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Mediterranean Coastal Areas (Island of Rhodes,
Kastela Bay, Syrian Coast, Malta and Cres/Losinj Islands)

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IMPLICATIONS OF EXPECTED CLIMATIC CHANGES ON THE ISLAND OF RHODES

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PREFACE

As part of the efforts of the United Nations Environment Programme (UNEP) to analyze the potential implications of predicted climate change and to assist the governments in designing policies and measures which may avoid or mitigate the expected negative effects of this change, or to adapt to them, the Oceans and Coastal Areas Programme Activity Centre (OCA/PAC) of the United Nations Environment Programme (UNEP), in co-operation with several intergovernmental and non-governmental organisations, launched, co-ordinated and financially supported a number of activities designed to contribute to an assessment of the potential impacts of climate changes and to the identification of suitable policy options and response measures which may mitigate the negative consequences of the expected changes.

As part of these efforts, Task Teams on the implications of climatic changes were established in 1987 for six regions covered by the UNEP-sponsored Regional Seas Programme (Mediterranean, Wider Caribbean, South Pacific, East Asian Seas, South-East Pacific and South-Asian Seas) with the initial objective of preparing reviews of the expected impacts of climatic changes on coastal and marine ecosystems, as well as on the socio-economic structures and activities of their respective regions. Five additional Task Teams were established later, two in 1989 (West and Central African, and East African regions) one in 1990 (Kuwait Action Plan region) and two in 1992 (Black Sea and Red Sea).

During the work on the Mediterranean regional study, it was felt that while the general effects might be similar throughout the Mediterranean region, the response to these effects would have to be highly site-specific. Therefore in the framework of the Mediterranean Task Team six specific case studies were prepared (deltas of the rivers Ebro, Rhone, Po and Nile; Thermaikos Gulf and Ichkeul/Bizerte lakes) by the end of 1989. The first site specific case studies had concentrated on low lying deltaic systems including these of the Ebro, Rhone, Po and Nile rivers. Following their publication by UNEP, the reports of the Mediterranean Task Team were published commercially in Book form by Edward Arnold (Jeftic *et al.*, 1992, Climatic Change and the Mediterranean). In preparing these case studies it had become apparent that prediction of impacts was constrained by the absence of scenarios of future climates on a regional, sub-regional and local scale.

Accordingly the Climatic Research Unit of the University of East Anglia had been commissioned by UNEP to attempt to produce a Mediterranean Basin scenario and to develop scenarios of future local climate for the selected case study areas. The scale of existing Global Circulation Models is such that determination of future temperature and precipitation patterns at a local level involves considerable uncertainty concerning future conditions. Without such local scenarios assessment of future impacts involves even greater levels of uncertainty, reducing the value of such assessments for immediate planning and management purposes. A suite of scenarios for the Mediterranean region were developed using the output from the GCM's coupled with a finer scale meteorological database. Scenarios for local sub-regions and areas were subsequently developed for those areas which were to be examined in more detail during the second generation of case studies.

Using the experience of these initial case studies, in 1990 the preparation of the "second generation" of site-specific case studies was initiated for the island of Rhodes, Kastela Bay, the Syrian coast, the Maltese islands and the Cres-Losinj islands.

The objectives of these studies were:

- to identify and assess the possible implications of expected climate change on the terrestrial, aquatic and marine ecosystems, population, land- and sea-use practices, and other human activities;

- to determine areas or systems which appear to be most vulnerable to the expected climate change; and

- to suggest policies and measures which may mitigate or avoid the negative effects of the expected impact, or adapt to them, through planning and management of coastal areas and resources;

using the presently available data and the best possible extrapolations from these data.

The "second generation" case studies utilised the regional and local scenarios developed by the University of East Anglia in attempting to assess and evaluate the implications of future changes on specific islands and areas covered by the Mediterranean Action Plan.

The Task Teams assembled for each of the second generation case studies were composed of experts from a wide variety of natural and social science disciplines, with specific knowledge of the areas concerned. In addition, the national and local authorities responsible for planning and developments in these areas were brought into the work of the Task Team from an early stage. Thus for example the Municipal authorities of Rhodes included the work of the Task Team within their coastal development planning and the Municipal authorities of Cres and Losinj hosted several meetings of the Task Team.

In order to ensure that the Task Teams retained as wide a perspective of the problem as possible several UNEP experts on Climate Change Impact Assessment were included at all stages of the preparation of these individual assessments. The full list of Task Team members responsible for this report is given in the Appendix to this report. A final joint meeting of representatives of the Task Teams and UNEP experts was held in Malta in September 1992 at which the conclusions and recommendations of each Task Team were reviewed, compared and finalised.

This report represents one of the five site specific assessments covered during the course of this work. Whilst it is important to recognise that climatic changes and sea level rise will have an impact on future use and development of the Mediterranean coastal areas, it is equally important to recognise that the rate and scale of other sources of change, such as land-use patterns and demographic changes may be of more immediate concern in certain areas. In this context, actions designed to address the future impacts of climatic change and sea level rise must be founded on a sound basis of immediate actions designed to reduce the rate of adverse changes resulting from uncontrolled development and use of the Mediterranean coastal environment and its resources.

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EXECUTIVE SUMMARY

This project forms part of a Coastal Area Management Programme (CAMP) for the Island of Rhodes (Annex I). This report is a result of the cooperative work of scientists of different disciplines who formed a Task Team to evaluate the implications of future climatic changes on the Island of Rhodes (Annex II). The project was carried out through the Mediterranean Action Plan of UNEP and the Greek Ministry of Environment. The objectives of the study were: to identify and assess the eventual implications of expected climatic changes on the various natural aspects and resources of Rhodes; to determine the most vulnerable areas and ecosystems; and to suggest necessary policies and measures to avoid and/or mitigate the negative effects of climatic changes.

Rhodes is situated at the SE corner of the Aegean Sea and is the capital of the Dodecanese Prefecture. It has an elongated shape with maximum length of 77 km, an area of 1400 km^2 and 191 km of coastline. It is a major tourist centre (about 850.000 tourist visitors in 1990) with a current population of 110.000 inhabitants.

The climate of Rhodes is typical Mediterranean with one cold and rainy period (November to March) and one warm and dry (April to October). The island is however, less warm in summer and less cold in winter than the other Aegean islands. Rainfall averages 714 mm yr^{-1}, higher than in other islands, while the prevailing winds are mainly from the NE and to a lesser extent, from the SW.

The island is formed from a variety of rock types (limestones, conglomerates, sands, gravels) and is characterised by smooth relief dissected by a number of valleys running NW-SE. Two thirds of the coastal zone is quite low (0 - 5 % inclination) especially where soft rocks such as alluvial gravels and sands outcrop along the shore. Many beaches in the NW part of the island currently experience high erosion rates while slumping and landslides occur in the coastal zone. Tectonic movement is quite high and along the northern shore, uplift of 1 mm per year has been noted. The island is affected by two different oceanographic regimes, one pelagic to the NW (Aegean) and one oceanic to the SE (Levantine). Strong currents pass through the Rhodes-Asia Minor Strait and long shore currents affect both the eastern and western coasts, which are also subject to severe wave attack in the rather rare event of strong Etesian and other winds.

The fresh water requirements of Rhodes are about 30 million m^3 yr^{-1}, an amount which is constantly increasing due to the tourist demands. Total precipitation on the island amounts to more than 160 million m^3 yr^{-1}. The main water sources are wells, springs and a dam, while the main aquifers lie in the alluvial deposits and the limestone karsts. Over-pumping of the alluvial aquifer has resulted in its salinisation in many parts of the island, making adequate water supply more difficult. The terrestrial ecosystems on the island are forests and shrublands, that have been badly damaged by fires in recent years. A unique butterfly community occurs at the so called "Petaloudes Valley", where particular conditions of temperature and humidity seem to occur. Coastal and marine ecosystems are generally oligotrophic.

The economy of Rhodes is principally based on tourism, which is dependent on the large number of hotels built along the islands beaches. The other sectors of the economy are marginal in comparison with tourism.

A detailed climatic scenario for the eastern Mediterranean and for Rhodes in particular was constructed by the Climate Research Unit of the University of East Anglia, on the basis of General Circulation Model scenarios of greenhouse effects. These scenarios indicate an increase in mean annual temperature of between 0.9 °C and 1.4 °C by the year 2030; an increase of between 1.5 °C and 3.3 °C by the year 2100; a rather small increase in the annual precipitation; and a sea level rise of about 20 to 30 cm by 2050 and of 60 to 100 cm by 2100 (Annex III).

The major impacts of these expected climatic changes on the insular environment of Rhodes are anticipated to occur in the coastal zones, on the soil, and on the aquifers, while the predominant socio-economic impacts will be on the infrastructure and in the tourist sector.

The coastal zone of the island is already being adversely affected by wave and current action, particularly in the northwest and this erosion will be further intensified by the sea level rise (SLR). Impacts will not be noticeable during the initial 40 cm rise but will be intensified under conditions of a 1 m rise. Due to further aridity of the soil and the torrential character of the rainfall, the present rate of soil erosion will be further aggravated.

Regarding water balance, the temperature rise will inevitably increase evapotranspiration and decrease total runoff and infiltration. The present surface reservoir will be filled more rapidly while the groundwater reserves will diminish due to lower infiltration, resulting in a lowering of the level of the aquifers and causing springs to dry up. As a consequence of SLR, sea water will intrude into the alluvial plains and the brackish water front will advance inland.

The anticipated temperature increase will lengthen the tourist season and this could be considered a positive consequence. The local climatic scenario also suggests that Rhodes will continue to constitute a fresh spot in a warmer Eastern Mediterranean. At the same time the incidence of fire will increase, and the maquis ecosystem will change to a more drought resistant community.

In the case of physical infrastructure, most impacts are expected on structures in the coastal zone. Fortunately most resort establishments are located at the back of the shore and the consequences of future sea level rise will be rather minor. However on the densely populated NW coast and northern tip of Rhodes, the impacts on existing infrastructure, which is built near the shoreline, is expected to be very significant.

Considering all of the available data and estimations, evaluated and used in this study, four zones of vulnerability were recognized in Rhodes as follows (in decreasing order of vulnerability):

Zone I includes the coastal lowland plains of up to 1 m altitude that will become inundated under a 1 m rise in sea level;

Zone II is the coastal or agricultural area contiguous with Zone 1 that will be affected by surface flooding during strong storms and by sea water infiltration of groundwater;

Zone III is the densely populated urban area protected by sea walls or breakwaters that could be overtopped by a 1 m rise in sea level; and,

Zone IV is the area of unique ecosystems vulnerable to the expected climatic changes (butterflies, gizani).

In order to address the identified impacts a series of actions and recommendations are suggested in this report, as follows:

1. there is a need to develop a coastal zone management plan that would provide for specific land use zones and where possible, set back zones along retreating shorelines. The building standards have to be adjusted in terms of legislation, efficiency and implementation that for example would provide no public compensation for losses due to erosion;

2. the freshwater resources should be explored and sustainably exploited on the basis of present and future rising requirements and capacity. There is a need for an integrated water management plan and for additional water supplies that could be provided by the construction of new dams and drilling of additional boreholes into karstic aquifers;

3. the burned and eroded sectors of Rhodes must be reforested and managed on the basis of scientific guidelines and advice; and

4. there is a need to evaluate the consequences of a lengthening of the tourist season in terms of the additional services that will be required and the effects on the islands economy, character and indigenous population.

1. INTRODUCTION

1.1. Background

This project forms part of the Coastal Area Management Programme (CAMP) for the Island of Rhodes, of the United Nations Environment Programme, Mediterranean Action Plan (UNEP/MAP) (see Annex I). The CAMP case studies, are mainly concerned with examining representative arid insular environments of the Mediterranean (Kastela Bay, Syrian coast, Izmir Bay, Rhodes island) and form the second series of climatic change impact studies conducted under the Mediterranean Action Plan.

This study is an integrated attempt to identify and estimate the impacts of the expected climatic changes on the insular environment of Rhodes. Though, the multidisciplinary task team was composed of eight national scientific experts from the academic and professional sector as well as two international experts (see Appendix). The task team has gathered into four meetings to discuss partial results during the progress of the project work (see Annex II). Field trips have been highly important for the efficient site study of the vulnerable areas.

Following the introduction, the background to the study is presented, together with a brief summary of the main features of the Island of Rhodes, and the premises and assumptions used to evaluate the impacts of climate change. In particular, the methodology used by the Climate Research Group of the University of East Anglia (Climatic Research Unit, 1992) to provide scenarios for the NE Mediterranean and Rhodes, is outlined. Some of the data on which these scenarios are based, were kindly provided by the Greek Meteorological Service.

The present environmental and socio-economic situation are described in detail. The climate of Rhodes is initially discussed and the features of various meteorological parameters such as temperature, humidity and rainfall are analyzed, and compared with those of other Aegean islands. Rhodes is cooler in summer and warmer in winter than the rest of the Aegean, a fact that makes this island an ideal resort area. A thorough overview of the islands geology and geomorphology, with special reference to the coastal lowlands, beaches and coastline is provided and the hydrogeology of each geological formation described. The current and future water requirements are examined in relation to the scenarios of future climate.

Related to the present and future climate, the oceanographic regime of the sea surrounding Rhodes, including currents, sea surface temperature, salinity, waves and sea level oscillations are examined and details of their variation in the different coastal areas of Rhodes are provided. The island is exposed to an open oceanic regime to the south and to a more enclosed marine environment to the north. Rhodes natural beauty is based on its characteristic ecosystems which are described from the perspective of ecology and conservation. Native and introduced forest trees, shrublands, and other terrestrial systems are all examined and special consideration given to the problem of fires and water shortage. The aquatic and marine ecosystems, flora and fauna are also described. Finally the socioeconomic aspects of the island are examined in the light of the last (1991) and previous census results, all of which indicate the dominant role of tourism in the economy of Rhodes. Industry, infrastructure, primary and secondary economic sectors are all directly related to tourism and this close inter-relationship is evaluated in the light of past experience and future prospects.

Following the description of the present state of the physical, biological and human environment of the island, the possible consequences of expected climatic changes are evaluated. The impacts of sea level and temperature rise on natural systems, including climate, coastal geomorphology, soils and erosion, hydrology and water resources, marine environment, terrestrial ecosystems and on the population and economy, are detailed.

However this study can not be considered complete without proposals for action that could be taken in order to address the identified impacts. Suggested actions and recommendations are provided in relation to all aspects of the island's projected development over the next 100 years, and in relation to the vulnerability assessment, which is further detailed in Annex IV.

The report represents an integrated approach and is the result of a cooperative team effort, undertaken by a multi-disciplinary Task Team, with the aim of providing an improved understanding of our changing environment. As such it provides the basis for decision makers to evaluate and adopt appropriate planning and management actions designed to meet the expected impacts of climatic changes. Although neither the magnitude nor the timing of climatic changes and hence the magnitude and timing of predicted impacts can be definitively predicted at present, one should not neglect taking inexpensive precautionary measures at this stage. Such precautionary measures should include detailed evaluation of the consequences of climatic changes and of feasible mitigatory measures.

1.2. Basic facts concerning the Island of Rhodes

Rhodes is the largest and most densely populated of the Aegean islands. It is situated at the SE corner of the Aegean Sea, and is the capital of the Dodecanese Prefecture which encompasses twelve islands. It has an elongated shape with a length of 77 km and a rather smooth relief in comparison with the neighbouring islands. The central mountain massif with its peaks of Attaviros (1215 m) Profitis Ilias (870 m) and Acramitis (900 m) is surrounded by smooth plains to the north and south and the island is fringed by a number of sandy beaches.

Going back into antiquity, it is certain that neither the Achaians when they settled on this island (at least as early as 1500 B.C.) nor Hippodamus (when he developed the city's plans, by uniting three other cities in 400 B.C.) considered that any consequences of climatic change might affect their settlement or city plans. Rhodes was and has remained an attractive, sunny, all year resort, purely Greek, in spite of the many conquerors that have passed through.

This island of outstanding natural beauty, favourable climate and important geographic location has been given more than ten names, relating to its shape, climate or other characteristics, including Rhodes (island of roses), Aethria (having clear sky), Asteria (star shaped), Macaria (happy), and Pontia (located at the sea). It was inhabited as early as Neolithic times and prehistoric remnants have been found at Lindos. Homer described it as a rich island, due in part to its privileged geopolitical position overlooking the sea lanes between east and west. The cornerstone of the islands development was the decision of the cities of Lindos, Cameiros and Ialyssos, to unite and to ask the famous architect Hippodamus of Militos to draw up plans for its development. Rhodes grew rapidly becoming a major cultural and artistic centre and the island enjoyed prosperity for about eleven centuries from 400 BC to 700 AD.

A shortage of freshwater was however always a problem, as is the case for most Aegean islands and destructive earthquakes such as those of 227 B.C. and 153 A.D. were also a major threat to Rhodes. In Greek-Byzantine times the strategic nature of Rhodes attracted conquerors such as the Persians (620 A.D.) the Arabs (653 and 807 A.D.) and the Genovese (1246 A.D.) who sold the island to the Ioannides in 1309. The Turks took over in 1522 and after them, the Italians from 1912 to 1945, when it became Greek again. Since 1945, Rhodes has become a major resort centre and is the only one of the Dodecanese group of islands which has had a continuous increase in both population and economic growth.

The island covers an area of 1400 square kilometres, and has a coastline of total length of 191 km. According to the 1981 census the population was 90,963 inhabitants giving an average density of 65 persons km^{-2}, and the city of Rhodes had a population of 41,425 people at that time.

A major feature of the demography of the island has been the reversal of the negative trend in population growth in 1971 to a positive trend in 1981; a reversal which has not occurred in other districts in the eastern Aegean. Major reasons for this change were: the return of emigrants; economic development, which encouraged people to remain on the island; and the attraction to the island of immigrant labour from other areas of Greece.

The total population of the island reached 110,000 people in 1991 which represents 67% of the population of the Dodecanese Prefecture compared to only 60% in 1981. The distribution of the population in urban, semi-urban and rural areas is 46.7%, 23.3% and 30.0% respectively. The majority of the population, 63.9% live in the lowlands, 19.02% in the hilly areas and 17.08% in the mountains.

The climate of Rhodes is temperate Mediterranean and the temperature is high throughout the year with the annual mean being 18.8 °C; maximum temperature in 1981 was 34.8 °C; minimum 4.2 °C. The average rainfall is 714 mm yr^{-1} and the number of rainy days is 94 a year. The regularly blowing winds and large number of sunny days during the winter are remarkable.

The morphology of the island is generally hilly with small valleys where agricultural activities are being developed. The lowlands in the south of the island cover 27% of the total area and provide 47% of arable land. Land use on the island is as follows: 16% arable; 47% pasture; 25% forest; 8% urban land, roads, etc.; 4% uncultivated; and, 2% covered by water.

The archipelagic nature of the Dodecanese Prefecture results in the social and economic isolation of the populations of individual islands. Transport costs raise the price of supplies and products and the flow of information is restricted, creating difficulties for introducing new technology and applications and in providing training.

Following its transfer to Greek sovereignty special customs regulations covering the Dodecanese were established aimed at the development of the area and leading to the creation of direct trade links with markets abroad. The gradual abolition of these privileges now causes difficulties in trade development. Another particular characteristic of this area is the existence of a 4% municipal tax on all imported goods.

The uneven development of the tertiary economic sector and its concentration on tourism has negatively affected primary production. In 1986, food imports reached a cost of 4 billion drachmas from a total import bill of 10.5 billion drachmas.

An increase in the use of agricultural machinery tends to improve productivity and to make prices competitive, but the low proportion of irrigated land together with the limited use of improved irrigation methods is a major constraint to intensive cultivation which is only around 15% of the total.

Agricultural production does not meet local market demand, leading to increased cost of products reflecting the added costs of transport and the profit of intermediaries. At the same time the volume of imports is continuously increasing. The lack of capital, lack of training and the advanced age of most of the agricultural population presents difficulties in implementing projects based on contemporary agricultural concepts. It should be noted in this context that the demands created by the tourist market are particularly influential and have serious consequences for the nature and limits to development of the agricultural sector.

Manufacturing is mainly carried out by small enterprises generally involving less than 5 persons and the contribution of this sector to the gross domestic product is approximately 10%. Large industrial concerns deal almost exclusively with the production of sparkling wines such as Cair, Fokiali and Emery. The strong influence of tourism explains to some extent both the flourishing handicraft enterprises which meet the needs of the tourist market and the absence of large factories.

The service sector covers a wide range of activities directly or indirectly determined by the tourist market. Retail and wholesale trade, restaurants, transport, banking and other economic activities, car rental, public health services and recreational activities influence and are influenced by, the tourist and hotel trade. The variety and quality of these services has itself contributed to the development of tourism. Tourism is therefore the dominant economic factor and an important contributor to gross domestic product. The tourist industry is the most dynamic agent of change with a strong influence on demand and supply in the wider tertiary service sector and on the primary and secondary sectors. The economy of the island, based as it is almost completely on the tourist market is influenced by external factors including international political and economic conditions, and shows an unequal "one-sided" development.

1.3. Climate change assumptions and methodology

1.3.1. The use of GCMs in regional scenario development

It is generally accepted that the results from General Circulation Models (GCMs) offer the best potential for the development of regional climate scenarios since they are the only source of detailed information on future climates which can be extrapolated beyond the limit of conditions which have occurred in the past.

GCMs are complex, computer-based, models of the atmospheric circulation which have been developed by climatologists from numerical meteorological forecasting models. The standard approach is to run the model with a nominal "pre-industrial" atmospheric CO_2 concentration (the control run) and then to re-run the model with doubled (or sometimes quadrupled) CO_2 (the perturbed run). In both, the models are allowed to reach equilibrium before the results are recorded. This type of model application is therefore known as an equilibrium response prediction.

The fact that the GCMs are run in equilibrium mode must in itself be regarded as a potential source of inaccuracy in model predictions. It can be argued that the predicted regional patterns of climate change will differ from those that will occur in a real, transient response world. This is because equilibrium results ignore important oceanic processes, not least: changes in ocean currents; effects resulting from the differential thermal inertia between different parts of the oceans; changes in the land and ocean interaction in local atmospheric circulation patterns; and, changes in the oceanic thermohaline circulation. Transient response predictions which should provide a more realistic estimate, are only now becoming available, under these models the CO_2 concentration increases gradually through the perturbed run and the oceans are modelled using ocean GCMs. However, the complexity of the problem in relation to present-day computing capability places uncertainty on the reliability of the results which is likely to remain the case over the next decade. The present study therefore is restricted to the use of results from equilibrium GCM experiments. The results from four GCMs developed for climate studies have been used to develop the scenarios used in this report. They are from the following research institutions:

- UK Meteorological Office (UKMO);
- Goddard Institute of Space Studies (GISS);
- Geophysical Fluid Dynamics Laboratory (GFDL); and
- Oregon State University (OSU).

The models vary in the way in which they handle the physical equations describing atmospheric behaviour. UKMO, GISS and OSU solve these in gridpoint form whereas GFDL uses a spectral method. All models have (within the constraints of model resolution) a realistic land/ocean distribution and oreography; all have predicted sea ice and snow; and clouds are calculated in each atmospheric layer in all models.

One problem with the application of GCMs to the study of climate impacts at a regional and sub-regional level is the coarse resolution of the model grid. The grid scale of the four models listed above ranges from 4° latitude x 5° longitude (OSU) to 7.83° latitude x 10° longitude (GISS). GCMs, therefore, have a spatial resolution of several hundreds of kilometres, which is inadequate for most regional climate change studies, particularly in areas of high relief. Presented here are a set of high resolution scenarios for the north-eastern Mediterranean, based on the statistical relationship between grid-point GCM data and observations from surface meteorological stations (Annex V).

1.3.2. Construction of sub-grid-scale scenarios

Kim *et al.* (1984) examined the statistical relationship between local and large-scale, regionally-averaged values of two meteorological variables: temperature and precipitation. They then used these relationships, developed using principal component analysis techniques to look at the response of local temperature and precipitation to the predicted change at GCM grid points. The area of study used by Kim *et al.* (1984) was Oregon State (U.S.A.) and although this paper contains certain statistical flaws, the underlying idea of statistically relating local and large-scale data is sound. The method of Kim *et al.* (1984) has been extended and refined by Wilks (1989) and Wigley *et al.* (1990).

The Climatic Research Unit (1992) have modified the methods of Kim *et al.* (1984) and Wigley *et.al.* (1990) for application in the Mediterranean region. In the model validation exercise carried out for the Mediterranean Project (Palutikof, *et al.*, 1992) it was established that no single GCM can be identified as being always the best at simulating current climate. This being the case, there is little merit in presenting scenarios based on only one model. Presentation of scenarios for each of the four models avoids this problem, since the task of deciding which model is "best", and/or of synthesizing the information to obtain a best estimate, is left to the impact analyst. Information from the four models has been combined into a single scenario for each variable, according to the method described below.

The problem with presenting the scenarios in this form is that resulting scenarios may be biased by the different equilibrium responses of the individual models. The global warming due to a doubling of CO_2 for the four GCMs, ranges from between 2.8°C for the OSU model to 5.2°C for the UKMO model run. We would therefore expect that the warming indicated by the UKMO GCM for the Mediterranean Basin would be greater than that suggested by the OSU model, even though the sensitivity of the region to climate change when compared to the global sensitivity might be the same. The individual model perturbations have therefore been standardized by the equilibrium (global annual) temperature change for that model, prior to the calculation of the four-model average.

A generalized computer program was needed that would be applicable throughout this geographically complex area and could be used with meteorological records of variable length and density. After investigating a number of approaches to the problem (Climatic Research Unit, 1992) we adopted the procedure summarized below:

1. data sets of monthly mean temperature and total precipitation have been compiled for the area surrounding the Mediterranean Basin. Stations used in this study of the north-eastern Mediterranean are listed in Annex V. Where possible, each record should be complete for the period 1951-88. Any station with a record length less than 20 years in the period 1951-88 for over six months out of twelve was immediately ;

2. then, for every valid station, the temperature and precipitation anomalies from the long-term (1951-88) mean were calculated. For this part of the work, which is the first step in the construction of the regression equations (the calibration stage), only the data for 1951-80 were used. The 1981-88 data were retained to test the performance of the regression models (the verification stage (Palutikof, *et al.*, 1992). For the calculation of the temperature anomaly Δt_{ij}, the simple difference was used:

$$At_{ij} = t_{ij} - T_j$$

where t_{ij} is the mean temperature of month j in year i; and T_j is the long-term mean for month j. The precipitation anomaly Ap_{ij} was expressed as a ratio of the long-term mean:

$$Ap_{ij} = (P_{ij} - P_j)/P_j$$

where P_{ij} is the monthly total precipitation in month j of year i; and P_j is the long-term mean for that month. If P_j is less than 1 mm, then this equation is modified to:

$$Ap_{ij} = (P_{ij} - P_j)/1.0;$$

3. the individual station anomalies are used to calculate regionally-averaged anomalies. The procedures described from here to the end of Point 6 are station-specific, and must be repeated for each station in the data set.

   A 5° latitude x 5° longitude square is centered over the station for which regression equations are to be developed (the predicted station). All the stations which fall within this square are used to calculate the regional averages. If the number of stations is less than three, for temperature; or four, for precipitation, the procedure is halted. For temperature, the anomalies for all stations in the 5° x 5° square are averaged month-by-month to produce an area-average time series. For precipitation, the substantial degree of spatial variability makes it advisable to area-weight the station anomalies before calculating the regional mean for each month. To do this, the 5° x 5° region is divided into 20 x 20 smaller squares. The precipitation anomaly value assigned to a particular square is that of the station nearest to it (with the restriction that the distance separating a square from its nearest station should be no greater than 1° - where the distance is greater the square is ignored). The area average is then the mean of the values in the 400 (or fewer, if any fail the minimum distance criterion) squares. This method is similar to the standard Thiessen polygon method;

4. regression analyses were performed using station temperature and precipitation anomalies as the predictants. These analyses were carried out on an annual and seasonal basis: winter (December, January, February), spring (March, April, May), summer (June, July, August) and autumn (September, October, and November). By considering the monthly values as separate observations within each season, we were able to extend the number of observations and so preserve a high number of degrees of freedom. The predictor variables are the regionally-averaged anomalies of temperature and precipitation;

5. in order to determine the perturbation due to the greenhouse effect at each station, the results from GCMs were employed. It is assumed that a GCM grid-point temperature or precipitation value is equivalent to a regionally-average value derived from observational data. For each of the four GCMs (GFDL, GISS, OSU and UKMO), the perturbed run and control run grid-point temperature (t) and precipitation (p) values are interpolated to the station position. Then, we obtain, for temperature:

$$Atm_i = t_i(2 \times CO_2) - t_i(1 \times CO_2)$$

   where Atm_i is the perturbation due to CO_2 or the "temperature anomaly" for model i and, for precipitation:

$$Ptm_i = [p_i(2 \times CO_2) - p_i(1 \times CO_2)] \times 100/p_i(1 \times CO_2)$$

   where Ptm_i is the standardized perturbation due to CO_2 or the "precipitation anomaly" for model i.

   The values for Atm and Ptm for each GCM are then substituted in the regression equations to obtain a prediction for the station perturbation of temperature (°C) and precipitation (%) due to CO_2;

6. the predicted change in temperature and precipitation for each model is divided by the equilibrium (Global mean) temperature change for that model. The results are then averaged across the four models to obtain a composite value;

7. the procedures from Points 3 to 6 is repeated for each station throughout the Mediterranean. The results can then be plotted and contoured to obtain a map of the expected patterns of temperature and precipitation change due to the greenhouse effect.

In order to arrive at this procedure, a vigorous investigation of the validity of the method has been carried out. In particular, the Climatic Research Unit (1992) have looked at:

- the use of other predictor variables in the regression equations;
- performance and verification of the regression equations;
- autocorrelation in the data; and
- multicollinearity in the predictor variables.

These aspects are discussed in detail in the University of East Anglia Final Report (Palutikof, *et al.*, 1992).

1.3.3. Climatic change scenarios for the NE Mediterranean

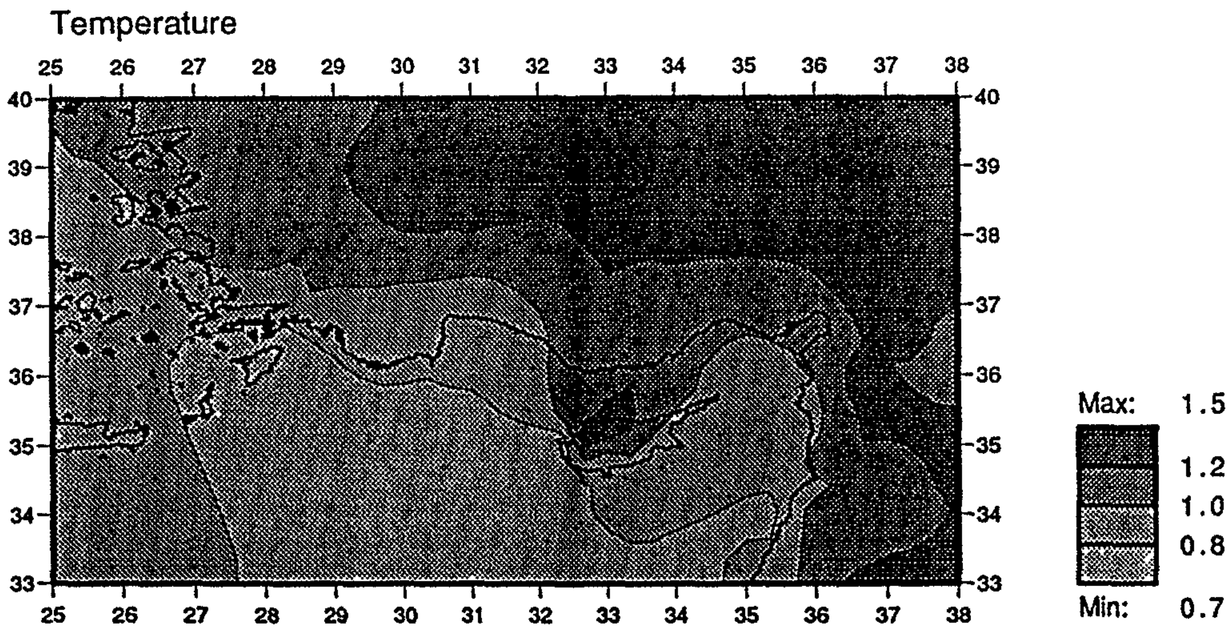
The sub-grid-scale scenarios, constructed according to the method outlined in Section 1.2, are shown in Figures 1-5. The temperature perturbations are presented as the model average change, in degrees Celsius, per °C global annual change. The precipitation perturbations are shown as the percentage change for each 1 °C global annual change. This procedure is described in greater detail, and the approach justified, in Section 1.2 and in Palutikof *et al.* (1992).

The problem with expressing the scenarios in this form is then to scale the values up (or down) in relation to some realistic estimate of the temperature perturbation to be expected from the greenhouse effect. The IPCC Report (Houghton *et.al.*, 1990) provides one such family of estimates. For their Business-as-Usual scenario of emissions, the likely increase of global mean temperature by the year 2050 is predicted to be about 1 °C above the present level. By the end of the next century, the increase is estimated at 3 °C above present-day. On this basis, the temperature and precipitation scenarios for the north-eastern Mediterranean presented in this report can be related directly to changes between now and the year 2050.

The scenarios for changes at the annual level are shown in Figure 1. In the north and east of the region the temperature change is indicated to be greater than the global change i.e. more than 1 °C per °C global warming. In the south and west the sensitivity should be slightly below the global value. The boundary between the two lies approximately along the coast. The greatest temperature increase (1.2-1.5 °C per °C global change) is indicated for the interior of Turkey; the countries bordering the eastern Mediterranean; and the north coast of Cyprus. Lowest changes (0.7-0.8 °C per °C global warming) are shown over the southeastern Dodecanese Islands, including Rhodes, and the extreme western tip of Cyprus. Precipitation is predicted to increase in the west and the extreme east of the study region, by up to 6% per °C global temperature change. Apart from western Turkey, the mainland coastal regions are all shown to experience a reduction in precipitation, to a maximum of -2 to -6% per °C global temperature change over the central southern Turkish coast and Cyprus.

In the winter months of December, January and February (Figure 2) the predicted temperature changes are between 1.8 °C and 0.5 °C per °C global change. Lowest temperature changes are found along the southwestern Turkish coast and the adjoining Greek islands. Highest changes (1.4 °C-1.8 °C per °C precipitation) shows a pronounced decline in the southwest of the study region (between -6% and -15% per °C global temperature increase). However, increased precipitation is predicted for Turkey, eastern Cyprus and the eastern Mediterranean coast. The greatest increase in precipitation is shown to be in the northern part of the study of 2-6% per °C global change.

Spring scenario temperature changes (Figure 3) follow the same pattern as those indicated by the annual and winter scenarios: a trend of decreasing sensitivity to the greenhouse effect from northeast to southwest. Precipitation amounts are predicted to increase in most areas with the exception of Cyprus and the adjoining coasts of Turkey and the eastern Mediterranean. The greatest increases are shown in the southwest and southeast of the region, between 6% and 15% per °C global change.



