of 8% of the mean annual precipitation, which is 767 mm (Kilakos and Drossos 1989). This signifies that a quantity of 19.7 Mm3 water per year is running off from the island's northern basins.

2.2. Water Balance

The knowledge of the water balance for each island's hydrologic basin is necessary in order to estimate the total annual water quantity available for exploitation. The total annual water quantity received on the island is 198 Mm3 (R+I table II). About 2 to 6% of the annual infiltration that is 20 to 60 Mm3 is escaping to the sea. It is also estimated that the water quantity available for further exploitation is rising to 40-50 Mm3/year, the greater part of which is from surface runoff (Iacovidis, 1988).

The total annual water quantity at the island's northern part (triangle Rhodes city - Fanes - Kolimpia) is 66 Mm3, to which about 9.2 Mm/year can be added further from ground water pumping and about 3.7 Mm/year from Loutani torrent (Kilakos, Drossos, 1989).

3. Hydrological conditions

3.1. Ground water

Rhodes island geological structure is complex and certainly controls the hydrogeological conditions.Following is a brief description of the hydrogeological behaviour of the various geological formations, the type and
development of the main aquifers and the hydrogeological projects required for ground water exploitation.

3.1.1. Hydrogeological behaviour of geological formations

3.1.1.1 Coastal and river bed alluvial deposits

The coastal and/or river bed deposits exhibit medium and locally high permeability. An unconfined freatic aquifer is developed inside the alluvial deposits which is fed by direct infiltration and torrent surface runoff. Over-exploitation of these aquifers occur through a great number of wells approx. 12 to 15 m deep.

3.1.1.2 Sgourou formation

It consists of intercalations of layers having variable lithology. Permeable layers of sand, sandstone pebbles and gravels alternate with impermeable clays and marls.

Rich confined aquifers are developed inside this formation. Their feeding is mainly by infiltration of rain water, whereas locally they are also enriched by torrent water. Also sufficient local water recharge occurs through the underlaying Archangelos limestones (fig. 2). Great number of boreholes with important yield (70 to 140 m3/h) have been drilled in Sgourou formation, but the intensive exploitation of aquifers has created already depletion conditions (e.g at Trianta region).

3.1.1.3 Levantinia

It consists of permeable (conglomerate, sandstones) and impermeable (marls, clays) phase intercalations (fig. 3). Aquifers developed in this formation are confined and they are of important potential in cases where there is a significant thickness of the conglomerate (up to 70m) and where there is a side feeding from limestone masses, like at the regions of Pastida, Kallithea and Afantou. Aquifers developed inside sandstone phases are of lower potential.

A great number of boreholes have been drilled in this formation but the aquifer has not been fully exploited. Successful test boreholes have been drilled recently which indicate new aquifer zones (Kilakos and Drosos, 1989).

3.1.1.4 Allochthonous limestones

Significant aquifers are developped inside this formation. Water movement is taking place inside developped karst system as well as at the tectonic discontinuities. Boreholes have recover aquifers of great potential (yield 100 to 200 m3/h). Significant results have also been obtained recently by boreholes inside porous formations and drilled through underlaying limestones (e.g. Elafokampos region). Water tapping possibilities however have not been depleted in these limestones (e.g. Archangelos, Malona, Salakos, Profitis Ilias region).

From the other geological formations occuring in the island, the flysch and the ophiolites are impermeable and only in their upper weathered part they can support low to medium aquifers. At the Vati Group the same is true only for its conglomerates. finally in the autochthonous limestones, which are mainly situated at the mountainous part of the island (Attaviros region), the water quantities runoff to the sea, while boreholes drilled there have proved unsuccessful.

Concluding we can say that the main aquifers which may be further exploitated occur in the coastal and riverbed alluvial deposits, the Sgourou formation, the Levantinian deposits and the Allochthonous limestones.

3.1.2 Hydrogeological projects

The freatic aquifer was up to about 1970 mainly exploited by wells of 12 to 15m depth, concentrated in the coastal zone and in torrent deposits. Up to today about 390 to 400 boreholes have been drilled (YEB, 1991) and the rate of drilling is continuously increasing as needs in water are rising. About 250 of boreholes occur in island's northern part, in the triangle Rhodes city - Fanes - Kolimpia.

The first expliotation was in Sgourou formation where the greater part of boreholes were drilled and yielded a production of 70 to 100 m3/h. Later the exploitation of the aquifers at Levantinia deposits started, which now procceed to a depth of up to 200 m, with significant results. Positive results had also occurred in exploiting water deposits in the underlaying limestones (Kilakos and Drossos, 1989).

