MEDITERRANEAN ACTION PLAN
PRIORITY ACTIONS PROGRAMME

UNITED NATIONS ENVIRONMENT PROGRAMME

WATER RESOURCES DEVELOPMENT OF SMALL MEDITERRANEAN ISLANDS AND ISOLATED COASTAL AREAS

DEVELOPPEMENT DES RESSOURCES EN EAU DES PETITES ILES ET DES ZONES COTIERES ISOLEES MEDITERRANEENNES

DOCUMENTS PRODUCED IN THE FIRST STAGE OF THE PRIORITY ACTION (1984-1985)

TEXTES REDIGES AU COURS DE LA PREMIERE PHASE DE L' ACTION PRIORITAIRE (1984-1985)

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This volume is the twelth issue of the Mediterranean Action Plan Technical Report Series.

This Series will collect and disseminate selected scientific reports obtained through the implementation of the various MAP components: Pollution Monitoring and Research Programme (MED POL), Blue Plan, Priority Actions Programme, Specially Protected Areas and Regional Oil Combating Centre.

Ce volume constitue le douzième numéro de la série des Rapports techniques du Plan d'action pour la Méditerranée.

Cette série permettra de rassembler et de diffuser certains des rapports scientifiques établis dans le cadre de la mise en oeuvre des diverses composantes du PAM: Programme de surveillance continue et de recherche en matière de pollution (MED POL), Plan Bleu, Programme d'actions prioritaires, Aires spécialement protégées et Centre régional de lutte contre la pollution par les hydrocarbures.

PREFACE

The United Nations Environment Programme (UNEP) convened an intergovernmental Meeting on the Protection of the Mediterranean (Barcelona, 28 January - 4 February 1975), which was attended by representatives of 16 states bordering on the Mediterranean Sea. The meeting discussed the various measures necessary for the prevention and control of pollution of the Mediterranean Sea, and concluded by adopting an Action Plan consisting of three substantive components:

- Integrated planning of the development and management of the resources of the Mediterranean Basin (management component);
- Co-ordinated programme for research, monitoring and exchange of information and assessment of the state of pollution and of protection measures (assessment component);
- Framework convention and related protocols with their technical annexes for the protection of the Mediterranean environment (legal component).

All components of the Action Plan are interdependent and provide a framework for comprehensive action to promote both the protection and the continued development of the Mediterranean ecoregion. No component is an end in itself. The Action Plan is intended to assist the Mediterranean Governments in formulating their national policies related to the continuous development and protection of the Mediterranean area and to improve their ability to identify various options for alternative patterns of development and to make choices and appropriate allocations of resources.

The Priority Actions Programme (PAP), a component of the integrated programme of the Mediterranean Action Plan (MAP) promotes the exchange of experience in the fields of integrated planning and management of resources in the Mediterranean coastal areas.

The starting point of the PAP activities is the awareness that the protection and sound management of the environment can only be implemented by means of a rational development which translates into an optimum exploitation of natural resources. The notion itself of environment in a broader sense and especially in the Mediterranean context is at the same time the most precious resource of the Area.

Within the framework of the definition of the PAP activities, the representatives of the Mediterranean governments, the Contracting Parties of the Barcelona Convention, have established the following priorities for the PAP:

- human settlements
- water resources management
- soil protection against erosion
- tourism
- aquaculture
- renewable sources of energy

In the abovementioned areas, the following activities are being completed:

- directories of Mediterranean institutions and experts
- water resources management
- integrated planning and management of Mediterranean coastal zones
- protection and rehabilitation of historic settlements
- land-use planning in earthquake zones
- soil protection against erosion
- solid and liquid waste management, collection and disposal
- development of tourism harmonized with the environment
- aquaculture
- renewable sources of energy
- environmental impact assessment
- balance between the hinterland and the coastal zones.

The United Nations Agencies, many international organizations and almost all Mediterranean countries take active part in all these activities.

This volume, which is the 12th in the Mediterranean Action Plan Technical Reports Series, contains selected documents concerning the Priority Action entitled "Water Resources Management of Mediterranean Small Islands and Coastal Areas" covering its first phase.

PREFACE

Le Programme des Nations Unies pour l'environnement (PNUE) a convoqué une réunion intergouvernementale sur la protection de la Méditerranée (Barcelone, 28 janvier - 4 février 1975) à laquelle ont pris part des représentants de 16 Etats riverains de la mer Méditerranée. La réunion a examiné les diverses mesures nécessaires à la prévention et à la lutte antipollution en mer Méditerranée, et elle s'est conclue sur l'adoption d'un Plan d'action comportant trois éléments fondamentaux:

- Planification intégrée du développement et de la gestion des ressources du bassin méditerranéen (élément "gestion");

- Programme coordonné de surveillance continue, de recherche, d'échange de renseignements et d'évaluation de l'état de la pollution et des mesures de protection (élément "évaluation");

- Convention cadre et protocoles y relatifs avec leurs annexes techniques pour la protection du milieu méditerranéen (élément juridique).

Tous les éléments du Plan d'action étaient interdépendants et fournissaient le cadre d'une action d'ensemble en vue de promouvoir tant la protection que le développement continu de l'écorégion méditerranéenne. Aucun élément ne constituait une fin à lui seul. Le Plan d'action était destiné à aider les gouvernements méditerranéens à formuler leurs politiques nationales en matière de développement continu et de protection de zone de la Méditerranée et à accroître leur faculté d'identifier les diverses options s'offrant pour les schémas de développement, d'arrêter leurs choix et d'y affecter les ressources appropriées.

Le Programme d'Actions Prioritaires (PAP), partie du plan intégré du Plan d'Action pour la Méditerranée (PAM), a pour but de promouvoir des échanges d'expériences dans les domaines de la planification intégrée et de la gestion des ressources des zones côtières méditerranéennes.

Le point de départ des activités du PAP est la connaissance que la protection et la promotion de l'environnement ne peuvent être réalisées que grâce à un développement raisonné qui se traduit par une exploitation optimale des ressources naturelles. La notion même de l'environnement, conçue dans un sens plus large, et tout particulièrement dans des conditions méditerranéennes, constitue en même temps la plus précieuse ressource de la Région.

Dans la phase de la définition des activités du PAP, les représentants des Gouvernements meditérranéens, Parties Contractantes de la Convention de Barcelone, ont précisé les domaines prioritaires du PAP, notamment:

- établissements humains;
- gestion des ressources en eau;
- protection des sols contre l'érosion;
- tourisme;
- aquaculture;
- sources d'énergie renouvelables.

Dans les limites des domaines précités, les actions suivantes sont en voie d'achèvement:

- répertoires des institutions et experts méditerranéens;
- gestion des ressources en eau;
- planification intégrée et gestion des zones côtières méditerranéennes;
- protection et réhabilitation des sites historiques;
- aménagement du territoire dans les zones sismiques;
- protection des sols contre l'érosion;
- gestion, collecte et élimination des déchets solides et liquides;
- développement du tourisme en harmonie avec l'environnement;
- aquaculture;
- sources d'énergie renouvelables;
- évaluation des impacts sur l'environnement;
- interrelation côte - arrière-pays.

A toutes les actions prennent part les organismes des N.U. et de nombreuses organisations internationales, y compris la participation active de presque la totalité des pays méditerranéens.

Le présent volume le 12ème de la Série des rapports technique du PAM, englobe un choix de documents relatifs à l'action prioritaire intitulée "Développement des ressources en eau des petites îles et zones côtières méditerranéennes", couvrant sa première phase.

EDITORIAL

The subject of this technical paper is "Water resources development of small Mediterranean islands and isolated coastal areas". It is based on the documents prepared in the course of the priority action holding the same title, which is within the activities of the Priority Actions Programme (PAP), of the Mediterranean Action Plan (MAP). The principal aim of this paper is to concisely describe the techniques and methods used and briefly review the situation in this field.

Since the activities within this action have not yet dealt with all the elements of water resources development of small Mediterranean islands and isolated coastal areas, the technical paper will be limited only to those included in the action. All the activities previous to the preparation of this paper are described in the introduction. The documents prepared in the course of this action will not be presented chronologically or in their original form, but in such a way as to describe clearly and concisely the basic subject, without superfluous details, inadequate for this kind of paper. Therefore, some documents will be presented partially and some in their entirety.

In this way, we want to produce a paper useful to local water authorities in this area, as well as to decision makers and technicians in the field of water resources development, with the aim of getting to know the situation in other areas, as well as gaining experience and possibilities for resolving the problems of water resources development of small Mediterranean islands and isolated coastal areas.

EDITORS

EDITORIAL

Cette communication technique a pour thème: "Developpement des ressources en eau des petites îles et des zones côtières isolées méditerranéennes". Elle repose sur les documents établis au cours de l'action prioritaire portant le même intitulé et menée dans le cadre des activités du Programme d'actions prioritaires (PAP) du Plan d'action pour la Méditerranée (PAM). La présente communication vise avant tout à exposer avec concision les techniques et méthodes utilisées ainsi qu'à examiner brièvement la situation dans ce domaine.