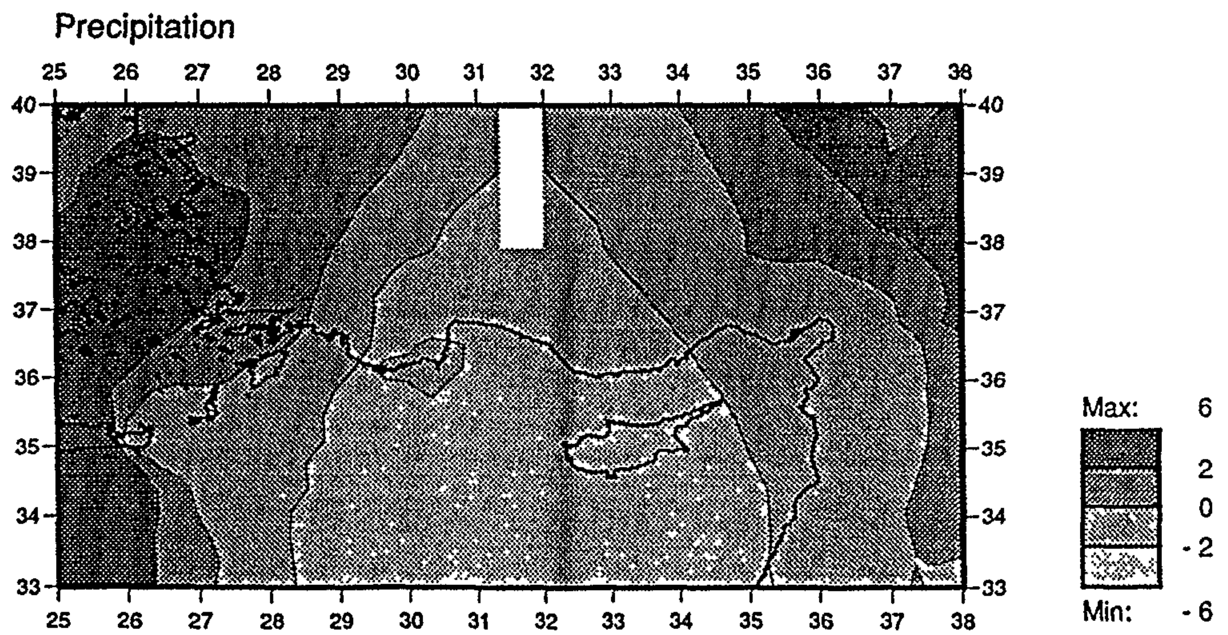


Figure 1 - Regional climate scenarios for the northeastern Mediterranean: annual temperature (Climatic Research Unit, 1992)

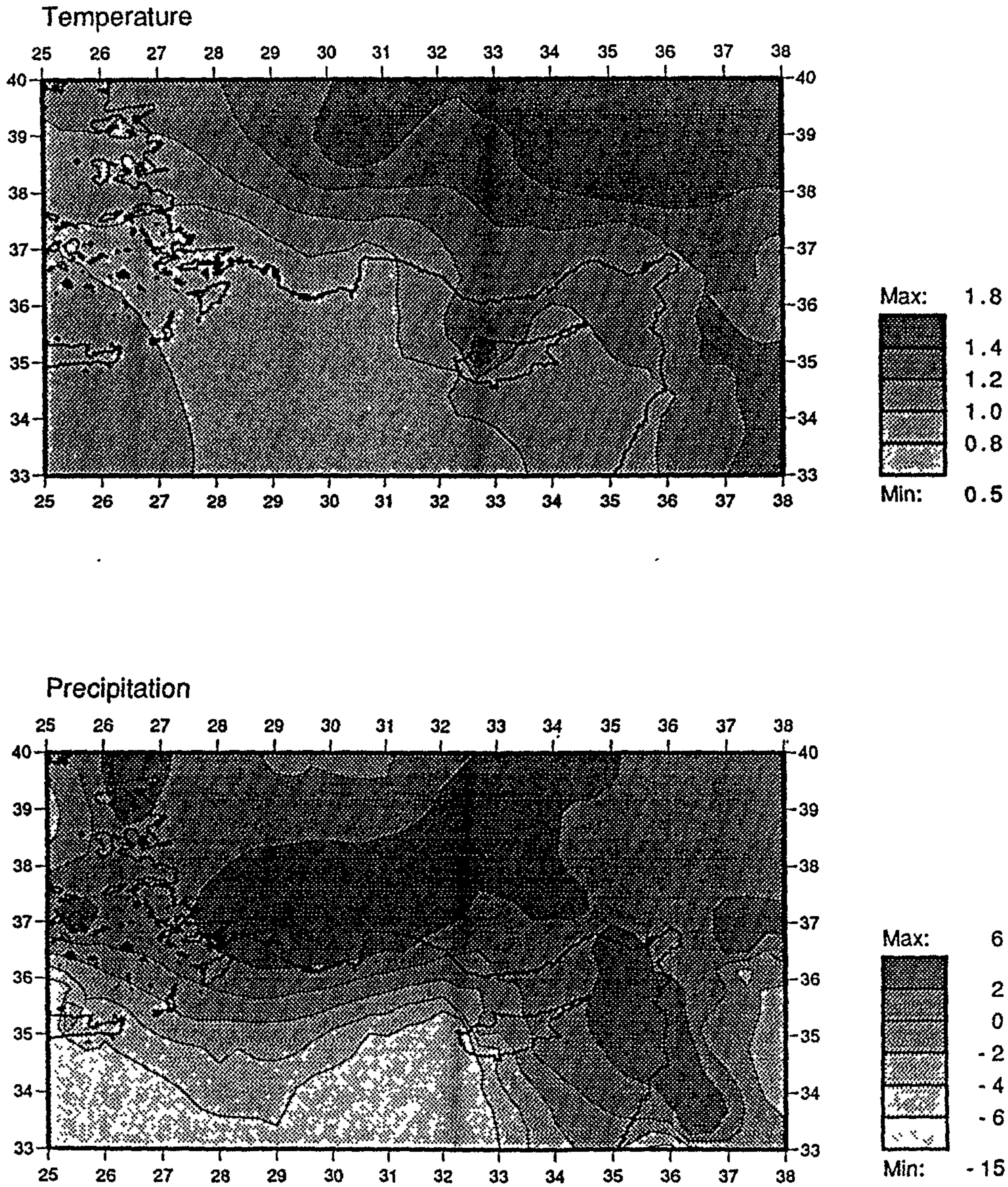


Figure 2 - Regional climate scenarios for the northeastern Mediterranean: winter temperature (Climatic Research Unit, 1992)

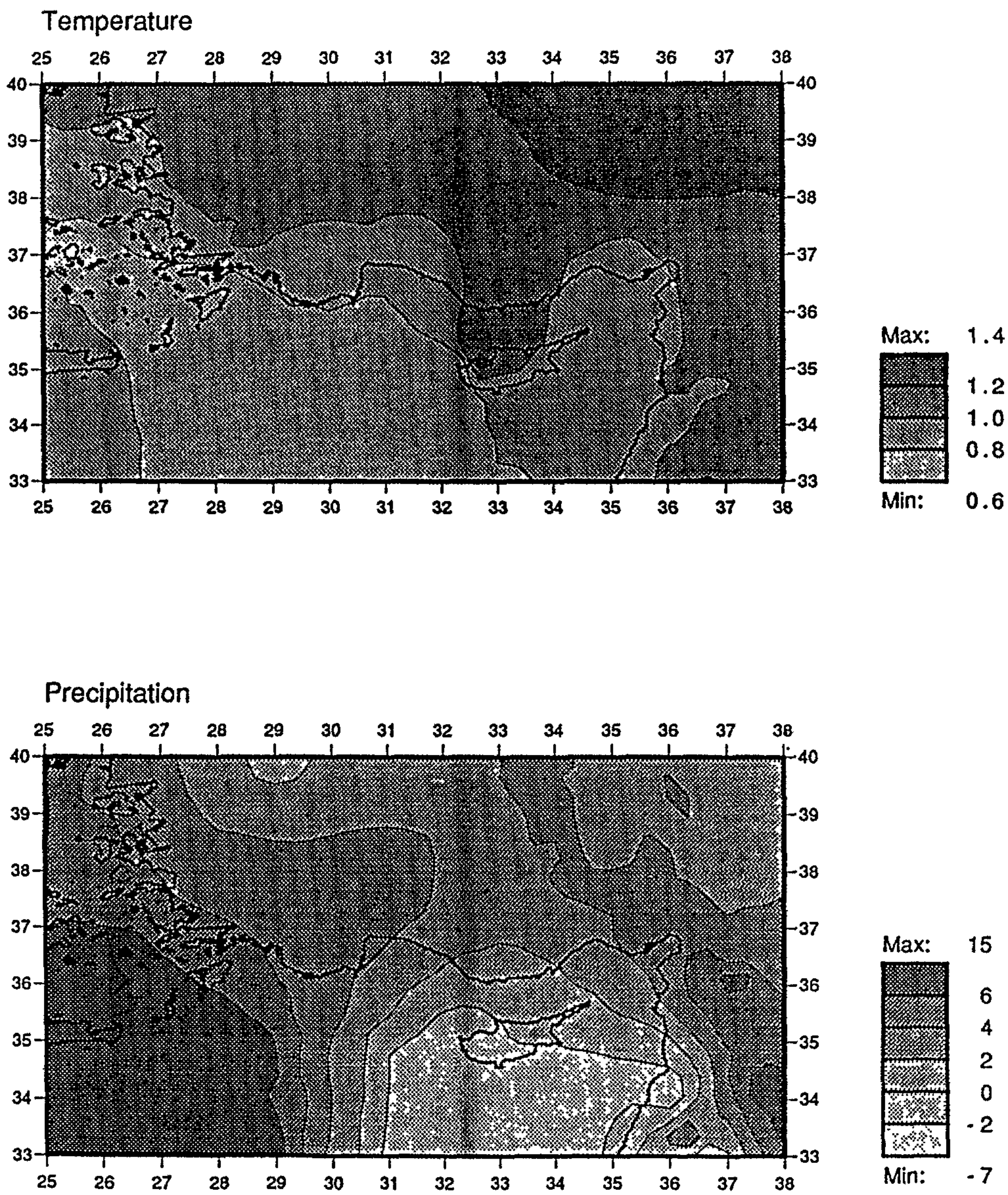


Figure 3 - Regional climate scenarios for the northeastern Mediterranean: spring temperature (Climatic Research Unit, 1992)

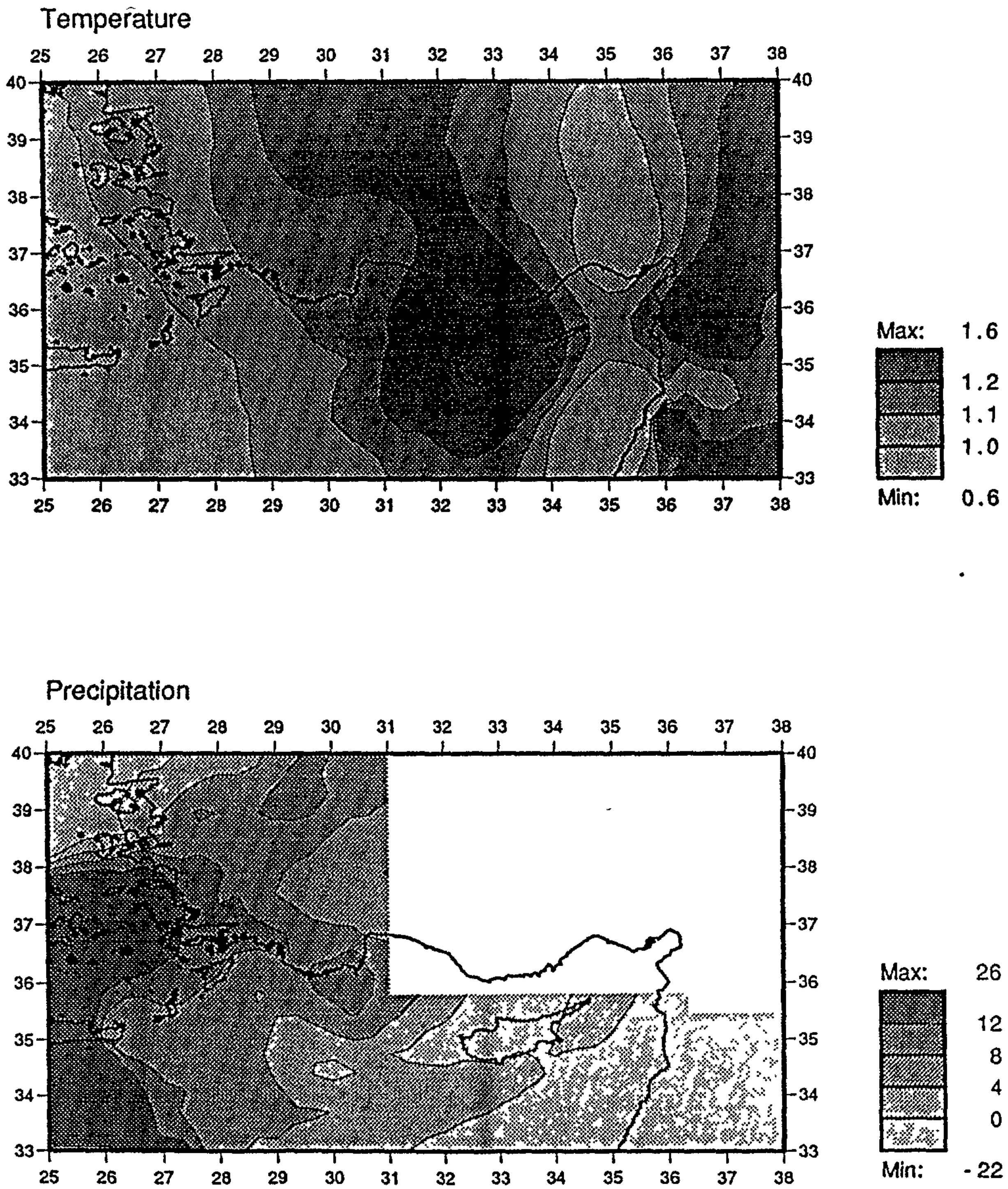


Figure 4 - Regional climate scenarios for the northeastern Mediterranean: summer temperature (Climatic Research Unit, 1992)

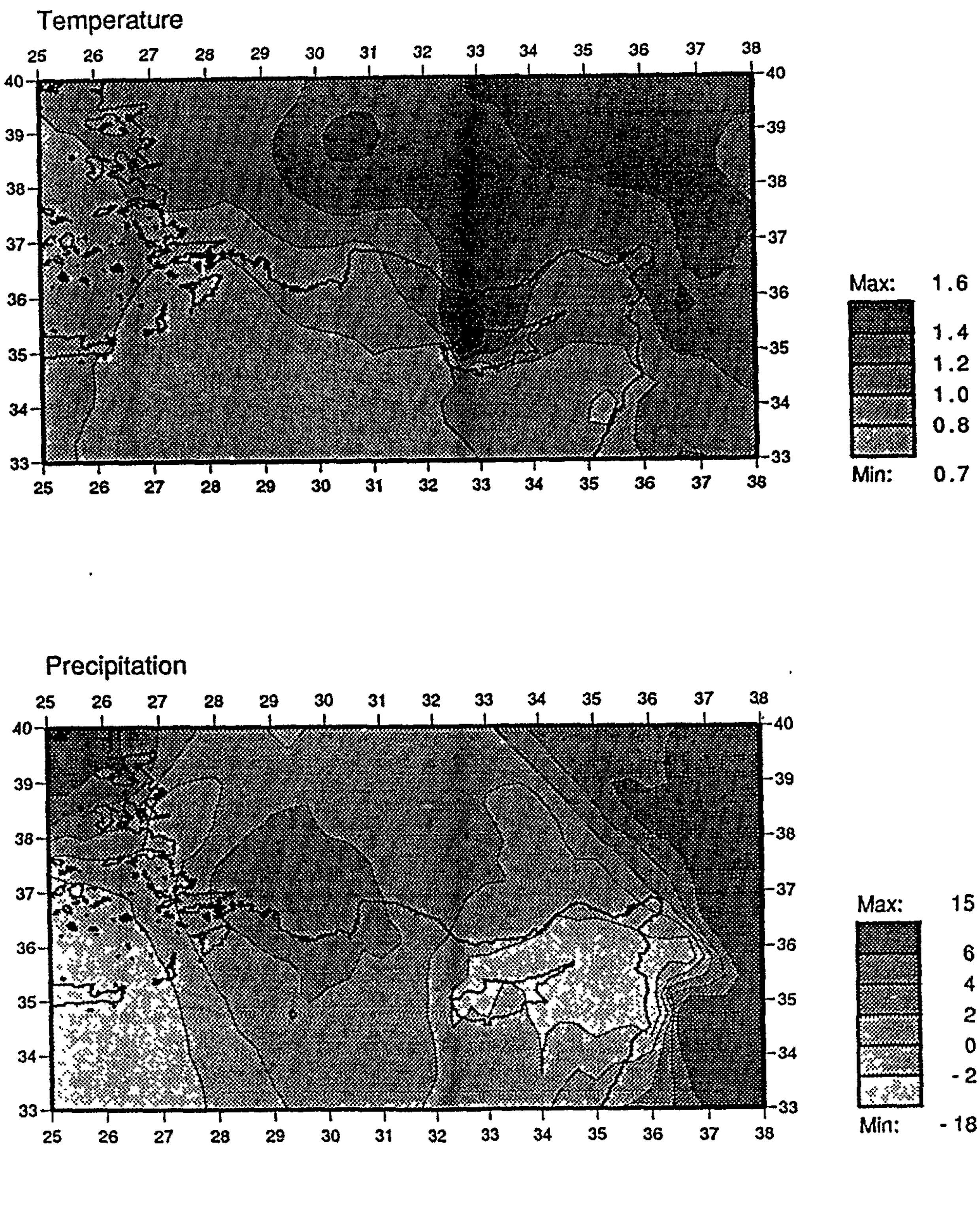


Figure 5 - Regional climate scenarios for the northeastern Mediterranean: autumn temperature (Climatic Research Unit, 1992)

The temperature scenario for summer (June, July and August) is substantially different from the annual pattern shown in Figure 4. Only limited areas have a sensitivity less than the global value: the extreme west of the study region including eastern Crete; the southeastern Mediterranean coast; and part of eastern Turkey. Elsewhere, the sensitivity is suggested to be higher than the global level, rising as high as 1.2-1.6 °C per °C global change over most of Cyprus, central Turkey and parts of the eastern Mediterranean islands. For the precipitation scenario, it was not possible to arrive at a prediction for the northeast of the study region, because the regression relationships were too weak. However, where a prediction is available, it suggests a decrease in precipitation for the extreme northwest and southeast of the study region. Elsewhere, precipitation is shown to increase, by as much as 12-26% per °C global temperature change over central Crete, the Cyclades and the northern Dodecanese.

The range and pattern of autumn temperature changes, as indicated by the scenario of Figure 5, are close to the annual values, with the greatest sensitivity in the northeast of the study region and the lowest in the southwest. Precipitation is indicated to increase in most areas, and particularly in the extreme northwest and the east of the study region where the indicated changes are +15% per °C global temperature change. Lower precipitation is suggested for the southwest of the study region, and for the land area adjoining the northeastern Mediterranean.

1.3.4. Conclusions

We have applied the methods developed by Kim et.al. (1984) and Wigley *et al.* (1990) to the problem of constructing sub-grid-scale climate change scenarios for the northeastern Mediterranean area. Regression equations were developed to predict station temperature and precipitation anomalies from regionally-averaged climate anomalies. We proceeded to substitute GCM perturbed-run minus control-run values of temperature and precipitation in the regression equations to obtain a prediction of the change due to the greenhouse effect at each station. The results were scaled by the equilibrium temperature of each of the four GCMs and an average for the four models obtained. The procedure was repeated for every station in the data set, and the results contoured to produce a scenario for the northeastern Mediterranean area.

Annual and seasonal scenarios for both temperature and precipitation change were produced. For temperature, the greatest sensitivity to the greenhouse effect was found in the mainland areas to the northeast of the study region. Temperature increases less than the global mean temperature change were indicated for the southwest of the region.

The scenarios for precipitation are much more difficult to evaluate. At the annual level, precipitation is shown to increase in the west and east, and to increase in the south-east, by up to 6% per °C global temperature change. Apart from western Turkey, the mainland coastal regions are all shown to experience a reduction in precipitation, to a maximum of -2 to -6% per °C global temperature change over the central southern Turkish coast and Cyprus. The problems associated with the construction of regional scenarios of precipitation change associated with the greenhouse effect are discussed at length in the Final Report for the UNEP Mediterranean Project (Palutikof *et al.*, 1992). The confidence that we can place in sub-grid-scale scenarios of precipitation is low.

2. THE PRESENT ENVIRONMENTAL AND SOCIO-ECONOMIC SETTING

2.1. Climate

2.1.1. General setting

The Island of Rhodes is situated in the Eastern Mediterranean Sea in the SE margin of the Aegean Archipelago. It exhibits a semi-mountainous and mountainous physiography with a number of small valleys where various agricultural activities take place. North of the Island of Rhodes and only a small distance from it lies the land mass of Asia Minor, while the surrounding sea varies greatly in depth at different points around the island.

The climate of Rhodes is typically Mediterranean, characterised by two climatically contrasting periods; one cold and rainy, lasting from November to March; and the second warm and dry, lasting from April to October (Mariolopoulos and Karapiperis, 1963), although the main features of the Mediterranean climate are characteristically uniform over much of the area. Variations in particular characteristics due to macro and especially to meso and microclimatic factors are apparent (Dikaiakos, 1982). These variations tend to become more pronounced in mountainous regions, inland valleys and highlands and are weaker in areas open to the sea, in coastal regions, and in smaller islands of low elevation.

The geographical position of Rhodes adjacent to the land mass of Asia Minor, the surrounding seas, and the semi-mountainous and mountainous topography, are the main physical and geographical factors affecting the local climatic conditions of the island throughout the year.

The dynamic atmospheric conditions affecting the climate of Rhodes are mainly depressions coming from the North Atlantic, the Gulf of Lion and the Northern Adriatic, as well as those which develop in the South Central Mediterranean around Tripolis, sometimes over the Aegean Sea and in the region of Cyprus. Siberian and Atlantic anticyclones, as well as those which develop over west and central Europe are also major dynamic atmospheric features which affect the climate of Rhodes.

These anticyclonic and cyclonic weather patterns are most frequent during the cold period of the year, disappearing or showing only low or very low frequency during the warmer season (Caralis, 1969). During the summer, weather conditions are dominated by the high pressure fields which frequently develop over western and central Europe and the Balkan Peninsula. These high pressure centres acting alone or often in association with the so called Indian lows or low pressure fields over the Eastern Mediterranean Sea produce a typical seasonal air stream over the Aegean Sea. This air stream, frequently coming from a northerly or northeasterly direction was well known even to the ancient Greeks, as "Etesian winds". In the central Aegean Sea these Etesian winds blow from the north, while in the south and along the southeastern margins of the Aegean Sea they blow from a northwesterly or even northerly direction.

On those days during which the Etesian winds blow mainly from the west, the weather conditions over Rhodes are typically calm and remain stable for long periods. The duration of sunshine displays high values reaching the theoretical maximum ones, the temperature does not go up very much while rain never appears in Rhodes. Rain is a rather rare phenomenon during the warmer periods of the year and especially the summer. When it does occur it appears as short showers locally as a consequence of strong or very strong thermal convection developed under particular conditions of atmospheric stability.

In contrast almost all the mean annual rainfall occurs during the cold period of the year, when rain is widespread occurring as pure frontal rain. There are additional periods during which rain falls as the combined result of upper atmospheric instability and low level forced convection. Such orographic rainfall can be considered as the only instances of local rain during the cold period of the year.

- During the same period continental arctic (cA), maritime arctic (mA), continental polar (cP), maritime polar (mP) and more rarely continental tropical (cT) air masses do invade the eastern Mediterranean area under the influence of the depressions and anticyclones mentioned above. Unusual rainfall events, sometimes very heavy ones, floods, hail, strong or very strong winds, storms, thunderstorms and gales, low or very low temperatures and frost appear during the invasion of these air masses. Their frequency of occurrence is dependent on both the nature of the phenomenon concerned and the type of the air mass with which the phenomenon is associated.

In contrast there are long or very long spells of mild and very good weather, characterized by a number of successive sunny days with relatively high temperatures and weak winds. This type of weather is the most prevalent over Rhodes during the cold period of the year and for this reason the climatic conditions during this period are considered to be very mild with a pronounced maritime character, which is also the case during the beginning (April/May) and the end (September/October) of the warm period.

Although the temperatures of the air remain more or less high during the summer, they cannot be characterized as hot or very hot from a human bioclimatic point of view. This is because the wind field over Rhodes during summer is exceptionally strong (Catsoulis, 1970) maintaining a constant cooling effect (Dikaiakos and Nastos, 1987).

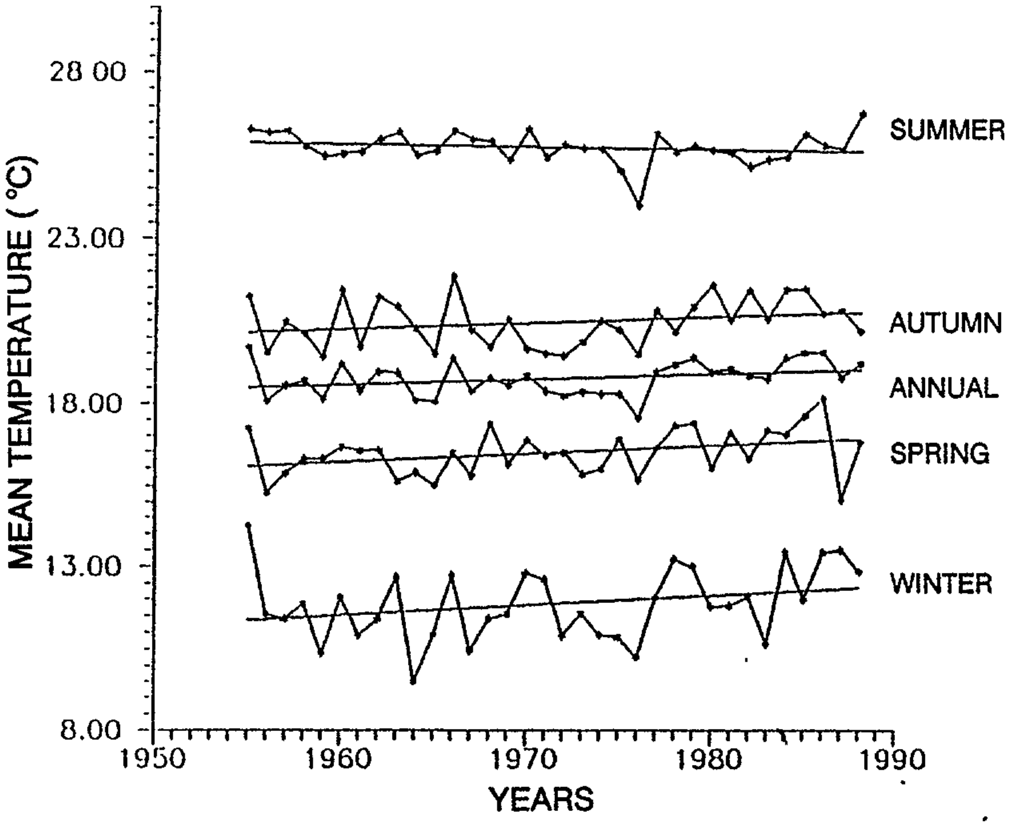
2.1.2. Temperature

The air temperature in Rhodes displays a simple annual curve and a mean annual value of 18.8 °C (Table 1; Figure 6). Following the classification of Haurwitz and Austin (1944) the curve belongs to the temperate type with a rather well expressed maritime character. The mean annual value of 18.8 °C, can be considered high, compared with the mean annual temperature regime for the whole of Greece. The value of 19.6 °C given by Mariolopoulos, (1961) and Karapiperis, (1962) suggests that Rhodes is on average, the warmest Greek island. In contrast however, during the warm period of the year and especially the summer, Rhodes is not the hottest Greek island. In July for example, the temperature of the air in Rhodes shows a maximum mean monthly value of 28.3 °C while at the same time the islands of Corfu, Mytilini, Zakynthos, Kythira and Crete (Heraklion) show mean monthly maxima of 30.7, 31.8, 30.3, 29.7, and 29.6 °C respectively (Mariolopoulos, 1961).

Maximum and minimum mean monthly air temperatures display an annual seasonal cycle similar to that of the mean monthly temperature, with the maximum occurring in August and the minimum in January. The temperature regime in February differs very little from that in January.

The maritime character of the climate of Rhodes can also be seen if the values for the mean annual range in air temperature and any other relevant indices are examined. The annual range in temperature is only 14.0 °C for example, and the value of Kerner's index of continentality is equal to 23.7 % and 33.6 % respectively showing clearly that Rhodes enjoys a purely maritime climatic character (Karapiperis, 1962).

Despite this maritime character air temperatures in Rhodes does not always remain close to average levels but varies significantly. Days with maximum temperatures higher than 30 °C or even 35 °C often occur in summer, and days with minimum temperatures near freezing occur in winter. The absolute maximum and minimum values for air temperature over the period 1955 - 1988 were 42 °C and -4.2 °C respectively.



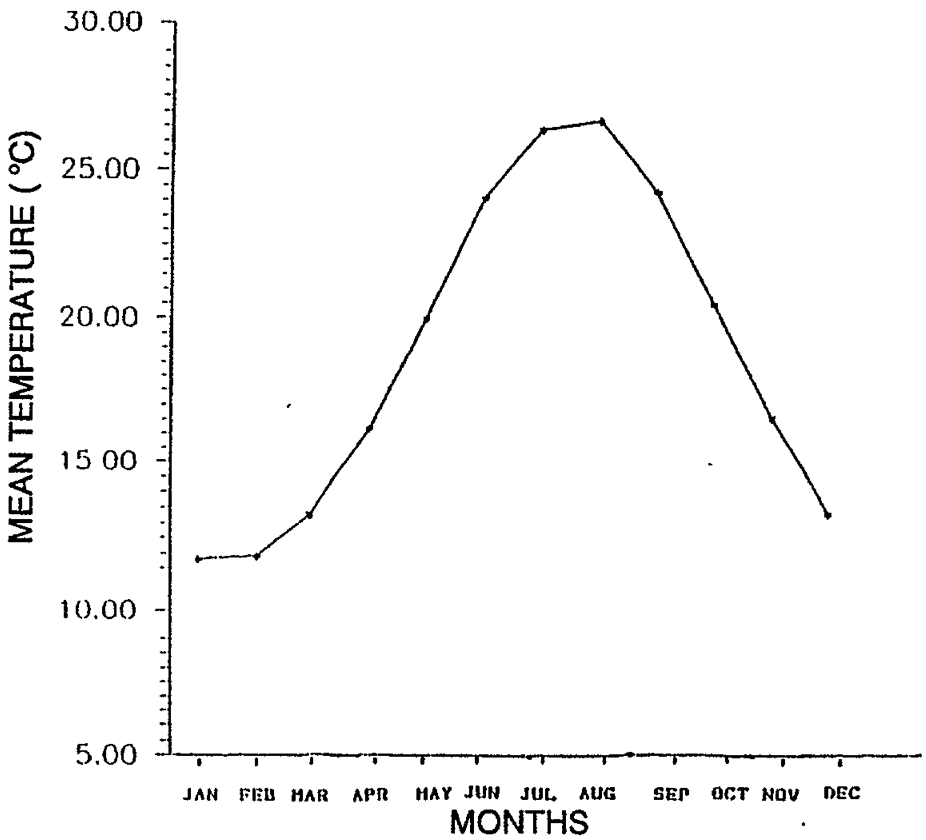


Figure 6 - Mean annual and seasonal temperature (1955-1988)

TABLE 1

Mean monthly and annual values of the air temperature (°C) in Rhodes (1955-1968)

J	F	M	A	M	J	J	A	S	O	N	D	Y
Mean temperature												
11.8	11.9	13.3	16.2	20.0	24.1	26.4	26.7	24.3	20.5	16.6	13.4	18.8
Mean max temperature												
15.1	15.4	16.9	20.1	24.5	28.7	30.8	31.0	28.4	24.7	20.3	16.7	22.7
Mean min temperature												
8.4	8.5	9.7	12.3	15.5	19.6	22.0	22.4	20.1	16.4	12.9	10.1	14.6

From Figure 6 it can be clearly seen that the mean annual and seasonal values of air temperature in Rhodes have shown a tendency to increase over the period 1955 - 1988 with the exception of summer temperatures which have shown a decreasing trend. More quantitatively, the mean annual, winter, spring and autumn temperature values over this period show positive increases of 0.49, 0.92, 0.76 and 0.58 °C respectively, while the mean summer values show a decrease of 0.25 °C. Although the length of the time series is rather short the magnitude and the consistent nature of these trends are both significant and interesting not only to theoretical but also to applied climatology.

2.1.3. Relative humidity

The relative humidity of the air in Rhodes shows a simple annual trend (Table 2; Figure 7), maximum and minimum monthly values occur in December (73%) and July (56%) respectively with a mean annual value of 60%.

TABLE 2

Mean monthly and annual values of relative humidity (%) in Rhodes (1955-1968)

J	F	M	A	M	J	J	A	S	O	N	D	Y
Relative humidity (%)												
71	70	69	67	64	57	56	58	61	67	72	73	60

In comparison to the mean monthly and annual values of relative humidity for other Greek islands (see e.g Theoharatos, 1978), it may be said that Rhodes is an island with very low humidity.

2.1.4. Rainfall

The mean annual rainfall total for Rhodes over the period 1955-1988 is 714.6 mm (Table 3). The maximum and minimum mean monthly rainfall occur in December (165.0 mm) and August (0.1 mm) respectively (Figure 8), while 85% of the annual total falls between November and March. During the warm period of the year and especially the summer, rainfall is very low indeed as it is in most coastal regions and islands of the Mediterranean Sea and particularly those in the eastern Mediterranean.

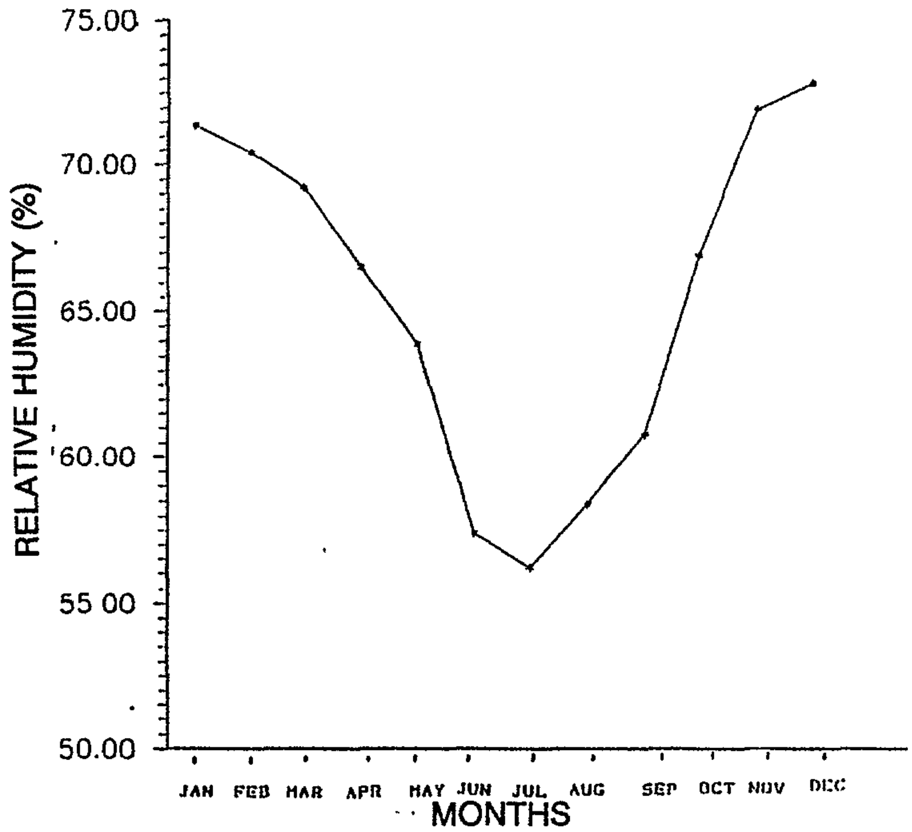


Figure 7 - Relative humidity

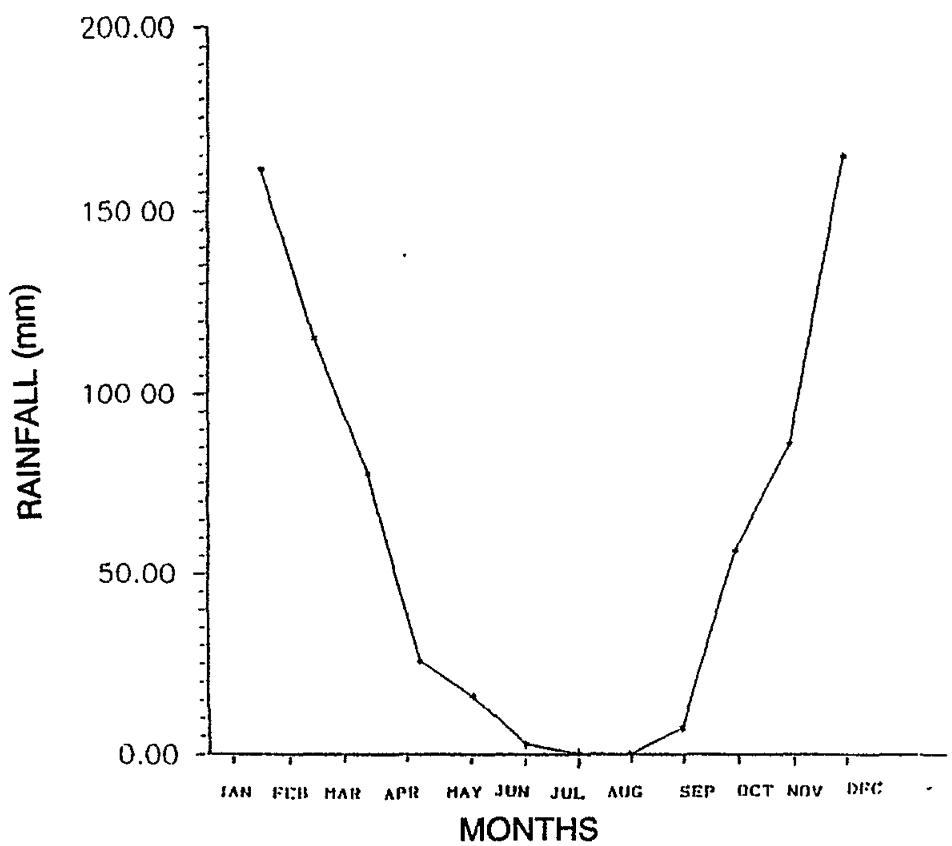


Figure 8 - Rainfall

Considering that the mean maximum (931.8 mm) and minimum (364.1 mm) rainfall values are shown by the islands of Icaria and Thira respectively then Rhodes with a mean annual rainfall of 714.6 mm can be considered one of the wetter islands of the Aegean Sea region.