Rising needs in water at Rhodes northern part however have resulted in over-exploitation of ground water deposits while intensive pumping has led to mostly irreversible consequences, such as drop aquifer's static level, borehole yield drop and aquifer contamination from sea-water intrusion. Typical is the case at Trianta region where, during the last two years, negative static levels of about 50 m below sea-level have been observed (YEB, 1991) and the aquifer has reached depletion limits. Other regions where negative static levels have been observed are Koskinou (-24m), Kalithies (-20m) and Asgourou-Faliraki (-8m) (Kilakos and Drossos, 1989).

The central and eastern part of Rhodes island also contains significant aquifers, particularly inside alluvial deposits (Phantidis, 1989).

The southern part does not have important aquifers except a small strip which includes the regions of Asklipio, Gennadio and Lahania.

On the mountain part regions of Kritinia, Emponas, Siana and Monolithos, test boreholes have been unsuccessful because the water probably flows to the sea.

An other indicative element for aquifer's annual recharge conditions and its exploitation conditions is its level variation. Based on the available data (Iakovidis, 1989) the following remarks can be made:

a) Coastal zone

Wells and boreholes in coastal zone exploit mainly, the freatic aquifer of alluvial deposits where there are no significant level variations. At the eastern part (Rhodes city, Kalithies, Afantou) the annual level variation is between 0.20 to 0.50m while a 0.10 to 1.50m level drop has been observed during the years 1986-1988. At the western part (Trianta through to Salakos) the annual level variation is between 0.10 to 1.50m with a 0.10 to 0.70m level drop during the same time as above (fig. 4). It must be noted that during dry periods in many locations the aquifers level is equal to sea level.

b) Inland zone

Here the variation in the water level is more complex. At the eastern part (Rhodes city, Koskinou, Kalithies regions) where Sgourou formation aquifers are over-exploited, the annual level variation is between 1.00 to 6.00m. During 1986-1988 the level drop was between 1.00 to 5.00m and in some cases the level drop was of the order of 25 to 50m. In the remaining regions of the eastern part (Archangelos) variation is between 2.00 to 3.50m with a level drop between 0.20 to 6.00m.

At the central part (from Maritsa to Archipolis) the annual level drop is between 0.30 to 9.00m and the level drop is between 4.00 to 6.00m.

At the western part of the island (Trianta region) the annual level drop is between 0.50 to 10.00m. Here the level drop from 1986 to 1988 was between 2.00 to 12.00m, but, due to intensive exploitation, significant level drops of up to 100m have been noticed.

At the remaining regions of the western part (from Kremasti to Salakos) the annual level drop is between 1.50 to 3.50m, with a small level drop, from 0.10 to 4.00m. It must be noted that in all central and western sectors, the exploited aquifers are within Levantinian deposits.

No data exists for the remaining regions of the island, in particular those at the southern part.

3.2 Springs

A great number of springs exists in the island, their yield is between 2 to 200 m3/h and the most important of them are located at the nothern part of the island. They belong to the following three types:

a) Springs developed at the tectonic contact of the overthrusted allochthonus limestones over impermeable formations. They have the most significant yield and they are fed from ground water circulating in the karstic limestone. They occur at the Salakos, Afantou, Archangelos and Apollon regions.

b) Springs at karstic aquifers which are present on autochthonus limestone masses of Attaviros. They are few, have low yield possibility and are found mainly at Sianna and St.Isidoros regions.

c) A number of springs are located in porous formations (e.g Sgourou and Levantinia formations) in contact between permeable and impermeable horizons and in fault zones. These springs usually dry out during the summer. They are found at Psinthos, Pastida, Gennadio and Kalathos regions.

The most important springs (with mean yield of over 30 m3/h) are at island's northern part are given at Table III. where given yield corresponds to spring mean yield during 1988-1991 (YEB Rhodes, 1991).

Early estimations calculated the water quantity discharged annually from the island's springs at about 32 Mm3 (Strogilis, 1980), while recent estimations (YEB Rhodes, 1991) indicate that this is only up to 6 Mm3. The data probably indicates that island's spring water quantity has diminished significantly over the recent years.

4. <u>Management of water resources</u>

The largest portion of island's water is used to cover domestic fresh and irrigation needs and only a small percentage is consumed for industrial use, for ships and for fresh water supply of the adjacent islands Simi and Halki.

Approx. 70% of the total annual water consumption (30 Mm3) is consumed by the island's nothern part (Table IV).

As far as fresh water supply is concerned, 82% of island's total annual consumption, (17 Mm3), is consumed by the island's northern part due to high population concentration and tourism. This demand increases every year.

In 1980 water to Rhodes city was supplied by 12 boreholes and 2 springs ammounting to 3.9 Mm3/year (Strogilis, 1980). In 1991 4.5 Mm3/year is consumed by the city's population but there are significant leakages in the water distribution network pipes (Mutin, 1991).

The total annual water quantity consumed for irrigation in the whole island is 13 Mm3/year and 59% of this is consumed in the northern part. However agriculture needs are expected to increase in the future (Phantidis, 1989).