Etant donné que les activités relevant de cette action prioritaire n'ont pas encore abordé tous les aspects du développement des ressources en eau des petites îles et zones côtières, ce document technique se borne aux éléments intégrés dans ladite action. Toutes les activités ayant précédé l'établissement de ce document sont décrites dans l'introduction. Les documents rédigés au cours de cette action ne seront pas présentés selon leur ordre chronologique ou sous leur forme originelle mais de manière à exposer avec clarté et concision leur sujet fondamental, sans les elourdir de détails superflus qui ne conviennent guère à ce genre de communication. Il s'ensuit donc que certains d'entre eux sont présentés de manière partielle et que d'autres le sont intégralement.

Ce faisant, nous souhaitons publier un document utile pour les autorités locales compétentes dans la région de même que pour les décideurs et techniciens en matière de développement des ressources en eau, leur permettent ainsi d'appréhender la situation dans d'autres régions et d'acquérir des enseignements et des moyens de résoudre les problèmes posés par le développement des ressources en eau des petites îles et des zones côtières isoleés méditerranéennes.

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PRIORITY ACTION "WATER RESOURCES DEVELOPMENT OF ISLANDS AND ISOLATED COASTAL AREAS"

By

JURE MARGETA
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Split, Yugoslavia

1. Background information

The Mediterranean Action Plan is a programme for Mediterranean countries in the implementation of the Convention for the protection of the Mediterranean Sea against pollution and its related protocols. The Convention has been in force since 1978, and its Contracting Parties are all Mediterranean countries (except for Albania) and the European Community.

The "Integrated Planning" component of the Mediterranean Action Plan (MAP) is expected to deal with the problems of development and its impact on the environment. It has been agreed that this particular component should consist of and operate on two planes:

1. Long-term development of the Mediterranean and the problems of development in relation to the environment (the Blue Plan).
2. Current and acute problems of development in the Mediterranean, the use of its resources, and the impact of both of these on the state of environment (the Priority Actions Programme).

The investigation of current problems and conflicts between development and the environment, as well as the assessment of the possible use of available resources in conformity with environmental protection principles is the primary task of the Priority Actions Programme (PAP). So far, six priority fields of the Priority Actions Programme have been identified, among them: rational management of fresh water resources.

In the course of PAP development, the priority action relative to water resources management was steered to the water supply problems of smaller Mediterranean islands. As a result, the 1984-1985 PAP programme on water resources issues envisaged the launching and implementation of the action entitled "Water Resources Development of Islands and Isolated Coastal Areas".

The main objectives of this action are to identify and analyse problems relevant to water resources management of Mediterranean islands and isolated coastal areas and to assist those states of the region facing the problems to resolve them.

The action's workplan includes:

(a) identification of the problems faced by the states;

(b) analysis of information on relevant problems of water resources development;

(c) co-operation with states in developing water resources;

(d) exchange of experiences on existing problems and suggestions for appropriate solutions.

2. The initial stage of the action

At the invitation of PAP/RAC (Regional Activity Centre), eight Mediterranean countries have been taking part in this action:

- Greece, with problems of water supply on the islands of Hydra, Nisyros and Patmos;
- Egypt, with problems of water supply in the coastal areas of Marsa Matruh, El Quasr, Ras el Hakma and Bagouch;
- Italy, the islands of Elba and Giglio;
- Spain, the water supply system on Mallorca island;
- France, water supply examples from the islands of Porquerolles and Port Cros;
- Tunisia, problems of water supply on the island of Kerkennah;
- Cyprus, water supply solutions in the Pissouri area;
- Yugoslavia, problems and solutions on the islands of Hvar, Brac and Silba.

The task was to collect, with the help of local experts and/or authorities, relevant information and insight into the problems of water supply and the possibilities for solutions as well as all natural, technical and economic elements which may influence the ultimate choice of solution.

3. Working meeting of consultants and experts

The working meeting of the consultants and experts on the Priority Action was held on the premises of PAP/RAC on 28 and 29 January 1985. The purpose of the meeting was to review and discuss the reports prepared by the mission, to consider comments and suggestions given by the PAP national focal points and to formulate proposals for co-operation with interested countries in the subsequent stages of this action.

The general proposals for co-operation with the interested countries were formulated at the meeting in accordance with these objectives. It was concluded that PAP/RAC should provide the co-operation with the countries in solving the problems related to water management on selected islands and in isolated coastal areas and should help in the transfer of knowledge and exchange of experiences between countries. Attention should be given to those problems which are common to at least several Mediterranean countries. The problems should be dealt with in such a way as to be useful to the other countries facing similar problems, and the documents produced should be used for the preparation of the respective manual.

According to these conclusions, PAP/RAC offered its co-operation to those countries having taken part in the former activities, as well as to other countries. Having received information from these countries, special missions of experts have been organised to solve some specific problems (Greece, Spain, Yugoslavia, Malta, Cyprus), while studies dealing with wider problems have also been ordered (Italy, France).

4. Seminar on water and sanitation in small Mediterranean islands and isolated coastal areas

PAP/RAC, in collaboration with WHO/EURO and Gobierno de la comunidad autonoma de las islas Baleares, consejeria de obras publicas y ordenacion del territorio, organized the seminar on water and sanitation in small Mediterranean islands and isolated coastal areas, which discussed the mission reports, case studies and other papers prepared by the participants.

The seminar made conclusions regarding the previous work and gave recommendations for the follow-up of the action.

The documents presented in the seminar represent the basis of this volume.

SYNTHESIS OF WATER RESOURCES DEVELOPMENT OF MEDITERRANEAN ISLANDS AND ISOLATED AREAS

By

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1. INTRODUCTION

The results obtained so far have confirmed that the water supply of small islands and isolated areas of the Mediterranean continues to be a major problem and limiting factor of their development.

Limited surface area, geography, arid climate, geology and morphology, are the factors that almost totally eliminate underground water accumulations. In addition to these precarious conditions for water supply, there is the problem of seasonal fluctuation of demand. Climate and geography have favoured tourism developments, but if tourism development is not properly balanced with nature's possibilities, ecological changes and environmental pollution can disrupt and hamper further development or even result in stagnation.

It is therefore indispensable to secure efficient water resources management, concurrent with the exploitation of other resources in the area, in order to reach a harmonious development in balance with nature. However, at present, the needs of small islands and isolated areas have outgrown local water resources and, therefore, they are obliged to seek other possibilities for fresh water supply.

2. LOCAL FRESH WATER RESOURCES

The most widely used local resource, is the accumulation of drinking water in traditional cisterms, which is able to meet population needs in rainy winter periods, but fails to do so during the summer. The main difficulty, apart from the old age of the cisterns, is the shortage of space for accumulation for the dry period. This is particularly true of northern and western parts of the Mediterranean, despite sufficient precipitation. On smaller islands the use of underground water can sometimes alleviate water shortage, but not entirely. Almost every island has some possibility for continuous or periodic exploitation of underground water. During the tourist season, however, these possibilities are the least exploitable. If necessary accumulation space for seasonal needs is secured, provided the spaces do not become contaminated by urban effluent or agricultural drain water, restricting use (Silba, Malta), the supply of water could be at its optimum. On the big islands which have larger aquifers, the main problem is overextraction which results in intrusion of the sea in the aquifers (Malta, Mallorca). This problem in some areas is successfully solved in combination with surface accumulations (Cyprus).

Permanent water courses are a rarity on small islands; periodic courses, especially of torrential type, are more frequent. These are used sometimes for periodic recharge of accumulations that serve as water supply for irrigation or for recharge of underground aquifers (Cyprus).

Separately, all these local resources are not sufficient to meet the needs but in most cases, if combined, can solve water supply problems or, at least, alleviate them considerably. The main hazard in local resource use is contamination. Therefore both water supply and waste water disposal from point and diffuse pollution sources, should be tackled together.

3. OTHER LOCAL POSSIBILITIES

Other local possibilities can be made use of, such as desalination of sea or brackish water and re-use of waste water. Desalination is practiced on small islands distant from the coast, and in combination with local energy resource use (solar energy). Perspectively, these are very adequate solutions.

In the Mediterranean region, a large number of desalination plants are in operation; the biggest are those on Malta. The main problem with these plants on small islands is the lack of skilled personnel and repair and maintenance shops.

The re-use of waste water is gaining importance, as water treatment solves two problems: protection of water resources from pollution and of fresh water for irrigation use. Thus, waste water re-use helps indirectly to solve the lack of water supply as treated waste water, used mainly for irrigation, frees a part of fresh water for other uses (Mallorca).

Another possibility is to activate underground aquifers by recharge or grouting, so as to prevent the infiltration of sea water into these aquifers. The re-use of waste water can considerably ease the problem of fresh water shortage in agriculture if necessary precautions are taken against a number of adverse effects. Considering water's value and the efforts and means that have to be invested to obtain fresh water in these areas, it is utterly irrational to reject used water. Treated, it can serve very well, either for watering or irrigation, and joined with other climatic advantages, improve considerably agricultural production.