All the mean monthly and annual values for the number of rainy days and intensity of rainfall (Table 3) can be considered as being high or even very high in comparison with corresponding values for other islands of the Aegean Archipelago.

TABLE 3

Mean monthly and annual values of rainfall, number of days and intensity of rain in Rhodes (1955-1968)

J	F	M	A	M	J	J	A	S	O	N	D	Y
Rainfall (mm)												
161.5	115.4	77.6	25.5	16.0	2.7	0.4	0.1	7.2	56.6	86.6	165.0	714.6
Number of days												
17.1	13.4	10.7	7.6	4.8	1.4	0.2	0.1	1.6	6.9	9.5	15.9	89.2
Intensity of rain in mm/number of Rain days												
9.4	8.6	7.2	3.4	3.3	1.9	2.0	1.0	4.5	8.2	9.1	10.4	8.0

Although rainfall in Rhodes may be considered relatively high, the water déficit of 607 mm (adopting a field capacity value for the soil of 100 mm) is very high and the water surplus of 407 mm is very low (Balafoutis, 1988). Adequate water supply is a serious problem for this island, particularly considering the large increase in population during the summer, due to tourism.

2.1.5. Winds

The wind system of Rhodes reflects the geographical position of the island.

The wind speed shows two annual peaks (Figure 9) as it does in many other islands of the Aegean Sea. The maximum appears in July (6.76 m sec^{-1}) with a secondary peak in April (4.87 m sec^{-1}). This annual pattern has all the typical features of a location with a monsoon climate and is due to the Etesian winds which are very strong and steady during the summer and particularly during July over much of Rhodes (Mariolopoulos and Karapiperis, 1963, p.18).

The importance of the geographical position of the island and the Etesian winds can easily be seen if wind roses for July and January are compared between Rhodes and the island of Thira (Figure 10). These two islands share a similar latitudinal position but Rhodes is situated at the southeastern margin of the Aegean Sea while Thira is more centrally located. In January southerly winds and in July westerly winds predominate over Rhodes while over Thira northerly winds predominate during both months.

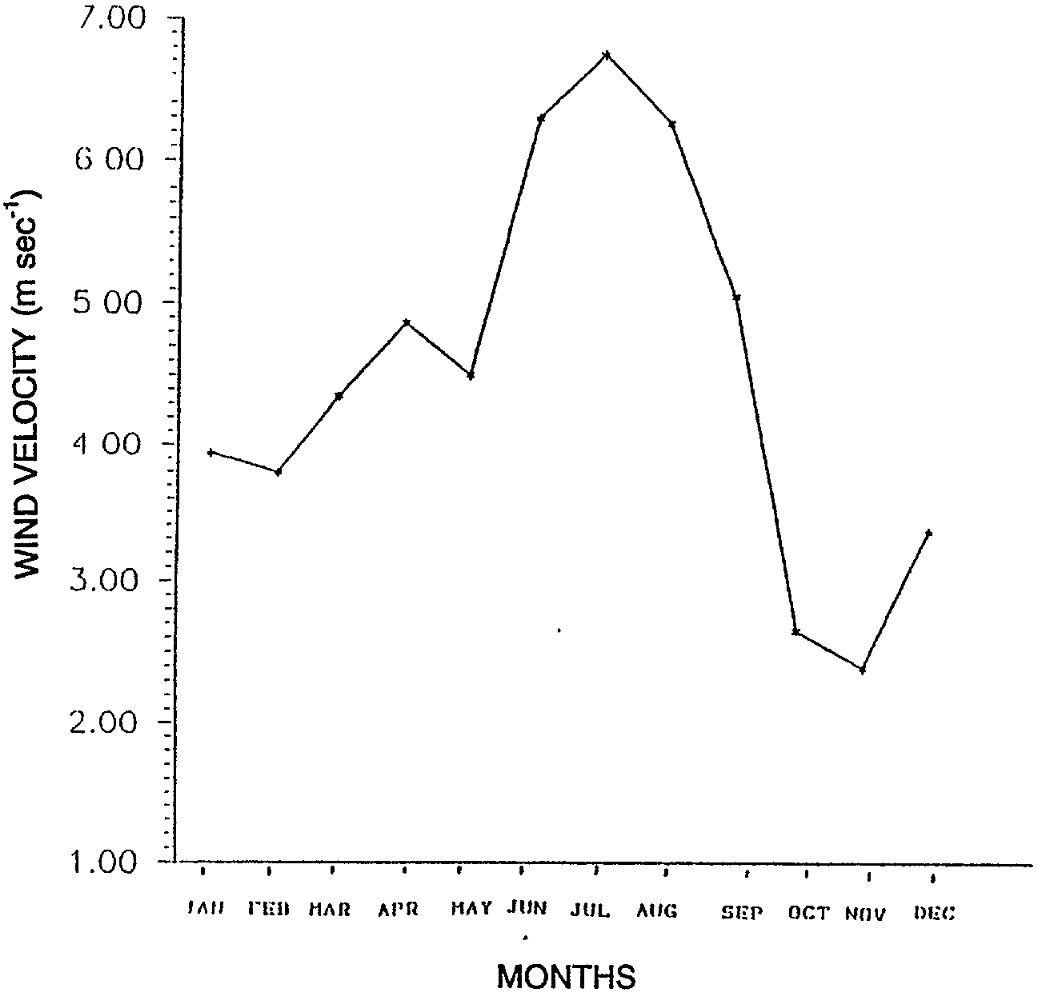


Figure 9 - Wind velocity

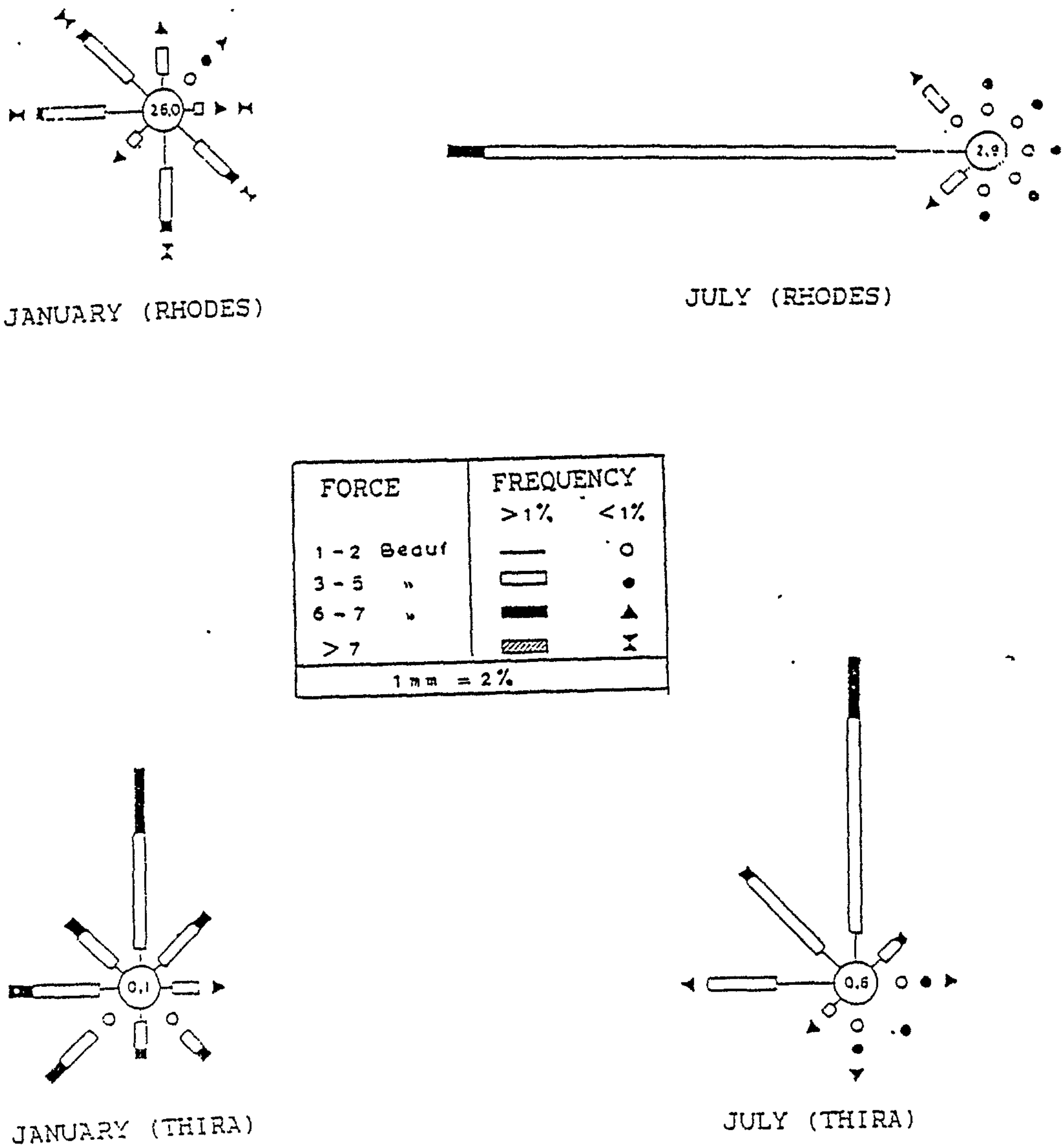


Figure 10 - Wind roses for January and July in Rhodes and Thira

2.1.6. Human bioclimate

The mean monthly values of both the cooling power of the air (CP) and the effective temperature (ET) were calculated according to the empirical formula of Cena *et al.* (1966) (Table 4; Figure 11). According to Cena's classification the outdoor human bioclimate is cold from December to April, cool in all other months of the year except in August when it may be considered warm. Although temperatures may be considered warm or even hot during the summer, the wind system and especially the Etesian winds which blow with high frequency and intensity during this period, increase the cooling power significantly rendering the outdoor environment less warm and hot from a human bioclimatic point of view. The importance of the Etesian winds can easily be seen if outdoor and indoor conditions during the summer are compared. According to the effective temperature the indoor environment is beyond the zone of human comfort and rather hot from the end of June to the end of the September. From the end of April to the end of June and from the end of September to the middle of October the indoor conditions fall within the range of optimum human comfort. During the winter months it is rather cool and cold.

TABLE 4

Mean monthly values of the cooling power and the effective temperature of the air in Rhodes (1955-1968)

J	F	M	A	M	J	J	A	S	O	N	D
Cooling power in mcal cm $^{-2}$ min $^{-1}$											
18.6	18.3	18.4	17.0	13.3	11.9	10.1	9.4	10.4	10.3	2.4	18.3
Effective temperature in °C											
11.6	11.7	12.9	15.4	18.6	21.7	23.5	23.9	22.1	19.1	15.9	13.0

2.1.7. Extreme events and other meteorological phenomena

Detailed data concerning the frequency of extreme events are not available at present. Those that are available for this study were provided by the National Meteorological Service of Greece and are presented in Table 5. On the basis of these data it may be suggested that most of the main meteorological phenomena which occur in Rhodes, do so with similar frequency and seasonal distribution to their occurrence in other Greek coastal regions and islands (vide e.g. Theoharatos, 1978, pp. 146, 147 and 149; Mariolopoulos, 1961,p. 37). In contrast the values for absolute maximum rainfall in 24 Hrs and the number of days a year with thunderstorms are extremely high.

TABLE 5

Extreme events and other meteorological phenomena (1955-1968)

J	F	M	A	M	J	J	A	S	O	N	D	Y
Absolute maximum temperature in °C												
22.0	22.0	27.4	30.6	34.8	37.4	40.0	42.0	36.6	33.2	28.4	22.8	42.8
Absolute minimum temperature in °C												
4.0	2.2	0.2	5.2	5.0	12.6	14.6	17.0	10.6	7.2	2.4	1.2	4.0
Absolute maximum rainfall in 24hrs in mm												
126.2	92.4	76.9	51.7	60.4	28.6	6.9	1.6	34.4	124.4	178.8	146.4	
Number of days with snow												
0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Number of days with hail												
0.8	0.5	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	
Number of days with thunderstorm												
5.8	5.3	3.8	2.0	2.3	0.6	0.2	0.1	1.0	4.8	4.7	6.1	
Number of days with dew												
4.6	4.0	6.2	6.9	5.9	3.5	3.0	3.7	4.9	6.8	7.6	5.5	
Number of days with frost												
0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

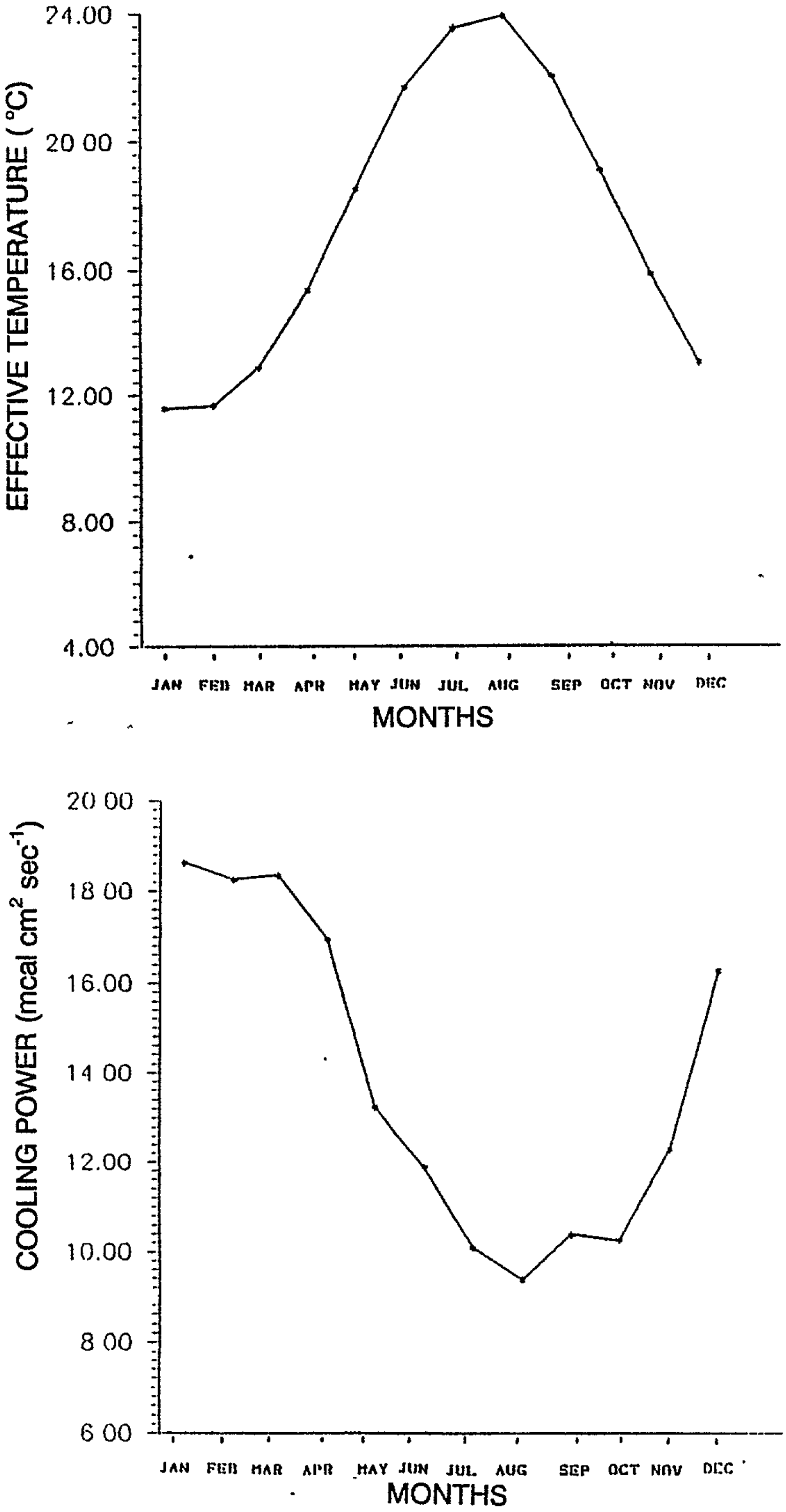


Figure 11 - Effective temperature (upper) and cooling power (lower)

2.2. Geography and geology

2.2.1. Geographical and geological settings

The Island of Rhodes is located in the southeastern part of the Dodecanese group of islands, at the eastern end of the Hellenic arc, which extends between the Peloponese and Asia Minor and includes the islands of Kythira, Antikythira, Crete, Kassos, Karpathos and Rhodes (Figure 12).

The Island of Rhodes (Figure 13) is elongated along its NE-SW axis, having a length of 77 km, and width of around 37 km. It is situated between 35° 52' and 36° 28' N and 27° 40' to 28° 16' E and has an area of 1400 km^2. The length of its coastline is about 191 km.

2.2.1.1. Stratigraphy

The rocks of which Rhodes island is constructed belong to three major tectonic units (Figures 14, 15): the lower unit, considered to be autochthonous and para-autochthonous; the intermediate allochthonous unit; and the upper neo-autochthonous unit (Mutti *et al.*, 1970).

a) The autochthonous and para-autochthonous lower unit includes the rocks of the Attaviros Group and the Kattavia Flysch. The Attaviros Group includes the Akramitis Limestones and the Kakoskala Marly Limestone. The Akramitis Limestone, with an average thickness of some 480 m, is about 800 m thick in the Attaviros area, and consists of thin to medium-bedded gray limestones with sparse chert nodules of Turonian - Middle Eocene age. The Kakoskala Marly Limestone which is 75 m thick consists, as its name suggests, of marly limestones with chert nodules. In the middle of this unit there is a layer of gray nummulitic limestone of Middle and Late Eocene age.

The Kattavia Flysch (1500 m thick) lies conformably over the Kakoskala Marly Limestone, it is of terrigenous origin and has a Middle Eocene age. In the Lindos region the flysch appears to be partially metamorphic.

b) The intermediate Allochthonous Unit consists of three sub-units:

- the lower sub-unit is in direct contact with the Kattavia Flysch and is composed of the Archangelos Group and the Archipolis Flysch. (Mutti *et al.*, 1970). The Archangelos Group is composed mainly of the Salakos Limestone (700 m thick) which has a Norian to Early Eocene age and consists of massive gray limestone, dolomitic limestone and dolomite. The Archipolis Flysch (110 m thick) is marly in its lower part, whilst the middle and upper parts are composed of alternating sandstones, conglomerates and marls. An Early Eocene age is attributed to this flysch;

- the upper sub-unit of the Allochthonous Unit is represented by the Profitis Ilias Group which includes two formations (Ferrari Aradicini, 1962): the Elaphokampos Cherty Limestone (250 m) formed mainly of Liassic dolomitic limestones, and the Malona Formation (200 m thick) composed of limestone with chert nodules, radiolarites, and marls. The age of the latter is from Early Liassic to Senonian. Between these allochthonous sub-units there are modest masses of ophiolite, composed of gabbro-diabase and serpentinite. An analogous stratigraphic picture is presented by the Kopria Diabase-Radiolarite formation whose age extends from the Jurassic to Early Cretaceous;

- the third sub-unit, which belongs to the intermediate allochthonous unit is the Lindos Limestone. This sub-unit is of uncertain tectonic position, it consists of thick-bedded crystalline limestones and is about 450 m thick. Within its middle and lower part there are stratigraphic layers containing benthic foraminifera which may indicate a Senonian age.

c) The neo-autochthonous sedimentary sequence (upper unit) lies in angular unconformity on the autochthonous and allochthonous units. This neo-autochthonous unit is mainly made up of the Vati Group and of the"Levantinian" deposits.

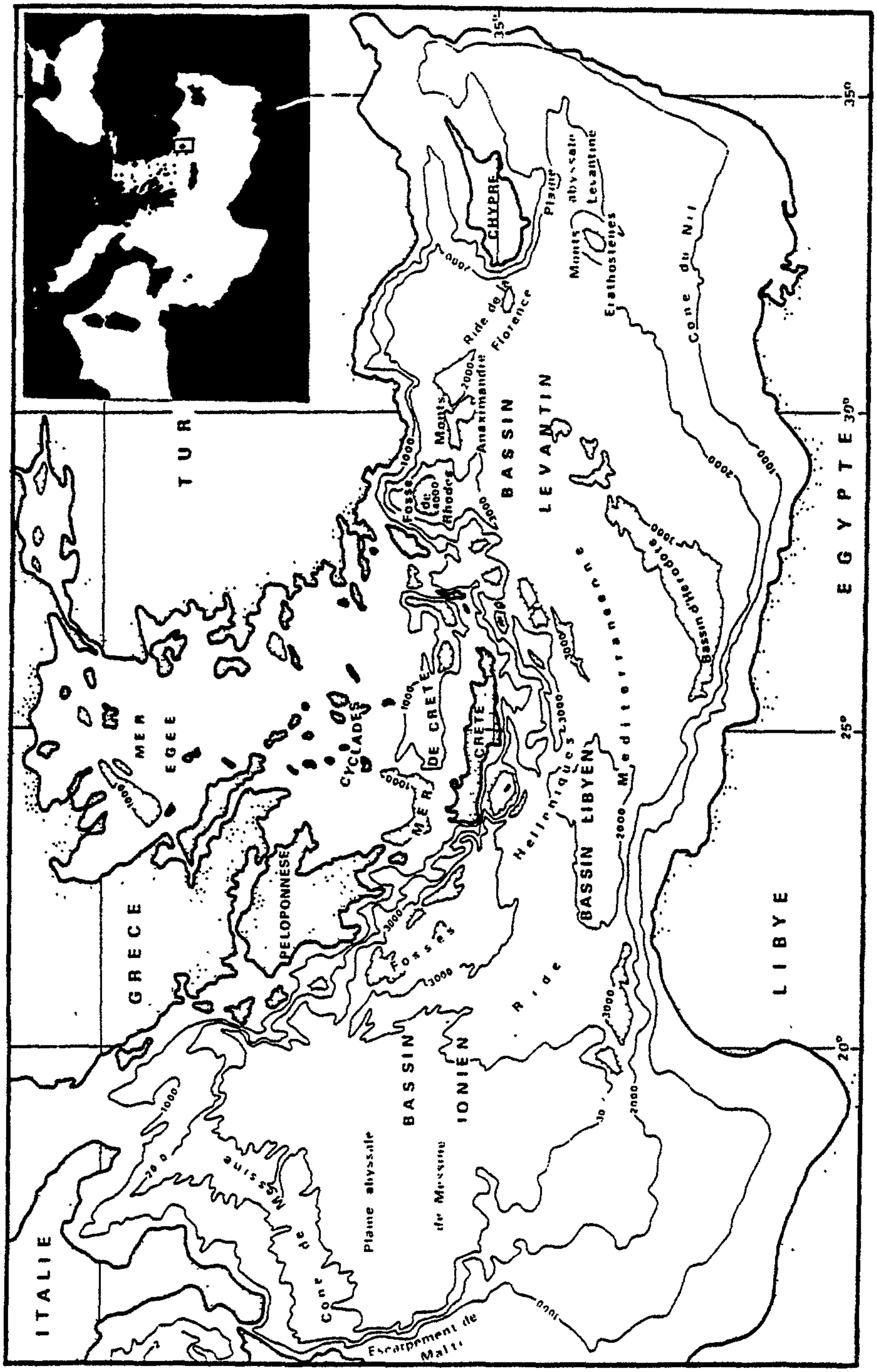


Figure 12 - The principal physiographic units of the NE Mediterranean basin

Figure 13 - Hypsometric and bathymetric map of Rhodes island and surrounding area (in m.)

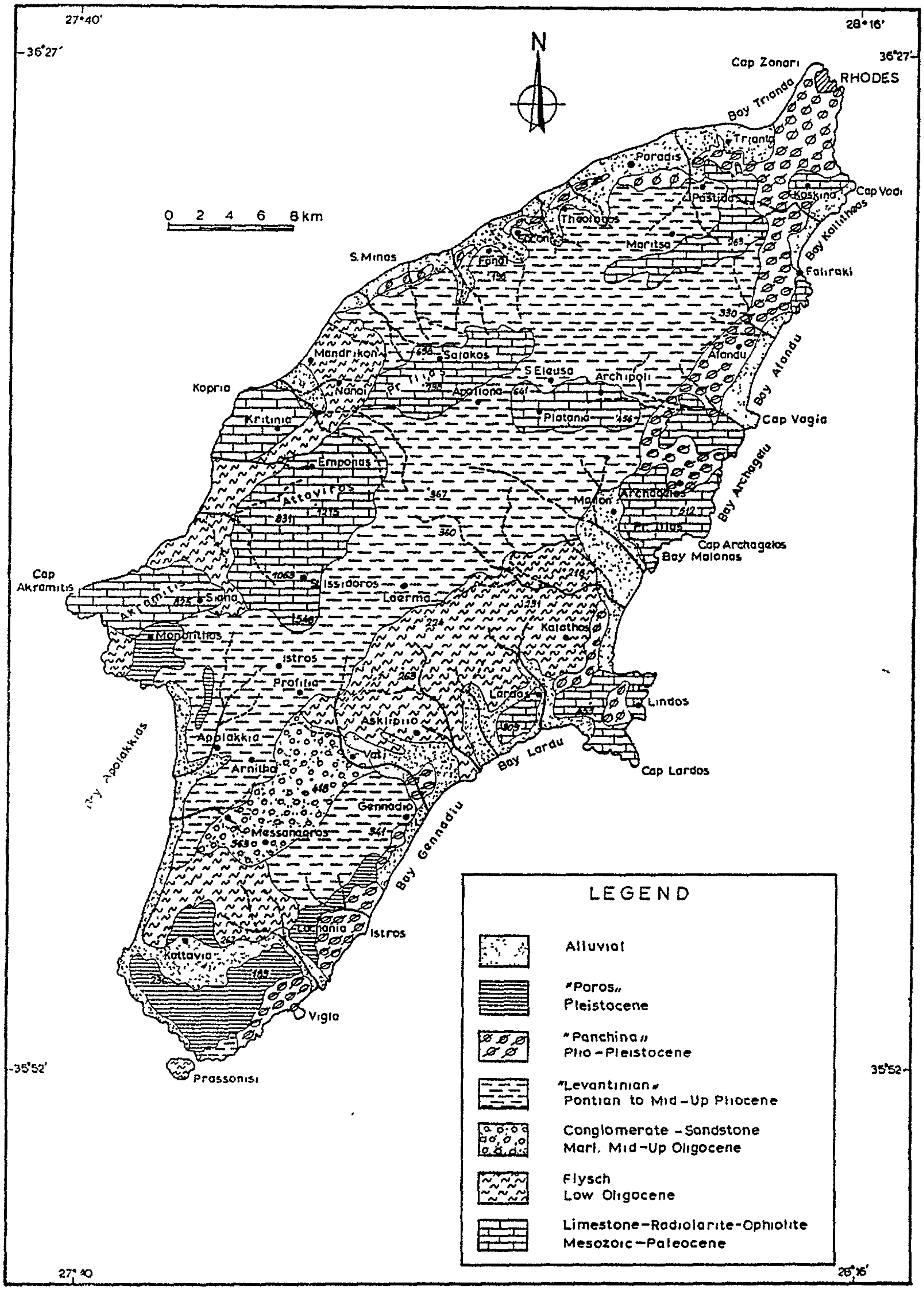


Figure 14 - Geological map of Rhodes island
(based on various sources combined with personal observations)

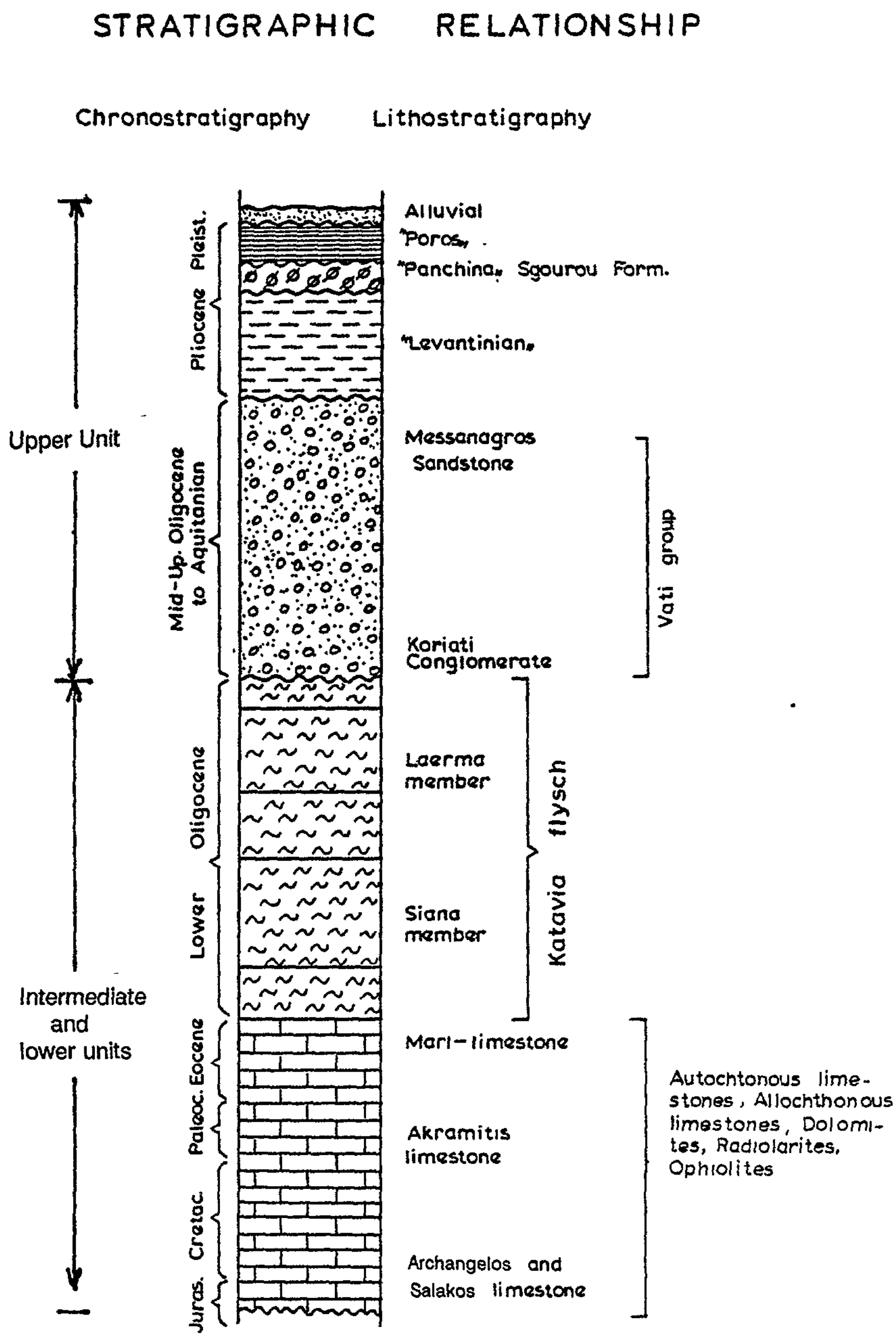


Figure 15 - Stratigraphic column of the rock formation shown on Figure 14

The Vati Group (Mid-Late Oligocene to Aquitanian), occurs in the central part of the Island of Rhodes; in the southern part of the island the group consists of the following formations in ascending order (Mutti *et al.*, 1970):

i) the Koriati Conglomerate (about 115 m thick), is represented principally by a conglomerate made of limestone, ophiolite and radiolarite clastics. It had been formed in a fluvial or deltaic depositional environment;

ii) the Dali Ash Flow (about 5 m thick), composed of pyroclastic deposits derived from a rhyolitic magma. It is an excellent marker horizon for chronostratigraphic correlation within the Vati Group (Gauthier *et al.*, 1976); and

iii) the Messanagros Sandstone-Conglomerate (about 450 m thick), considered to be deposits of marginal turbidities within which palaeocurrents indicate a main sediment transport direction from the west. A conglomerate (100 m thick) is present at the base of this formation, it is composed of ophiolite, limestone and radiolaritic rock-fragments and was deposited in a fluvial environment. The uppermost part of the Messanagros formation which consists of sandy clay, ophiolitic conglomerate and sandstones, is considered to represent deposits formed at the margin of a deep basin.

The "Levantinian" deposits (Desio, 1931) are considered to be all the Neogene continental clastic deposits which are present in the Island of Rhodes. They lie in angular unconformity, on top of the Vati Group, have a thickness of several hundred metres and are of Pontian age. Their depositional environment is partly fluvial and partly lacustrine. The fluvial components are characterised by a gravelly-sandy facies whilst the lacustrine ones consist of marly-sandy facies. In the northwest and eastern coast of the island the "Levantinian" deposits are covered by the transgressive deposits of the Sgourou Formation (170 m thick). They consist of marls, sands and gravels. A layer of fossiliferous calcarenite named "panchina" is often present at the top of the Sgourou Formation. Its age extends from the Upper Pliocene to Lower Pleistocene. In the inland areas of Rhodes and on the Levantinian deposits a calcareous palaeosoil known as "Poros" (Desio, 1931; Ormobelli and Montanari, 1967) is widely present. It is usually found at the margins of palaeolakes having a probable age of Lower Pleistocene.

d) The geological sequence of Rhodes island is completed by alluvial deposits in the form of terraces, landslide deposits and talus scree slopes.

2.2.1.2. Geological structure

The geological structure of the Island of Rhodes includes three tectonic systems:

a. a system of tight folds, locally overturned, present particularly within the Kattavia Flysch and the Attaviros Group; the principal direction of the fold axes is from NE to SW and they plunge towards the SW. This tectonic phase has a Middle Oligocene age, and took place after the deposition of the Kattavia Flysch and before the Vati Group transgression (Mutti *et al.*, 1970);

b. a younger tectonic system of folding is superimposed on the previous one and was formed during a tectonic phase which took place within the Upper Oligocene. It has its main structural trends along a NW-SE direction and plunges to the SE (Tournouer, 1975); and

c. a system of normal faults cuts all the previous structures and dissects wide portions of the island into horst and graben. Some of these faults are synsedimentary to the "Levantinian" formation while others postdate them.

Finally, the existence of marine terraces, raised at different altitudes, indicates recent vertical tectonic movements of the island.

2.2.2. Geomorphology

The relief of the Island of Rhodes is smooth and includes hills, hillocks and small mountains (Figure 13). This smooth relief is related not only to the lithology, but also to the existence of a dense drainage network which covers almost the whole island. The drainage divide runs in a NE-SW direction and the numerous torrent streams and creeks that flow towards the coasts are NW-SE trending (Geodicke, 1977). The coastal geomorphology is an expression mainly of lithology. Thus, the areas of Akramiti, Lindos and Profitis Ilias, which consist of igneous rocks, hard limestones and cohesive conglomerates, with a relatively higher resistance to erosional processes appear to have steep coasts and limited littoral deposits. In contrast, the remainder of the coastline which is formed of easily eroded sedimentary formations, is geomorphologically active (Figure 14). Evidence of this situation is not only the sandy, conglomeritic and gravely deposits which are present alongshore, but also the existence of a multiform valley system which is progressively altering the basic geomorphology and the configuration of the shoreline itself (Figures 16, 17).

The flatlands (Figure 16) can be divided into two main categories: those of the hinterland and those of the coastal lowlands:

a. the hinterland flatlands are hilly areas having an elevation of between 200 and 300 m and almost flat tops. They occur in the Kattavia region, where Holocene sediments of significant thickness have been deposited over the top of the flysch formation. This landform extends immediately north of Prassonisi Cape and to a limited extent in the Malona area. All these flatlands are of Holocene age and their formation has been affected not only by tectonic activity, regional lithology and morphology, but also by the development of numerous drainage systems (Tournouer, 1975); and

b. coastal lowlands extend around 2/3 of the coast of Rhodes. They include the areas: around the city of Rhodes extending to the town of Salakos; between the southern side of Cape Akramiti and the western end of Kattavia plain; and, the sector from Gennadion Bay to a point immediately south of Lindos. Other significant lowlands include those which extend from the northern part of Lindos up to the Malona area; the lowland of Kalithies; and, the area south of Faliraki.

The width of the coastal lowlands varies between 500 and 5,000 m (Figure 16). They have developed from extensive valley-systems, which in turn are exclusively formed on easily eroded rock formations. A good example is found in the coastal region at the northern end of the island where the slopes of the coastal lowlands are only on average between 2 and 5%.

2.2.3. Coastal processes and shoreline features

Morphological processes and the stability of the shorelines around the Island of Rhodes depend upon the sediment input; the lithology and geotectonic structure of the coastal zone; and, external factors such as waves, winds, sea level changes and longshore currents.

Correlation of the slope and regional lithology and structure indicates the presence of three main categories (Zamani *et al.*, 1979): low slopes (0-5 %); intermediate slopes (5-15%); high slopes (15-20%) and very high slopes (>20 %). The areas of low slopes (0-5%) correspond to Plio-Pleistocene and recent deposits and include the coast SW of the city of Rhodes and between Lindos and Prassonisi. The rest of the island's coastline is characterized by intermediate slopes of between 5 and 15% (Figure 16).

Only four coastal locations are characterised by high or very high slopes: north of Cape Prassonisi; Acramitis; Lindos; and, Profitis Ilias. In these areas the lithology consists of Mesozoic limestones and the high and very high slopes have been caused by Quaternary and Neogene tectonic activity. Tectonic activity which continues to modify the slopes at present.