The most important projects realised in the recent years for water resources management are the following:

a) Construction of Apollakia dam having 8 Mm3 capacity and irrigating 8.5 10^6 m2. To this day it has only been filled up to 1/4 of its capacity (Mutin, 1991).

b) Steps limiting borehole drilling have been applied in order to rationalize ground water quantity.

c) Test boring and state programme on productive boring has been carried out to cover Rhodes city immediate needs, tourism needs and for the adjacent islands.

5. Ground water quality

In general ground water quality varies within satisfactory levels. Local contamination at coastal zones is mainly due to sea-water intrusion. Bacterial contamination of aquifer has also occured locally. Brackishness fronts located on the island are noted on fig 5 and appear in regions where uncontrolled overpumping occurs which exceed supply limits of the aquifer.

At the nothern part of the island a brackishness front exists in the eastern coastal zone of Kallithea and Kolimpia bay, whereas in Kalithies it lies about 500 m in from the coast. Note that at Kallithea boreholes (where limestones cover the land up to the coast) Cl ions concentration reached 545 mg/l on summer 1989 (Mutin, 1991). To the western coasts a brackishness front exists in the coastal zone of Trianta and Damatria. In Trianta region a 106 mg/l Cl concentration has been measured.

At the southern part of the island, problem of sea intrusion also exists in the eastern coastal zone between Gennadio and Lahania as well as in a zone east of Lahania up to 2 km from the coast. At the western coasts similar situation exists at Kameiros, at about 500 m from the coast, and Mandriko beach.

Except the above mentioned regions, slight brackisness of aquifers was recently noticed at certain boreholes in Koskinou area. Cl ion concentration has increased from 50 mg/l in 1975 to 60-80 mg/l in 1989 (Mutin, 1991). In these boreholes bacteria contamination has occured as well.

6. Discussion on climate variations-implications-proposals

The climatic changes due to greenhouse effect would have quantitative and qualitative implications on the water balance of Rhodes. The quantitative effects is yet too difficult to be defined exactly. For this reason in this chapter qualitative estimations on these effects are made and finally a programming strategy is proposed for the quantitative definition of the effects and measures are suggested to confront them in the short and in the long term.

According to UNEP/WMO/IPCC conference (1990) before the end of 2100, temperature on the planet would increase between 1.5 to 4.5 NC and sea-level would rise from 20 to 100cm. A more recent scenario developped at East Anglia University (Guo et al. 1991) refering to the North-eastern Mediterranean and to Rhodes island particularly. According to this scenario the expected rise in the mean annual global temperature would be about 1 NC before 2050 and 3 NC before the end of 21th century. For Rhodes island, in particular, the forecast by 2050 is a temperature rise from 0.7 to 0.8 NC and rainfall decrease from 4 to 8%. For the end of 21th century, the estimations for the island are temperature increase between 2.1 - 2.4 NC and a rainfall decrease of 12 - 24%. (As it has been noticed by researchers, estimations for rainfall have low degree of confidence).

Based on the above it is deducted that the temperature rise would result inevitably in a rise of the evapotranspiration and decrease of total runoff and infiltration. This decrease of the total rainfall volume would in turn affect the water quantity received on the island. The expected increase in the summer period would result in a more arid conditions while at the same time the more extensive duration of the touristic period would increase the water needs.

Regarding the surface water if as expected, meteorological phenomena would acquire torrential character, they would favour the increase of surface runoff to the detriment of the infiltration process. Apart from this a decrease of the surface runoff volume is expected in general. As a result the intensification of the erosion is expected to be associated with aridity and plantation decrease. All these would result to a decrease of the water percolation ability of the ground. The final result would be the decrease of the aquifer feeding.

As a result there will be a need for a surface water exploitation project. Similar projects for island have been made to this day such as construction of dams, lake-reservoirs, torrent etc.

For the ground water, the above mentioned decrease in the aquifer feeding would result to level drop, yield decrease and drop of the pumping level. Inevitably, pumping will be extended to greater depths leading to cost increase for ground water exploitation. Particularly, grave situation could be developed in areas of over-pumping, as it is today the island's northern regions.

It seems that the ground water reserves have not been fully exploited and that additional ground water quantities may be drawn from some hydrological basins. Four such basins have been defined in island's northern part. It is, however, necessary to define the exact location on the new boreholes and their exploitation degree, in order not only to confront long term implications from climatic changes but also to confront today's bad management implications of the ground reserves.

The expected sea-level rise, the decrease of aquifer feeding and the eventual over-pumping would also result in sea-water penetration and advance of the brackishness front. This, would be particularly intense in areas where brackish phenomena already existed today, whereas new areas with the same problem would appear.