4. OUTSIDE SOURCES SUPPLY

For outside supply, tankers are mainly used. A large number of island resorts use this seasonal water supply as a supplement to water supplied in cisterns. However, the problems with this are very high costs, inadequate port facilities, limited storage capacity on land and poor water quality. Although, for the majority of small islands, this represents the only way of securing water during the high season, it is not likely to meet their full needs, or the demands and standards of modern tourists. Consequently, water supplied by tankers has yet to be improved and requires more attention in the future.

Undoubtedly, the best solution for supplying water to islands is connecting them to the mainland by a submarine waterpipe system, or to regional or local systems. A restricted number of islands, have this possibility, mainly those that are near the coast or are sufficiently important to have these connections. In addition to high costs, another drawback is the vulnerability of the system. Therefore, it is believed that this solution should be combined and supplemented with other adequate reserve possibilities.

5. MANAGEMENT OF WATER RESOURCES

Limited fresh water resources with high demand and strongly fluctuating consumption require complex solutions based on several resources, as well as an overall management system efficient under all conditions of consumption. But, such an efficient system is not easy to create under the given circumstances of shortages in skills and services and the remoteness of the area. Many such systems are below the required level and need improvement in both quantity and quality of water. It has been proved in practice that modern sophisticated solutions are not always those best for small islands and should therefore be avoided. Simpler solutions are better, even when they are less efficient. Therefore, traditional solutions and their improvement and prevention from decline, should be given priority. Traditional solutions are found on many islands and are the widest used for individual water supply systems. In combination with other sources, they are an important contribution to water supply on small islands and isolated coastal areas.

There is, however, the failure (in all cases) to regard island water resources as one whole system, both as the water supply source and the recipient for effluent water. The continuity and cyclic character of water resources in such areas as small islands and isolated natural entities should be observed. Failure to observe the principles of water resources management will cause disturbances hazardous to the human environment and to the development of economy and community in general. Therefore, an efficient exploitation of water resources is needed if we want to organise life and production in these areas in the best possible way.

No recognising the interconnection of water resources elements often results from inadequate research, i.e. from lack of reliable data. Municipalities in question are not financially equipped for data collecting or for hiring necessary skill and, therefore, their water resources development essentially relies on national support and on international institutions.

Activities engaged so far within the frame of the priority actions have proved that the Mediterranean region has a series of positive experiences in water resources development and also necessary skilled manpower capable of solving these problems.

Therefore cooperation among countries by way of various relevant activities and transfer of knowledge is necessary in order to promote and further improve the practice and knowledge of water resources development in these areas.

HYDROLOGY AND WATER BALANCE OF SMALL ISLANDS

By

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ABSTRACT

The water balance concept is illustrated by describing the simplified water balance of a hypothetical small island in the Mediterranean. The different hydrological measurements and survey methods to determine the individual water balance components are treated giving particular emphasis to the uncertainties involved.

The treatment of the water balance concept is preceded by a general description of water occurrence on small islands and is followed by a discussion on the relationship between hydrology on the one hand and water reources assessment and management on the other.

1. CONDITIONS FOR WATER OCCURRENCE

Within the definition of the IHP Project, small islands are islands of less than 1000 km^2.

Figure 1 gives a schematic representation of the water resources of a small island.

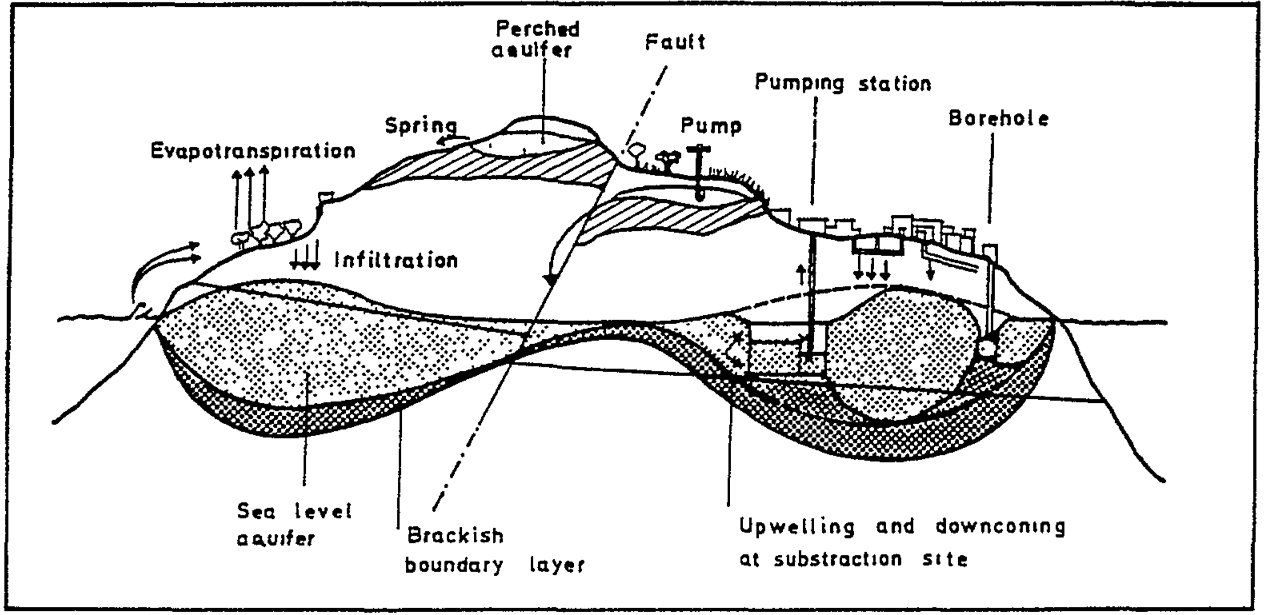

Fig.1 Schematic representation of Gozo Island after Macelli, human settlement in Gozo.

Except along the Dalmatian coast, where rainfall is more abundant, the annual average precipitation is less than 700mm. The most frequent values are between 400 and 600mm. The multi-annual variation in rainfall in the Mediterranean climate is significant. Several years of below average annual rainfall are followed by a few years higher than average.

Potential evaporation in the Mediterranean (water being available for evaporation from the whole year) is about 1200mm per year, which is double the total rainfull. It is thus clear that, except for the Dalmatian coast, there is a precipitation deficit during most of the year.

The Mediterranean climate is characterised by dry, warm summers. Most of the rain falls in autumn and winter. This is also the period when the water demands for agriculture and tourism are at their lowest. This imbalance can only be offset through storage of water in the rainy seasons for later use in summer. As small islands usually have low altitudes and the distance of any point on the island is always close to its coastline, the possibility of storing surface water is absent or very limited.

Often the only storage possibility is underground. Mediterranean islands are mostly of volcanic or limestone origin and thus, in general, have one or more aquifers. Some of the aquifers are at elevated levels resting on an impervious substratum. these aquifers are protected from seawater intrusion with excess water flowing out from springs at the base of the aquifer. Most of the islands have at least one aquifer at about sea level. These aquifers are liable to seawater intrusion after long periods of over-exploitation or when inappropriate methods of withdrawal have been used.

The most important manageable water source on the small islands of the Mediterranean is groundwater. It is exploited by springs, wells, boreholes and underground galleries. Rainwater is also an important source for what is called dry farming, although it is not managed. In former times, rainwater was often captured on impervious surfaces such as roofs and stored in cisterns for domestic use. In some situations, the only possibility is the re-use of treated waste water, the importation of fresh water or the desalination of seawater.

2. THE WATER BALANCE CONCEPT

The water balance of a hydrological unit is very useful for the understanding of the hydrological system. A water balance is a balance of water inputs, outputs and changes in storage over a specific period of time.

The input into the fresh water resources of an island is its precipitation; the outputs: evapotranspiration and loss of fresh water to the sea; the change in storage: the change in water content of the soil and aquifers plus the change in surface water storage.

On small islands, in many cases, the only manageable part of the hydrological cycle is the aquifer. We will see that the aquifer is managed by changing the water table and that losses are diminished by increasing water use.

To illustrate the usefulness of the water balance concept, we will take as an example an island with the following characteristics:

Surface area : 1000 km^2
Precipitation : 600 mm per year on average
Water use : 31 million m^3/yr at present
while for the future : 45 million m^3/yr is planned

We further know the distribution of the rainfall and water use for the months of the year. We assume that the island is geologically and morphologically homogeneous and has one or more aquifers of which the largest one is at about sea level. As it is a small island we also assume that there are no rivers.

On the lefthand side of Table I, we can see the rates of precipitation and the direct losses through evaporation and surface runoff for the four seasons, and on the righthand side the accumulated volumes at the end of each season. We have started the calculation at the end of the dry season when the groundwater level storage is at its lowest.

The lower line of Table I gives the amounts of precipitation minus the "unmanageable" losses, which is equal to the recharge into the aquifer. From Table I, one can see that of the total rainfall of 600 mm per year, 212 mm reaches the aquifer for storage. (The percentage of recharge varies enormously from island to island; it may be as low as 5 per cent of the precipitation).