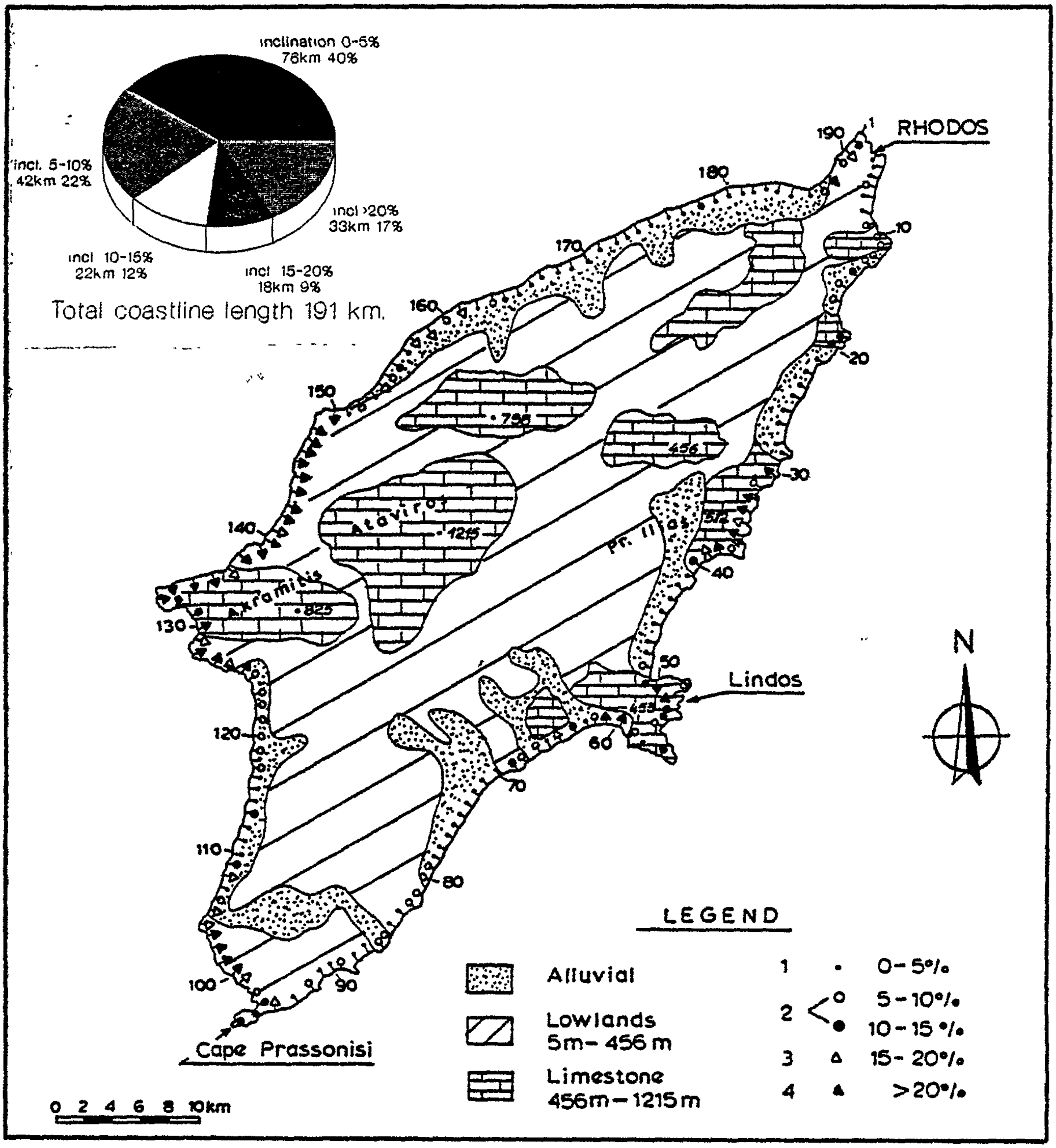


Figure 16 - Geomorphological map and coastal slope distribution of Rhodes Island

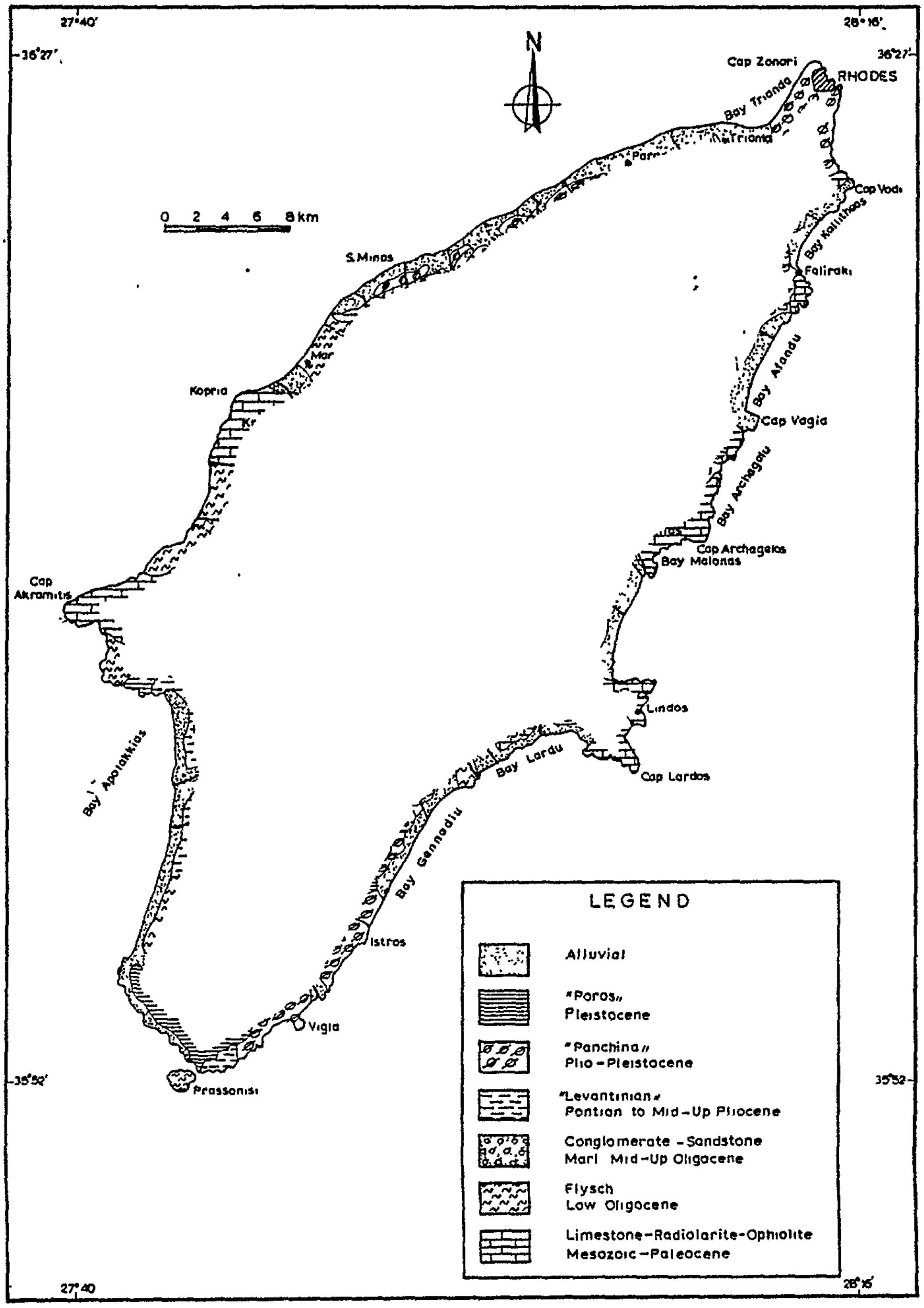


Figure 17 - Geological map of the coastal zone of Rhodes island

In terms of their stability, the coastal zones with highest resistance to external influences such as water flow, land slides, and marine forces are those with high and very high topographic inclination resulting from limestone outcrops. In contrast the coastal zones with low slopes (0-5%) formed on Plio-Pleistocene sequences, are characterised by shoreline instability. These coasts are mainly affected by the surface water flows through the various drainage networks whose presence is not only persistent but is also quite extensive (Zamani *et al.*, 1979).

2.2.4. Subsidence

Land-subsidence in Rhodes occurs mainly in the NW part of the island and is due to burial and compaction of the sediments derived from the weathering of the surrounding rocks (marls, and sandstones, not cohesive conglomerates, and limestones, Desio *et al.*, 1931). This phenomenon also occurs, but to a lesser extent, in other areas of the island, for example, to the north of Lindos and in the area between Kalithies and Faliraki. In these areas land subsidence is caused mainly by sediment overload. However, tectonism (normal faulting) is the main factor that directs the downward and upward movements and enhances the occurrence of landslides. The role of tectonism is particularly evident along the coasts of the Lindos area, where, following seismic activity in 1926 the limestones were uplifted about 15 cm relative to sea-level, as shown by the sea level traces observed there.

2.3. Hydrology and water resources

2.3.1. Introduction

In the last few years the need for rational management of the water potential and for the development of new water resources on the Island of Rhodes has become vital as a consequence of:

- the continued growth of the island's permanent population;
- the extensive development of tourism; and,
- the continued increase in water use per inhabitant.

The problem of water supply has become particularly acute during the last two years which have been dry. According to 1987 estimates the total annual consumption of water has risen to 30 Mm ^{3}. It should be noted that a high proportion of the total water consumption (67% to 70%) is used for domestic and irrigation purposes in the northern part of the island, in the triangle Rhodes - Fanes - Kolimpia, where development and economic activities are most intense.

The total annual domestic water consumption is 17 Mm ^{3}, and a further 13 Mm ^{3} yr $^{-1}$ are used for irrigation. Part of this consumption is also used to cover the needs of nearby islands which belong to the same district i.e. Symi and Halki. Today the island's natural water resources are exploited through wells and from the island's main springs, while a dam at Apollakia has a capacity of 8 Mm ^{3}.

Rhodes island exhibits important hydrogeological features due to the complex structure of its rock formations. Studies conducted to date provide inadequate information concerning groundwater trapped in aquifers and about possibilities for future surface water exploitation.

Recent drilling has been intense, particularly in the northern hydrological basins. The lack of management of water resources and the continued unbalanced development of water needs may create major supply risks in the future. Already in certain coastal areas, groundwater is brackish due to excessive pumping. Moreover, a significant drop in aquifer level has been observed (even below sea-level) associated with marked decline in borehole yield.

2.3.2. Water balance

The whole island has 51 hydrologic basins (Figure 18). The main watershed divides the island into western and eastern parts, the latter containing the larger and more developed basins. The greatest water runoff occurs in the western sector of the northern section of the island (Kilakos and Drossos, 1989).

Surface runoff occurs mainly through torrential streams which do not flow permanently throughout the year. Large streams, however, flow for longer periods during rainy years and exhibit significant flood volumes (Table 6). There is however a severe lack of monitoring of the island's torrent yields and only in the northern part has there been relatively systematic measurement of discharges. Total annual surface runoff estimates for the island are based mainly on extrapolation to similar hydrological basins.

TABLE 6

Most significant torrent streams and their catchment areas

Torrent name	Area of Catchment basin (km^2)
Gadoura	160
Asklipio	107
Makaris	75
Loutanis	60

According to Iakovidis (1988), the surface runoff coefficient for the whole island is 10.5% of the mean annual precipitation which is 710 mm, giving a total annual surface water runoff of 105 Mm^3. The surface runoff coefficient for the Apollakia dam is 11.5% of the mean annual precipitation (583 mm) or 3.2 Mm^3 water runoff annually. The mean surface runoff in the northern part of the island over the last decade, is of the order of 8% of the mean annual precipitation (767 mm, Kilakos and Drossos 1989). This means that at least 19.7 Mm^3 of water a year is flowing from the island's northern catchment basins.

A knowledge of the water balance for each of the island's hydrologic basins is necessary in order to estimate the total annual water quantity available for exploitation. The balance between precipitation inputs and evapotranspiration losses is around 198 Mm^3 of which 105 Mm^3 is lost through run-off and 93 Mm^3 reaches the groundwater (Table 7). About 2 to 6% of the annual infiltration, that is 2 to 6 Mm^3, escapes to the sea. It is estimated that the quantity of water available for further exploitation is as much as 40-50 $Mm^3\ yr^{-1}$, the greater part of which is from surface runoff (Iakovidis, 1988).

The total annual water available to the island's northern triangle between Rhodes - Fanes - Kolimpia is 66 Mm^3. This suggests that about 9.2 $Mm^3\ yr^{-1}$ can be added to existing supplies by groundwater extraction and about 3.7 $Mm^3\ yr^{-1}$ from the Loutani torrent stream (Kilakos and Drossos, 1989).

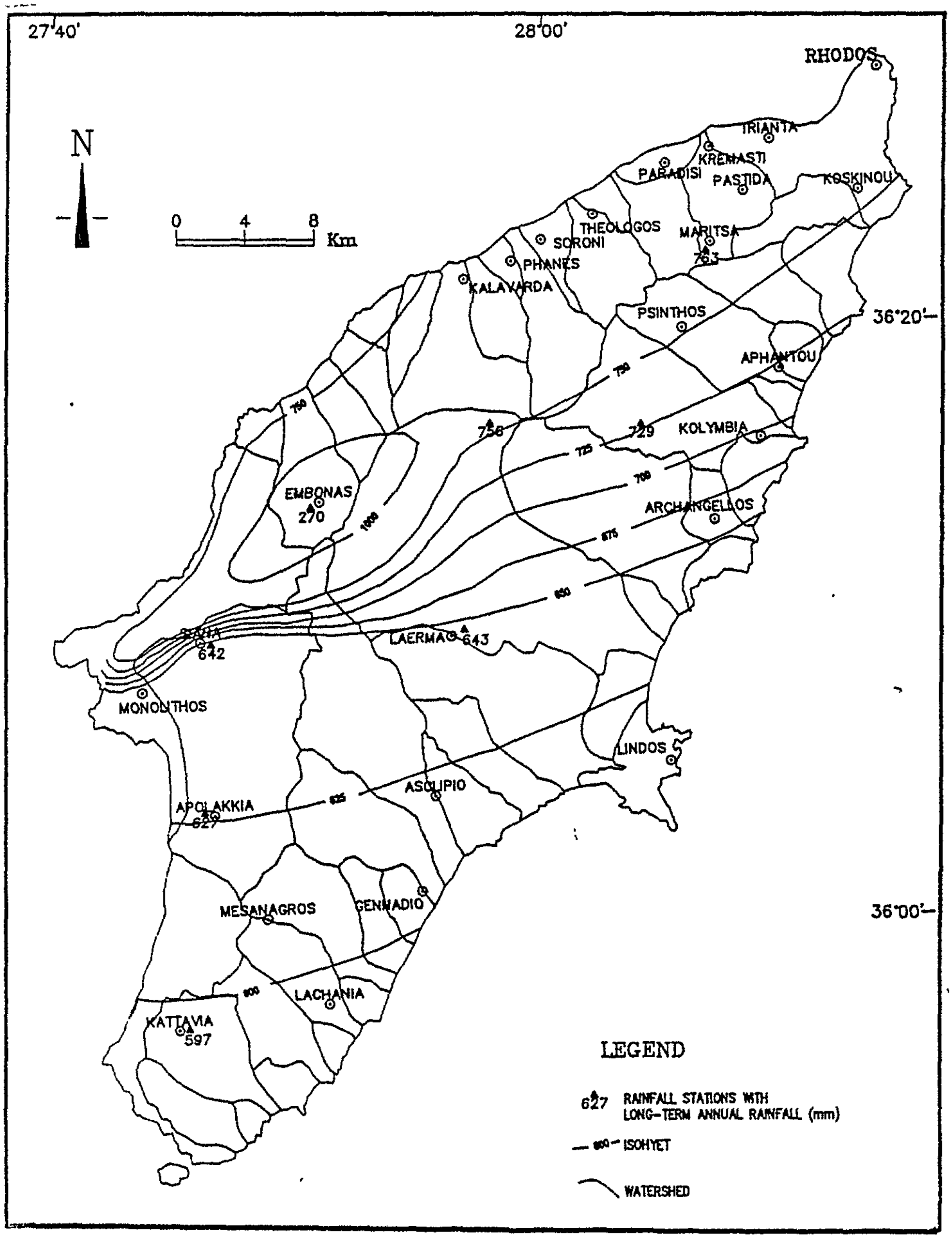


Figure 18 - Hydrologic basins and isohyets (after Iakovidis, 1988)

TABLE 7

Water balance of Rhodes island

		Iakovidis, 1988 Whole island		Kilakos, Drossos, 1989 Island's North. Part	
Mean annual precipitation		710 mm		767 mm	
Total study area		1403 km^2		320 km^2	
Precipitation	(P)	995 Mm^3	100.0%	245,0 Mm^3	100.0%
Evapotranspiration	(E)	797 Mm^3	80.0%	179,9 Mm^3	73.0%
Runoff	(R)	105 Mm^3	10.5%	19,7 Mm^3	8.0%
Infiltration	(I)	93 Mm^3	9.5%	46,4 Mm^3	19.0%

2.3.3. Hydrological conditions

2.3.3.1. Groundwater and the hydrological behaviour of the geological formations

The complex geological structure of Rhodes island controls the groundwater conditions and the following paragraphs provide brief descriptions of: the hydrogeological behaviour of the various geological formations; the type and development of the main aquifers; and, the hydrogeological projects carried out for groundwater exploitation.

Coastal and river bed alluvial deposits

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

These alluvial deposits consist 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, being mainly fed by infiltration of rain water, although locally they may also be enriched by torrent water. In addition significant local water recharge occurs through the underlying Archangelos limestones (Figure 19a). A large number of boreholes with high yields of between 70 to 140 m^3 hr^{-1} have been drilled into the Sgourou formation, but the intensive exploitation of these aquifers has already resulted in depletion in areas such as the Trianta region.

Levantinian Formation

This formation consists of permeable conglomerate and sandstones intercalated with impermeable marls and clays (Figure 19b). Aquifers developed in this formation are confined and are of important potential in cases where the conglomerate is very thick (up to 70 m); and where there is lateral percolation from neighbouring limestones, as in the cases of the Pastida, Kalithies and Afandou regions. Aquifers developed within sandstones have a lower potential yield.

Many boreholes have been drilled in this formation, but the aquifer has not been fully exploited. Successful test boreholes have been drilled recently which have indicated new aquifer zones (Kilakos and Drossos, 1989).

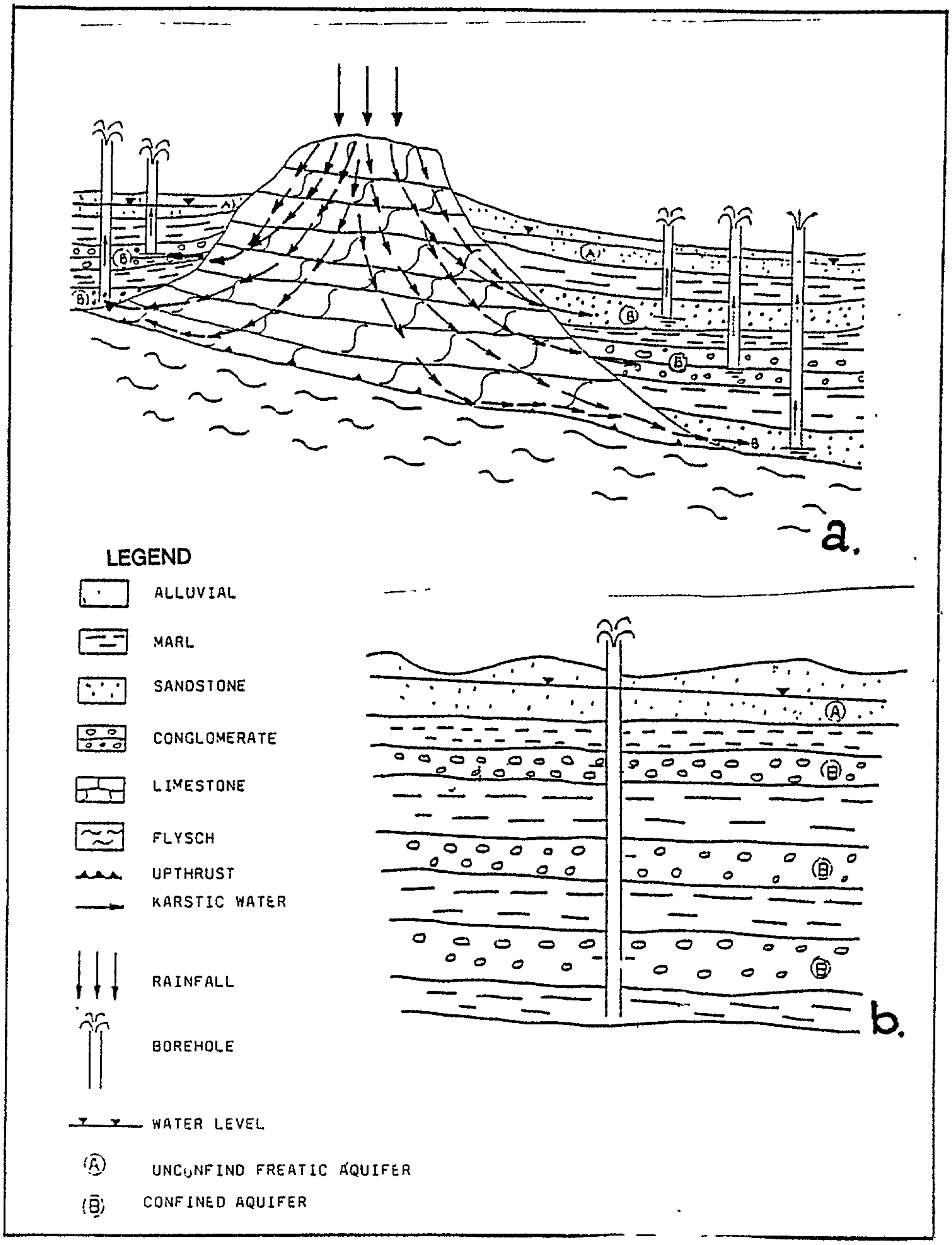


Figure 19 - Hydrogeological conditions (Strogilis, 1980)
(a) Sgourou formation and underlying limestone archangelos area
(b) Levantinia deposits - City of Rhodes area

Allochthonous limestones

Significant aquifers are developed within this formation. Water moves within a well developed karstic system, and also along tectonic discontinuities. Boreholes have revealed aquifers of great potential (yield 100 to 200 m^3 hr^{-1}. Significant results have also been obtained recently in the Elafokampos region from boreholes drilled through porous formations into the underlying limestones. The possibilities of water extraction from these limestones have not been exhausted in areas such as Archangelos, Malona, Salakos, Profitis Ilias.

Other Formations

Of the other geological formations of the island, the flysch and the ophiolites are impermeable and only in their upper weathered part can they support low to medium volume aquifers. The same is true of the Vati Group, except for its conglomerates. Finally in the autochthonous limestones, which are mainly situated in the mountainous Attaviros region of the island, boreholes have proved unsuccessful.

To conclude, it may be stated that the main aquifers which may be further exploited occur in the coastal and river-bed alluvial deposits; in the Sgourou formation; in the Levantinian deposits; and in the Allochthonous limestones.

2.3.3.2 *Groundwater projects*

Up until about 1970 the phreatic aquifer was mainly exploited via 12 to 15 m deep wells concentrated in the coastal zone and in riverine deposits. Up to the present about 390 to 400 boreholes have been drilled (YEB, 1991) and the rate of drilling is increasing as the need for water grows. About 250 of the existing boreholes are in the island's northern triangle between Rhodes - Fanes - Kolimpia.

Initial exploitation was of aquifers in the Sgourou formation where the majority of wells were drilled and yielded a production of 70 to 100 m^3 hr^{-1}. Later, exploitation of the aquifers in the Levantinian deposits commenced and this is now carried out to a depth of 200 m, with significant results. Positive results were also obtained in exploiting aquifers in the underlaying limestones (Kilakos and Drossos, 1989).

Increasing water use in northern Rhodes has resulted, however, in over-exploitation of groundwater resources and intensive pumping has generally had irreversible consequences, such as drops in aquifer level and water yield and contamination of aquifers by sea-water intrusion. Typical is the case of the Trianta region where, during the last two years, levels have dropped to about 50 m below sea-level (Phantidis, 1991) and the aquifer has reached depleted status. Other regions where decreasing levels have been observed are Koskinou (-24 m), Kalithies (-20 m) and Asgourou-Faliraki (-8 m) (Kilakos and Drossos, 1989).

The central and eastern parts of Rhodes island also contain significant aquifers, particularly in alluvial deposits (Phantidis, 1989). In contrast the southern region does not have important aquifers except in a small strip which includes the regions of Asklipio, Gennadion and Lahania.

In the mountain regions of Kritinia, Emponas, Siana and Monolithos, test boreholes have been unsuccessful and groundwater probably flows out to the sea.

An indicator of an aquifer's annual recharge conditions and its exploitation is the variation in height of the aquifer surface. Based on available data (Iakovidis, 1989) the following remarks can be made.

Wells and boreholes in the coastal zone which exploit mainly the phreatic aquifer of the alluvial deposits display no significant changes to the level of the surface. To the east around Rhodes city, Kalithies, and Afandou the annual variation in aquifer height is between 0.20 to 0.50 m while a 0.10 to 1.50 m level drop has been observed during the years 1986-1988. In the west from Trianta through to Salakos the annual level variation is between 0.10 to 1.50 m with a 0.10 to 0.70 m level drop over the same period (Figure 20). It must be noted that during dry periods in many locations the aquifer height declines to around sea level.

In the inland zone variation in water level is more complex. In eastern areas around Rhodes city, Koskinou, and Kalithies where the Sgourou formation aquifers are over-exploited, the annual variation in level is between 1.00 to 6.00 m. Between 1986 and 1988 levels dropped between 1.00 to 5.00 m and in some cases by as much as 25 to 50 m. In the remaining areas to the east around Archangelos, the annual variation is between 2.00 and 3.50 m with an overall decline of between 0.20 to 6.00 m from 1986 to 1988. In the central region from Maritsa to Archipolis the annual variation in level is between 0.30 to 9.00 m and the overall decline was between 4.00 and 6.00 m.

In the Trianta region to the west the annual variation is between 0.50 and 10.00 m. Here the drop in level from 1986 to 1988 was between 2.00 to 12.00 m, but, due to intensive exploitation, significant drops of up to 100 m have been noted at some sites.

In the remaining areas to the west from Kremasti to Salakos the annual variation in level is between 1.50 to 3.50 m, with a small decline of 0.10 to 4.00 m. It must be noted that in all central and western sectors, the exploited aquifers are within the Levantinian deposits.

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

2.3.4. Springs

A great number of springs occur on the island, with a yield of between 2 to 200 $m^3\ hr^{-1}$. The most important are located in the north and are of the following three types:

a) Springs developed at the tectonic contact of the over-thrusted allochthonus limestones with underlying impermeable formations. These have the most significant yields, are fed from groundwater circulating in the karstic limestone and, occur in the Salakos, Afandou, Archangelos and Apollon regions;

b) Springs fed from karstic aquifers are present in the autochthonous limestone masses of Attaviros. They are few; have low potential yield; and are found mainly in the Siana and St. Isidoros areas.

c) A number of springs are located in porous formations such as the Sgourou and Levantinian formations, at the contact between permeable and impermeable horizons and in fault zones. These springs usually dry out during the summer. They are found in the Psinthos, Pastida, Gennadion and Kalithies regions.

The most important springs having a mean yield of over 30 $m^3\ hr^{-1}$ are in the north of the island and are listed in Table 8. The values given for yield are based on mean spring yield over the period 1988-1991 (Phantidis, 1991).

Early estimates calculated that the volume of water discharged annually from the island's springs was around 32 Mm^3 (Strogilis, 1980), while recent estimates (YEB, 1991) indicate that present yield may be only up to 6 Mm^3. These data indicate that the volume of spring water has diminished significantly in recent years.

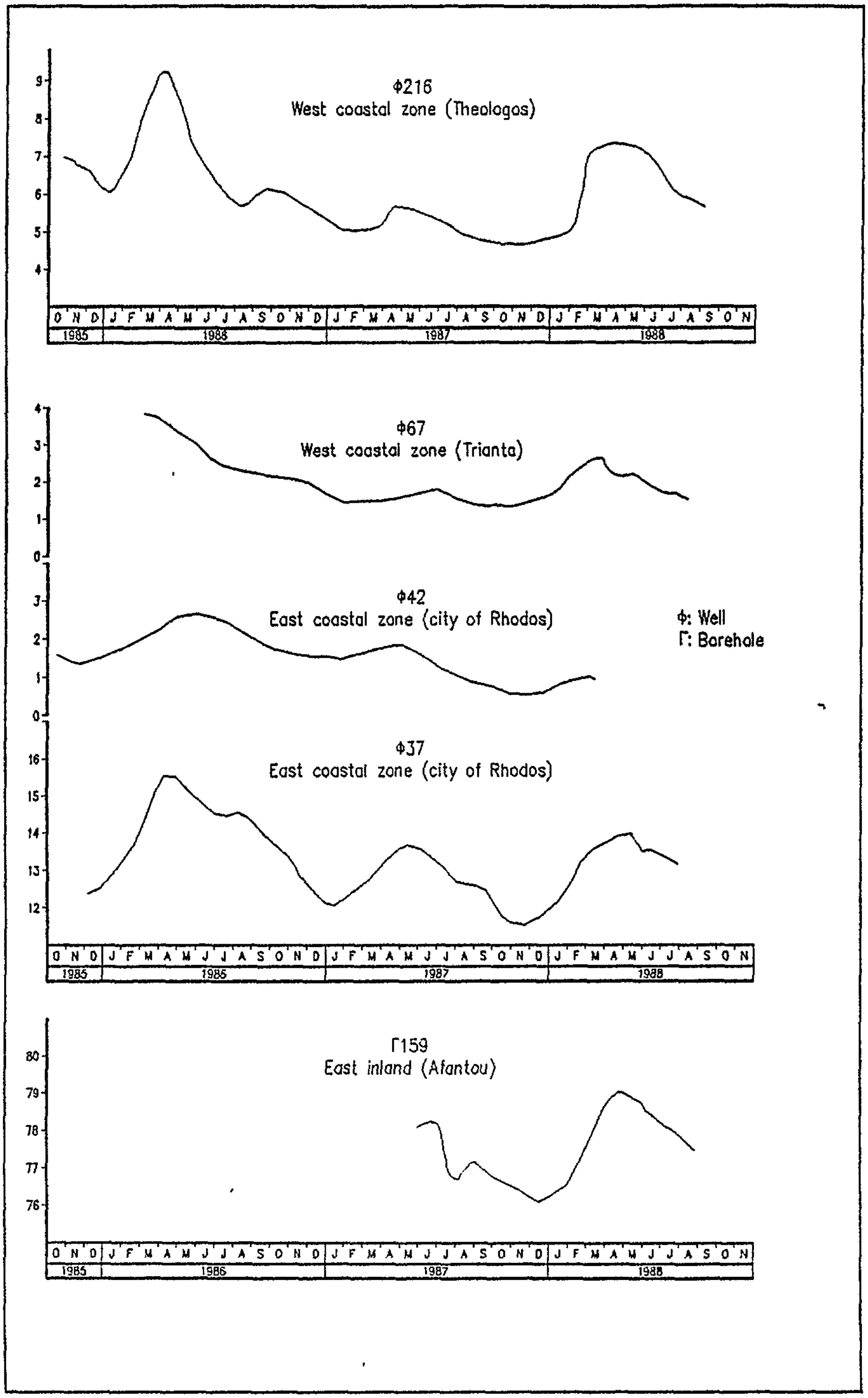


Figure 20 - Water level variations (Kilakos and Drossos, 1989)

TABLE 8

Most important springs

No	Island's part	Place name	Community	Yield (m^3 hr^{-1})
1	East	Epta piges	Afandou	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

2.3.5. Water resource management

The majority of the island's water supply is used for domestic fresh-water and irrigation purposes and only a small percentage is consumed by industries, by ships and to provide the fresh water supply of the adjacent islands, Symi and Halki.

Approximately 70% of the total annual water consumption (30 Mm ^{3}) for all purposes is consumed in the island's northern part (Table 9).

TABLE 9

Water consumption

USE	Water quantity Mm ^{3} yr $^{-1}$			
	Present consumption			2010 projection
	Iakovidis, 1988	Kilakos & Drossos, 1989	Mutin, 1991	YEB, 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	7.6	-	-
Other uses (Hotels)	-	1.5	-	-

As far as the domestic fresh water supply is concerned, 82% (14 Mm ^{3}) of island's total annual consumption (17 Mm ^{3}), is used in the north due to high population concentration and tourism. This demand increases every year.

In 1980 water amounting to 3.9 Mm ^{3} yr $^{-1}$ was supplied to Rhodes city via 12 boreholes and 2 springs (Strogilis, 1980). By 1990 the city was provided with water through 25 boreholes and 3 springs yielding 8 Mm ^{3} yr $^{-1}$ (Mutin, 1991). It should be noted here that the quantity of 8 Mm ^{3} yr $^{-1}$ includes losses, mainly due to leakages in the distribution network. Thus probably only 4.5 Mm ^{3} yr $^{-1}$ is actually consumed by the city's population.

The total volume of water used annually for irrigation over the whole island is 13 $Mm^3\ yr^{-1}$ of which 59% is consumed in the northern part. Agricultural needs are expected to increase in the future (Phantidis, 1989).

The most important water resource management projects completed in recent years include:

a. construction of the Apollakia dam having 8 Mm^3 storage capacity and irrigating 8.5 $10^6\ m^2$. To date the reservoir has only been filled to a quarter of its capacity (Mutin, 1991);

b. steps limiting borehole drilling have been applied in order to rationalize groundwater use; and

c. test boring and state programmes of installing productive boreholes have been carried out to meet the immediate needs of Rhodes city, tourism and the adjacent islands.

2.3.5.1. Fresh water consumption

During the last few decades many changes have occurred in water consumption patterns on the Island of Rhodes.

The first has been the enormous increase in tourist arrivals. From 230,000 visitors in 1970 to over 1,000,000 in 1990. The second change has been the increased *per capita* demand from 70 litres per person per day twenty years ago, to more than 150 litres per person per day at present. The third change has been the increased demand for water for irrigation both in Rhodes and in the other islands of the Dodecanese. For example, each summer more than 49.000 tons of fresh water are imported from the nearby island of Symi.

All of these factors make the present status of water supplies critical during the dry summer months and create very serious problems. Up to now remedial measures have been economically very expensive and not environmentally sustainable since there is a lack of knowledge concerning the existing trends and of the relevant parameters. For example there is no information whatsoever concerning the environmental cost of over-pumping which has resulted in the salinization of many wells, an irreversible phenomenon.

Taking into account both possible future climatic changes and human behaviour (increase in consumption per person) new measures are urgently needed. For example, in all pumping systems that are close to the sea, a device to measure salt content must be added.

About 50% of the domestic water consumption is used just for toilet flushing and one conservation measure would be the development of saltwater toilet systems. Taking into account the high cost of the water used for irrigation, every project that deals with irrigation must be economically rationalized. It is absurd to use water for growing potatoes in Rhodes when a kilogramme of potatoes has a production cost of more than 0.5 tons of water and the economic cost of water is much higher than the value of the potatoes produced. Therefore all these primary sector development "projects" must be re-examined.

2.3.6. Groundwater quality

In general groundwater quality varies within satisfactory levels. Local contamination in coastal zones is mainly due to sea-water intrusion. Bacterial contamination of aquifers has also occurred locally. The location of areas of brackish water intrusion on the island is illustrated in Figure 21 and these occur in regions where uncontrolled over-pumping occurs, exceeding the aquifer recharge rates.