Greater degree of brackishness will be present at the freatic aquifer while at the coastal zone numerous wells would operate in ever more increasing difficulties.

The karstic aquifers of Sgourou and Levantinia formations would be subject to longer term implications, such as progressive sea water contamination, particularly in nearshore areas.

The decrease in aquifer feeding will also affect the island's springs. Their decreased yields, which has been observed in the recent years, should continue and most of them are expected to cease. Their exploitation, however, is necessary in the mid-term providing that appropriate work is planned in advance for the exact evaluation of their capacity.

It is evident that the problem of water resources should be con fronted, in the short as well as in the long term as a matter of high priority by the desision makers in order to avoid disastrous effects on the island. It is necessary, to follow a global rational plan, with short and long term objectives, which should include research for new water resources, construction and water resources management.

Short term actions can be:

- Protection of aquifers which are already under intense exploitation. These actions may include limitation measures for drilling new boreholes, prohibition of borehole drilling in basins where aquifers are on the limit of depletion (e.g. Rhodes, Kalithies, Pasaoutia, Voukoulia regions) and renewing of water distribution networks (particularly in Rhodes city).

- Completion of borehole research programme proposed by the Ministry of Agriculture. Particular target can be the exploration of the Archangelos limestone masses as well as the definition of the escaping water quantity at the sea in the Attaviros limestone region.

- Monitoring of surface and ground water so that a calculation of the water balance in the hydrologic basin can be carried out and a mathematical model for aquifer quality and capacity development predictions be developed.

The main projects proposed for confronting the water problem is the construction of seven dams at the areas of Soroni, Kritinia, Afantou, Gadoura, Katavia, Katavia and Lardou having a total capacity over 90 Mm3 and the building of 46 reservoirs having a total 10 Mm3 capacity.

Long term basic actions can be the construction of large hydrogeological projects like dam at Gadoura having capacity of 67 Mm3 and at Afantou with 18 Mm3 capacity.

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TABLE I

MOST SIGNIFICANT TORRENTS AND THE AREAL EXTEND CORRESPONDING HYDROLOGIC BASINS

Torrent Name	Surface of Hydrologic Basin (km2)
Gadouras	160
Asklipinos	107
Makaris	75
Loutanis	60

TABLE II

WATER BALANCE OF RHODES ISLAND

	Iakovidis, 1988 Whole Island	Kilakos,Drossos 1989 Island's Noth. Part
Mean Annual Precipitation	710mm	767mm
Total Study Area	1402Km2	320Km2
Precipitation (P)	995 Mm3 - 100,0%	245,0 Mm3 - 100,0%
Evapotranspiration (E)	797 Mm3 - 80,0%	179,9 Mm3 - 73,0%
Runoff (R)	105 Mm3 - 10,5%	19,7 Mm3 - 8,0%
Infiltration (I)	93 Mm3 - 9,5%	46,4 Mm3 - 19,0%

TABLE III

MOST IMPORTANT SPRINGS

No	Island's Part	Place Name	Community	Yield (m3/h)
1	East	Epta piges	Afantou	210
2	East	Fleva	Archangelos	55
3	Central	Nimfi	Dimilia	76
4	Central	Belanidi B	Psinthos	51
5	Central	Fassouli	Psinthos	50
6	Central	Kariona	Apollon	30
7	West	Pigadia	Salakos	40

TABLE IV

WATER CONSUMRTION

U S E	Water Quantity Mm3/year			
	Todays Consumption			2010 Projection
	Iacovid 1988	Kilạkos and Drossos 1989	Mutin 1991	YEB Rhodes 1991
Total islands consumption	29,9	-	-	63,0
Northern part consumption	21,6	23,0	-	-
Total consumption for fresh water supply	17,0	-	-	13,3
-Northern part consumption	14,0	13,9	-	-
-Rhodes city consumption	8,0	7,4	8,0	-
Total consumption for irrigation	12,9	-	-	49,7
-Northern part consumption	7,6	7,5	-	-
Other uses (Hotels)	-	1,5	-	-

* Reference to 1987.