Table I

	Rates in mm during				Accumulated volumes in hm^3 at the end of			
	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer
Precipitation	175	250	125	50	175	425	550	600
Direct evapotranspiration	-70	-80	-105	-45	-70	-150	-255	-300
Direct loss surface runoff	-27	-42	-17	-2	-27	-69	-86	-88
Precipitation minus unmanageable losses	78	128	3	3	78	200	209	212

The basic manageable water management unit on this small island is the groundwater aquifer. Its water balance is described by this formula: the change in storage equals recharge minus the evaporation from the aquifer minus the discharge to the sea minus the water use.

In a hypothetical situation where the climate is the same every year, the storage in the aquifer would be the same at the end of each summer. The change in storage would therefore be zero, or in other words, the accumulated volume of recharge minus losses would be zero at the end of the hydrological year.

Table II gives the water balance of the island where there is no water use at all. In such a situation the evaporation from the reservoir and the discharge into the sea would be maximal (105 and 107 million m^3 respectively).

Both the evaporation and the discharge are greatest when the water table is highest. The relative importance of the two depends on the geology of the island. If the resistance to groundwater flow is high, evaporation will be the greater loss. On the other hand if resistance is low, as in the case of rocks with large fissures, fresh water flows to the sea easily.

We can only manage a groundwater aquifer by changing the water table. By using the water, we lower the water table, and by lowering the water table, we reduce the losses occurring through evaporation and discharge to the sea.

Table II

	Rates in mm during				Accumulated volumes in hm^3 at the end of			
	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer
Recharge to aquifers	78	128	3	3	78	206	209	212
Water use	0	0	0	0	0	0	0	0
Evapotranspiration from aquifer	-20	0	-20	-65	-20	-20	-40	-105
Discharge into the sea	-5	-48	-50	-4	-5	-53	-103	-107
Recharge minus losses	53	80	-67	-66	53	133	66	0

Table III shows the water balance of the island with the present water use, distributed as it presently is over the seasons of 31 million m^3 per year. The losses through evapotranspiration and discharge to the sea are 39 million m^3 lower than in the case of no water use.

Two figures in the table have to be looked at to know whether the *situation is acceptable. The first is the discharge to the sea during the* summer months. In this case, this is equivalent to 3 mm, which is assumed to be enough to keep the sea water out of the aquifer of this island. If it were 2 mm, sea water encroachment would occur. The other figure is the accumulated storage at the end of the summer. If this figure were negative the aquifer would be depleted, and trouble would soon occur.

Table III

	Rates in mm during				Accumulated volumes in hm^3 at the end of			
	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer
Recharge to aquifers	78	128	3	3	78	206	209	212
Water use	-6	-4	-6	-15	-6	-10	-16	-31
Evapotranspiration from aquifer	-17	0	-17	-52	-17	-17	-35	-87
Discharge into the sea	-4	-43	-43	-3	-4	-47	-91	-94
Recharge minus losses	50	81	-64	-67	50	131	68	0

Table IV shows the balance for a water use of 49 hm^3 per year, with an increase during the summer months. The situation is just at the limit. With this particular water use, the maximum of annual water use seems to be reached.

Table IV

	Rates in mm during				Accumulated volumes in hm^3 at the end of			
	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer
Recharge to aquifers	78	128	3	3	78	206	209	212
Water use	-10	-5	-10	-24	-10	-15	-25	-49
Evapotranspiration from aquifer	-16	0	-17	-45	-16	-16	-32	-77
Discharge into the sea	-4	-40	-40	-3	-4	-44	-84	-86
Recharge minus losses	48	83	-62	-69	48	131	69	0

It is still possible to safely withdraw more from the aquifer. As explained above we manage groundwater by changing the water table. Table V shows that if one draws additional water from the aquifer in spring, and stores it in a reservoir until it is needed in summer, one can take out in total, 55 million m^3.

Table V

	Rates in mm during				Accumulated volumes in hm^3 at the end of			
	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer
Recharge to aquifers	78	128	3	3	78	206	209	212
Water use	-10	-5	-25	-15	-10	-15	-40	-55
Evapotranspiration from aquifer	-16	0	-15	-43	-16	-16	-30	-74
Discharge into the sea	-4	-40	-36	-3	-4	-44	-80	-83
Recharge minus losses	48	83	-73	-58	48	131	58	0

The above figure of 55 million m^3 would be the hydrological maximum. In reality, however, there will always be technical and economic constraints which will make it impossible to abstract the maximum.

3. HYDROLOGICAL MEASUREMENTS AND STUDIES

The determination of the water balance components.

The important hydrologically-related parameters mentioned in the water balance example are:

Precipitation
Evapotranspiration during and directly after rainfall
Surface runoff
Recharge of aquifer
Evapotranspiration from the aquifer
Groundwater discharge into the sea

Of these parameters, only precipitation is measured directly. All the others have to be determined through indirect measurement or derived through calculations and comparisons. The result is that we need much more data and information than would be expected from a simply water balance equation. These data need to be spatially and temporally determined, for example: topography, morphology and geology do not change quickly over time; water and land-use change slowly; and precipitation is highly variable.

A second complicating factor is the large spatial variability. Most small islands are not very homogeneous geologically and morphologically. Soils vary over small distances and there are many different land uses. Rainfall will be higher on the windward side of the island and at higher altitudes. Evaporation will be lower in a grassland area than in a forest. Infiltration into the soil will be higher where the surface is flat and the ground more permeable.

As most of the water balance components cannot be measured directly, we need to understand the total hydrological behaviour of the island very well. This understanding requires studying the behaviour of the most important water resources, the aquifers, over many years and under different circumstances. In particular, it is necessary to cover sequences of wet and dry years, and to monitor behaviour under extreme conditions.

Precipitation

Precipitation is measured by rain gauges. Their necessary spatial distribution depends on the spatial variability of the rain over the island. Daily measurements would be sufficient for most applications, but not for all. Infiltration and surface runoff studies at the least, need hourly measurements.

Direct evapotranspiration

When rain falls, some of the water is intercepted by the leaves of trees and plants, by roofs, or is temporarily stored on or in the upper part of the soil, where it evaporates or transpires back into the atmosphere. It is not possible to measure this direct evapotranspiration. Results of research from small plots are available however and calculation formulas exist. These formulas require information on sunshine radiation, windspeeds, temperatures, rainfall intensities, soils, land use and vegetational cover. It is thus possible to calculate at least approximate values for direct evapotranspiration.

Direct surface runoff

This is the runoff which, during and after rainfall, flows directly over the surface into the sea. Like direct evapotranspiration, it is difficult to determine it for a whole island, as it is not possible to measure all the small streams on the island, and because of the dimensions of the island, the small streams do not aggregate into larger rivers. Again, research results on small plots are available, approximate formulas exist and realistic extreme values can be determined.

Recharge into the aquifer

This should be considered as a derived parameter. One possibility for determining the recharge is to subtract from the precipitation, losses through direct evaporation and direct surface runoff. Because of the uncertainties of the last two parameters, this is not a very safe method. The other possibility is to measure the increase in the level of the water table, or increase in pressure in the aquifer, after periods of rainfall. This last method requires a good knowledge of the aquifer which is, in any case, always necessary. One needs to know the extent of the aquifer and its composition; that is the permeability and the effective porosite of the material of which the aquifer is made.

Water use

Water use is a hydrology-related parameter. If one does not know how much, where and when water is drawn from an aquifer, it is not possible to understand the behaviour of the aquifer. The official public abstraction is generally wellknown. It is more difficult to determine diffuse private uses from wells, boreholes and springs. The water quantities drawn from wells and boreholds equipped with pumps can be inferred from the characteristics of the pump and the amount of electricity or oil consumed.

Evapotranspiration from the aquifer

Evaporation and the water taken from the aquifer by plants and trees with deep roots, either directly or indirectly, can not be measured directly. A particular difficulty is the large variability in soil characteristics. Thus, even when the evaporation and transpiration of a particular crop on a particular soil is measured with a lysimeter (a container with soil), plants and a controlled environment), it is not possible to extrapolate the values obtained over the whole or even part of the island in a straightforward manner. One is thus compelled to use empiric formulas, based on climatic, soil, land use and aquifer data. In addition, one can obtain information on the evapotranspiration by measuring changes in the chemical and isotope composition of the water of the aquifer.

Groundwater discharge into the sea

To determine aquifer discharge into the sea, one needs to know the form of the aquifer and its composition. The composition is inferred from geological information, including seismic and geophysical surveys from samples taken from boreholes, and from pumping tests. The form of the aquifer, that is the upper and lower boundaries, are determined by measurements in existing or specially drilled boreholes and extrapolated over the whole area by geological and geophysical surveys.

For the upper boundary this is quite straightforward. It is measured in metres down from the ground surface. In the case of an unconfined aquifer (an aquifer which is not imprisoned between impervious layers), the height of the water table is measured. In the case of a confined aquifer, one needs to know the elevation of the roof of the aquifer and the pressure of the water against the roof at a given place. Several complications might occur, for example, if there are a number of more or less communicating reservoirs and/or unknown abstractions of groundwater nearby.