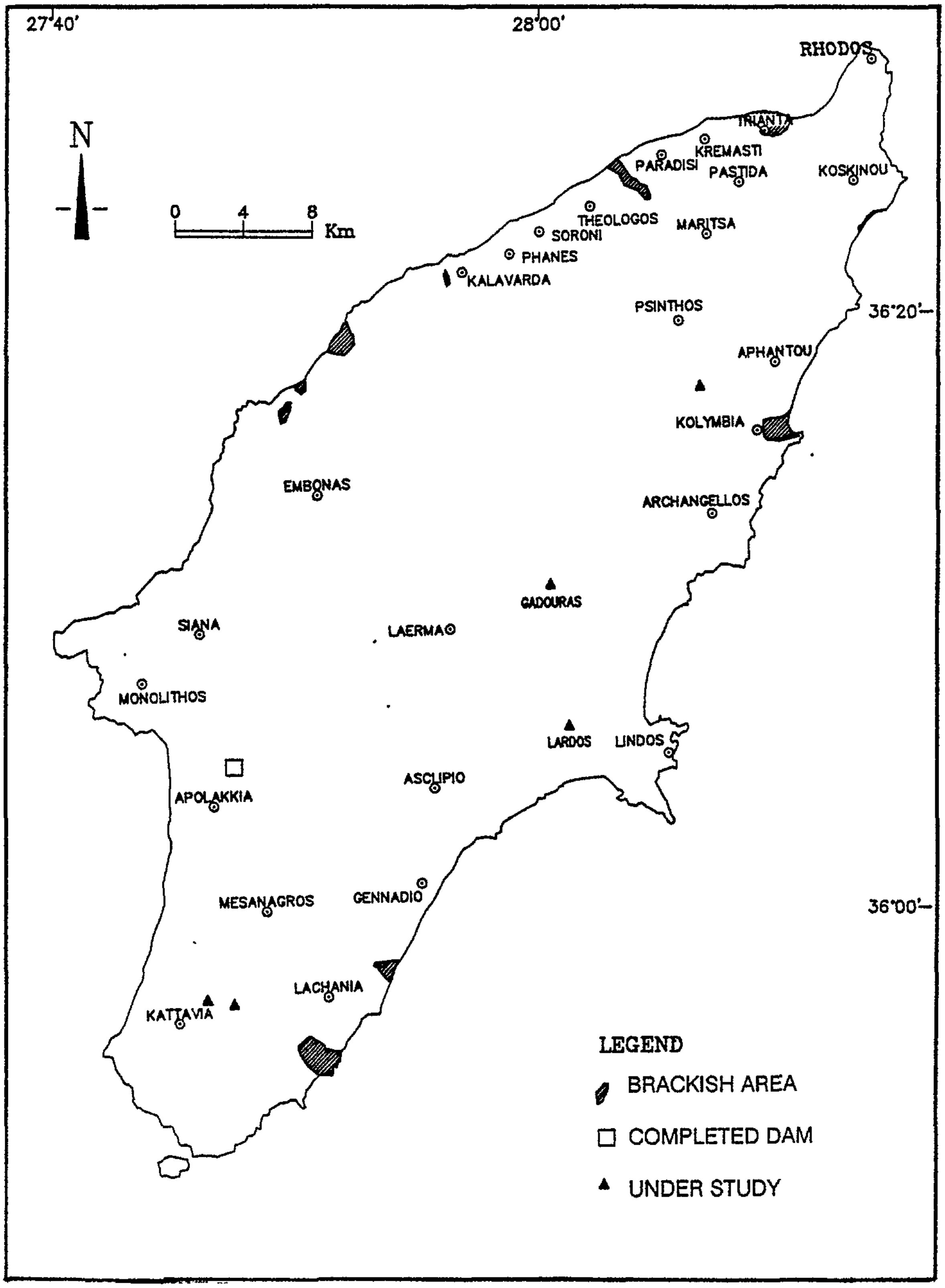


Figure 21 - Areas of saline water intrusion into groundwater and dam locations

In the northern part of the island a brackish front exists in the eastern coastal zone of Kalithies and Kolimpia Bay, whereas in Kalithies it lies about 500 m in from the coast. Note that at Kalithies where limestones extend to the coast, chloride ion concentrations reached 545 mg l^{-1} in boreholes during the summer of 1989 (Mutin, 1991). On the western coasts brackish fronts exist in the coastal zones of Trianta and Damatria and in the Trianta region a 106 mg l^{-1} chloride concentration has been measured.

In the southern part of the island, problems of saline water intrusion also exist in the eastern coastal zone between Gennadion and Lahania as well as in a zone east of Lahania up to 2 km from the coast. In the west a similar situation occurs at Cameiros, at about 500 m from the coast, and inland from Mandriko beach.

In addition to these regions, slight brackishness of aquifers has recently been noticed at certain boreholes in the Koskinou area. Chloride ion concentration has increased from 50 mg l^{-1} in 1975 to 60-80 mg l^{-1} in 1989 (Mutin, 1991). In these boreholes bacterial contamination has also occurred.

2.4. Marine physical processes

2.4.1. Introduction

The Island of Rhodes together with the islands of Karpathos and Kassos form what is usually termed the Eastern Straits of the Cretan Sea. These straits separate the Cretan Sea and indeed the whole Aegean Sea from the Levantine Sea. A 16 Km narrow passage separates the northern edge of Rhodes from the mainland of Asia Minor. The maximum depth of this passage, also named the Strait of Rhodes, is approximately 350 m. To the southwest lies the strait of Karpathos, which is 40 km wide and has depths of more than 700 m. The western submarine slopes of Rhodes are not very steep and face the northeastern part of the Cretan sea while the eastern slopes are very steep and further to the southeast the water depths reach a trough 4000 meters deep. This is the area where the so-called Rhodes Gyre is situated, one of the major features of the Eastern Mediterranean. It is a sub-basin cyclonic feature and a permanent characteristic of the northwestern Levantine Basin. The hydrology and general circulation characteristics of the Levantine Sea and of the Eastern Mediterranean have been the subject of a number of papers during the last few decades. A major step towards the understanding of the phenomenology and the dynamics of the area has been achieved through the international program POEM and its coordinated basin scale cruises that started in 1986. General reviews of the Eastern Mediterranean can be found among others in Hopkins (1978), Hecht *et al.* (1988), and Ozsoy *et al.* (1989).

The area southeast of Rhodes is believed to be the formation zone of one of the most important water masses of the Mediterranean, the Levantine Intermediate Water (LIW) (Ovchinnikov, 1984). The other two important water masses of the Eastern Mediterranean are the North Atlantic Waters and the Eastern Mediterranean Deep Waters. During winter, northerly dry and cold winds (the so-called Poyraz winds) blow from continental Asia Minor to the northern Levantine basin. These winds are strengthened as they pass through the Taurus mountains along the Turkish coast. Since they are cold and dry they are very effective in cooling the surface waters in the Rhodes gyre and also in raising their surface salinity through high evaporation. Thus the density of the surface waters in the centre of the dome of the gyre is increased and the newly formed waters sink at the periphery of the gyre and are subsequently arrested at intermediate depths. After their formation the LIW waters spread at intermediate depths inside the Eastern Mediterranean, pass through the straits of Sicily to the Western Mediterranean and eventually go through the Gibraltar straits. They then sink into the Northern Atlantic and travel westwards as far as the eastern coasts of the American continent.

2.4.2. Currents

The Rhodes gyre is permanent but undergoes changes in intensity, shape and extension on a seasonal and probably interannual basis (Figure 22). Its maximum intensity is found over the deep trough mentioned above but it is sometimes extended eastward up to the western coasts of Cyprus. Its southward extent is usually limited by the so-called Marsa-Matruh anticyclonic gyre which dominates the area northwest of Egypt. Between the Rhodes gyre and the Turkish coast flows the Asia Minor Current which moves westward along the south coast of Turkey. This strong current transports large amounts of heat and salt westward and it eventually reaches the northern part of Rhodes (Nittis *et al.*, 1990a).

In summer, the Asia Minor Current enters the Aegean through the Rhodes strait and continues its course towards the north, along the eastern Aegean. This passage through the Rhodes strait results in a very strong westward moving current inside the strait, with mean velocities reaching 40 cm sec^{-1}.

In winter, the current through the Rhodes strait is weakened because only part of the Asia Minor current passes through the strait. At this time, after reaching Rhodes, the major part of this current turns to the southwest, moves along the eastern coast of Rhodes, passes east of Karpathos island and then enters the Aegean through the strait of Kassos island. It then moves northward but when it reaches Karpathos it is divided into two parts. One continues its path to the north along the eastern Aegean while the other bifurcates to the west and forms a belt around the Cretan sea.

As far as the currents around Rhodes are concerned, we can conclude that the strongest currents are found in the Rhodes strait during summer with typical westward velocities up to 40 cm sec^{-1}. On the eastern coast the currents are directed toward the southwest with typical velocities of the order of 10 cm sec^{-1}. Finally along the western coasts, the currents are much weaker especially during summer.

2.4.3. Temperature/salinity

Based on its temperature-salinity characteristics the water column can be subdivided during summer into the following layers (Hecht *et al.*, 1988).

A surface mixed layer 30 m to 50 m thick, usually called the Levantine Surface Waters (LSW) is produced locally during the summer, by excess heating and evaporation and overtops the lower salinity North Atlantic Waters (NAW). The temperature of this layer can reach 24-25 °C in the open sea in August and possibly higher values in shallow coastal areas, while its salinity reaches a maximum in September, with values up to 39.3 p.s.u. The exact value of this maximum seems to depend strongly on the interannual variability of the atmospheric parameters. In fact, recent measurements in the Cretan Sea (September, 1990) carried out by the University of Athens and the Institute of Marine Biology of Crete indicated surface salinity values as high as 39.55 p.s.u., which is much higher than the expected climatological mean for the area. This is probably an indication of sea response to the particularly dry weather that prevailed in the area during the period 1987-1990.

Below the LSW layer a sharp salinity minimum indicates the presence of North Atlantic Waters. These waters enter the Mediterranean through the Gibraltar straits, and are transported eastward by the North African Current. After entering the Eastern Mediterranean this current leaves the north African coast and travels eastward as a mid ocean current or jet (the so-called Mid-Mediterranean jet). Due to mixing, the salinity of the NAW layer increases as it propagates to the east. In the northern Levantine typical salinity values range from 38.7 to 38.9 p.s.u. The bottom of this layer is usually found at 80 to 100 m.

Immediately below the NAW layer we find the Levantine Intermediate Water (LIW) layer which is characterized by a salinity maximum. The core value of this maximum is 39.1 p.s.u. while the temperature at the core lies between 14.7 and 15.5 °C. The extent of the LIW depends on the area but it usually extends to 350 m occasionally reaching the 500 m depth.

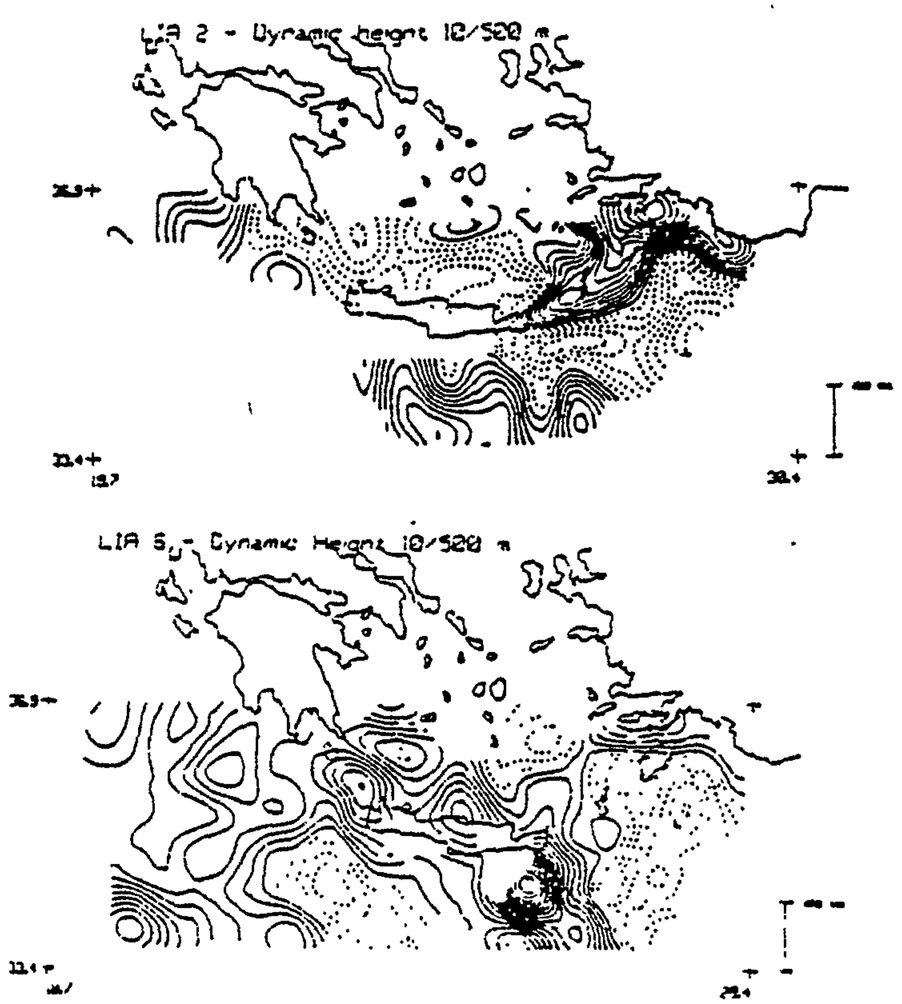


Figure 22 - Meandering cyclonic Rhodes Gyre for winter (upper) and for summer (lower) (Nittis *et al.*, 1990a)

Finally, below 1500 m we find the Eastern Mediterranean Deep Waters (EMDW) with characteristic salinity of 38.6 p.s.u. and temperature of 13.3 ° C. Between the LIW and the EMDW lies a transition layer with intermediate characteristics.

In winter, convection mixes the surface waters to a depth which ranges from 150 m to 400 m, depending on the area. The NAW layer cannot be distinguished any more in most of this sector (with the exception perhaps of the Marsa-Matruh gyre). Surface salinities are lower than in summer and have typical values of salinity from 38.8 - 39.1 p.s.u. Surface temperatures range from 14.5 to 16 ° C.

2.4.4. Waves

The surface wave regime depends mainly on the winds that prevail in each area. Based on unpublished data from the Greek Meteorological Office, the most frequent winds are from the West (40.24%), the NW (12.40%) and the SW (7.84%) while of minor occurrence are winds from the SE (7.61%), from the S and N (3.26 and 2.55% respectively) and finally from the E and NE (2.24 and 0.75% respectively). Winds with strength less than 1 on the Beaufort scale account for 23.09% of all winds.

The W and NW winds have an important fetch and thus can generate high waves at the western coasts of the island. By applying empirical formulas for the computation of the significant wave height, we calculated that winds from these two directions with a force of 7 on the Beaufort scale, can generate waves having significant height of 2.5-3 m if their duration is 10 hours, and 4 m if their duration exceeds 36 hours. We should note at this point that the W and NW winds prevail during the summer period and rarely attain strengths greater than 7 B. Maximum strength observed is 8 B, with a frequency of occurrence 0.03% and 0.06% respectively, which amounts to a total of 3 and 6 hours approximately.

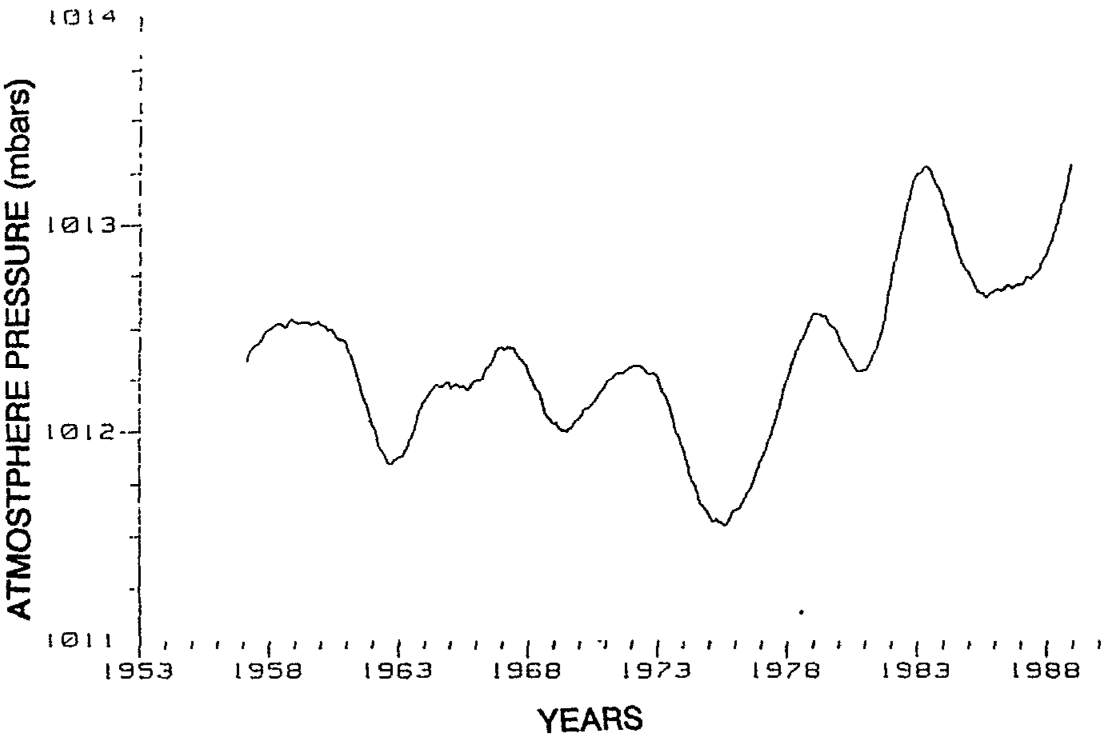
In contrast winds from the E and especially from SE, although less frequent, are much stronger and as a result they are more effective in wave generation. These winds occur during the winter and are related to the passage of the cyclonic disturbances through the area. At 7 B they have an annual frequency of occurrence 0.59%, at 8 B 0.22% at 9 B 0.06% and at 10 B 0.01% (52, 20, 5 and 1 hr respectively). This means that once or twice per year, SE winds blow under severe storm conditions and can generate waves with a significant wave height of 5 to 6 meters. What should be noted at this point is that these winds are related to low atmospheric pressures which, because of the inverse barometric effect also increase the mean sea level. Thus the destructiveness of these events can be very important since the significant wave height and increased mean sea level result in waves breaking closer to the shoreline.

2.4.5. Sea level

The mean tidal range in the port of Rhodes for the period 1956-1978 was only 13 cm, while the maximum tidal range observed during this period was 45 cm (data from Greek Hydrographic Service) (Fig. 22). These data agree well with results of tidal models for the Aegean which, for the semidiurnal tides, show the existence of a modal point somewhere in the Cyclades (Papaioannou, 1990). In this area tidal ranges are of course close to zero and increase as one moves to the south and to the north. They reach their maximum values in northern Greece.

Sea level oscillations in the range of a few days (storm surges) are also not very important in the area under study. The results of research conducted by the University of Athens (Nittis *et al.*, 1990b) showed that storm surge maxima occur in the northern Aegean, while in the Rhodes area they rarely exceed 20 cm. This fact is related both to the track of the cyclones during the winter season over the wider area and to the small "piling-up" effect in the straits, compared to the greater effect caused by the continuous coastline of northern Greece.

Figures 23 and 24 illustrate the variations in atmospheric pressure, air temperature, sea level and rainfall during the last 25 years for the island of Rhodes.



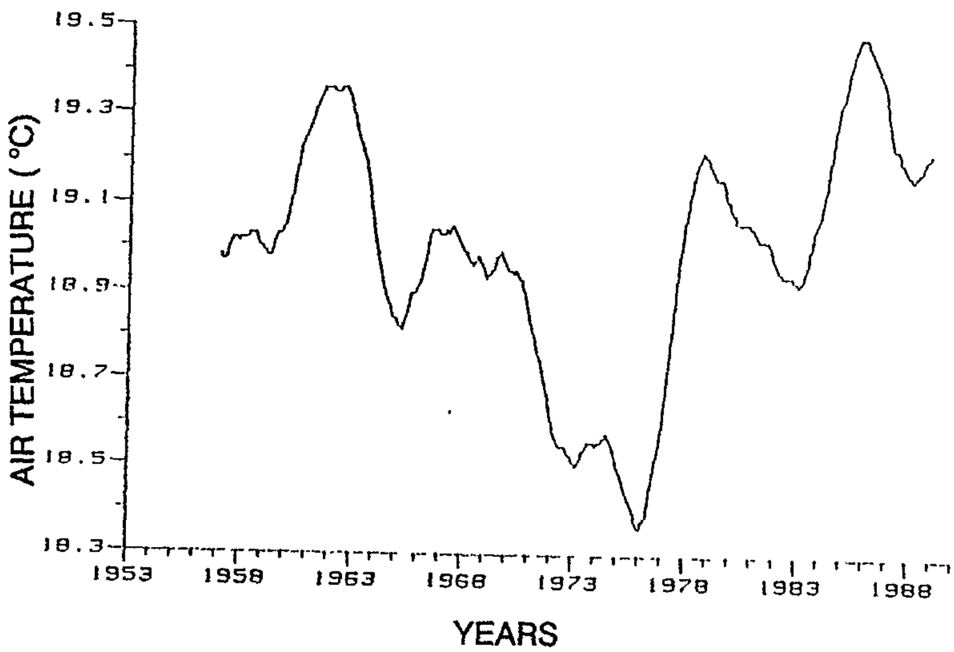
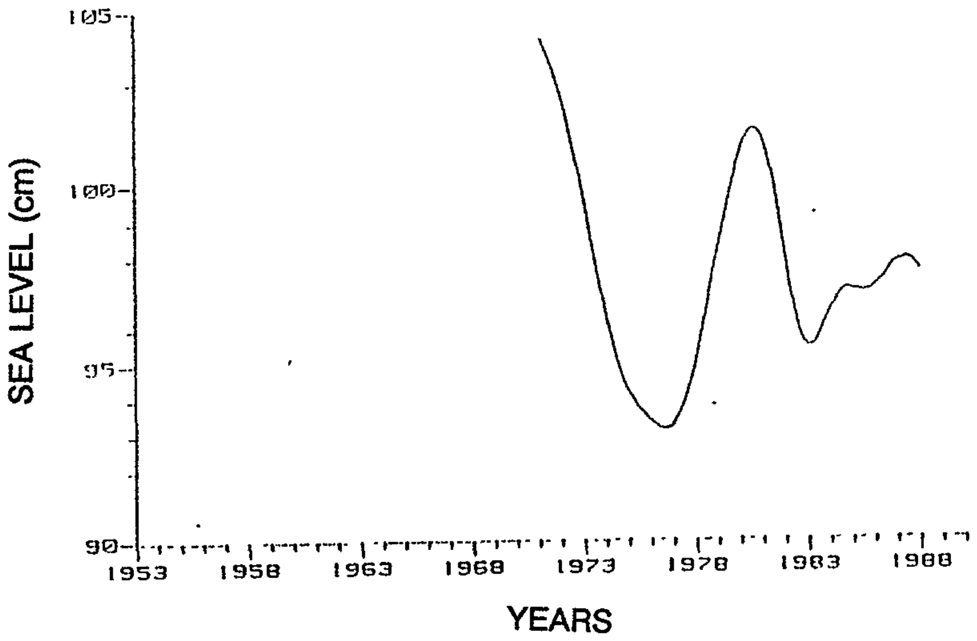


Figure 23 - Mean Annual Atmospheric pressure (upper) and Air Temperature (lower) of Rhodes (1953-1990)



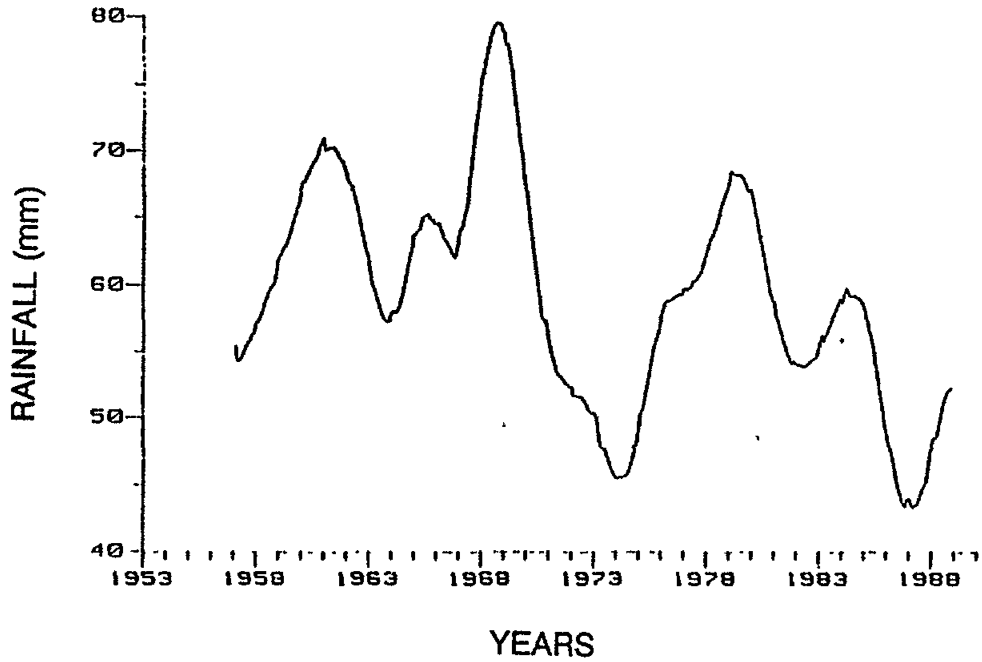


Figure 24 - Mean Sea level oscillations (upper) and rainfall (storm surges) (lower) at Rhodes (1953-1990)

2.5. Ecosystems

2.5.1. Natural terrestrial ecosystems

Three basic Mediterranean terrestrial ecosystem types occur on the Island of Rhodes, namely: forests, shrublands and wetlands.

2.5.1.1. Forests

Almost all forests on Rhodes consist of conifers, pines or cypresses and their cover is relatively high, reaching a value of over 40% compared to the mean value for Greece of only 19%. This deserves special mention because signs of degradation of this habitat have become evident during the last few years. For example, an area of about 40 km^2 was destroyed by fire in 1988.

The pine *Pinus brutia* is the dominant native species while *Pinus halepensis* was introduced during and subsequent to the Italian occupation of the island. The Cypress (*Cypressus sempervirens*) has two forms, the wild native form and the cultivated one with a "vertical" shape. As a consequence it is easy to distinguish areas of planted and native pines and cypresses.

2.5.1.2. Shrublands

The shrublands in Rhodes cover about 35% of the island surface. Two major Mediterranean ecosystem types can be distinguished. At the wet end, the dense evergreen shrub community, phrygana dominates, while towards the dry end the evergreen scrub is replaced by an open scrub community, the maquis. As far as maquis ecosystems are concerned, there is agreement in the use of terminology, while phrygana ecosystems are often referred to by the term garrigue.

The plants that dominate the maquis ecosystems are adapted to summer drought stress by means of evergreen sclerophylly while those in the phrygana ecosystem, display seasonal dimorphism (Margaris, 1980) by which they considerably reduce the mass of transpiring leaves during summer.

The maquis

The dominant evergreen shrub of the maquis ecosystems of N.E. Rhodes is *Arbutus adrachne* which often becomes a conspicuous tree, forming lush, impenetrable thickets mixed with *Erica arborea* and *Quercus coccifera*. This high shrubland continues in the more humid lowlands in the northern part of the island and in other places as well, as elevation becomes higher. In the drier south the maquis is less luxuriant and *Quercus coccifera, Olea europea* (wild form) and *Pistaca lentiscus* replace *Arbutus adrachne*. Additional typical species found in the maquis of Rhodes include the evergreens *Ceratonia siliqua* (possibly an ancient introduction) *Myrtus communis and Laurus nobilis*.

The Phrygana

The Phrygana is composed of undershrubs such as thyme, *Thymus capitatus*; dwarf heather, *Erica manipuliflora*; *Sarcopoterium spinosum; Cistus* species; spiny broom, *Calicotome spinosa*; the spiny, *Genista acanthoclada;* and in the south on Mount Attaviros, *Euphorbia acanthothamnos*. Most of these species are also common to the Cretan phrygana, but a speciality of Rhodes is *Lithodora hispidula* with its needle-sharp hairs and bright blue flowers. Figure 25 illustrates the distribution of this ecosystem type on Rhodes.

Since the rather "wet", by Aegean standards, climate of Rhodes can support maquis, the existing phryganic communities can be characterized as man-made resulting from anthropogenic mismanagement with fires and overgrazing. The almost desert condition of Mount Attaviros can be considered as a typical case.

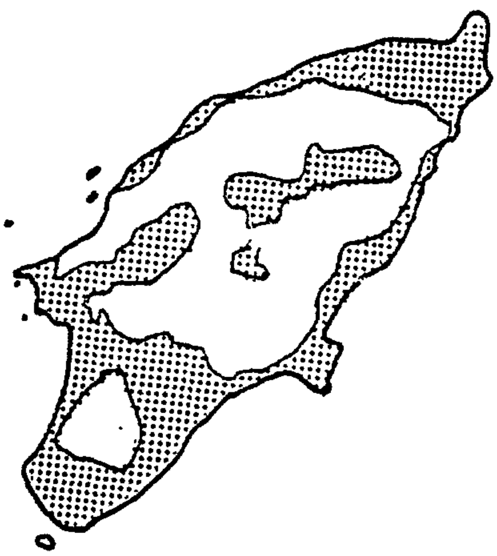


Figure 25 - The Phrygana ecosystems of Rhodes island from the remote sensing map of Greece (Diamantopoulos, 1983)

2.5.2. State of the natural environment and current problems

The combination of high temperatures and water deficiency during the summer leads to a high frequency of fires. The association of this climatic type with fire is well known and Shantz (1947) refers to them as "fire-type" stating: "that this type was ever free from fires seems unlikely".

In the course of their evolution ecosystems subject to frequent fires for thousands of years may have developed properties which make them extremely flammable. In fact these ecosystems may need to be burnt deliberately every so often to prevent flammable materials accumulating, since subsequent fires would generate very high temperatures resulting in turn in real catastrophes (Figure 26). Biswell (1974) suggests that: "Fire in chaparral is both natural and inevitable. It has always occurred and probably always will, because the vegetation becomes extremely dry near the end of a long, hot, nearly rainless summer. At that time also, humidity may be extremely low and winds high".

Wood as fuel for heating and cooking was previously of great importance for the island's people. Socio-economic changes resulting in the introduction of central heating systems with petrol, electricity and gas in bottles have reduced fuelwood collection from forests.

A major problem related to pine forests, has resulted from new chemical products which can be considered as "substitutes" for natural ones such as resin. Although resin collection was an important economic activity some years ago, it has now become unprofitable. The resin collectors, being the past protectors of forest have disappeared and the invasion of forests by shepherds and their flocks has become the new reality in forest exploitation.

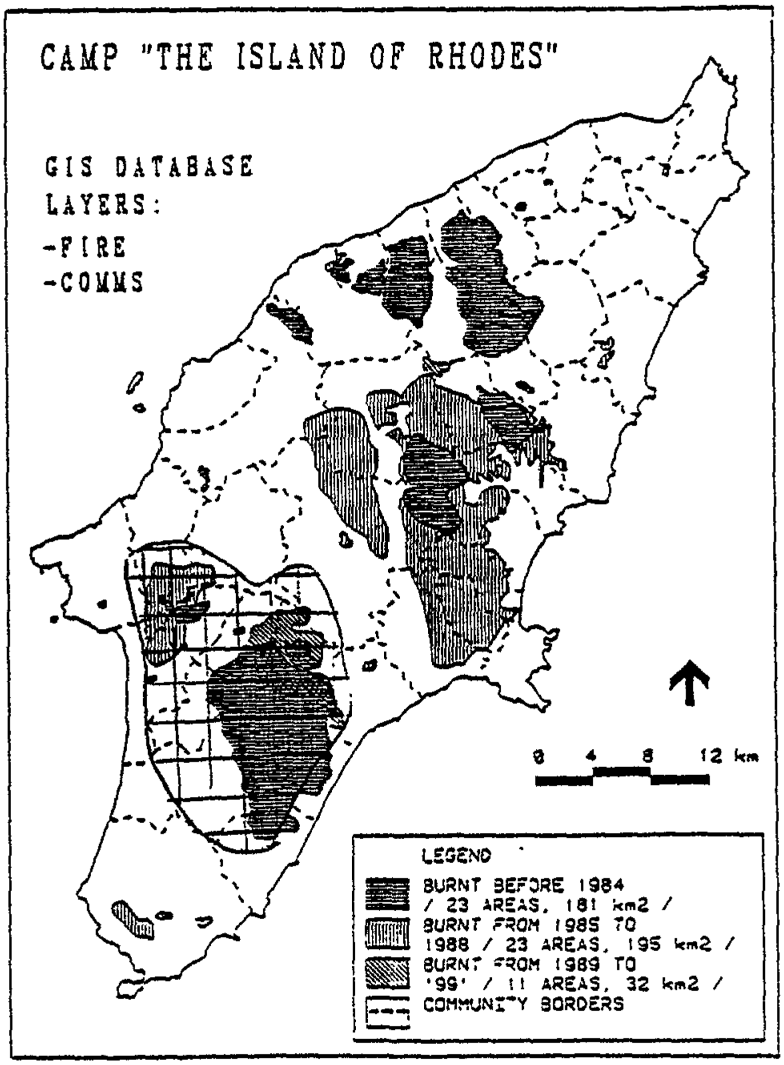


Figure 26 - Burnt areas of Rhodes island (CAMP/GIS Team).
The cross-hatched area is an estimation of the 60 km2 burned area in 1992

Fire prevention policy in Rhodes has proved to be one of fire delay and prevention. Fuel accumulates in the form of dead, dry, organic material such as pine-needles and when sooner or later fires do occur, high temperatures are developed. In addition the high volumes of flammable material result in the rapid spread of the fire area and the results are potentially disastrous. In Rhodes the "all fires are bad" viewpoint predominates and there is an almost complete lack of desire to acquire knowledge and assimilate the experience of successful alternative approaches, such as controlled burning.

Every summer following outbreaks of fire and because no information concerning alternative strategies is available to politicians and decision makers, reforestation is decided upon as the only solution. This so-called reforestation is carried out with non-indigenous species which, from an ecological perspective can disrupt the indigenous flora and fauna.

2.5.3. The natural environment of Rhodes and its flora

Only a few plants are endemic to the island, including *Dianthus rhodiums* (shrubby pink) and *Consolida arenaria* (sand-dune lark spur). Others, such as *Lithodora hirsuta* have their centres of distribution in the island and extend their range both east and west.

The flora of Rhodes seems to be poorer in comparison with Crete and even Karpathos island (taking into account the difference in the area). This can be explained to some degree by the absence of the highly diverse types of terrain which form the micro-habitats of many Cretan endemics. Recent research has revealed however that some characteristic species well known from the flora of Crete are also present on the Island of Rhodes.

The cypress (*Cypressus sempervirens*) for example which was known as a native only in the gorge of Samaria, in Crete, is also present in a curiously patchy distribution on the Island of Rhodes (Rackham, 1991) and, according to our observations, in the island of Symi. In addition the Cretan Palm Tree, *Phoenix theophrasti*, is present on Rhodes as well.

Finally Rhodes is the last station for some plants of "eastern" origin. For example *Liquidabar orientalis*, called in Rhodes zydia, is an eastern tree common in wet places and dominating the Petaloudes (butterfly) valley. It is totally absent from Crete. A non-European thistle, *Carlina tragacanthifolia*, is also common on Rhodes as is *Trifolium clypeatum*, a clover common on Rhodes and also found in Karpathos although nowhere else in Europe.

2.5.4. The valley of butterflies (Petaloudes)

"Petaloudes" (the Greek name for butterflies) is the popular name of the valley which is the island's major tourist attraction. This spectacular butterfly [1] biotope, which is due to a rather uncommon ecological phenomenon, exhibits a remarkably high population density of the insect *Panaxia quadripunctaria Roda*.

The Valley of Butterflies which covers 60 ha, is located in the northern part of the island, 26 km from the town of Rhodes and 6 km from the western coast. Along the Pelican river, a broadleaved deciduous forest occurs dominated by *Liquidambar orientalis*, a tree up to 20 m high. In addition, *Platanus orientalis L., Cercis siliquastrum L., Styrax officialis L., Phillyrea latifolia L.* and *Nerium oleander L.* are also found in the area. Understorey layers are very poorly developed. The area from the head of the river to the hill top is covered by a *Pinus brutia* forest which, with the exception of *Liquidambar orientalis*, contains species common all over Greece. The butterfly species does not seem to be associated with any particular plant species and this valley is not the only habitat of *Panaxia* in Greece. It has been recorded on many other islands as well as in mainland Greece, but nowhere is its density comparable to that found on Rhodes. The classification of *Panaxia* sites is controversial, as it could be argued that at least some of them are not primary habitats, but only migratory stations.

The factors stimulating the yearly migration of *Panaxia* are mainly climatic. The island's minimum temperatures in conjunction to maximum humidity values along the valley seem to be the dominant factors in determining the suitability of the butterflies fragile environment. Water availability is a prerequisite for the survival of mature individuals. Temperature, another abiotic factor, regulates the horizontal and vertical movement of the insects from warmer to cooler sites in the biotope. Until the early 1970s the valley was the only secondary biotope. Following a continuous decline in the number of insects throughout the previous decade the situation became critical in 1983. Nowadays, several sites have become secondary habitats, such as those at Fassouli and Nanoi. However, these biotopes have population densities far lower than those in the Valley of Butterflies.

Agricultural activities including: irrigation changes to the insular landscape; the increased use of pesticides and in particular the summer air-spraying of pesticides against *Dacus olei*; and the use of UV mosquito traps have serious consequences for *Panaxia* affecting its habitats and migratory routes. The Valley of Butterflies seems to be the most seriously affected since its limited area carries an enormous tourist load (more than 250.000 tickets per year).

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[1] Despite popular belief *Panaxia* is not a butterfly but a genus of day flying moths, Editor.

2.5.5. Managed ecosystems

2.5.5.1. Cultivated land

Plant and animal components of semi-arid Mediterranean ecosystems show adaptive strategies by which, under normal conditions, they overcome periods of stress resulting from water scarcity and at the same time make efficient use of water when available.

During the more than 2,000-year period of exploitation, traditional social systems were developed and a "stabilization" of the desertification process was reached. The most useful strategies were the terracing of slopes and the development of agricultural and grazing management systems.