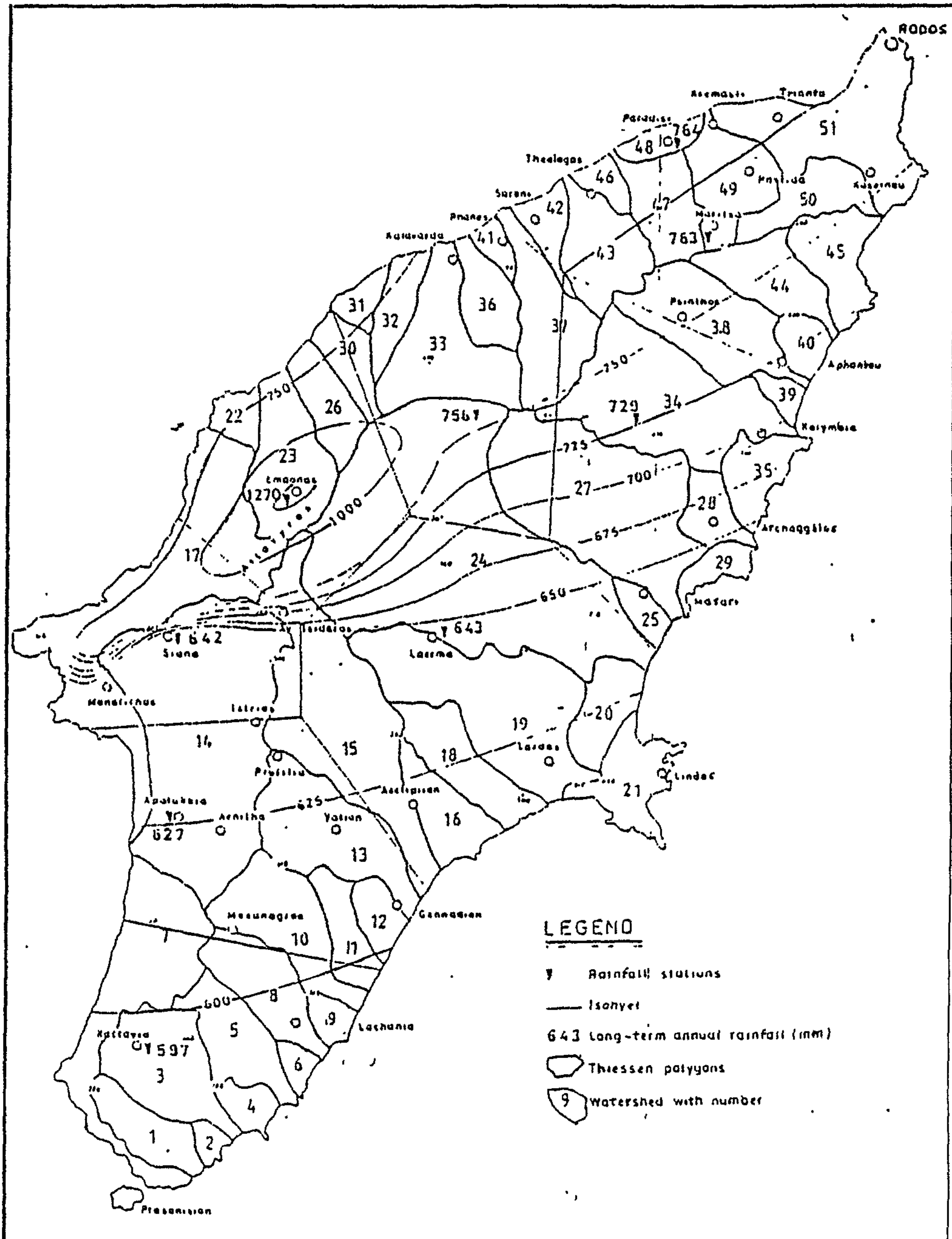

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Figure 1 - Hydrologic basins and isohyet lines (Iacovidis, 1988)