In a case where the impermeable bottom formation is very deep, as is the case in many of the small islands of the Mediterranean, the fresh water aquifer will float on the seawater. The boundary between fresh and salt water will not, in most cases, be very abrupt. There will be a zone of gradual transition. The determination of the depth of the boundary layer is done by taking measurements mostly in specially drilled boreholes and through geophysical electric resistivity surveys.

When both the form and the composition of the fresh water body are known, the discharge of fresh water into the sea can be calculated. This calculation may be difficult in largely fissured or karstified terrain. Extra information may, in this case, be obtained through areal remote-sensing around the island to locate fresh water outflows. When the fissures are larger, the flow can be measured in the same way as for rivers or pipes.

4. INTEGRATION OF THE HYDROLOGICAL STUDIES IN THE WATER BALANCE

In the previous paragraphs, we have elaborated on the difficulty of determining directly the different water balance components. We have also seen that the values obtained from each separate hydrological study are only approximative. The real figures may be 10 to 60 per cent higher or lower. Such uncertainties are, of course, not acceptable in situations where water is a scarce resource.

The hydrological and other-related information that can be measured or otherwise obtained is considerable. Scientific knowledge and experience obtained elsewhere is also available. We are thus faced with a situation where we need to know a number of things, and where we have a great deal of information and general knowledge. It is therefore necessary to bring the knowledge and data together in a coherent framework in approximately the same way as one would solve a number of unknowns from a set of equations. In such a way, the uncertainties can be diminished and we can come closer to the true values.

This is done by making a representation of the whole hydrological system. It can be done in our mind, described on paper or as a set of mathematical calculations and comparisons. Such a representation can be called a model. The more information, formulas and comparisons one has and the more complicated the situation is, the more it becomes necessary to use a mathematical model on a computer.

After such a model is set up, it is tested by putting in the measured and estimated values of the parameters and variables for a certain time period. After this, the model system is checked to ascertain that it behaves like the real system. If the response is not good, the model has to be changed. This process is continued until the model behaves correctly under different real situations. The greater the differences in circumstances tested, in particular, wet and dry years, the better the model will represent the real behaviour of the exploited aquifers, and the greater will be our confidence in its capacity to predict the possibilities and consequences of engineering constructions and management decisions. The model will then prove to be a real planning and management tool.

The above description of models might give the impression that a mathematical model is only useful if there are a great deal of data and it is during the last stages of a study. This impression is wrong. The construction and use of a model is useful even at the start of a study. Several hypotheses can be tested, the sensitivity of possible studies and measurements can be evaluated and the whole study can then be planned in a coherent and economic way.

5. THE RELATION BETWEEN HYDROLOGY AND WATER RESOURCES ASSESSMENT AND MANAGEMENT

The relationship between hydrology and water resources assessment is very close as can be seen from the following definitions:

The definition of hydrology, as used within the IHP is:

> Hydrology is the science that deals with the waters of the earth, their occurrence, circulation and distribution, their chemical and physical properties, and their reaction with their environment, including their relation to living beings.

The definition of water resources assessment as used by UNESCO and WMO and as accepted within the framework of the UN Water Conference is:

> Water resources assessment is the determination of the sources, extent, dependability and quality of water resources on which is based an evaluation of the possibilities of their utilisation and control.

An evaluation or assessment of water resources is thus simply not possible without hydrological measurements, knowledge and studies.

The words "water management" have been interpreted in many different ways. It should have something to do with the rational use of water as a resource. At the level of a small island where water is a limiting factor, this should mean water as a total resource system and not only one or more sub-systems. Every additional use and every new water capturing engineering structure may upset the delicate balance of recharge into the aquifers and encroachment of seawater. Even the construction of a road, for example, may have an effect on water resources.

The problem of increasing pollution in the aquifers is serious. On many islands, the nitrate concentrations, caused by insufficient treatment of waste waters and increased use of fertilizers by farmers, are augmenting. Thus also, the agricultural policies and other economic and legal frameworks have an impact on water resources. All these possible impacts can only be determined through thorough hydrological and other water sciences studies.

ANALYSIS OF AQUIFERS OF A VOLCANIC ISLAND

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1. INTRODUCTION

Within the framework of the project "Water Resource Management in Small Mediterranean Islands and Isolated Coastal Zones" being carried out by the Regional Activity Centre for the Priority Actions Programme of the UNEP's Mediterranean Action Plan, a two week visit was made to the island of Nisyros in October 1985. The mission consisted of Dr Franjo Fritz, Geologist from the Institute of Geology of Croatia, myself, and Mrs A Vittoriou, Geologist from the Institute of Geology and Mineral Exploration of Greece.

The objective of this visit was to define an investigation programme with a view to determine the available quantity of groundwater for augmenting the water supply of the island.

This objective was set on the basic thesis that:

(a) maximum generation of local water resources should be sought;

(b) the minimal investigations for finding water locally had not yet been done.

The purpose of this paper is to present a summary of the mission's results and the approach that was adopted in defining the investigation programme, giving consideration to the short time normally available for such missions, the low funding normally available for such investigations for small islands such as Nisyros, and the pragmatic pressure usually exerted in obtaining results at the least possible costs.

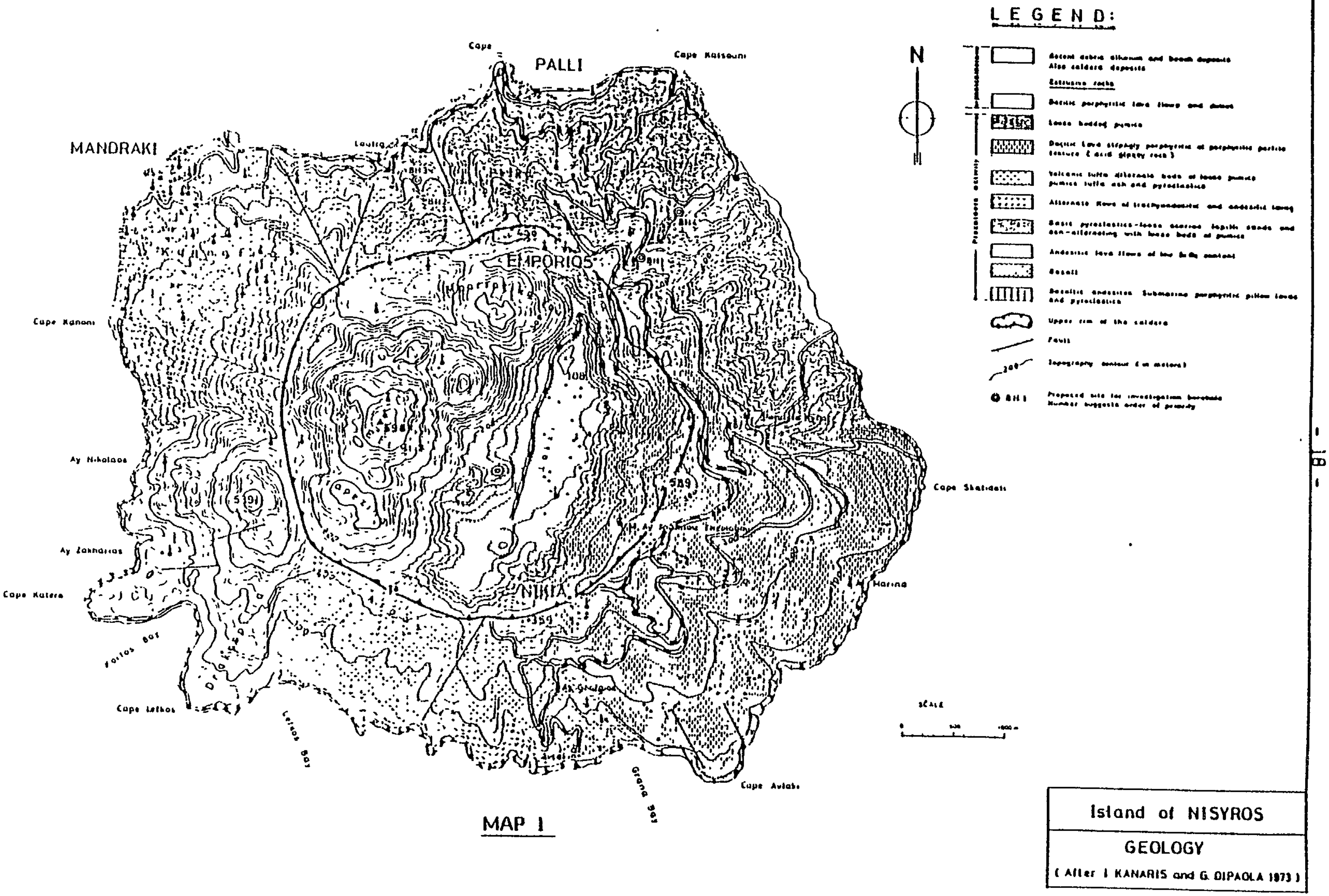
2. SUMMARY OF MISSION RESULTS

2.1 Location

Nisyros is an island of the Dodecanesse archipelago in the southeastern Aegean Sea of Greece at 30° 35' N latitude and 27° 11' E longitude, 10 miles south of the island of Kos and 8 miles northwest of the island of Tinos. It is only 10 miles from the coast of Turkey. Figure 1 shows the location of Nisyros.