Advanced agricultural practices developed during the last few decades in the lowlands of mainland Greece provide products of such improved quality and in such quantity and variety that "terrace agriculture" has been unable to match them. Abandonment of terraces has resulted in turn in the disruption of traditional grazing management systems. Fires, combined with overgrazing have become a reality on almost all islands of the Aegean including the Island of Rhodes where desertification rates have increased dramatically, reaching catastrophic levels.

2.5.5.2. Bottom land cultivation

Today cultivation in Rhodes covers about 20,000 ha, of which 10% are irrigated and more than 80% are located in bottom land. There are two basic crops, vegetables (mainly tomatoes and water melons) and grapes.

In the past these vulnerable products which are consumed only fresh, would deteriorate in the hot dry months if they were held in store before consumption. This problem combined with the long distance from continental Greece did not guarantee their export. However, the seasonal population increase due to tourism led to an increase in local demand for fruits and vegetables during the summer. This high demand has resulted in an increase in local production. According to recent statistics, annual production of tomatoes in Rhodes has reached more than 35,000 tons.

In the case of water melons, there has been a continuous increase in production to more than 8,000 tons per year, but unfortunately, the efficiency of production is only about 60% compared to the average for the rest of Greece.

Grapes have not been seriously affected by this so called intensification of agriculture, mainly because dry varieties are produced for the making of high quality wine. Rhodes produces more than 10,000 tons of wine per year.

Theoretically, the agricultural decline and abandonment of terrace cultivation has increased land available for grazing. On the other hand, disruption of the traditional management systems of grazing, with the resultant fires and overgrazing, have become major problems, which have not only had impacts on the natural ecosystems but have also increased erosion, and directly affected other critical factors such as water resources. Over exploitation of the island ecosystem by grazing animals has already resulted in serious degradation of plant cover and biomass, leading directly to a serious decline in economic yields from animal husbandry.

2.5.6. Marine ecosystems

The geographical position of the island, its limited continental shelf exposed to the open seas and the strong surface currents from the NW Levantine and the SE Aegean, are the major factors controlling the dynamic hydrography of the marine environment. In addition, possible upwelling along the coastal zone may contribute to the coastal circulation and mixing of waters. Hence, the residence time of the coastal waters are particularly short. This, in combination with the low nutrient concentrations reflects the prevailing oligotrophic character of the area. The low density of zooplankton and the high diversity of species are indicators of the mixing processes of the offshore waters. The species of benthic fauna in the fine sediments along the NW coast decrease with depth (Coccosis *et al.* 1991).

Anthropogenic activities have no impact on coastal waters, bathing quality and the microbiological load is well below the national and EEC standards (Ministry of Environment, 1989).

2.6. Population and economy

2.6.1. Population

The population of Rhodes is spread over forty-two scattered villages and the town of Rhodes. According to the 1991 census, the population of the town of Rhodes and some villages in the northern part (Ialyssos, Kalithies, Faliraki and Afandou) has increased over the previous ten years. The total population of the island reached 109,532 in 1991, 67.4% of the population of the Dodecanese, as opposed to 62.7% (90,963) in 1981 (Table 10).

TABLE 10

Greece and the Dodecanese - Population 1961-1991

Area	Population				Area (km^2)	Population density, 1991
	1961	1971	1981	1991		
Greece	8,388,553	8,768,641	9,740,417	10,256,464	131,957	78
Pref. of Dodecanese	123,021	121,017	145,071	162,493	2,714	60
County of Rhodes		70,110	90,963	109,532	1,561	70

1961, 1971, 1981: Censuses
1991: Greece and Prefecture of Dodecanese: Census County of Rhodes: consultant's estimates

This increase is due to tourism which has encouraged people to remain on the island and has also attracted employees from other areas of Greece. Around the town of Rhodes there are many suburbs and villages (Ixia, Asgourou, Kremasti, Paradisi, Pastida, Maritsa, Damatria and Tholo) where complete urbanisation has taken place. In these areas the secondary and tertiary production sectors are dominant, mainly in the form of tourism services for the hotels along the Rhodes - Paradisi axis. Thus these areas have been transformed from rural to 'dormitory' villages. In Paradisi in particular the construction of Rhodes International Airport on the most fertile plain of the island has played a major role in this transformation. Afandou, the island's second most fertile plain after that of Paradisi has been developed into a golf course.

In the villages of Kalithies and Afandou the same phenomenon is observed, Kalithies in particular provides an extreme example, where employment in tourism and related commercial activities has reached high levels. In many villages there is an increase in land prices and a frenzy of construction work.

In the rest of the island, the central, mountainous and the southern parts, the primary production sector predominates, with cultivation and animal breeding. The decreased population resident in mountain villages is again due to the development of coastal tourism based on large hotel complexes which provide centres of employment. It is not unusual for a farmer to be seasonally employed in tourism which creates local agricultural labour shortages during the summer.

In the largest section of the island, the population seems to have undergone a slight increase or to have remained stable according to the statistics (Table 11) but in reality it has decreased. The reason is that as the census is carried out on Sundays, it is easy for a large number of the island's inhabitants to go from the city of Rhodes to their villages, and register there, since greater village populations provide more state funds.

In conclusion we can say that there is a population shift towards the urban centres, an in-migration to Rhodes from the surrounding islands and the rest of Greece. In addition, in recent years, there has been a population movement from the countries of the European Community toward the city.

According to Tables 12 and 13 which apply for the Prefecture of the Dodecanese as a whole, but are particularly applicable to the Island of Rhodes, the active population by sector of employment has increased by 0.7%. In 1981 this constituted 32.3% of the total population. The only exception which can be observed since then is a decrease in the primary sector of around 0.8% but this is not shown by the statistics as many people who are registered as farmers actually work in the construction, services, and other sectors.

The greatest increase has been in the trade and tourism sectors, where the number of employed people more than doubled, being derived mainly from the primary sector. In the secondary sector we observe an increase in employment in construction and public works (0.3%); while mining/quarrying and manufacturing showed a small increase (0.4%). It is worth noting that in 1986, 29.2% of the labour force was employed in trade and tourism; 17.6% in other services; 14.7% in construction; 12.0% in agriculture and animal husbandry; and 10.4% in mining/quarrying and manufacturing.

Unemployment is seasonal and high during the winter months, when the tourist season ends. During the summer months unemployment is as low as 1-2%.

2.6.2. Primary activities

The primary sector (agriculture, animal breeding, forestry and fishing) in the Dodecanese and in particular in Rhodes has shrunk, as illustrated by the fact that in 1986 the primary sector contributed a mere 7.6% to the gross local product (Table 13).

The cultivated areas on the island, including fallow land, cover an area of 272,925 ha which constitutes 64% of the total cultivated area within the Prefecture (Table 14). The percentage of irrigated land is low and declined until 1987 remaining constant at 25,000 Ha between 1987 and 1990.

There has also been a considerable decrease in agricultural and animal production, including poultry. The fishing activities are negligible.

As regards aquaculture, a large fish farming unit has been constructed in the area of Kattavia, using tanks on dry land for fish and prawns, in addition to a fish-spawning station. Opinions on the potential for the development of fish farming differ, although the island has natural bays which might be suitable for such activities.

The Fisheries Department of the Prefecture is of the opinion that the island's coastal waters are not suitable for the installation of fish farming units because the sea is very deep. This, however, may be an excuse so that hotels may be built in these regions, especially since the development of Southern Rhodes is a matter of capital and nothing else. Noticeable is that an area of publicly-owned coastal land is currently being auctioned off by the state.

TABLE 11

County of Rhodes
Population 1971, 1981, 1991 by municipality or community

Municipality - Community	Population			Rate of Growth		Percent Composition (1)		
	1971	1981	1991	1971-1981	1981-1991	1971	1981	1991
Greece - Total	8,768,641	9,740,417	10,256,464	10.6 %	0.5 %	100.0 %	100.0 %	100.0 %
Prefecture of Dodecanese	121,017	145,071	162,439	1.93 %	1.14 %	1.4 %	1.5 %	1.6 %
County of Rhodes - Total	70,110	90,963	109,532	2.64 %	1.87 %	57.9 %	62.7 %	67.4 %
Municipalities - Total	36,427	44,443	52,734	2.01 %	1.73 %	52.0 %	48.9 %	48.1 %
Megalo Chorio (Tilos Island)	175	189	183	0.77 %	-0.30 %	0.2 %	0.2 %	0.2 %
Megisti (Megisti Island)	268	222	238	-1.97 %	0.72 %	0.4 %	0.2 %	0.2 %
Rhodes	33,100	44,425	49,657	2.27 %	1.83 %	47.2 %	45.5 %	45.3 %
Symi (Symi Island)	2,497	2,273	2,344	-0.94 %	0.31 %	3.6 %	2.5 %	2.1 %
Chalki (Chalki Island)	387	334	312	-1.46 %	-0.68 %	0.6 %	0.4 %	0.3 %
Communities - Total	33,683	46,520	56,797	3.28 %	2.02 %	48.0 %	51.1 %	51.9 %

1) Dodecanese % of Greece, Rhodes County % of Dodecanese
Municipalities and Communities % of Rhodes County

Sources: 1971 and 1981 Census figures; 1991, Greece and Prefecture of Dodecanese Census figures; County of Rhodes, Municipalities and Communities Consultant's estimates

TABLE 12

Prefecture of Dodecanese
Active population by sector of employment 1981-1986

	Number			Dodecanese Rate 1981-1986	Percent composition			Location Quotient for Dodecanese 1981
	Dodecanese		Greece 1981		Dodecanese		Greece 1981	
	1981	1986			1981	1986		
Primary	5,990	6,000	972,091	0.0 %	12.8 %	12.0 %	27.4 %	47 %
Mining-Quarrying.	83	210	22,957	20.4 %	0.2 %	0.4 %	0.6 %	27 %
Manufacturing	4,727	5,200	664,322	1.9 %	10.1 %	10.4 %	18.7 %	54 %
Electricity etc.	412	500	25,425	3.9 %	0.9 %	1.0 %	0.7 %	123 %
Construction	6,740	7,400	326,390	1.9 %	14.4 %	14.7 %	9.2 %	156 %
Trade & Tourism	11,787	14,620	433,944	4.4 %	25.1 %	29.1 %	12.2 %	205 %
Transport etc.	4,730	5,250	266,517	2.1 %	10.1 %	10.5 %	7.5 %	134 %
Financial	1,188	1,350	126,703	2.6 %	2.5 %	2.7 %	3.6 %	71 %
Other Services	7,966	8,860	531,869	2.2 %	17.0 %	17.6 %	15.0 %	113 %
Young	739	810	89,036	1.9 %	1.6 %	1.6 %	2.5 %	63 %
Not reported	2,508	0	84,543	100.0 %	5.4 %	0.0 %	2.4 %	224 %
TOTAL	46,870	50,200	3,543,797	1.4 %	100.0 %	100.0 %	100.0 %	100.0 %

Notes: Electricity etc. also includes gas, steam and water
Transport etc. also includes storage and communications
Financial includes banking, insurance, real estate, etc.
"Young" includes those that enter the labour force for the first time
Sources: 1981, Census; 1986: estimates of the Administration of the Prefecture of Dodecanese

TABLE 13

Prefecture of Dodecanese
Gross income - Million drachmas

	1981		1986		Average Annual Rate of Growth 1981-1986
	Amount	%	Amount	%	
Primary	1,860	7.9 %	3.880	7.6 %	13.04 %
Mining & Quarrying	99	0.4 %	496	1.0 %	30.81 %
Manufacturing	2,390	10.1 %	5.366	10.5 %	14.43 %
Electricity-Gas-Water	516	2.2 %	1.290	2.5 %	16.50 %
Construction	2,836	12.0 %	6.264	12.3 %	14.12 %
Trade-Restaurants-Hotels	7,452	31.6 %	16.857	33.1 %	14.58 %
Transport-Storage-Commun.	2,515	10.7 %	5.643	11.1 %	14.42 %
Banks-Insurance etc.	650	2.8 %	1.351	2.7 %	12.97 %
Other Services	5,283	22.4 %	9.736	19.1 %	10.73 %
TOTAL	23,601	100.0 %	50.885	100.0 %	13.66 %

Source: Administration of Prefecture of Dodecanese

TABLE 14

Total cultivation including fallow land in the Island of Rhodes (1985-1990)

	Total cultivated land (Ha)	Irrigated land (Ha)
1985	273,463	27,259
1986	191,805	24,610
1987	269,054	22,533
1988	267,169	25,592
1989	268,549	25,334
1990	272,925	24,597

Source: Unofficial figures, Agricultural Dept of the Prefecture of Dodecanese

2.6.3. Industry and energy

The secondary sector in the Dodecanese contributes only a small proportion of the gross local product, 10.5% (Table 13) and it employs a small percentage of the work force. It is marginal to the whole economy and survives by satisfying the needs of the tourist industry and its infrastructure. It mainly consists of ceramic factories, popular art workshops, factories producing drinks, cakes and pastries, clothing, furs etc. Due to the increase in the construction sector, many factories produce ready-made cement, bricks, marble, tiles, paints, aluminium construction materials, and carpets. The shift of investment toward tourist enterprises, the high labour cost and other factors have resulted in the closure of former factories producing tobacco, pasta, concentrated tomato paste and others products.

The geographic distribution of activities in the secondary sector is of interest. They are concentrated along the first five kilometres of the Rhodes-Lindos and Rhodes-Kalithies roads, in the already intensively developed area of the disused slaughter house, and in the Asgourou area. The latter was developed without being incorporated into any integrated development or town planning programme. Certain initial procedures concerning the demarcation and topographic survey of the industrial zone were carried out, but no infrastructure work has been undertaken in the area. The existing quarry in the area of Kalithies will be transferred to a new site in a 150 Ha area of pine trees. The first stage of infrastructure work (widening of forest roads) has already taken place.

In the energy sector, since there is no local fuel production in Rhodes, fuel for electricity production has to be imported and this results in a very high cost of energy. The power generating station is situated at Soroni village near the shore. Only very few private companies have explored the possibilities of alternative energy sources such as wind power. Solar power is used only for domestic water heating.

2.6.4. Infrastructure

The Dodecanese islands have a higher road density than the rest of Greece (Table 15). However, the road network is not considered adequate. Within the framework of the Structural Funds of the European Community, a programme of widening rural roads has begun. Most of these run through the few forested areas which remained after the catastrophic forest fire of 1987 when almost 50% of Rhodes forests were destroyed. Further felling of trees will be necessary for this road widening. The deforestation has resulted in increased erosion, especially in the case of sudden heavy rains, a phenomenon which has been occurring with greater frequency over the last few years.

TABLE 15

Total road length in Greece and in Dodecanese

1984	TOTAL ROAD LENGTH KM	ROAD LENGTH/AREA (Km/ooo Ha)
GREECE	40,199	3,064
DODECANESE	2,354	3,588

Source: Ministry of Interior, unpublished report

The communication between Rhodes and the mainland is more than adequately served by the ferries. Inter-island services, however are inadequate and have to be made via Piraeus. The problem here seems to be acute since the ships which serve these so-called "non profit" routes often lack adequate insurance, speed and comfort. Port facilities are satisfactory and serve commercial ships. There is no marina for yachts and pleasure craft, but one is planned for the town of Rhodes.

There are direct regular airlinks to and from Athens, Thessaloniki, Crete and the other islands and the airport is also used for summer charter flights. Services are run by the National Airline Olympic Airways. Lack of adequate air service in the winter has caused tourism to be concentrated in summer.

The island suffers from deficient telecommunication connections to the mainland and there is no electronic data transfer system (EDT) which would make possible the relocation of some business activities on the island.

The water supply does not fully satisfy domestic and industrial demands. There are a variety of reasons for this, including low rainfall, insufficient reservoir capacity and old and inefficient water distribution systems.

The sanitation and sewage systems on the island are frequently unable to cope with the demands. The problems are exacerbated during the tourist season when demands are much greater.

In general the island has an infrastructure which is inadequate to satisfy the present requirements of the tourist sector.

2.6.5. Tourism

Tourism first started in the Island of Rhodes during the Italian occupation. The Italians constructed a solid road network, airport, and port; developed existing natural beauty spots, such as the Valley of the Butterflies and Kalithies; and built the first hotels in 1926. By 1930 Rhodes had 574 beds in 8 hotels. Shortly before the war a level of 10,000 arrivals was reached and up until 1963 tourist development continued at a moderate pace. Between 1963 and 1977 hotels were constructed at the rate of 650 beds per year, most of them in the town of Rhodes only. Parallel to this development, a considerable number of tourist units were built in Ixia in the greater area of Trianta, in the Koskinou area and Faliraki (Figures 27, 28, 29).

In terms of its geographic distribution, tourism has developed mainly in the town of Rhodes and in the northern triangle. However in the future new tourist locations are to be created in the south of the island. The majority of existing tourist units are currently located along the roads between Rhodes and Faliraki; and between Rhodes and the airport; almost all are next to the sea.

From the above it may be concluded that tourism is today the most important element of the economic life of the island, since it employs directly and indirectly a large number of people. In fact tourism in the Dodecanese is of national importance, second only in terms of tourist beds to Attica. A considerable amount of foreign currency is earned in the region. The Island of Rhodes provides plentiful accommodation in all hotel categories. The number of arrivals to the Island of Rhodes alone reached 844,477 in 1990.

Despite the high level of tourist development which has taken place, the island is still in need of a higher marketing profile and improved air links. We can also say that the integration of hotel developments into the natural environment has been minimal to date.

(For the compilation of the section on Population and economy, the works of Anonymous, 1988, E.E.C., 1989, Papastamatiou, 1985, Papachristodoulou, 1985 and Yiannopoulos, 1985, were used).

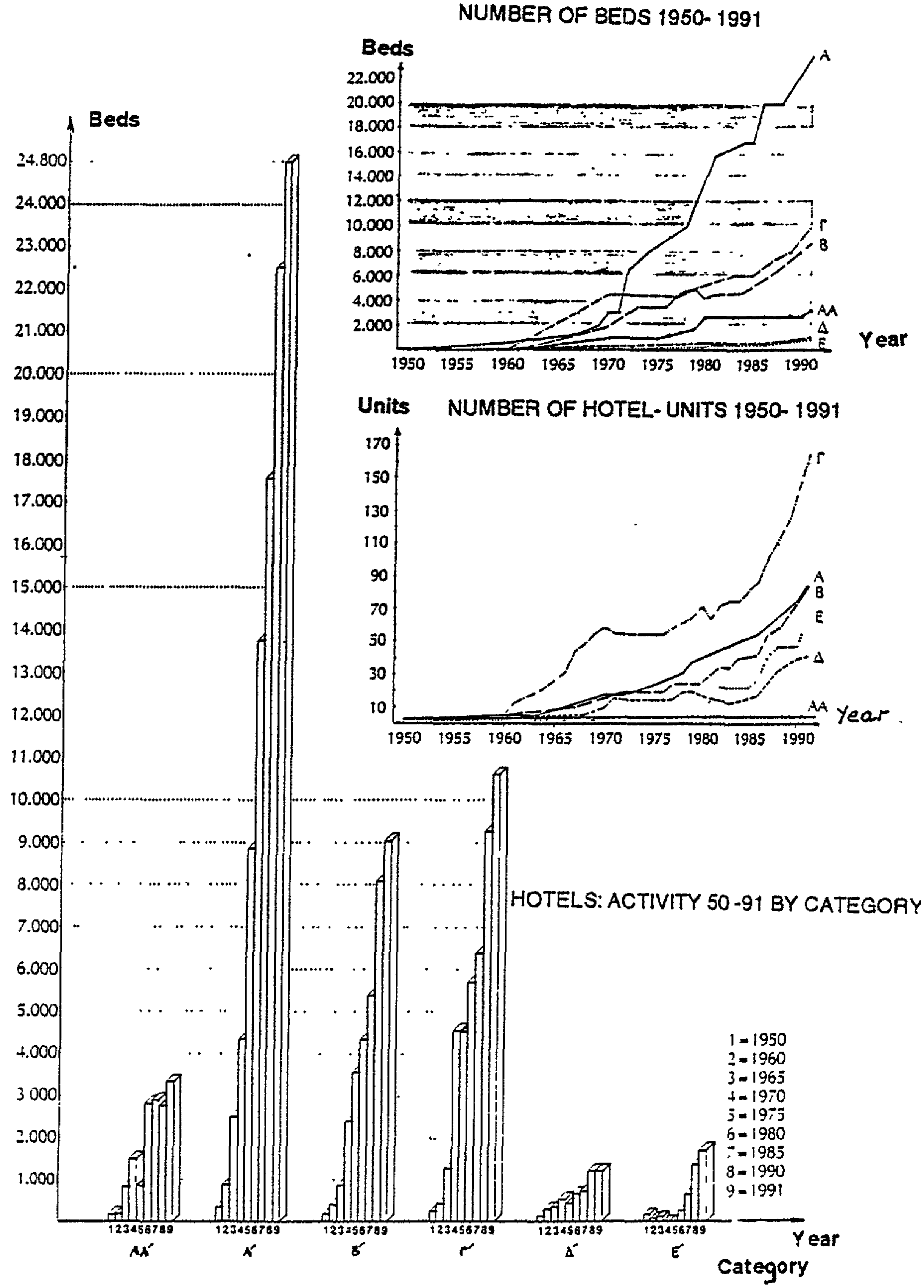
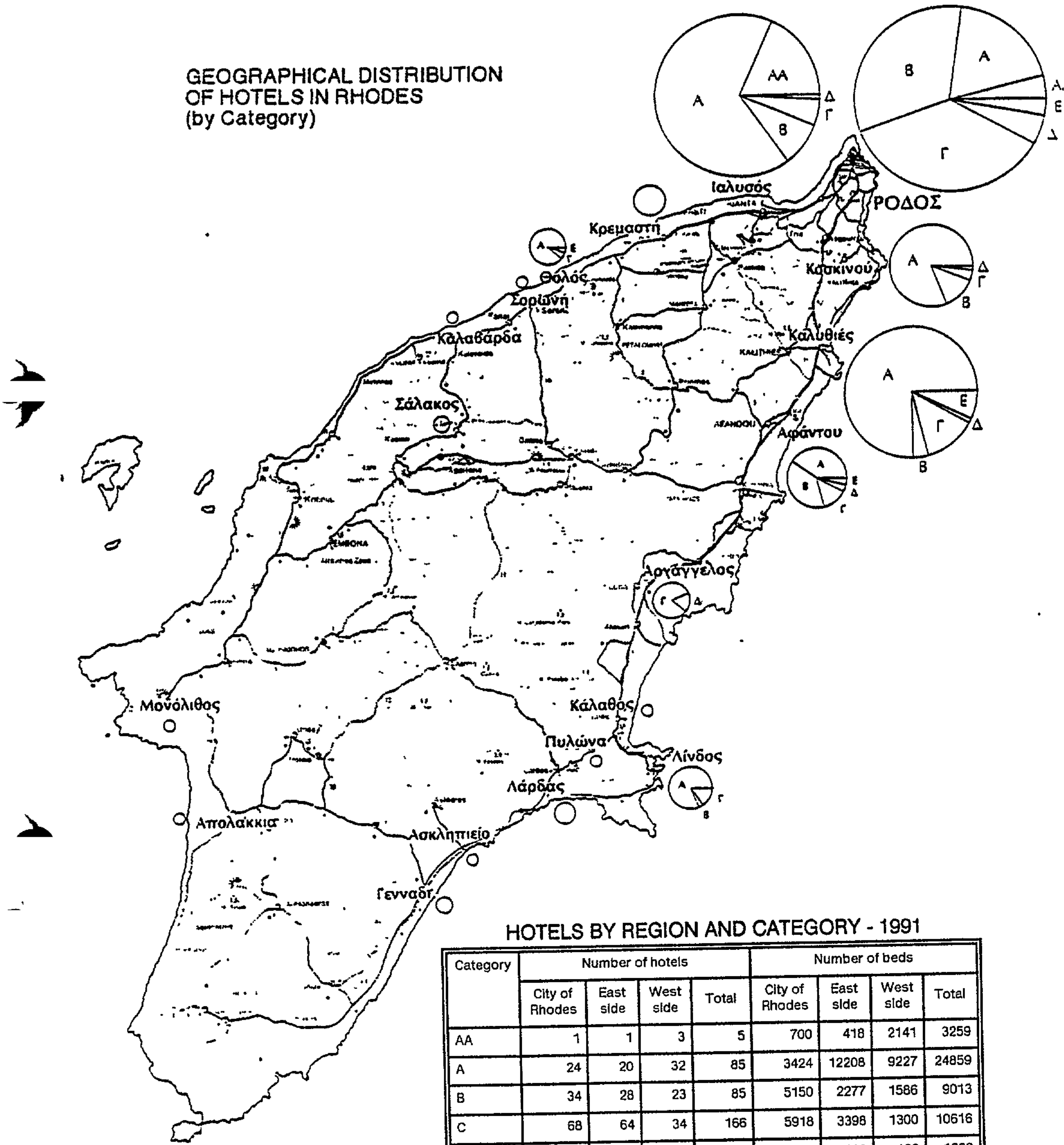


Figure 27 - Number of beds for Rhodes island



HOTELS BY REGION AND CATEGORY - 1991

Category	Number of hotels				Number of beds			
	City of Rhodes	East side	West side	Total	City of Rhodes	East side	West side	Total
AA	1	1	3	5	700	418	2141	3259
A	24	20	32	85	3424	12208	9227	24859
B	34	28	23	85	5150	2277	1586	9013
C	68	64	34	166	5918	3398	1300	10616
D	23	13	5	41	711	383	166	1260
E	37	23	7	67	826	655	187	1668
Total	187	158	104	449	16729	19339	14607	50675

Source: Association of Hotel Owners

Figure 28 - Geographical distribution of hotels in Rhodes (by category)

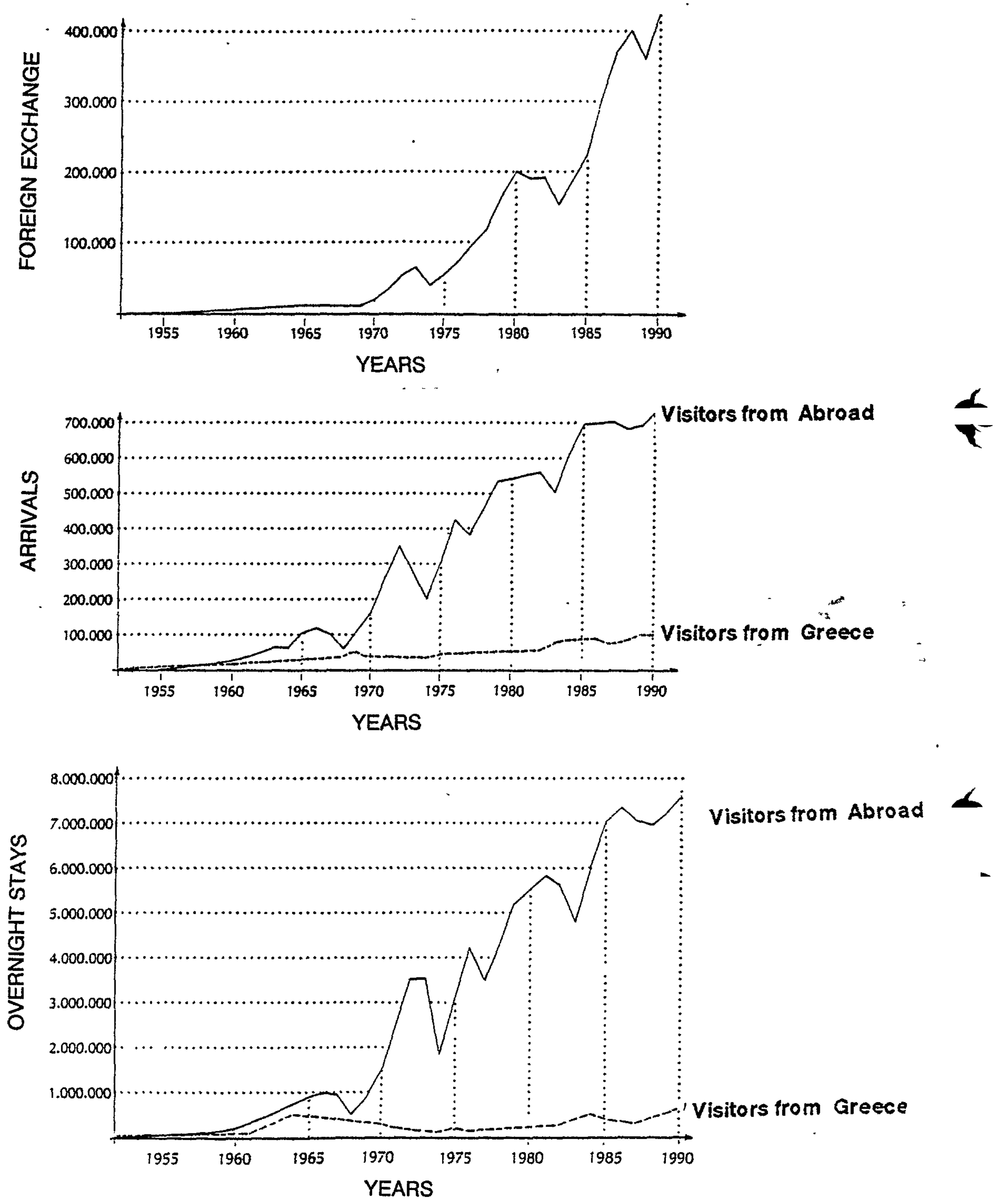


Figure 29 - Growth in foreign exchange earnings, visitor arrivals and overnight stays for Rhodes, 1952-1990

3. EVALUATION OF THE IMPACTS OF CLIMATIC CHANGE

3.1. Introduction

The Earth's climate has been subject to continuous natural changes throughout its existence. These changes have resulted in significant impacts on all life forms on the planet. Temperature and sea level variations appear to have played a critical role in recent changes, especially during the Pleistocene. Today, due to expanding human activities, climate seems to be changing at a faster rate than before. This has become obvious in the last 300 years when the agricultural and industrial revolutions reached their peak. The continuous increase in the atmospheric concentration of radiatively active gases, which absorb some of the radiation emitted by the Earth, has led to a warmer and probably, in many areas, drier planet.

There is a natural greenhouse effect which maintains Earth as a warm planet. Emissions resulting from human activities are substantially increasing the atmospheric concentration of greenhouse gases including: carbon dioxide, methane, chlorofluorocarbons (CFCs) and nitrous oxide. These releases will enhance the natural greenhouse effect, resulting in additional warming of the Earth's surface. The main greenhouse gas, water vapour, may also increase in response to global warming and further enhance the process.

It is known that the Earth's average temperature has very rarely varied by more than 1 or 2 °C over the past 1000 years, whilst during the most recent Ice Age it was only about 5 °C colder than it is now (Figure 30). The global mean surface temperature has increased by 0.3-0.6 °C over the last 100 years and global sea level has increased by 10-20 cm over the same period. Global warming of only a few degrees may have a profound effect on climate.

Under the IPCC, Business-as-Usual greenhouse gas emissions scenario (Houghton *et al.*, 1990) a rate of increase of global mean temperature during the next century of about 0.3 °C per decade (with an uncertainty range of 0.2 to 0.5 °C per decade) may be expected. This will result in a likely increase in global mean temperature of about 1 °C above the present value by 2030 and 3 °C before the end of the next century. The rise will not be steady because of the influence of other factors.

The predicted sea level rise according to the IPCC climatic scenario is about 20 cm in mean sea level by 2030 and 65 cm by the end of the next century. This is mainly due to thermal expansion of the surface sea water and the melting of some of the alpine glaciers and land based polar ice cap (Figure 31).

There are many uncertainties in predictions particularly with regard to the timing, magnitude and regional patterns of climate change, due to incomplete understanding of several physical processes.

Regional climate changes would certainly differ from the global mean. At present, confidence in the detailed prediction of regional climate changes and their timing is low. However attempts to model these changes have been developed by climatologists, using computer processed numerical meteorological data, simulated on a grid scale. General circulation models offer the best potential forecast available at the moment for the development of regional climatic scenarios. This task team based its work on one of these regional climatic scenarios (see section 1.3.1 above).

Currently, there is only limited agreement between the various GCM model predictions and observations. The reasons are mainly that the climate models are still at an early stage of development and the signal to noise ratio is very low.

The fact that we are unable to reliably detect the predicted signals today does not mean that the hypothesis of greenhouse enhancement is wrong, or that it could not become a serious problem for mankind in the decades ahead.

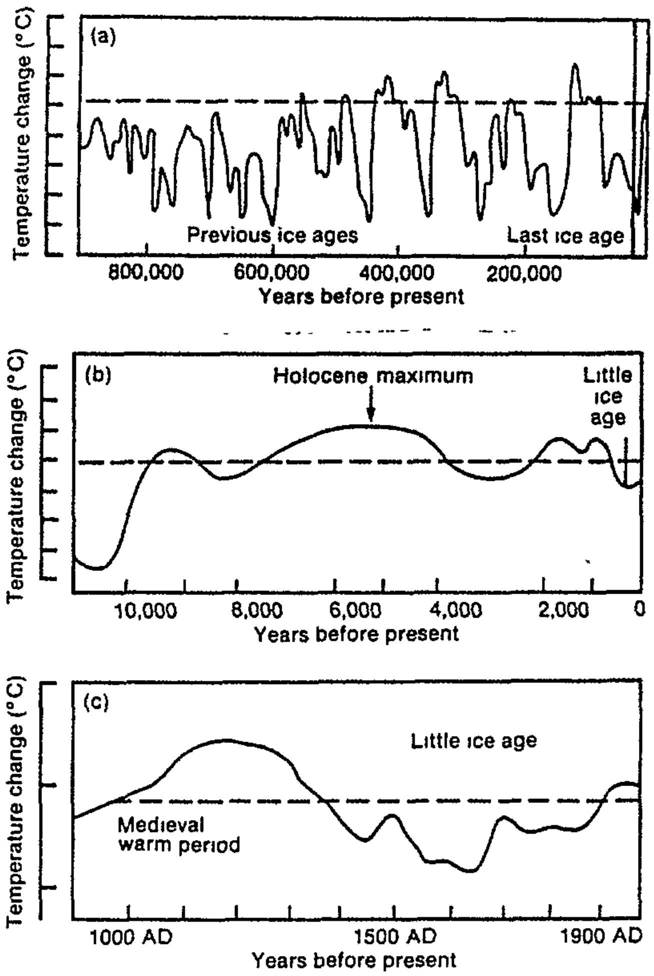
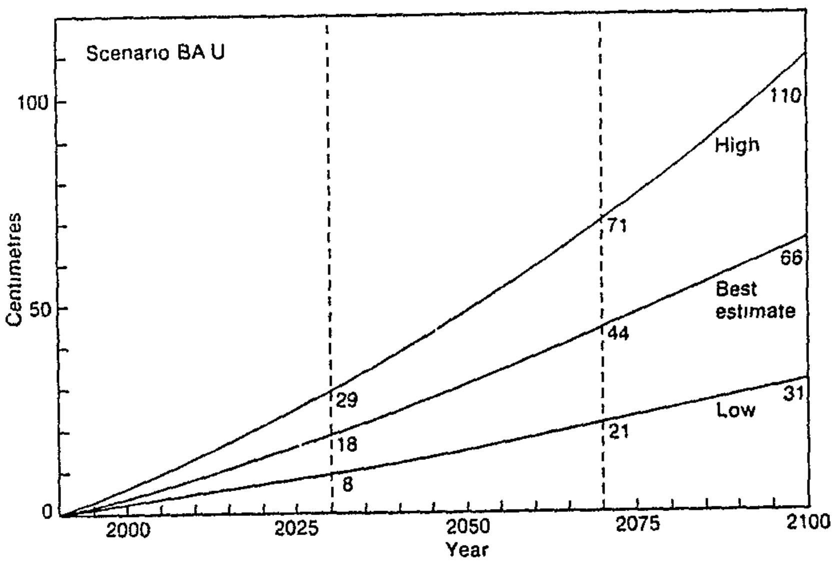


Figure 30 - Schematic diagrams of global temperature variations since the Pleistocene on three time-scales:
(a) the last million years, (b) the last ten thousand years, and (c) the last thousand years (IPCC, 1991)



(a)

	Thermal Expansion	Mountain Glaciers	Greenland	Antarctica	TOTAL (cm)
HIGH	14.9	10.3	3.7	0.0	28.9
BEST ESTIMATE	10.1	7.0	1.8	-0.6	18.3
LOW	6.8	2.3	0.5	-0.8	8.7

(b)

Figure 31
(a) Global sea level rise (SLR), 1990-2100 for Policy Scenario Business-as-usual(BAU)
(b) Factors contributing to SLR (IPCC, 1991)

3.2. Climate

3.2.1. Local scenario of climate changes

For this report the best available regional scale climatic scenario for the north-eastern Mediterranean basin has been used. The Climatic Research Unit (UK) has specifically developed for UNEP a computer simulation of atmospheric general circulation for the NE Mediterranean based on meteorological data from long term (1951-88) records for temperature and precipitation collected at local stations (Annex III).

The output provides a valuable information base concerning the spectrum of possible regional climatic changes for temperature and, with a lower degree of confidence, for precipitation.

According to this model the temperature changes for the area of the Dodecanese islands are expected to be lower than the global mean values, thus continuing the present local regime of a fresh insular spot even in a warmer NE Mediterranean.