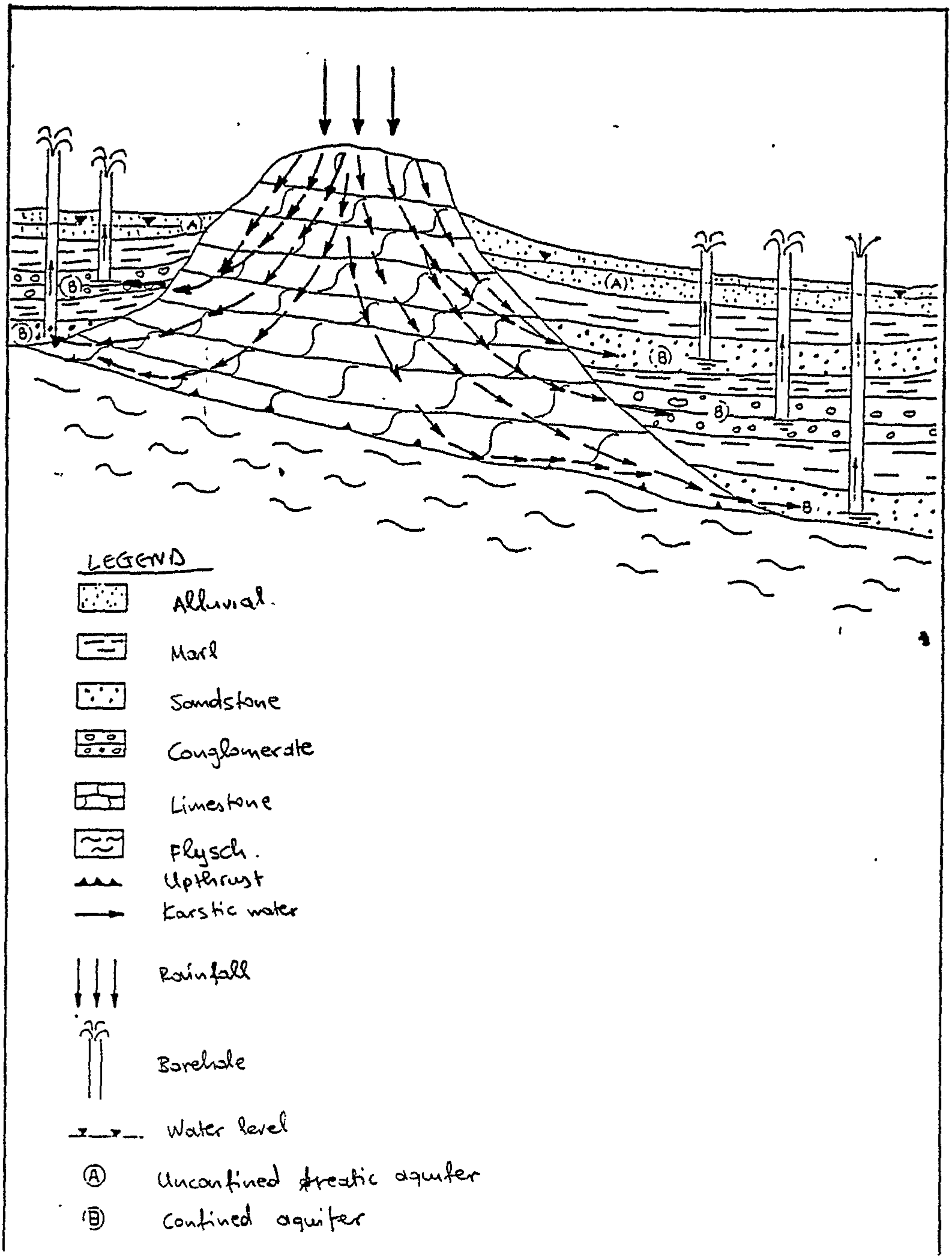

Figure 2 - Hydrogeological conditions of Sgourou formation and undelaying limestone - Archagelos area (Strogilis, 1980)