2.2 Topography and geogorphology (See Map 1)

Nisyros, a young volcanic island, has the shape of a truncated cone rounded at its base, with a perimeter of 25 km. Its maximum diameter of 8 km is in the NW-SE direction while its total area is 42 km^2

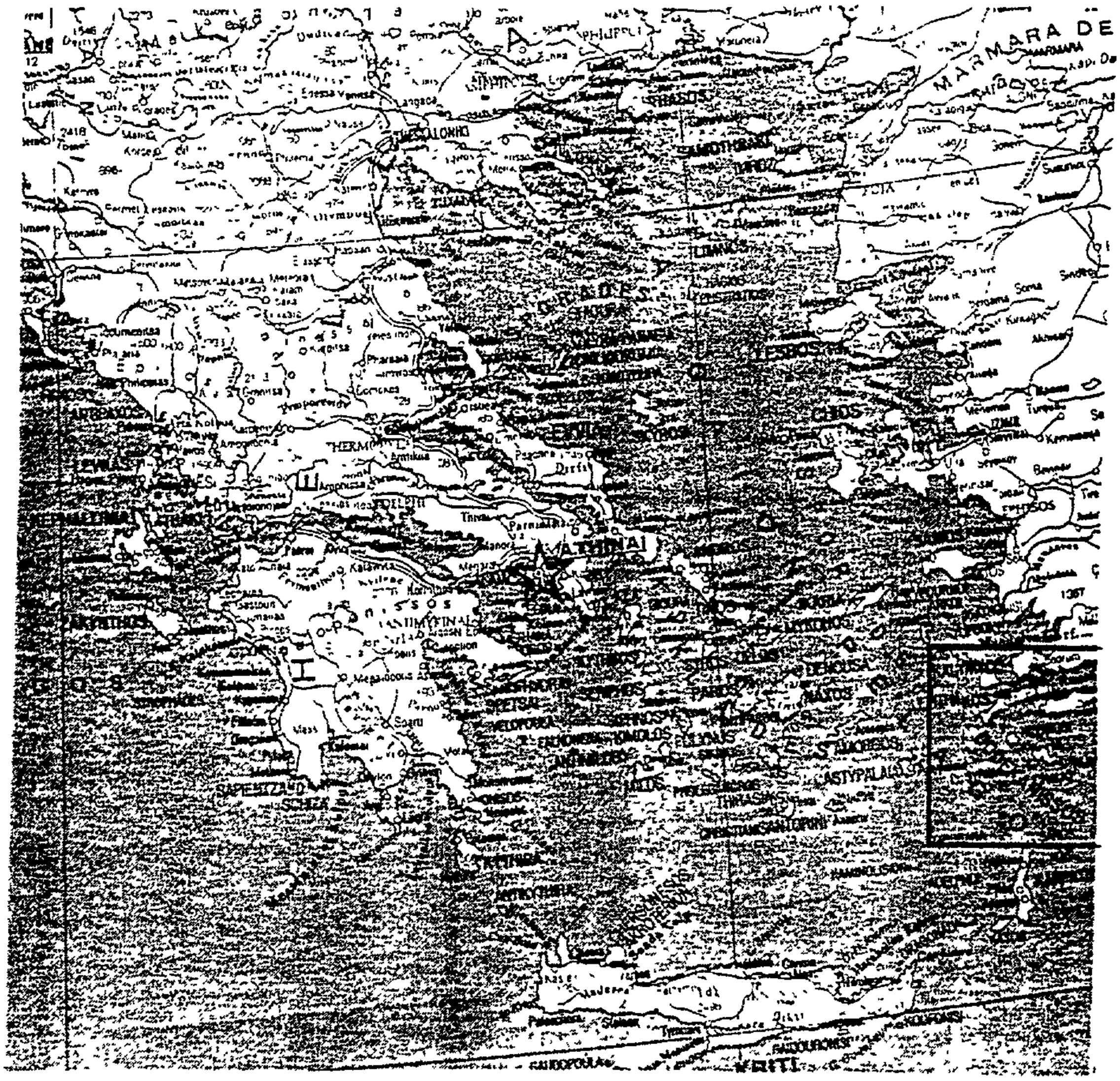


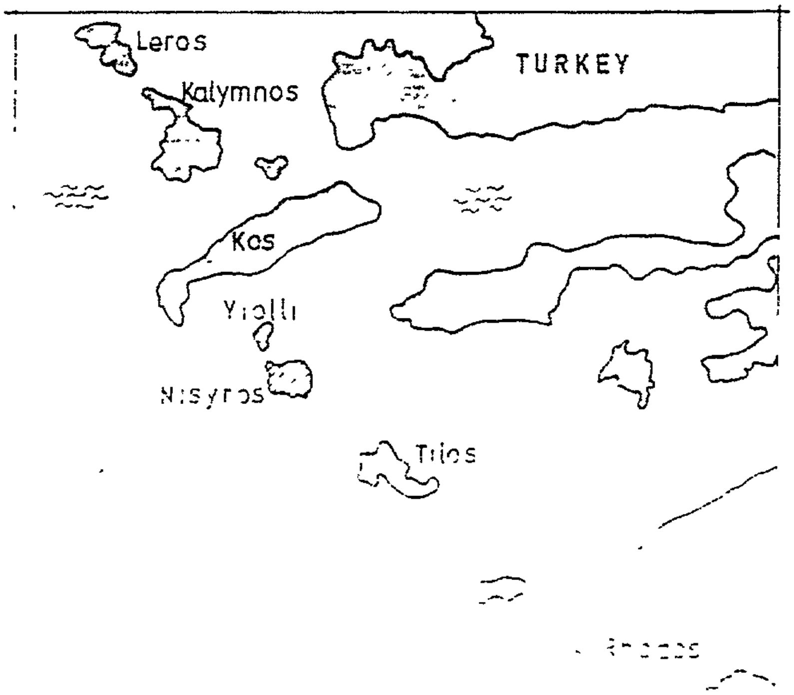
MAP I

Island of NISYROS

GEOLOGY

(After I KANARIS and G. DIPAOLA 1973)


MARMARA DE
THESSALONIKI
LESBOS
CHIOS
ATHINAI
KRITI


Leros
Kalymnos
TURKEY
Kos
Yialli
Nisyros
Tilos
Rhodos

It consists of abrupt, precipitous cliffs with slopes rising at an average topographic slope of 20 to 30 per cent to the highest peaks in the centre, Profitis Elias 698 m, Ayios Georghios 519 m and Ayios Ioannis 588 m.

In the centre, and inbetween these peaks, a large depression (a typical caldera) is formed 2.5 km long and 1 km wide. In the caldera (its lowest elevation is about 100 m), there exist five craters with active fumaroles.

The topography on the flanks reflects to some degree the surface rocks and their deep torrential valleys, some relatively mature, but most others quite young. Coastal plains with limited width are found in the southern and eastern parts.

The drainage pattern is radial - away from the rim of the caldera. Most of the valleys are V-shaped and, only near the coast, do these attain a relatively mature stage. The absence of alluvium in the torrential streams is attributed to the high relief, the limited size of the catchments and the small flows that are experienced only for a small duration, possibly due to the high infiltration rates of the catchment rocks.

Nisyros is quite green with low shrubs and bushes and rainfed fruit trees (fig trees, almond trees, olives, etc.). Extensive terracing on the steep slopes has conserved the soil and the island appears to be quite fertile. The total lack of water resources for irrigation has directed the local farmers to engage totally in rainfed agriculture.

2.3 The geology of the island

The island of Nisyros is made up of a conical volcano whose activity is generally believed to have started in the end of the Miocene and Pliocene periods with successive eruptions during more recent geological times. The existence of the volcano is a consequence of the subduction of the African Plate under the Aegean Plate (5).

Summit type of central vent eruptions are believed to have occurred in two periods, each resulting in lava flows and pyroclastics. These are the procaldera and the post-caldera eruptions (6).

The caldera is the major volcanic-tectonic characteristic of the island which appears to have been created by the collapse of the central vent after repeated explosions and the creation of a large underground magma chamber.

Following the geologic map prepared by G. Dipaola (1973) during his study of the geothermal potential of the island, the following can be distinguished:

Volcanic action started with submarine extrusion of lavas in the form of distorted globular masses, Pillow-Lavas, with a high content of Basalt. These can be observed at sea level, especially near Mandraki. This was followed by extrusion of Andesitic lava flows of low SiO_2 content which can also be seen at Mandraki in the north and at Lefkos Bay in the south, at a low elevation from sea level. In sequence, alternating extrusions of trachyandesitic and andesitic flows appear to have occurred as quite extensive lava flows are exposed in all directions away from the present day caldera; similarly Dacites, containing more silica than an average andesite, are exposed on the flank in the southeast - this formation being quite extensive. Normally, these are often so viscous that they scarcely flow at all.