For temperature, the local annual changes for Rhodes are expected to be 0.7-0.8 °C higher per °C of global warming, while for precipitation a pattern of an annual decrease of 0 to 2% per °C of global temperature increase, is suggested. Annex III gives the specific outlook not only for the entire year but for each season.

During the winter months of December, January and February the predicted temperature changes are between 0.5 and 0.8 °C per degree of global change and precipitation increases between 0 and 2 % per °C of global change.

During spring the scenario suggests temperature changes will follow the annual pattern of 0.6 to 0.8 °C per degree, while precipitation values increase 4-6% per °C of global change.

The scenario for the summer (June, July and August) is substantially different in the case of temperature from the annual pattern, showing an increase of between 1.0-1.1 per °C of global temperature change. Precipitation during this period may increase by between 4 and 12 % per °C of global change.

The autumn scenario suggests temperature changes between 0.7 to 0.8 °C per degree of global temperature change, and a precipitation increase of between 0 and 2% per °C of global change.

3.2.2. Consequences for climate

An attempt to assess the implications of a possible future global temperature increase for two aspects of the climate of Rhodes is based on the data taken from the report of the Climatic Research Unit (CRU) of the East Anglia University (Climatic Research Unit, 1992).

These implications concern changes in temperature and precipitation (Table 16) which may take place by the middle of the next century when the mean global temperature could be 1 °C higher than today. From the data of Table 16 it is easy to see that:

a. The annual and seasonal temperature changes are all positive and relatively small or even very small, since:

i. the minimum and maximum seasonal changes are 20%, 30% or even 40% smaller than the global mean change. Exceptions are changes to the maximum in summer and autumn on the one hand, and the minimum in summer on the other, which are only 20% and 10% greater respectively than the changes in global mean;

ii. the changes to maximum annual and seasonal temperature in Rhodes are smaller than the corresponding changes for the whole NE Mediterranean region and changes in winter and spring are the smallest in the region; and

iii. the mean annual temperature change in Rhodes is lower, not only than the global mean change but also than the mean for the NE Mediterranean region.

b. The annual and seasonal precipitation changes which are expected to occur in Rhodes by 2050 are positive and relatively quite significant, except in the case of the summer when the change is likely to be negative although in practical terms very small. Precipitation could increase by an amount varying between 0 - 22.1 mm in winter; 3.6 - 7.15 mm in spring; and 18.0 - 39.1 mm in autumn. The precipitation in summer is expected to decrease by between 0.6 and 0.8 mm only. Annual precipitation is expected to increase overall by an amount varying between 20.8 mm and 67.8 mm.

TABLE 16

Minimum (m) and maximum (M) seasonal and annual
(the annual values are calculated from the seasonal ones)
air temperature and precipitation changes in the North-Eastern Mediterranean (N-E-M) and the Island of Rhodes for a mean global temperature increase of one degree C.
The seasonal values of Rhodes are assessed from figures 2, 3, 4 and 5

	WINTER		SPRING		SUMMER		AUTUMN		ANNUAL	
	m	M	m	M	m	M	m	M	m	M
Air temperature change °C										
N-E-M	0.6	1.6	0.7	1.3	0.8	1.4	0.7	1.5	0.7	1.4
RHODES	0.6	0.8	0.7	0.8	1.1	1.2	0.8	1.2	0.8	1.0
Precipitation % change										
N-E-M	(-14)	9	(-10)	19	(-25)	26	(-17)	26	(-8)	7
RHODES	0	5	3	6	(-25)	(-18)	12	26	3	10

From all these data it can be concluded that the climate of Rhodes could become warmer and rather wetter as the mean global temperature increases due to the greenhouse effect. The rate of the temperature change is slower than the global rate and much slower than the maximum rate for the NE Mediterranean region. The rate of precipitation change is likely to be one of the fastest in the region. Thus, it could be said that the climate of Rhodes, compared to that of the NE Mediterranean, is thus expected to become relatively cooler and wetter.

3.3. Coastal geomorphology

3.3.1. General

The Island of Rhodes has been tectonically active throughout its geomorphological history and is subject to the subduction processes that are still taking place in the eastern part of the Hellenic arc. This high tectonic activity is manifested by the occurrence of earthquakes and fault movements that produced the high relief central massif and the geomorphologically young coast.

In addition to tectonic movements, eustatic sea level changes have also critically affected the coastal evolution of Rhodes. Uplift rates vary from 0 mm yr^{-1} at Prassonisi island in the south, to 1 mm yr^{-1} at the northernmost part, where values of 3.8 m uplift has been recorded over a time span of about 4,000 yr. (Pirazzoli *et al.*, 1989).

The third factor contributing to coastal geomorphology is the sediment inputs combined with the high energy wave environment resulting from the open sea regime to the NW and the south.

Until recently traditional uses of the coastal land and environment were adapted to the needs of the local population. Recently however, the rapidly expanding tourist enterprises have established a more intensive use of the coastal zone. This has affected its stability and rendered it more vulnerable to changes in sea level such as those that could be induced by global changes.

The coastal lowlands in Rhodes will be the first to experience the impacts of a gradual sea level rise, which would reinforce erosion cycles and reshape the coastal zone, especially at the beaches on the NW shore of the island. The tectonic uplift could compensate for only a minor part of the expected SLR, especially at the northern tip of the island.

Buildings on the island are located at a reasonable distance from the coast and are satisfactorily protected because the building tradition and existing legislation is generally respected. In the N-NW, most estates are generally sited behind the winter wave break line, where the dynamic sea conditions and currents reinforced by storm surges result in a significant, broad, wave break area.

In general the present coastal use provides enough space for accommodation, in the event that a landward coastline migration takes place. Even under accelerated SLR scenarios, sea surges will barely reach the upper reaches of the backshore zone.

Assuming that the future sediment depositional regime will not be greatly different in magnitude compared with the present, impacts are expected to be significant only in several pocket beaches of the NE and SE parts of the island. There, several rock enclosed small sandy strips of width between 7 and 12 m across and some coastal roads might gradually be covered by rising sea level.

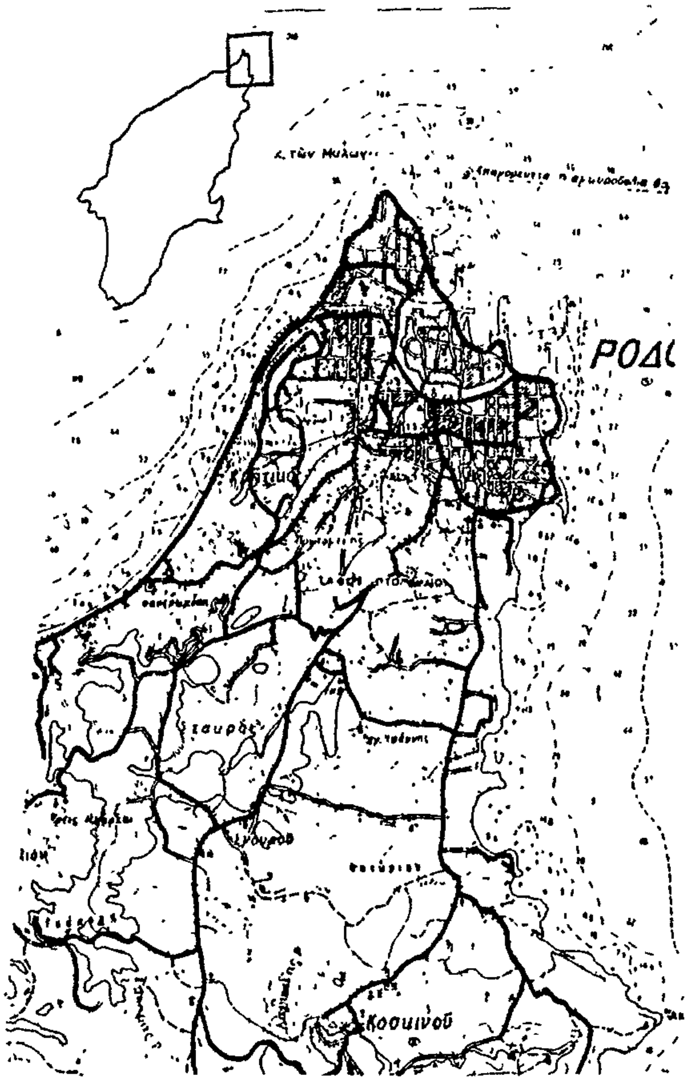
The following paragraphs provide an examination of the possible impacts in each of the recognisable coastal zones of Rhodes. We distinguish two general areas, the northern coastal zone, which includes the northern "triangle" and the southern coastal zone, which is the southern "triangle". The northern one exhibits the most interesting and varied sectors and is thus examined in more detail.

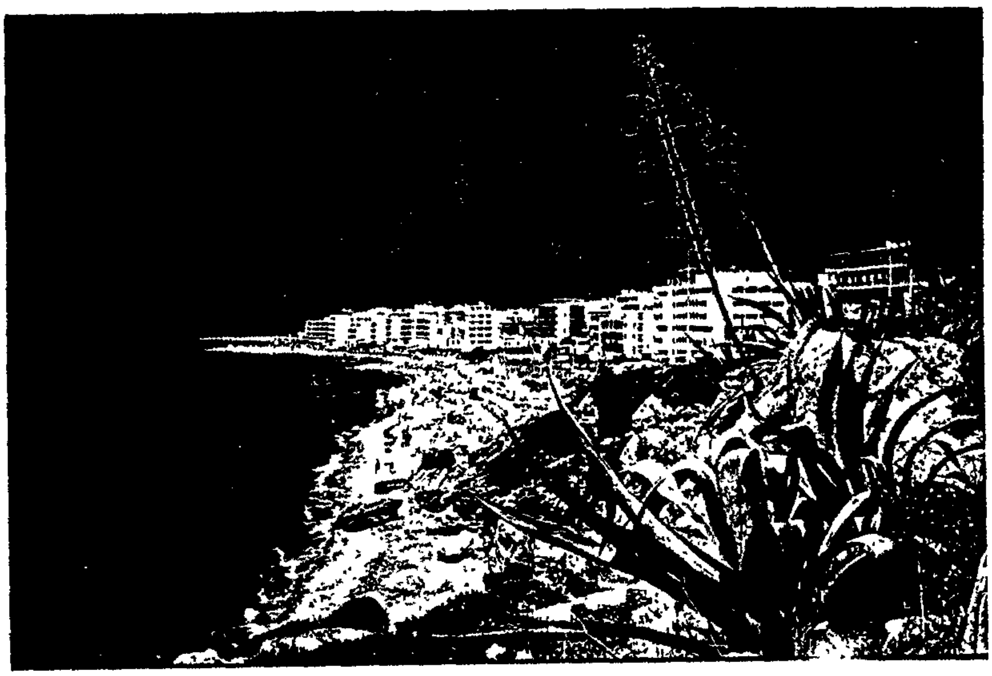
3.3.2. Northern coastal zone

Far North

This is composed of: the strip of sandy beach which surrounds the city of Rhodes and is of high tourist importance; the sloping cliffs to the west; and the rocky, low relief beaches to the east (Figure 32). Due to its morphology the urban area is not expected to experience significant impacts from SLR (picture 1). The most vulnerable sectors include the port and part of the city's sea wall which is 1-1.5 m high. Potential impacts will be partially mitigated by the observed tectonic uplift that has been occurring in the Rhodes area.

Figure 32 ---->
Northern tip of the Island of Rhodes





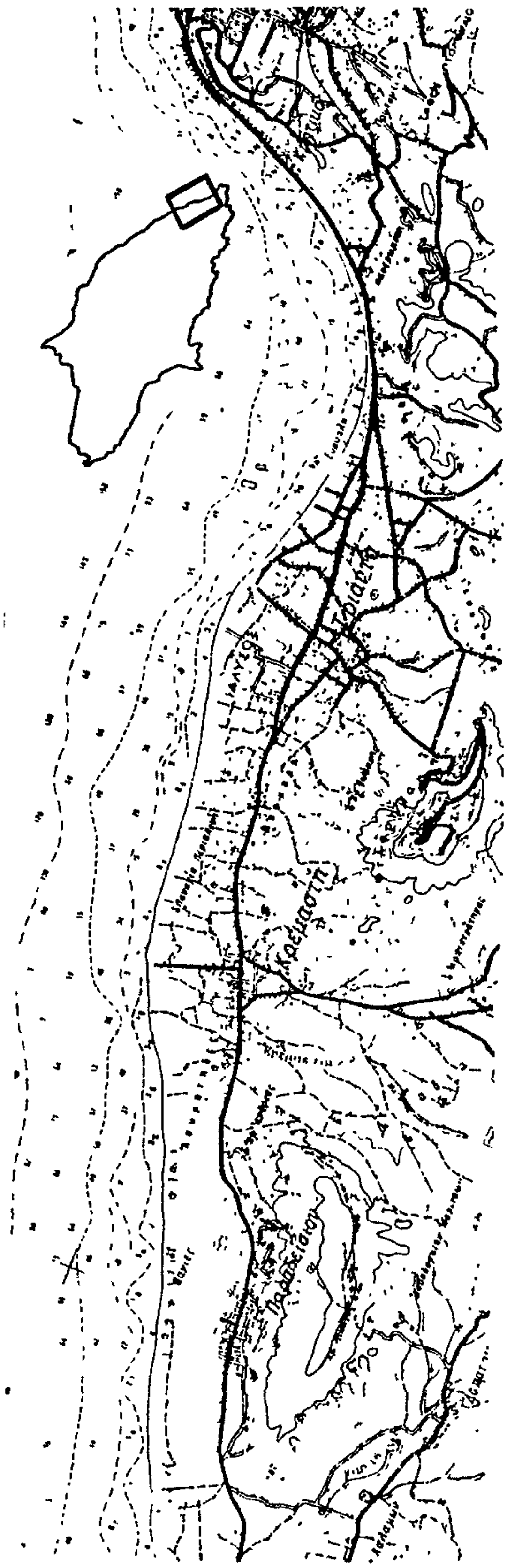
Picture 1

North western part

Ixia, Ialyssos

In this area, the recreational coastline is composed of gravel and wave energy is high because of exposure to the strong N-NW winds. The lack of fine sediment is mainly due to dynamic wave action and to the limited sediment input from the land. The erosional regime will be further aggravated by the anticipated sea level rise. Fortunately most hotel establishments are located behind the back shore of this retreating coastal zone (Figure 33). As a result no important impacts are expected from a 10-20 cm SLR. However this infrastructure would have to be readjusted to future conditions under a higher mean sea level. It should be noted that a coastal protection project for a part of the coastline is planned by local authorities.

Figure 33 ---->
Detail of the northwestern coast of Rhodes



Kremasti, Paradisi, Tholo, Soroni, Ancient Cameiros, Skala

This sector is the southern continuation of the previously described coast (Figure 34). Pronounced retreat of up to 200 m has taken place since 1978. Local observations estimate that a coastal retreat of 1 m yr^{-1} has occurred during the last four years. This may possibly be attributed to the construction of the pier for the Public Electricity Company. Several constructions built in 1974 some 50 m away from the sea, are now partially submerged (see picture 2). Finally in a few locations some houses stand very close to the sea and might be vulnerable to a future SLR.

Local authorities are constructing sea-walls at Soroni to address these problems. A similar effort is under way to counter the serious coastal erosion problems at Tholo.

Another problem which will be accentuated by a future SLR is the reduced agricultural fertility of the coastal soils, due to salinization. This impact is expected to affect a large number of greenhouses which are situated close to today's shoreline. Although the backshore has a considerable slope, the area is vulnerable even to minor SLR.

We can conclude that the north-western coastal zone should be considered as a high risk area due to the dynamic character of the marine environment, although only a few, small, exposed parts of the coastal road will experience impacts from SLR.

Another vulnerable site is the electrical power-plant, which is expected to feel the impacts of higher sea level since it is situated on the coastal plain, about 100 m from the shore (picture 3).

Finally, SLR would gradually reshape the estuaries in this area but these consequences will be of low significance since most rivers are small and their estuaries cover a limited area.

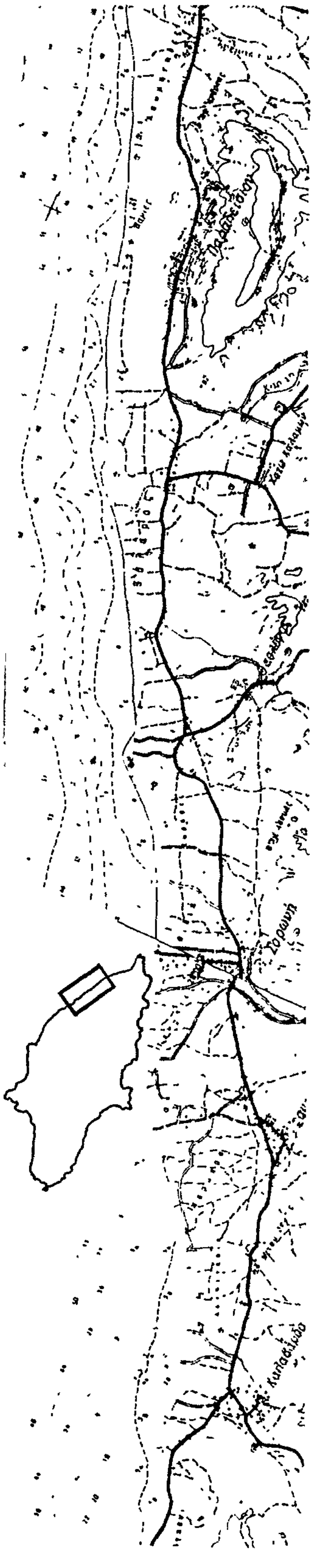
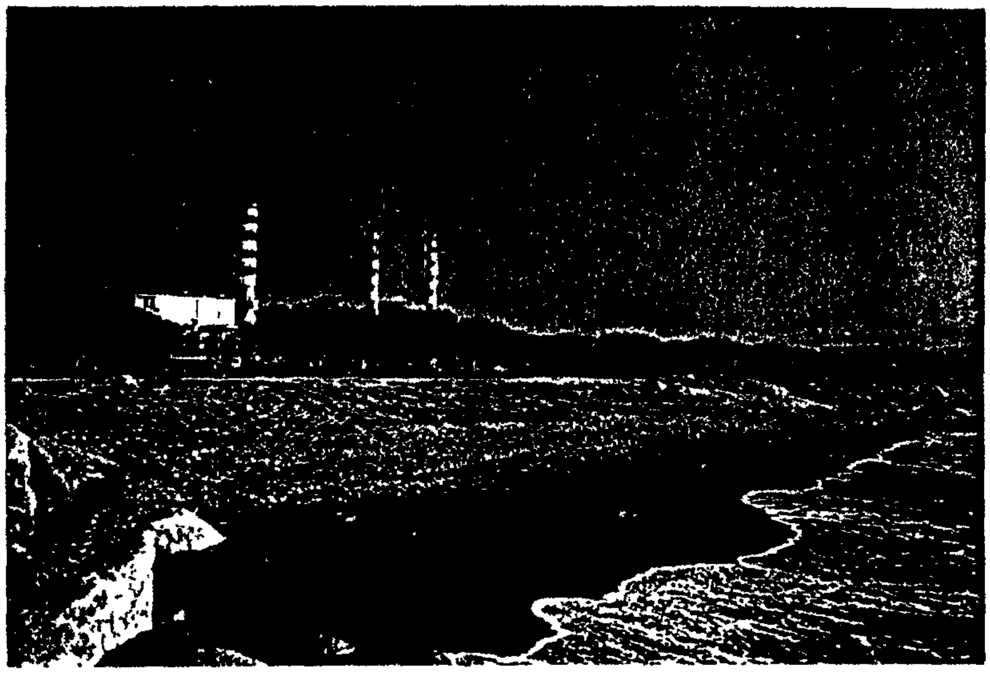


Figure 34 ---->
Continuation of the northwestern coast of Rhodes

Picture 2



Picture 3

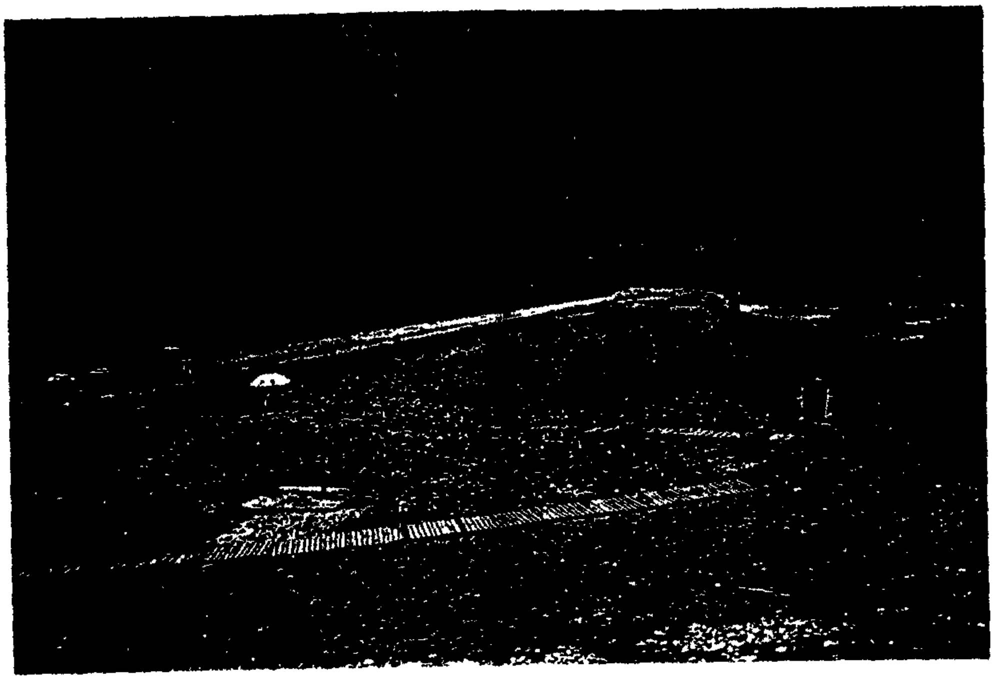
The coastline in this area will be affected by the anticipated sea level rise, especially under storm surge conditions which will gradually cause extensive coastal retreat. However, this gradual coastal reshaping is unlikely to result in significant impacts with a 10-20 cm rise in mean sea level. Only a few removable recreational facilities, built with no authorization, are located at the beach and are subject to high risk. Several narrow strips of coast enclosed by the coastal road, would experience intensified coastal erosion. This erosion is already noticeable since there is limited space inland to accommodate coastal regression.

The north-eastern part

Koskinou, Kalithies, Afandou, Archangelos, Lindos and Gennadion

No significant changes in the coastline are currently taking place here and only a seasonal shoreline migration has been noticed, due to the winter high wave break. There are stable sand dunes in several locations.

Impacts are expected to be minor since most of the beaches are broad and have a small inclination (Picture 4). However, the small pocket beaches of the Lindos area are in danger, if sea level rise is not compensated for by tectonic uplift.



Picture 4

3.3.3. Southern coastal zone

The natural coastal dynamics of the southern half of the island are remarkably undisturbed at present (Picture 5), consequently significant impacts from anticipated sea level rise are not expected. A few enclosed sandy beaches at the southern end of the island might experience adverse impacts, but significant impacts are not expected on the northeastern side due to the presence of sand. The small sandy spit connecting Cape Prassonis with Rhodes may be gradually submerged (Picture 6).

Picture 5

Picture 6

3.4. Soils and erosion

All soil types on the island exhibit the common characteristics of low organic matter (less than 2%), high $CaCO_3$, and low soil moisture. Thus, a 1-2 °C increase in peak summer temperature is not expected to influence the rate of decomposition of organic matter particularly in view of the reduction in soil moisture during the warm seasons. No significant implications for soil fertility in the island are expected as a consequence of the anticipated temperature rise.

Impacts resulting from salinization due to saline water intrusion are expected mainly along the western coast where the land terraces used for agriculture are close to the sea.

Erosion, which is a major problem in Rhodes, is expected to increase as a consequence of the climatic changes. The impact of temperature rise and the torrential character of the rainfall will alter the particle characteristics of the arid soil surface. Thus surface runoff, erosivity and the sediment carrying capacity of the runoff are all expected to increase when rain drops contact the dry soil.

3.5. Hydrology and water resources

The climatic changes due to greenhouse warming will have both quantitative and qualitative implications for the water balance of Rhodes. The quantitative effects are difficult to determine accurately at this time. Therefore only qualitative estimations of these effects can be made. A programming strategy is proposed for the future quantitative definition of these effects, and measures are suggested to confront them in the short and long term.

Based on the climatic scenario developed for Rhodes, it is deduced that the temperature rise would result in small decreases in total annual precipitation, a rise in the rate of evapotranspiration and a decrease in total runoff and infiltration. The changes to these parameters will affect the water balance of the island. Thus it is anticipated that more arid conditions would prevail during the summer which in combination with an extended tourist season would result in increased water demand and adversely affect water balance.

Regarding surface water, rainfall is expected to become more torrential, which would favour an increase in surface runoff compared with infiltration, although a decrease in the total volume of annual surface runoff is expected. As a result, increased erosion is expected in association with increased soil aridity and a decrease in plant cover. All these factors would result in a decrease in recharge rates for groundwater and aquifer reserves.

The expected high erosional regime will accelerate sedimentation and filling rates of the present reservoir at Apollakia, thus reducing its water storage capacity. Such accelerated rates of sediment mobilisation will have to be taken into account in future planning of dams and reservoirs on the island, which form part of the wider programme of water management needed for the island.

As regards groundwater resources, decreased aquifer recharge will result in a drop in level, a decrease in sustainable yield and a drop in the pumping level. Inevitably, pumping will be extended to greater depths leading to increased costs for groundwater extraction. Critical situations could arise in areas of over-pumping, as is the case today in the northern regions.

From our data it seems that present groundwater reserves have not been fully exploited and that additional groundwater could be drawn from some hydrological basins. Four such basins have been identified in the island's northern part. It is necessary, however, to define the exact location of the new boreholes and their rates of extraction and to change present day poor groundwater management practices in order to address the long term implications of climatic changes.

The expected sea-level rise, the decrease in aquifer recharge and the eventual over-pumping would also result in increased sea-water penetration and advance of the brackish water fronts (Figure 35). This, will be particularly intense in areas where salinisation of groundwater is already occurring and will appear in other areas not currently affected. A greater degree of brackishness will occur in the phreatic aquifer while in the coastal zone a number of wells are likely to become saline.

The confined aquifers of the Sgourou and Levantinian formations in particular, will be threatened by the longer term implications of climatic change, while other aquifers in limestone will be in danger of contamination, particularly in nearshore areas.

The decrease in groundwater recharge will also affect the island's springs. Their decreased yields, which have already been observed in recent years, will continue and most of them are expected to dry up completely. Exploitation of spring water is necessary in the mid-term, provided that their sustainable capacity is more precisely evaluated.

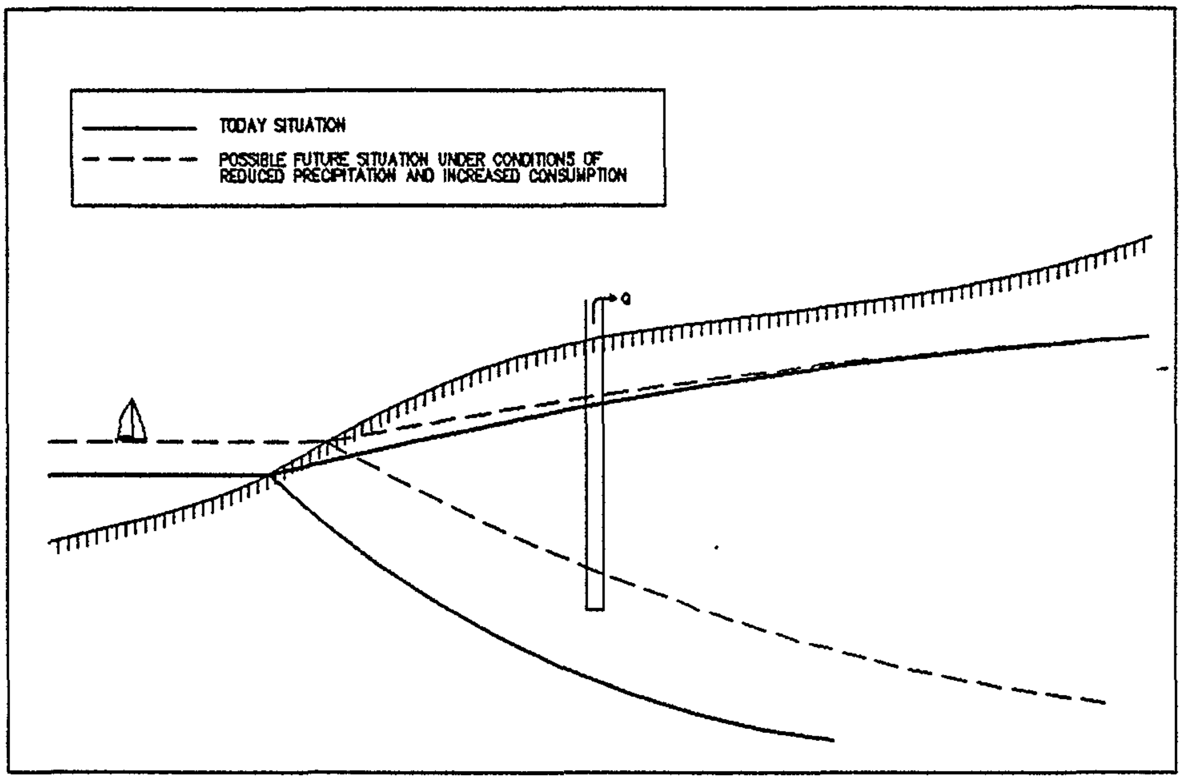


Figure 35 - Schematic view of the possible impacts of the SLR on coastal aquifers

3.6. Marine environments

In the relevant chapter (Figs. 21-22) variations in atmospheric pressure, air temperature and rainfall were presented for the period 1953-1989. Unfortunately the available sea level data cover a much shorter period. Assessing the impacts of sea level changes on the marine environment is therefore somewhat difficult. The following are a few conclusions based on the data in Figures 21-22, which form the basis for assessing the impacts of future changes:

- all these parameters have shown marked interannual variation during the last few decades;
- the relative sea level in Rhodes has undergone similar oscillations to those of other stations in Greece and in fact sea level seems to be the parameter with the best spatial coherence over the wider area;
- a decrease in air temperature has been observed from the early sixties to the early seventies, a feature common to other Aegean stations, followed by an increase thereafter. The increase at Rhodes is the largest observed in the Aegean;
- both air temperature and atmospheric pressure have increased since 1973; and
- rainfall has continuously decreased from the early seventies to the present.

The above observations indicate the complexity of the climatic regime of the area. Obviously, a very important parameter of the climate of the region is the "climate of the ocean". Indeed, Rhodes lies in the path of the Asia Minor current which transports large amounts of heat from the northeastern Levantine Basin. This means that the local air temperature is significantly influenced by changes in the heat content of the Asia Minor current.

It may be concluded that the present and the future climate of Rhodes, depends substantially on the adverted "oceanic climate" of the North Levantine Basin which must therefore be studied if one desires to have any degree of confidence in future predictions.

It is known that the ocean exhibits significant thermal inertia. As a consequence climatic changes in the sea water masses are taking place over longer time scales than those in the terrestrial environment. Therefore no clear picture of the future impacts of climatic changes on the physical dynamics of the sea water column around the Island of Rhodes can be drawn. The future characteristics of several local oceanographic features such as coastal upwelling, currents and wave height should be modelled. The present low residence times and the high rates of mixing of coastal water around the island, could prevent future sea water stratification which might be expected under future climate change scenarios in semi-enclosed bays.

3.7. Ecosystems

An increase in temperature combined with a possible decrease in rainfall, will change the climate of Rhodes to a more arid mediterranean type. In addition a general northward shift of the bioclimatic zones is expected over a wider area.

In the shrublands a succession from maquis to phryganic ecosystems would occur without human interference. But, a careful study of the island shows that many problems currently arise from human mismanagement and improper use of ecosystems and control of overgrazing for example, is urgently needed.

The present accumulation of forest biomass creates a very fragile situation and forest fires are a major problem in Rhodes. The increase in temperature and aridity will accentuate the problem of forest fires. New management techniques, such as controlled burning are urgently needed even if climatic changes do not occur.

Another point of concern must be the protection of the burnt sites, from both the invasion of such areas by shepherds and from unscientific reactions based on the false impression that reforestation is needed in order to protect the environment. Recent scientific data have shown that regeneration can take place if burnt areas are protected and left to recover by themselves.

The reaction of the sensitive butterfly population of the Petaloudes Valley to eventual changes in temperature and humidity should be studied. An increase in temperature might force this population to move to a higher altitude. Overseas migration might increase the total insular insect population.

The impacts of the temperature rise on the oligotrophic regime of the marine environment are expected to be insignificant for the area of Rhodes.

Taking the above into consideration the Task Team considers that the development of a new environmental strategy, which incorporates a consideration of the impacts of climatic changes, could have benefits for the environment of Rhodes. Appropriate actions would result in higher plant cover in degraded areas, and at the same time minimise erosion. Such benefits would in turn result in increases in the natural resources of soil and water.

3.8. Population and economy

The anticipated climatic changes will have direct economic consequences since changed weather and climate will directly affect the holiday market. The present climate is the most important factor which makes Rhodes an outstanding holiday resort, and is the major promotional asset to the tourist industry.

In Rhodes, climatic conditions determine the duration of the holiday season while the natural environment including both the lowlands and the mountain areas are Rhodes' greatest assets. At present the diverse flora and fauna; a clean and transparent sea; a combination of calm sea for swimming and areas with waves suitable for water sports; varied sea shore types; clean beaches; and the high quality of coastal water combine to form the basic attractions of Rhodes as a tourist destination.

As has already been noted, numerous hotels are situated very close to the beach (Figure 28). They will certainly face problems in the event of flooding as a consequence of eventual sea-level rise. This could occur, particularly in enclosed bays, during storm surges, reinforced by strong south winds where waves will be prolonged, washing away the exposed sea-wall surfaces. These impacts are not expected to be noticeable over the next 50 years during the initial stages of a 10-20 cm sea level rise. However they could become significant in about 100 years under conditions of a 1m rise in sea level and will have important economic repercussions on land and property values.

Sea-water will also inundate wide sections of the coastal plains, including such economically important areas as Faliraki, where the beaches and associated recreational infrastructure may be destroyed under prolonged wave action. In the area of Paradisi airport, accelerated sea level rise and storm surges could cause serious damage to the low-lying airport area, with serious economic impacts. Finally some coastal roads are expected to be affected due to their location in vulnerable low-lying areas.

4. SUGGESTED ACTIONS AND RECOMMENDATIONS

4.1. Suggested actions in coastal zone management

Since a great part of the coastal and maritime zone consists of soft-rocks, many landslides and landfalls occur. As a result, steps have to be taken by constructing sill-diversions and dams so that the water flow of torrents is reduced or diverted. Reforestation of the bare and burned areas of the Island of Rhodes is of high priority in order to reduce the erosive force of sudden flows and consequently diminish their periodically major impacts on the coastal zone.

The narrow width of the NW coastal zone, which is of major importance to the tourist industry has resulted in major erosion problems. Since much of the infrastructure has been built immediately inland from the shore, retreat of the shoreline is impossible. Consequently there is a need for a rational approach to coastal protection, which would require actions such as natural beach nourishment by releasing the torrent outputs, construction of protective works, and new regulations covering the location of future construction. Many of these measures have been or are being planned by local authorities and private investors. However in the long run it may be unrealistic to continue occupation of a retreating shoreline by continued strengthening of existing defence structures. Hard engineering defensive constructions are in general not recommended, since they do not accommodate the long term impacts of anticipated sea level rise. Despite these problems, the defence of the vulnerable NW coastline, through construction of marine structures, including groynes, sea-walls, and breakwaters in particular areas of tourist investment, may be economically necessary. Such construction may be needed in order to protect, in the short term, the sandy recreational beaches, and provide defense against more intensive future wave activity.

Another rational approach recommended for management of the entire coastal zone of the island would be the establishment of setback lines and zoning, with identification of areas for less urbanized settlement and the adoption of more "open-space" tourism, particularly in the case of the future development of southern Rhodes.

Our observations indicate that in general, if the existing land use and building legislation is slightly revised in order to accommodate the potential impacts of future sea level rise and, if these revisions are followed by users, as has been the case up to now, then there will be little if any adverse economic impacts on the coastal zone and its development. Proper coastal zone management and planning, which incorporates a consideration of future sea level rise would necessitate building only at a reasonable distance from the present shoreline, thus delineating an essential setback zone that will accommodate, with minor disturbances, future coastal regression. Present coastal building legislation should be revised so that any deviation from the agreed policy would not be covered by any social or public insurance (Figure 36).

Given the continued uncertainty concerning the timing and magnitude of future sea level rise, it is difficult to determine which policies should be implemented immediately. A low level of awareness on the part of both public and decision makers currently exists concerning the consequences of climatic change. At present coastal degradation on Rhodes is not considered serious, although it is the coastal zone which forms the basis for tourist investments. This study has identified the areas vulnerable to sea level rise and hence the authorities have to evaluate and decide on the basis of economic considerations which strategy should be followed in each sector of the coastal zone. The cost of strategies include: defending, accommodating or retreating within each zone. It must be stressed to both decision makers and investors that immediate actions to mitigate the anticipated impacts of climatic changes are administratively and financially easier to implement sooner rather than later.