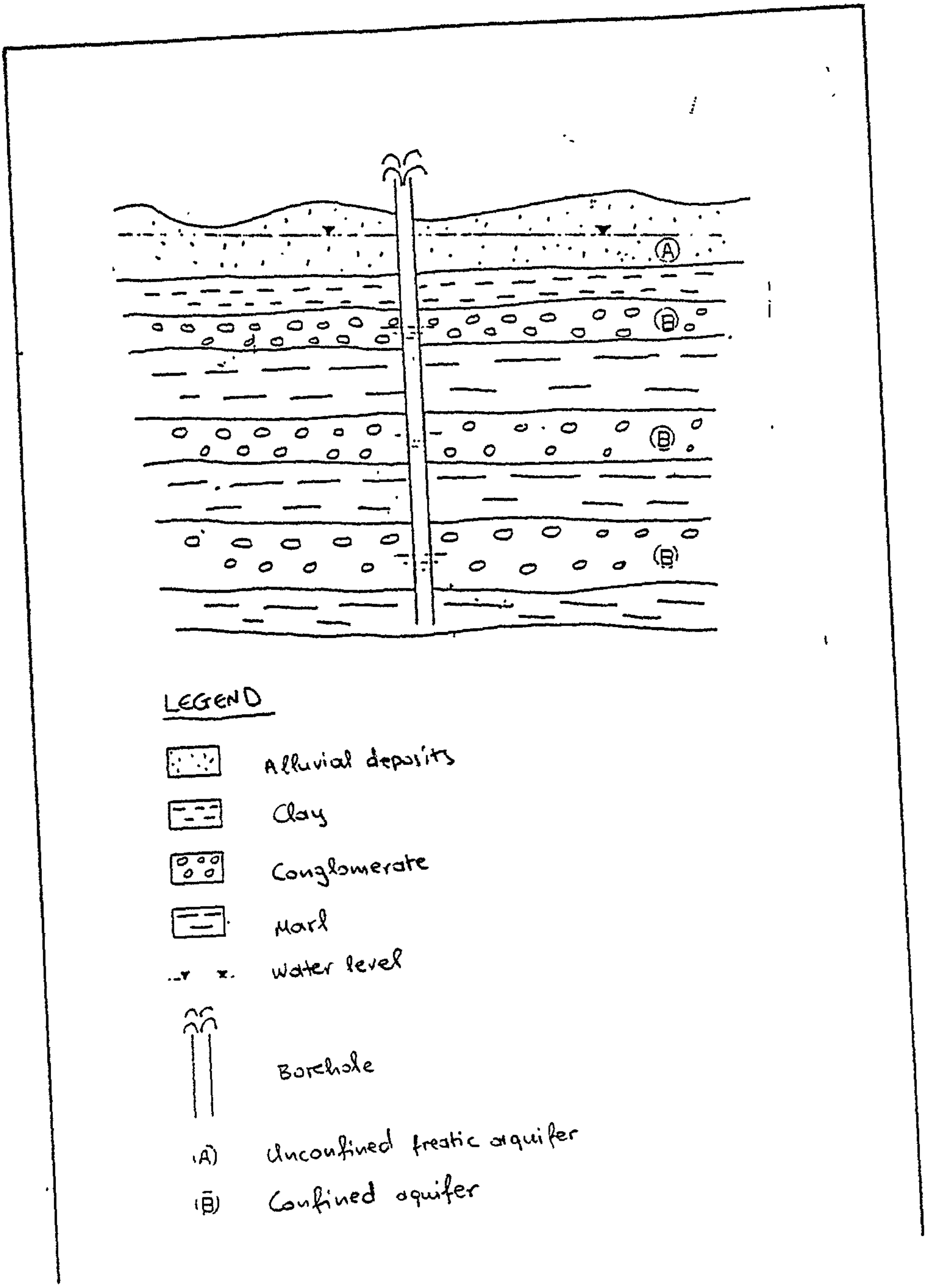

Figure 3 - Hydrogeological conditions of Levantinia deposits - City of Rhodes area (Strogilis, 1980)