In between the andesitic, the trachyandesitic and dacitic flows, there are beds of pyroclastic formations which cover quite extensively the northern half of the island. In the northeastern area, from the Monastery of Kyra Panayia following a line from Emporios village to the coast, the pyroclastics are basic, consisting of loose beds of pumice and agglomerates. In the area of Loutra-Mandraki and Cape Kanoni up to the rim of the caldera, and in the south between Lefkos Bay, Grana Bay and the rim of the caldera, the pyroclastics consist of volcanic tuffa, ash beds and anglomerates.

Finally, in the area between the villages of Emporio-Loutra and Palli, bedded loose pumice in considerable thickness has formed a mantle over the trachyandesitic and andesitic lava flows, filling in all the previous valleys and depressions.

In this area, this vesicular glassy rock of low density is relatively well sorted and in sufficient thickness to make it attractive for commercial quarrying and exploitation. Pyroclastics outcropping near the coast in this area and at points where the pumice has been quarried appear to be unsorted and are in a chaotic homogeneous mixture of large and small fragments characteristic of pyroclastic flows. This formulation is expected to be of low permeability. The pumice beds on top appear to be extremely permeable and tree roots extend vertical to lengths of more than 15 metres at sections where the purmice has been excavated.

With the extrusion of the Dacitic lava flows, followed by the large and relatively thick formation of the bedded loose pumice, the pro-caldera activity was completed.

The post-caldera activity consists mainly of the extrusion of very viscous, homogeneous Dacitic lava, highly crystallised, which heaved itself sluggishly to the surface, filling the greatest part of the caldera to form very high domes and also gradually flowing up to the sea in the southwestern part of the island. The highest mountains of the island, Profitis Elias (698 m), Mboriatico and Trapezina are the dacitic domes created by this activity.

The formation of the caldera along a ring-like fault of 4 km diameter and the subsequent extrusion of the dacitic lava have resulted in "dry valleys", the most notable, of course, being in the Lakki area in the centre but also in other valleys of smaller size. An interesting one is in the north bounded by the Pr. Elias and Mboriatico Vouno domes and the rim of the caldera in the north. This valley of considerable catchment is infilled by debris and brecia resulting from the fault action. No outlet for surface water exists and no signs of water ponding can be observed. The surface water infiltrates into the subsurface as quickly as it arrives at its deepest part. Other minor dry valleys can also be observed in between the dacitic domes and the northwestern part of the rim of the caldera.

The present post-volcanic activity is indicated by its "fumarolic" condition, quietly blowing steam in the main well-like craters in the caldera with highly altered rocks around them which are soft, crumbly and of buff-yellowish colour. The existence of hot points as at Emporios Village and the hot springs at Loutra, Palli and Avlaki are also quite indicative.

2.4 The hydrogeology

In volcanic islands, geological heterogeneity is the rule rather than the exception. Such variation complicates the establishment of fresh water bodies. In geologically young volcanoes, the young surface rocks allow rainwater to penetrate deeper. Conversely, prolonged exposure to weathering reduces the permeability due to the formation of clay which infills the fissures and fractures impeding the rainwater absorption and increasing the surface runoff. Thus, it is generally accepted (7) that the younger the volcano, the better are the prospects for water.

On the other hand, the very limited area and relatively low elevation of very small islands, precludes the establishment of fresh groundwater bodies, and together with high permeability, the formation of fresh water lenses of significant extent or thickness.

A model volcano would have periodic eruptions of lavas and/or pyroclastics with differences in composition. The extrusions would represent a heterogeneous accumulation of lava flows superimposed on each other, varying in thickness and number, often separated by a layer of ejecta; pyroclastics settling out of the atmosphere following a period of explosive violence of the volcano; or flows of pyroclastics which had accumulated at the rim, either because of their own weight or especially by the action of water. These extrusions are apt to be intersected by dykes of lava.

An idealized volcanic dome (from Cox, 1954) is shown in Fig.2 (8).

The high infiltration capacity of the young volcanic rocks is due to the extensive fracturing and openings in fissures. In decreasing order of importance, the permeability is high in scoriae, breccia zones between lava flows, shrinkage cracks caused by surface cooling from beneath individual flows which cut through the flows in prismatic columns, gas vesicles, fractures as a result of mechanical forces acting on the cooled lava, etc. (9).

Horizontal permeability is much greater than vertical because shrinkage cracks, scoriaceous, breciated and cavernous zones are concentrated between flows. The internal parts of the flows are generally far less permeable. Dykes frequently form barriers to horizontal flow and consequently groundwater may accumulate between them or against the downstream wall. Also, fractures on the country rock caused by the dyke may be worthwhile for drilling since they may store water.

It is very difficult to evaluate the existing rock formations on Nisyros in terms of their relative permeability because of lack of detailed information on their fracturing and fissures, massiveness and other characteristic features. Nonetheless, on the basis of the reconnaissance field trip and literature, the various rocks in terms of decreasing permeability would qualitatively be as follows:

(a) The bedded loose well-sorted pumice which appears to be quite extensive and thick in the area of Emporios-Loutra-Palli. This is expected to be very pervious, similar to well-sorted clean gravels.

(b) Pyroclastics, when they are well sorted and loose and deposited from the air rather than from mudflows (scoriae, lapilla, bombs); possibly in the area near the rim of the caldera.

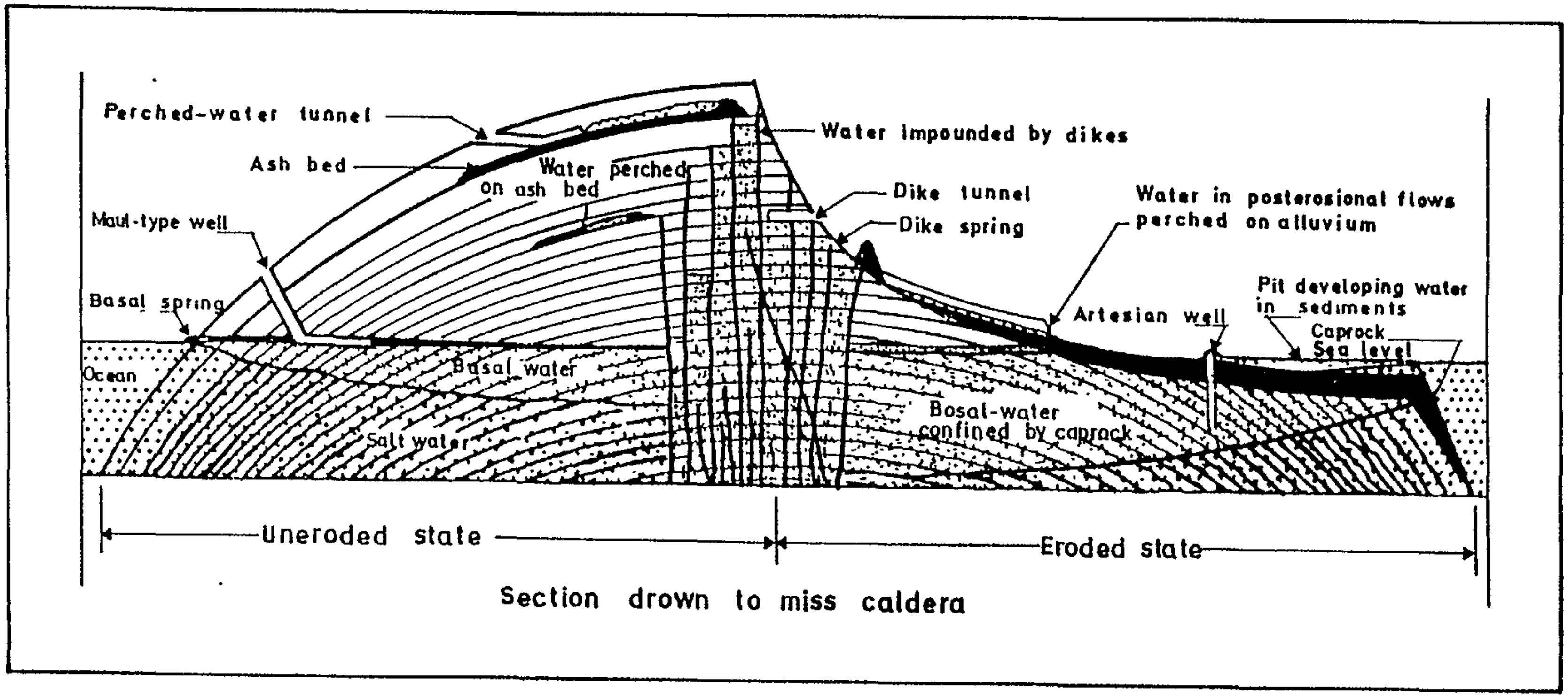


Fig.2 Occurrence and development of groundwater in an idealized Hawaiian volcanic dome (from Cox, 1954)

(c) Andesitic lava flows, especially in deficient in silica, tend to be quite pervious.