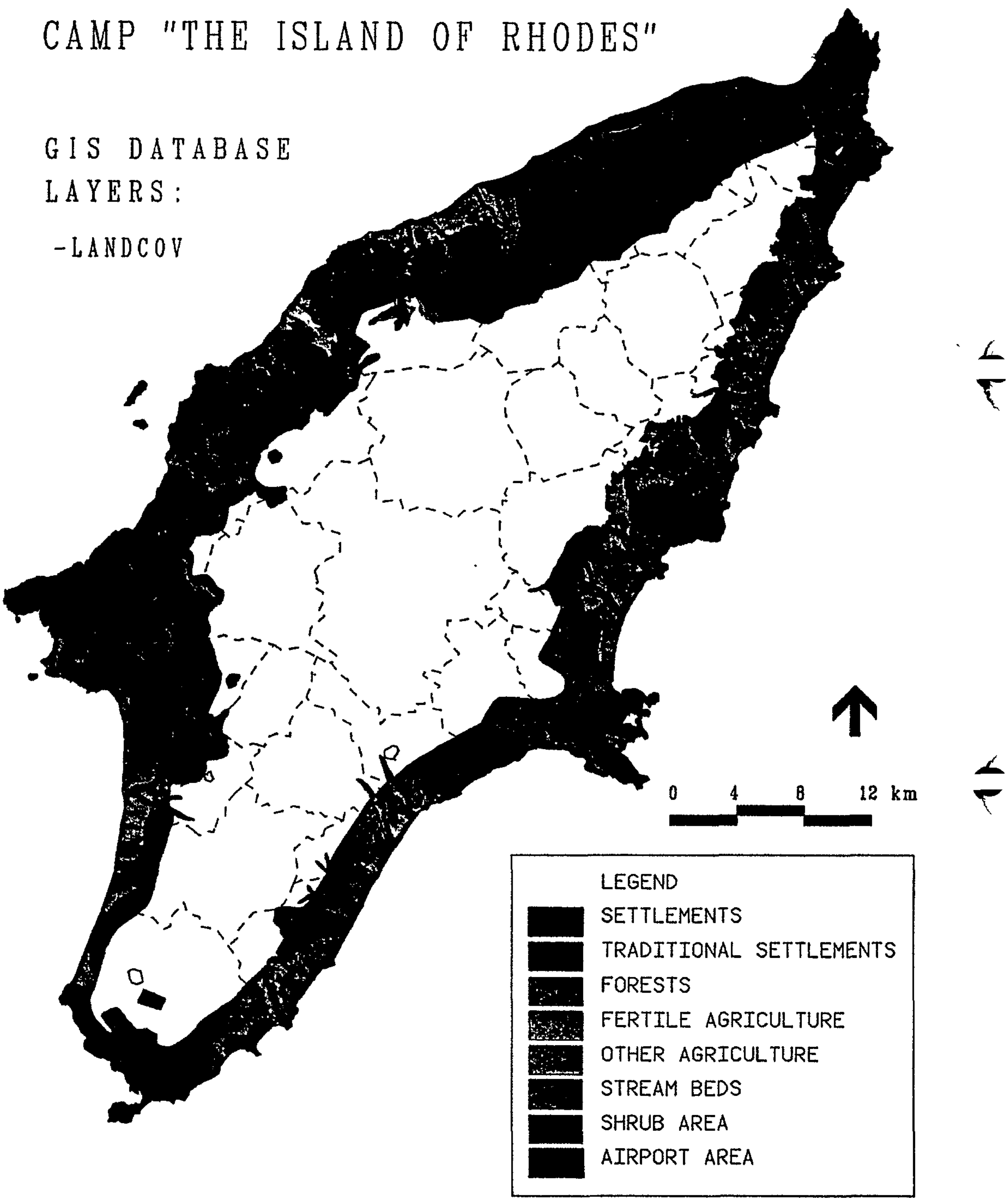


Figure 36 - Coastal land use map of Rhodes (CAMP/GIS-team)

4.2. Suggested actions for water management

Obviously both short and long-term problems of water resource availability should be addressed by decision makers as matters of high priority. It is necessary to follow a rational plan, with defined short and long term objectives, which should include research for new water resources, and a water resource management plan.

Short term actions should include:

- protection of aquifers which are already under intensive exploitation: including limitation of the numbers of new boreholes; and prohibition of borehole drilling in basins where aquifers are at their present limits such as those of Rhodes, Kalithies, Pasaoutia, and Voukoulia;
- completion of the borehole research programme proposed by the Ministry of Agriculture. A particular target should be the exploration of the Archangelos limestone masses as well as the estimation of water losses to the sea in the Attaviros limestone region;
- monitoring of surface and groundwater so that a calculation of the water balance in each hydrologic basin can be carried out and a mathematical model for prediction of aquifer quality and capacity development can be developed;
- the main projects proposed to address the water problem are the construction of six dams in the areas of Soroni, Kritinia, Afandou, Gadoura, Katavia and Lardou having a total capacity of over 90 Mm^3; and, the building of 46 reservoirs having a total capacity of 10 Mm^3; and
- reduction of the losses due to leakage in the domestic water distribution network through renovation and replacement, particularly in Rhodes city.

Long term actions should include the construction of large hydrogeological projects, like the dam at Gadoura, having a capacity of 67 Mm^3 and that at Afandou which has a 18 Mm^3 capacity.

4.3. Need for actions in ecosystem management

Theoretically the agricultural decline and the abandonment of terrace cultivation increases available land for grazing. However fires and overgrazing which have replaced the traditional systems of land-use have resulted in the denudation of vegetation in many areas. This environmental problem also results in increased erosion, that negatively affects water resources, and soil properties including soil fertility. It is known that in Rhodes, as in other parts of Greece, destruction of the island ecosystem by grazing animals has already resulted in serious degradation of the plant cover and biomass.

Anticipated climatic changes will not seriously alter the existing situation which is already grave. Therefore immediate action is necessary to limit the impacts of grazing animals that inhibit the natural reforestation of burned areas.

4.4. Recommendations

In conclusion, the following actions are recommended in the face of the anticipated impacts of climatic changes on the Island of Rhodes:

Short term actions:

- mapping of coastal areas and lowlands vulnerable to sea level rise;
- delineating the future coastline under differing scenarios of sea level rise including a 1.00 m SLR;
- detailed mapping of all the structures presently existing in the coastal zone;
- studying of the effects of existing marine structures on the sediment budget of the island;
- development of a water management plan for all island water resources;
- identification of all areas where infiltration of saline water into the aquifers occurs; and
- revision of the building legislation and construction standards, and also coastal land use planning.

Long term actions:

- monitoring of all physical variables on the island, including amongst others, meteorological, oceanographic and climatological parameters and comparing the trends with those suggested by the present scenarios (Palutikof, 1992; Climatic Research Unit, 1992);
- studying the hydrogeological behaviour of all water catchment basins;
- measuring the sediment load carried by the various rivers to the coastal zone; and
- observing strict implementation of the revised legislation.

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APPENDIX

TASK TEAM MEMBERS

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ANNEX I

THE COASTAL AREA MANAGEMENT PROGRAMME (CAMP) FOR THE ISLAND OF RHODES

INDIVIDUAL ACTIVITIES

I. IMPLEMENTATION OF LEGAL INSTRUMENTS

1. Land-Based Sources and Dumping Protocols
2. Liquid Waste Management
3. Energy Protocol (Contingency Plan) and MARPOL Convention
4. Monitoring and pollution in Rhodes Coastal Region

II. RESOURCES

5. General Water Resources Master Plan
6. Implications of the Expected Climatic Changes on the Island of Rhodes

III. ACTIVITIES

7. Programme of Environmentally Sound Energy Planning
8. Programme of Protection of Historical Settlements

IV. PLANNING AND MANAGEMENT

9. Training Programme on GIS
10. Environmental Impact Assessment (EIA)
11. Development Scenaria
12. Training Programme on Integrated Planning
13. Integrated Planning Study for the Island of Rhodes
14. Specially Protected Areas

ANNEX II

WORKING TIMETABLE

Nomination of the project co-ordinators	Feb. 1990
Establishment of the Task Team	Jul. 1990
Preparatory meeting of the Task Team	23-24 Oct. 1990
Provisional data collection and relevant documentation	Feb. 1991
Analysis and Evaluation of the data and documentation collected	Apr. 1991
Submission by the Task Team members of individual draft reports	May 1991
Presentation and discussion of the draft reports at the 2nd Task Team meeting	24 Jun.1991
Presentation and discussion of the reviewed draft reports at the 3rd Task Team meeting	9 Oct.1991
Presentation and discussion of the final draft reports at the 4th Task Team meeting	30-31 Mar.1992
Preparation of the final draft report	May 1992
Co-ordinator's field trip to Rhodes	Jun. 1992
Co-ordinators editorial corrections of the final draft report	Jul. 1992
Submission of the comments on the final draft report by Task Team Members	Jul. 1992
Submission of the final draft to UNEP/MAP	Aug. 1992
Presentation of the final draft to the local authorities of Rhodes	Oct. 1992

ANNEX III

SCENARIOS FOR THE PREDICTED CLIMATE CHANGE IN RHODES DEDUCED FROM SCENARIOS SUGGESTED BY IPCC AND THE UNIVERSITY OF EAST ANGLIA

SCENARIOS		TIME HORIZON			
		2030		2100	
IPCC GLOBAL (Business as usual)					
Temperature		+ 1.8°C (?)		3°C	
Sea level		+ 18 cm +/- 10 cm		+ 65 cm +/- 35 cm	
IPCC Southern Europe (Business as usual)					
Temperature		+ 2°C winter + 2 - 3°C summer		-	
Precipitation		+ 0 to 10 % winter - 5 to (-15 %) summer		-	
Soil moisture		- 15 to - 25 % summer		-	
Univ. East Anglia NE Med		% per°C global	for 1.8°C global	% per°C global	for 3°C global
Temperature	Winter	0.5-1.8	2.3-3.24	0.5-1.8	1.5-5.4
	Spring	0.6-1.4	1.08-2.52	0.6-1.4	1.8-4.2
	Summer	0.6.1.6	1.08-2.88	0.6-1.6	1.8-4.8
	Autumn	0.7.1.6	1.26-2.88	0.7-1.6	2.1-4.8
	Annual	0.7-1.5	1.26-2.7	0.7-1.5	2.1-4.5
Precipitation	Winter	-15 -6			
	Spring	-7 -15			
	Summer	-22 -26			
	Autumn	-18 -15			
	Annual	-6 -6			
Univ. East Anglia for Rhodes		°C per global °C	for +1.8°C global	°C per global °C	for 3°C global
Temperature	Winter	0.5-1.8	0.9-1.44	0.5-1.8	1.5-2.4
	Spring	0.6-0.8	1.08-1.44	0.6-0.8	1.8-2.4
	Summer	1.0-1.1	1.8-1.98	1.0-1.1	3.0-3.3
	Autumn	0.7-0.8	1.26-1.44	0.7-0.8	2.1-2.4
	Annual	0.7-0.8	1.26-1.44	0.7-0.8	2.1-2.4
		% per global °C	mm	% per global °C	mm
Precipitation	Winter	0-2	0-13	9-4.8	0-21
	Spring	4-6	5-10	7.2-14.4	10-17
	Summer	4-12	0.2-0.75	12-39.6	0.38-1.26
	Autumn	2-4	3.8-8.6	4.2-9.6	6.3-14.5
	Annual	-2-0	(-21)-0	(-4.2)-0	(-30)-0

ANNEX IV

ASSESSMENT OF THE VULNERABILITY OF RHODES

In attempting to compile the study of the assessment of the vulnerability of Rhodes by applying the seven step approach as described by the advisory group of IPCC, a considerable body of data has been collected. These data are however inadequate, both at a national and a local level, to provide a quantitative assessment of vulnerability. As a result, the vulnerability assessment study described below, although it includes the quantitative data available to date, is largely qualitative.

STEP 1: DELINEATION OF CASE STUDY

Rhodes is an island with a rather straight stretch of coastline, quite extensive coastal zone and a large urban area lying at its northern tip. No big rivers, marshes or embayments exist. Our observations indicate under the ASLR 1 scenario (0.3 m sea level rise), there will be minor, if any, impacts on the island. In contrast under ASLR 2 scenario, (1 m sea level rise), the impacts will be noticeable.

From the above, four impact zones (Figure IV-1) were recognized in terms of increasing vulnerability, as follows:

IMPACT ZONE I: Coastal zone with altitude of up to 1 m.
IMPACT ZONE II: Unprotected alluvial (agricultural or not) lowlands (villages included), beyond I.Z.I.
IMPACT ZONE III: Urban areas protected by breakwaters (mainly the Rhodes city area).
IMPACT ZONE IV: Two ecosystems are included here:
a) the Butterfly (Petaloudes) Valley;
b) the estuary with the fish gizani, lying in the eastern part of Rhodes.

The boundary conditions are given in Table IV-1, where the unfavourable conditions of subsidence were added, based on the work of Pirrazzoli *et al.*, (1989).

STEP 2: INVENTORY OF STUDY AREA CHARACTERISTICS

These are given in Tables IV-2A to 2B. However, Tables IV-2C and 2D are incomplete due to the lack of data.

STEPS 3-6: DEVELOPMENT FACTORS, PHYSICAL CHANGES, RESPONSE STRATEGIES, COSTS, EFFECTS, VALUE AT RISK

The data necessary for compiling the tables needed for these steps are not available now or are incomplete. In order to obtain these data one must spend considerable time in the central offices and at the local authorities. In fact, the amount of time needed is estimated as about half of the time which was required for the whole project.

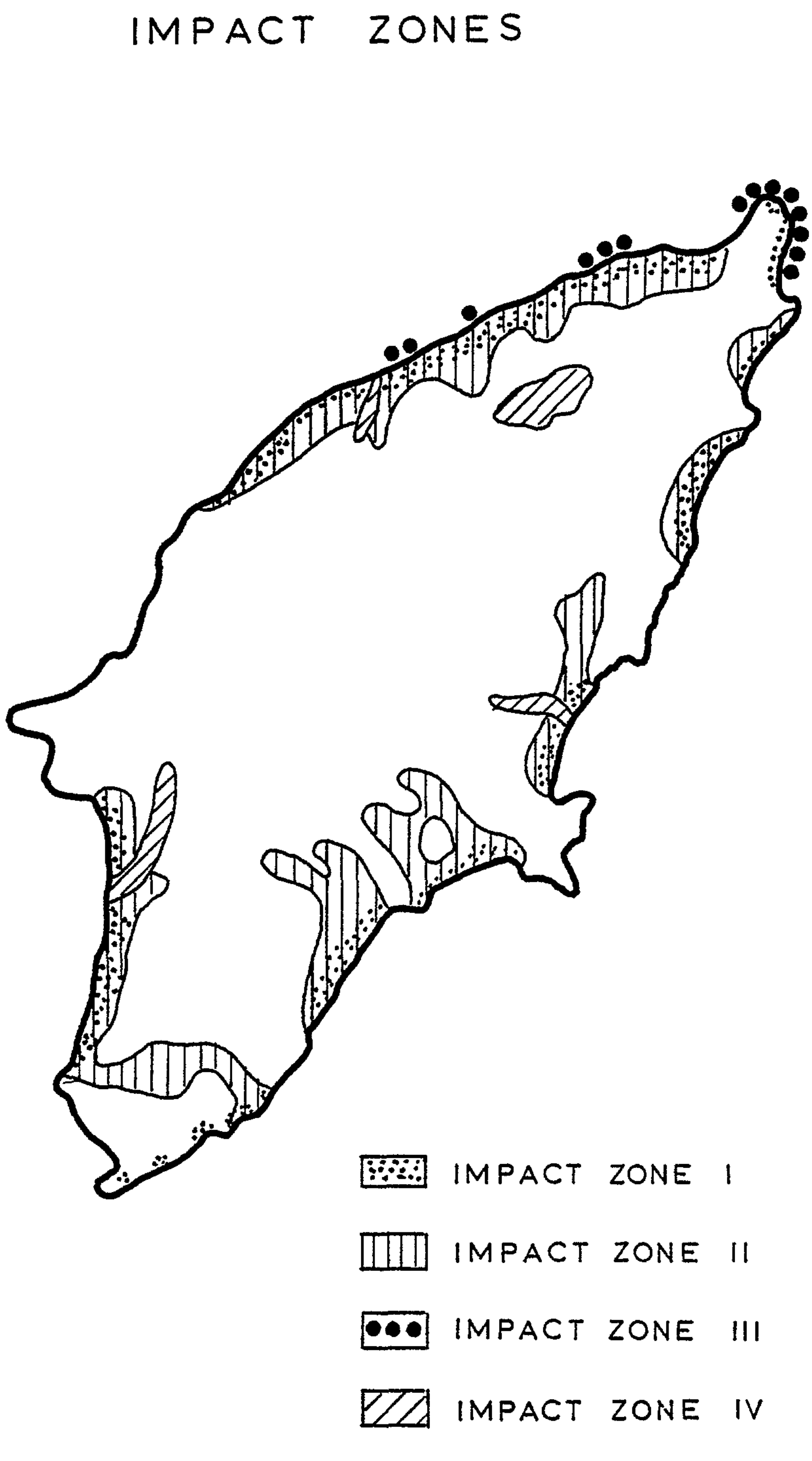

Figure IV-1 - Impact zones for Rhodes island

STEP 7: IDENTIFICATION OF STUDY OF ASSISTANCE NEEDED

Given the considerable lack of quantitative data, we proceeded to the compilation of Tables IV-II.1 and IV-II.2 that indicate the types of assistance needed.

In the category VA-LIO (legislative/institutional/organizational) we observe that (Table IV-II.1) in the level A, partial problems exist in the legislation, which has to be modified and implemented strictly, and the executive powers of the local governments need to be more clearly defined in relation to regional and central government power. In level B, partial problems might exist in terms of delimiting the responsibilities of the parties involved. In addition there is a lack of CZMP plan and control system for the whole island. In contrast, the manpower is adequate for the projects needed. Finally, in level C there is not enough knowledge and staff motivation to implement the suggested actions. This, however, is rather easily achieved if the decision makers adopt the suggestions made in this report. In the light of the above this category is characterized as being of medium vulnerability (Table IV-II.2).

In the category VA-ECF (economic/financial), the situation is different (Table IV-II.1). In levels A and B there is a problem in terms of financial support from the nation or the region for implementing the response options. However, there should be no problem in obtaining funds for these projects from the European Common Market (EEC), of which Greece is a member, since the trend of financing environmental programmes will increase in the future. This, though, requires a management capability on the part of the personnel in terms of preparing the proposals and carrying out the funded projects. Thus, this category is characterized as being of high vulnerability (Table IV-II.2).

In the technical category (VA-TEC) (Table IV-II.1), there are partial problems concerning the existing experience related to CZMP issues (level A), to daily management and monitoring (level B), and to data availability (level C). Regarding the data availability, it should be noted that most of the data required exist, but they are not accessible due to organizational and classification problems. In the other parameters of this category there is no particular problem, since many projects related to coastal management have been carried out successfully on a local scale. Therefore, the vulnerability of this category is characterized as medium (Table IV-II.2).

In the fourth and final category, the cultural-social (VA-CSO) (Table IV-II.1), there is a need for developing educational programmes related to problems of coastal management and environmental control, (level A) and of programmes aimed at raising public awareness (level B). Also, there is a need to convince the public, especially the local population, that they should not consider the coastal zone as their personal property for exploitation, mainly for tourism, but as a common heritage (level C). Generally, though, the population of Rhodes island is of high cultural and social level and in this respect the category related to cultural and social aspects is characterized as being of low vulnerability (Table IV-II.2).

CONCLUSIONS

In conclusion it can be said that the type of assistance needed for the island of Rhodes to meet the impacts of the ASLR, are mainly of an economic nature (financing, funding, etc.), while partial assistance is needed to reform the existing legislation, to define the areas of responsibility, to acquire some additional specialized technical knowledge, and to organize a central databank of all data related to the physical parameters of the Island of Rhodes.

TABLE IV-1

BOUNDARY CONDITIONS RELATED TO SEA LEVEL RISE AND CLIMATE CHANGE

BOUNDARY CONDITIONS	UNITS	ASLR 1	ASLR 2	UNFAVOURABLE
Accelerated Sea Level Rise				
sea level increase 2100	m	0.3	1.0	1.0
maximum rate of change	mm yr^{-1}	3.5	15	15
Other Possible Conditions				
increase in storms	%	-	-	10%
increase in peak river discharge	%	-	-	7%
change in temperature	°C	-	-	+ 3°C
change in precipitation	% or mm	-	-	+5%
change in evaporation	% or mm	-	-	+ 15%
subsidence				- 1.0

TABLE IV-2A

NATURAL SYSTEM DATA: PHYSICAL CHARACTERISTICS

TYPE OF DATA	UNITS	DATA VALUE
Natural Coast Types		
flat/sandy (beaches/dunes)	km	76
flat/mud (salt marshes, mangrove swamps)	km	-
cliff soft	km	64
cliff hard	km	51
glaciated/periglaciated	km	-
lagoon/spit	km	-
barrier coast	km	-
estuarine/delta	km	4
coral reefs	km	-
Artificial Coast Types		
sea dikes/sea walls	km	5
river dikes/revetments	km	-
detached breakwaters/groynes	km	-
other	km	-
Local Subsidence at Different Locations		
natural subsidence	mm yr^{-1}	1
man-induced subsidence	mm yr^{-1}	-
Design water level at different locations	m	2.5
Flood prone area (area flooded at design water levels)	km^2	0.76
Average tidal range	m	0.13
Seasonal fluctuation mean sea level	m	0.20
Annual average wave climate at different locations (used for morphological aspects)	m	2.5 - 6.0
Design wave height at different locations (used for structural aspects	m	4.0 - 7.0
Average annual sediment load rivers	tons yr^{-1}	missing
Average annual river discharge	m^3 s^{-1}	105 - 10^6 m^3 yr^{-1}
Peak discharge (1 in 100 years)	m^3 s^{-1}	150 - 10^6 m^3 yr^{-1}
Area with (potential) salinity problems	km^2	152 (76 x2)

TABLE IV-2B

HABITAT	UNIT	IMPACT ZONE I	IMPACT ZONE II (km^2)	IMPACT ZONE III (km^2)	IMPACT ZONE IV
Coastal zone			32.1	1.6	
Dunes	km^2	10			
Butterfly Valley	km^2				0.6
Gizani fish	km^2				0.3

TABLE IV-2C

SOCIO-ECONOMIC SYSTEM DATA: GENERAL INFORMATION

TYPE OF DATA	UNITS	DATA VALUE	
		NATION *	STUDY AREA **
Gross Domestic Product ***	1 dr	11.10^{12}	$3.06.10^{10}$
Population	# people	10^{7}	$1.1.10^{5}$
Population distribution in study area			
- Impact Zone I	# people	missing	1,000
- Impact Zone II	# people	missing	26,800
- Impact Zone III	# people	missing	50,000
- ecological, etc.	# people	missing	-
Subsistence population	# people	missing	40,000
Capital value ***	1 dr	11.10^{5}	20.10^{5}
Agricultural area	km^2	39,330	276
Recent average growth rate			
- GDP	% yr^{-1}	1.5	13.6
- Capital value	% yr^{-1}	1.2	13.6
- Population	% yr^{-1}	0.5	2

1 dr = local currency (year)

* Values of 1991

** Values of 1987 for whole Dodecanese

*** Figures for GDP and capital value of the study area not adjusted for inflation

TABLE IV-2D

SOCIO-ECONOMIC SYSTEM DATA: LAND USE AND VALUES

PRODUCTION USE AND CAPITAL VALUES								
	IMPACT ZONE I		IMPACT ZONE II		IMPACT ZONE III		IMPACT ZONE IV	
ACTIVITY	(km^2)	(dr km^{-2})	(km^2)	(dr km^{-2})	(km^2)	(dr/km^2)	(km^2)	(dr km^{-2})
Agriculture								
low	-	-	0.10	4-10^7	-	-	-	-
high	-	-	0.50	6-10^7	-	-	-	-
Industry								
low	-	-	0.10	4-10^7	-	-	-	-
Fisheries	-	-	0.10	4-10^7	0.10	-	-	-
Urban								
low	-	-	0.2	8-10^7	0.3	8-10^7	-	-
high	-	-	0.2	12-10^7	1.3	12-10^7	-	-
Recreation								
low	-	-	12.1	14-10"	1.6	-	0.6 gizani	4-10^7
high	-	-	20	6-10"	-	-	0.3 butterfly	6-10^7
Forestry								
low	-	-	-	-	-	-	-	-
high	-	-	-	-	-	-	-	-
Aquaculture								
low	-	-	-	-	-	-	-	-
SUBSISTENCE USE AND SUBSISTENCE VALUES								
	(km^2)	(pe km^{-2})	(km^2)	(pe km^{-2})	(km^2)	(pe km^{-2})	(km^2)	(pe km^{-2})
Agriculture								
low	-	-	0.10	-	-	-	-	-
high	-	-	0.50	-	-	-	-	-
Industry								
low	-	-	0.10	-	-	-	-	-
Fisheries	-	-	0.10	-	-	-	-	-
Urban								
low	-	-	0.2	-	0.3	-	-	-
high	-	-	0.2	-	1.3	-	-	-
Forestry								
low	-	-	12.1	-	-	-	-	-
high	-	-	20.1	-	-	-	-	-
Recreation								
low	-	-	-	-	1.6	0.6	-	-
high	-	-	-	-	-	0.3	-	-
Aquaculture								
low	-	-	-	-	-	-	-	-
high	-	-	-	-	-	-	-	-

TABLE IV-II.1

CONSTRAINTS RELATED TO IMPLEMENTATION FEASIBILITY

IMPLEMENTATION ASPECTS	PROBLEM	PARTIAL PROBLEM	NO PROBLEM
VA-LIO (legislative/institutions/organizational)			
Level A: (basic req.)			
existing legislation	-	X	-
existing inst./org.	-	-	X
executive powers	-	X	-
Level B: (oper.impl. aspects)			
special tasks/respons.	-	X	-
communication struct.	-	-	X
staffing/facilities	-	-	X
exist.CZMP plan etc.	-	X	-
Level C: (quality, funct. effect)			
staff education level	-	-	X
knowledge/man.capab.	-	X	-
staff motivation	-	X	-
VA-ECE (economic/financial)			
Level A:			
national econ. bearing cap.	X	-	-
Level B:			
nat./reg. funding possib.	X	-	-
internat. funding possib.	-	-	X
Level C:			
fin. management capab.	-	X	-
VA-TEC (technical)			
Level A:			
techn. knowl/experience	-	X	-
techn. institutions	-	-	X
Level B:			
operat. structures	-	X	-
staffing and facilities	-	-	X
Level C:			
staff education level	-	-	-
techn.qualif./capab.	-	-	X
staff motivation	-	-	X
data availability	-	X	-
VA-CSO (cultural/social)			
Level A:			
cultural	-	-	X
socio-econ.	-	X	-
Level B:			
cultural programmes	-	X	-
socio-econ. programmes	-	-	X
Level C:			
recent cult.achievem.	-	-	X
recent socio-econ.achievem.	-	X	-

TABLE IV-II.2

VULNERABILITY RELATED TO IMPLEMENTATION FEASIBILITY

	LOW	MEDIUM	HIGH	CRITICAL
VA-LIO	-	X	-	-
VA-ECF	-	-	X	-
VA-TEC	-	X	-	-
VA-CSO	X	-	-	-

ANNEX V

STATIONS USED IN SCENARIO CONSTRUCTION FOR THE NORTH-EASTERN MEDITERRANEAN

BULGARIA

	Station	E	N	HT	PRN	TEM	P%	T%
1.	SOFIA	23.3	42.7	564	1951-1989	1951-1979	67	72
2.	PLOVDIV	24.8	42.2	160	1951-1970	1951-1970	92	92
3.	BOURGAS	27.5	42.5	28	1951-1989	1951-1979	63	70

CYPRUS

	Station	E	N	HT	PRN	TEM	P%	T%
4.	PAPHOS	32.4	34.8	10	1951-1989	1951-1989	100	100
5.	PRODHROMOS	32.8	35.0	1380	1967-1989	1959-1989	98	99
6.	LIMASSOL	33.0	34.7	10	1951-1989	1951-1989	100	98
7.	NICOSIA	33.4	35.2	160	1951-1989	1951-1989	100	100
8.	LARNACA	33.6	34.9	3	1951-1989	1951-1989	100	100

EGYPT

	Station	E	N	HT	PRN	TEM	P%	T%
9.	SALLOUM	25.2	31.5	6	1951-1987	1951-1987	99	89
10.	SIDI-BARANI	26.0	31.6	23	1951-1987	1951-1987	100	99
11.	MERSA-MATRUH	27.2	31.3	30	1951-1989	1951-1987	99	97
12.	NOUZHA	30.0	31.2	7	1951-1987	1951-1975	100	56
13.	ROSETTA	30.4	31.4	3	1951-1987	-	74	0
14.	DAMIETTA	31.8	31.4	5	1951-1987	-	99	0
15.	PORT-SAID	32.3	31.3	6	1951-1987	1951-1987	99	98
16.	SAKHA	30.9	31.1	n/a	1951-1987	-	96	0
17.	TANTA	30.9	30.8	8	1961-1986	1951-1986	100	100
18.	ZAGAZIG	31.5	30.6	13	1961-1986	1951-1986	100	100
19.	CAIRO	31.4	30.1	74	1951-1989	1951-1986	99	83
20.	GIZA	31.2	30.0	22	1951-1986	1975-1986	100	100
21.	ISMAILIA	32.3	30.6	12	1951-1986	1951-1986	64	42

GREECE

	Station	E	N	HT	PRN	TEM	P%	T%
22.	MIKRA	23.0	40.5	61	1951-1989	1951-1987	96	100
23.	LARISSA	22.4	39.6	74	1951-1989	1951-1987	94	97
24.	AGXIALO	22.8	39.0	n/a	1956-1987	1956-1987	100	98
25.	TRIPOLIS	22.2	37.6	660	1957-1987	1957-1987	100	100
26.	KALAMATA	22.1	37.0	5	1951-1989	1951-1988	94	95
27.	TANAGRA	23.5	38.3	n/a	1957-1986	1957-1986	99	99
28.	ATHENS	23.7	38.0	107	1951-1989	1951-1988	98	97
29.	HELLENIKON	23.7	37.9	10	1951-1989	1951-1987	84	80
30.	KYTUIRA	23.0	36.2	n/a	1955-1987	1955-1987	100	100
31.	SKYROS	24.6	38.9	5	1955-1987	1955-1987	100	100
32.	MILOS	24.5	36.7	n/a	1955-1987	1955-1987	99	100
33.	ALEXANDROUPOLI	25.8	40.9	3	1951-1987	1951-1987	100	100
34.	MITILIA	26.4	39.2	n/a	1955-1987	1957-1987	100	99
35.	NAXOS	25.5	37.1	9	1955-1987	1955-1987	100	100
36.	SOUDA	24.1	35.6	161	1958-1989	1958-1986	97	97
37.	ANOGIA	24.9	35.3	n/a	1951-1985	-	96	0
38.	HERAKLION	25.2	35.3	48	1955-1986	1951-1988	97	97
39.	IERAPETRA	25.8	35.0	n/a	1956-1987	1956-1987	99	99
40.	SITIA	26.1	35.2	28	1951-1985	-	87	0
41.	KARPATHOS	27.2	35.5	20	1971-1988	1971-1988	95	95
42.	RHODES	28.1	36.4	12	1955-1988	1955-1988	100	100

ISRAEL

	Station	E	N	HT	PRN	TEM	P%	T%
43.	LOD	34.9	32.0	49	1951-1989	1951-1988	93	100
44.	JERUSALEM	35.2	31.8	809	1951-1989	1951-1980	97	100

JORDAN

	Station	E	N	HT	PRN	TEM	P%	T%
45.	IRBID	35.9	32.6	585	1955-1989	1955-1989	100	100
46.	RUWASHED	38.2	32.5	686	1960-1989	1961-1989	100	100
47.	AMMAN	36.0	32.0	771	1951-1989	1951-1989	100	100
48.	DEIR-ALLA	35.6	32.2	-224	1952-1989	1952-1989	100	100
49.	MAAN	35.8	30.2	1069	1960-1989	1960-1989	100	100
50.	WADI-YABIS	35.6	32.4	-200	1960-1989	1960-1989	100	100
51.	MAFRAQ	36.3	32.4	686	1960-1989	1960-1989	96	98
52.	ER-RABBAH	35.8	31.3	920	1960-1989	1961-1989	100	95
53.	JORDAN-UNIV	35.9	32.0	980	1960-1989	1961-1989	100	90

LEBANON

	Station	E	N	HT	PRN	TEM	P%	T%
54.	BEIRUT	35.5	33.9	24	1951-1985	1951-1985	80	84
55.	RAYACK	36.0	33.9	921	1951-1984	1951-1985	76	80
56.	TRIPOLI	36.0	34.6	10	1951-1982	1951-1980	77	76

LIBYA

	Station	E	N	HT	PRN	TEM	P%	T%
57.	DERNA	22.6	32.7	9	1951-1988	1951-1988	31	50
58.	TOBRUQ	24.0	32.1	14	1951-1973	-	100	0
59.	ADEM	23.9	31.9	155	1951-1988	1951-1975	96	93

SYRIA

	Station	E	N	HT	PRN	TEM	P%	T%
60.	ALEPPO	37.2	36.2	393	1951-1989	1952-1988	97	99
61.	LATTAKIA	35.8	35.6	9	1952-1989	1952-1988	90	94
62.	DEIR-EZZOR	40.2	35.3	212	1951-1989	1952-1988	97	99
63.	PALMYRA	38.3	34.6	404	1955-1989	1955-1988	97	99
64.	DAMASCUS	36.2	33.5	724	1951-1989	1951-1988	97	99
65.	SAFITA	36.1	34.8	n/a	1959-1988	1959-1988	100	100
66.	IDLEB	36.7	35.9	n/a	1955-1988	1957-1988	100	100
67.	HAMA	36.8	35.1	n/a	1955-1988	1956-1988	100	100
68.	HOMUS	36.7	34.8	n/a	1955-1988	1955-1988	100	100
69.	NABEK	36.7	34.0	n/a	1955-1988	1959-1988	100	100
70.	SUEIDA	36.6	32.7	n/a	1958-1988	1958-1988	100	100
71.	TELSHEHAB	36.0	32.7	n/a	1958-1988	1958-1988	100	100
72.	HASAKEH	40.8	36.5	300	1957-1988	1957-1989	100	100
73.	KHARABO	36.5	33.5	620	1946-1988	1956-1989	100	100
74.	JARABLUS	38.0	36.8	350	1957-1988	1957-1989	100	100
75.	JABAL	38.7	33.5	722	1958-1989	1958-1989	100	100
76.	MESELMIYIE	37.2	36.3	425	1946-1988	1957-1989	100	100
77.	RAQQA	39.0	36.0	250	1957-1988	1958-1989	100	100
78.	TARTOUS	35.9	34.9	5	1957-1990	1957-1989	100	100
79.	TEL-ABIAD	39.0	36.7	349	1957-1988	1957-1989	100	100

TURKEY

	Station	E	N	HT	PRN	TEM	P%	T%
80.	EDIRNE	26.6	41.7	48	1951-1989	1951-1988	95	98
81.	CANAKKALE	26.4	40.1	3	1951-1989	1951-1988	96	98
82.	IZMIR	27.3	38.4	25	1951-1989	1951-1988	96	98
83.	MUGLA	28.4	37.2	646	1951-1989	1951-1988	94	96
84.	ISTANBUL	29.1	41.0	40	1951-1989	1951-1988	97	98
85.	BURSA	29.1	40.2	100	1951-1989	1951-1980	95	97
86.	AFYON	30.5	38.8	1034	1951-1989	1951-1988	97	98
87.	ISPARTA	30.6	37.8	1043	1951-1989	1951-1988	97	98
88.	ANTALYA	30.7	36.9	43	1951-1989	1951-1988	96	98
89.	KASTAMONU	33.8	41.4	799	1951-1989	1951-1988	97	98
90.	ANKARA	32.9	40.0	894	1951-1989	1951-1988	97	98
91.	KONYA	32.5	37.9	1022	1951-1989	1951-1988	93	98
92.	KAYSERI	35.5	38.7	1070	1951-1982	1951-1988	97	91
93.	ADANA	35.3	37.0	66	1951-1985	1951-1986	95	93
94.	SAMSUN	36.3	41.3	44	1951-1989	1951-1988	97	98
95.	SIVAS	37.0	39.8	1285	1951-1989	1951-1980	97	100
96.	MALATYA	38.3	38.4	998	1951-1989	1951-1988	92	98
97.	URFA	38.8	37.1	547	1951-1989	1951-1988	94	96
98.	RIZE	40.5	41.0	4	1951-1989	1951-1988	90	96
99.	ERZINCAN	39.5	39.7	1215	1951-1989	1951-1988	95	96
0.	DIYARBAKIR	40.2	37.9	677	1951-1989	1951-1988	95	98

E - latitude
N - longitude
HT - height above sea level (m)
PRN - length of precipitation record
TEM - length of temperature record
P% - percentage of precipitation record present
T% - percentage of temperature record present