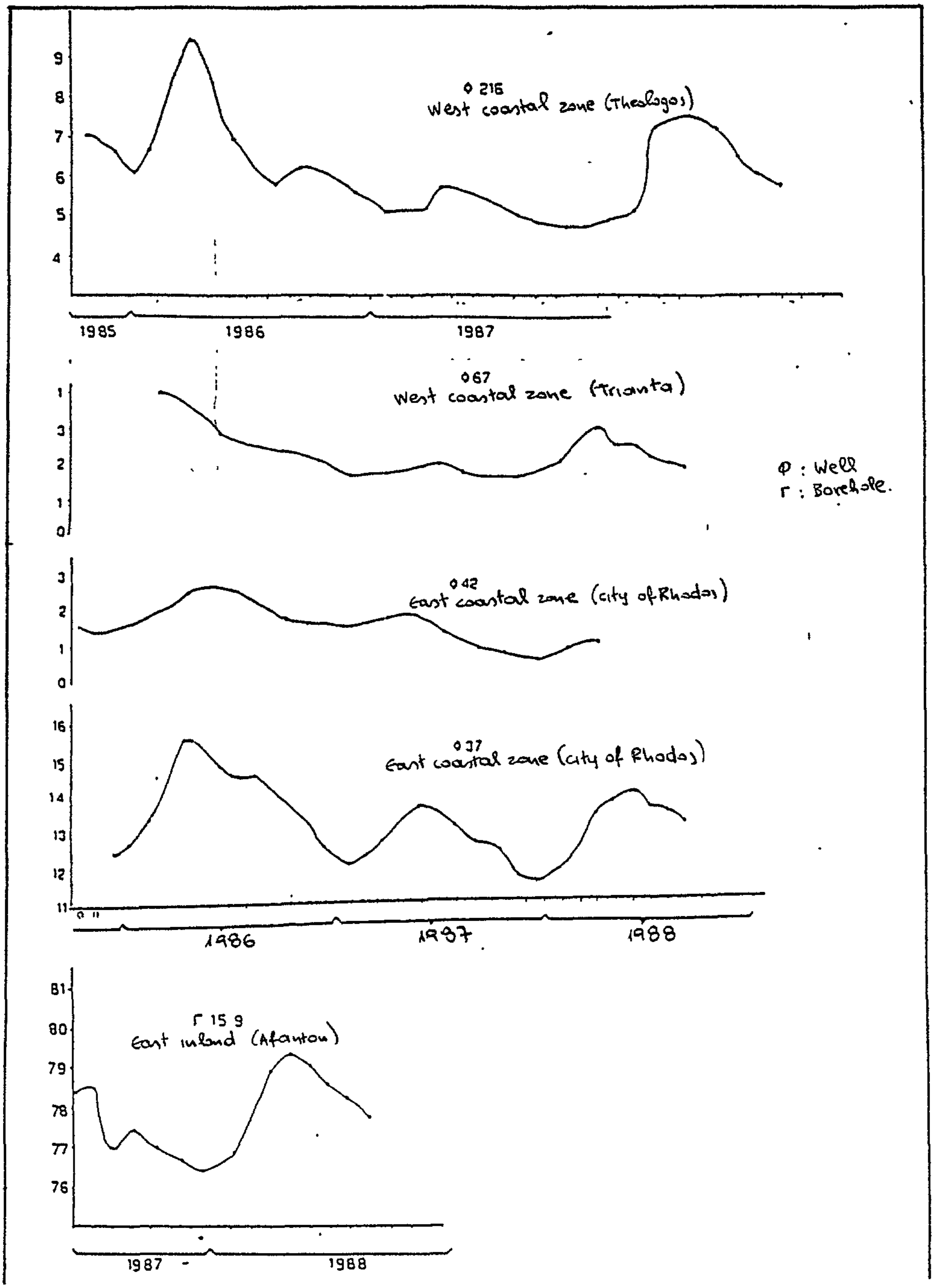

Figure 4 - Water level variation (Kilakos-Drossos, 1989)

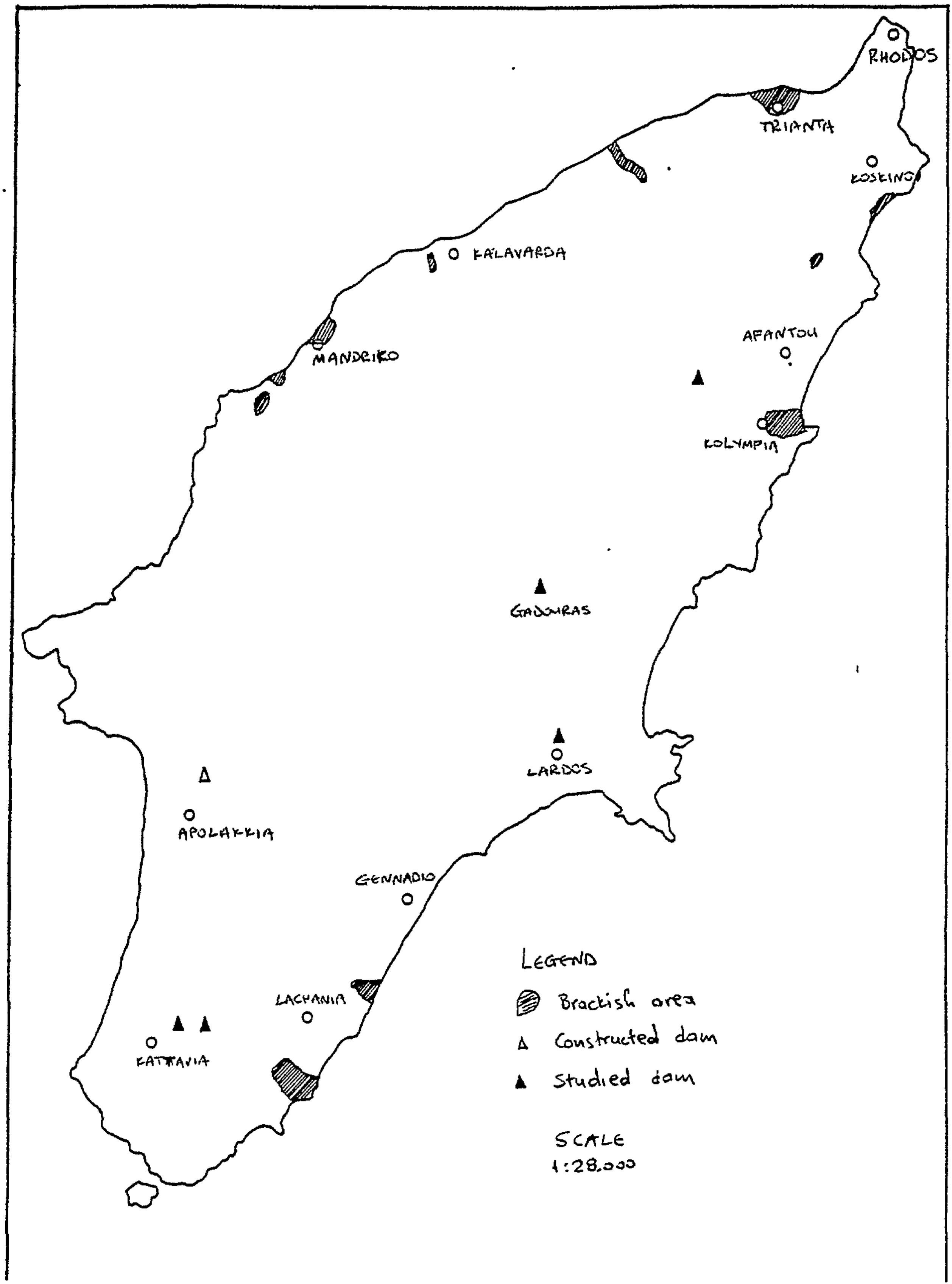

Figure 5 - Brackishness fronts and dam locations