(d) Debris and breccia resulting from faulting as in the "dry valleys" between the outer rim of the caldera and the dacitic domes.

(e) Trachytes-trachyandesites which tend to have less and narrower fissures and the brecciated parts are compact.

(f) Dacites containing more silica than an "average" andesite. These are very viscous, homogeneous and crystallised tending to have fewer and narrower fissures.

(g) Rhyolites which are highly viscous and with high content of silica.

(h) Unsorted compacted pyroclastics resulting from mudflows as observed underlying the pumice beds in the area of Loutra-Palli.

At any one location, a sequence of these rocks may be met, thus the overall permeability would depend on the volcanics met, bearing in mind that the same lava flow will be more fractured at its outer parts and less in the central parts. In between lava flows the interconnection would be rather low but the permeability is expected to be high along the same lava flow.

Values of 50 to 250 m^2/day for transmissivities in pyroclastics and a coefficient of storage of 0.03 have been reported while for volcanic tuffs and lava flows, values between 1000 to 6000 m^2/day with a storage coefficient of 0.2 to 0.3 are not uncommon (10).

The area of the caldera is not expected, from the hydrogeologic point of view, to offer good potential for groundwater prospecting due to the attenuation of the volcanic rocks rendering them more argillaceous. Quality considerations and the possible greater abundance of dykes and consolidation after the collapse of the caldera is also a constraint.

2.5 Water balance considerations

(a) Rainfall

There is no rainfall record for the island of Nisyros but on the basis of an available record for a number of other islands in the region over a period of 17 to 31 years, it appears that the annual average rainfall on the island should be around 700 to 730 mm.

(b) Runoff

Although the topography of the island is very steep and both the average rainfall and intensity of rainy events appear high, the indication of runoff is very small. The valleys and gorges do not suggest sizeable volumes of runoff and reports from the local people confirm this.

Although there are no measurements whatsoever, it appears that runoff occurs only in the event of very intensive rainfall and that flows are maintained probably only for the duration of that event or slightly longer. The high infiltration capacity of the catchment rocks due to their extensive fissuring and fracturing, the very pervious beds of pumice where this occurs, and the abundant vegetation and terracing, control runoff, which is not expected to be more than 5 to 10 per cent of the average rainfall.

(c) Evapotranspiration

Evapotranspiration is expected to be high due to the island's exposure to winds, its high vegetation and its latitude.

No measurements are available but the expected annual potential evapotranspiration could easily be estimated at 1.5 to 1.7 m. The apparent high infiltration of the island's volcanic rocks reduces this considerably and not more than 55 to 65 per cent of the total water crop is expected to be lost.

(d) Estimated water balance

In trying to form a crude idea of the hydrogeologic conditions of groundwater reserves on the island of Nisyros, an overall water balance is estimated. An additional difficulty, of course, is to define the water reserves per area since the surface catchments may not coincide with the groundwater contributory catchments. Although it might be safe to differentiate the caldera area from the groundwater areas distributed radially outside the rim of the caldera, this may not be applicable in the area of the high dacitic domes and the intervening "dry valleys" which may contribute groundwater flow towards the outer parts rather than towards the caldera.

The total water crop of the island of 42 km^2 with an average annual rainfall of 700 mm is about 29 million m^3 (MCM). some 65 per cent of this is expected to return to the atmosphere as evapotranspiration, reducing it to some 10 MCM. Of this, some 10 per cent can be assumed to outflow to the sea as runoff through the drainage system and overland sheet flow, reducing the total water crop even further to 9 MCM.

After subtracting the water crop falling within the general caldera area (12 km^2), the water crop left for the area outside the caldera (30 km^2) is about 6.5 MCM or 0.220 MCM per km^2 of area. These estimates assume a 30 per cent recharge from the annual average rainfall of Nisyros which is not uncommon for young volcanic islands confirmed by estimates from other similar islands (11).

(c) Hypothesis on groundwater occurrence

The question that arises is what happens to this annual water crop that recharges the groundwater. The island clearly suffers from lack of fresh water with no apparent springs except for a well-type spring fed by a perched water-table at the Monastery of Kyra Panayia, and coastal thermal springs at Loutra, Palli and Avlaki which have reported widespread seepage along the coastal area in their vicinity. Not even temporary springs operating after the wet season have been identified by the local people. The permeability of the surface rocks is very high and there is an absence of any sizeable surface runoff.

The fresh groundwater is expected to occur as a lens shaped body, commonly called Ghyben-Hersberg lens, which floats on and displaces seawater by virtue of the difference in densities of fresh and seawater. This lens under homogeneous, isotropic conditions has a lenticular shape with its upper and lower boundaries forming parabolas, which results from the flow of fresh groundwater through the aquifer towards the coast in response to the hydraulic gradient. A transition zone of mixed fresh and salt water is expected to exist, produced by tidal fluctuation (if any), wave activity and seasonal variation of recharge. Its thickness depends on the disturbance and the flow velocity (and thus, permeability) in the fresh portion of the lens. If it is high, then the transition zone is thin.

The extent of the fresh water lens will depend on the head above mean sea level which in turn depends on the horizontal permeability and outflow to the sea. Certainly most of the annual recharge is expected to be lost to the sea and to the transition zone.

The only sure method of checking the validity of these indirect methods in estimating the groundwater storage, position, shape of lens and transition zone, is with boreholes. Although boreholes, in combination with geophysical surveys, could help in qualitatively evaluating the approximate position of the seawater.

The highly dynamic groundwater conditions anticipated on Nisyros (high infiltration capacity, and absence of springs, although there is great variation of rock units in depth and high relief) and the direct and fast penetration of recharge to sea level altitudes within the island are expected to influence the relationship between the fresh water body and the underlying saline water. This dynamism accentuates their mixing and thus reduces the amount of fresh groundwater available as a resource. A very careful skimming procedure of the available fresh water lens will have to be devised so that a part of the fresh water lens can be made available.

(f) The quality of groundwater

The quality of groundwater that may exist as a fresh water lens creates some concern. Obviously, its contamination by sea water is of primary importance and will depend on its distance from the coastal area, since the further away the lens is the greater thickness it is expected to be; the proximity to the transition zone which depends mainly on the head of fresh water above mean sea level, and finally; the mode of pumping which may easily create upconing.

Of equal importance is the contamination that may be effected on fresh groundwater by host rock, the existing tectonics and the activity of deeper rocks and their geothermal energy (12). This is indicated by hot springs which because of temperature, not considering sea water contamination, may result in water, high in undesirable elements.

Under usual conditions in temperature zones, dissolving of silicates and other elements from fissured non-carbonate rocks is slow and a low ion content is expected, as for example, in the high altitude spring of Kyra Panayia (1300 umhos/cm). But, with residual volcanic activity, waters with particular chemical composition may arise. Certainly, surface water coming in contact with lower parts of the caldera acquires an undesirable quality and therefore, this might be one good reason for avoiding prospects for fresh groundwater in this area.

2.6 The demand and existing water supply sources

(a) The demand

The permanent population of the island, distributed in four major villages, is about 800. With tourism, it rises to about 3000 in the summer. The volume of water required throughout the year, assuming a daily consumption rate of 100 litres per person, is about 51 000 cu m.

This demand which appears to be near its minimum requirement can be further analysed using a continuous average rate of 1.6 litres per second or 5.8 cu m per hour. Seasonally, this can be analysed into 3.2 cu m per hour in winter and about 12 cu m per hour in the summer.

(b) Existing sources of supply

There is no source of domestic water on the island except that from rain-harvesting in the winter. Each house is equipped with subterranean cisterns for storing water harvested from rain, falling on the roofs. The capacity of these cisterns varies from 4 cu m (old houses) to 50 cu m (restaurant).

In addition, there are communal cisterns of larger capacity each constructed in step-like fashion, the foof at each step being the catchment for the rain.

At Mandraki and Palli, two cisterns are used for storing water imported from nearby islands by boat.

During the summer of 1984, 17 boat-loads of 650 cu m each were imported to Mandraki, total of 11 000 cu m; and 6 boat-loads, 700 cu m each or a total of 4 200 cu m were imported to Palli. This brings the overall total of imported water to about 15 000 cu m.

In addition to the individual cisterns on each house, the total communal cistern capacity on the island isabout 16 000 cu m.

In Mandraki and Palli, where irrigation practice is limited, there are a number of shallow wells in recent alluvium holding generally, brackish water (3 000 µmhos/cm). Some of these wells are used for watering animals, for consruction purposes and other municipal needs.

Cisterns resembling shallow wells are also found in many parts of the island, each with a small catchment area (25 sq m) especially prepared to direct rainfall into the cistern.

2.7 Objectives and criteria adopted in resolving the problem

(i) Some conclusions from the reconnaissance study

Some basic theses adopted as a result of the field study and the available references are:

(a) A number of eruptions resulted in a number of lava flows with intervening pyroclastics which were deposited on the flanks of the vulcano in some sequence;

(b) The lavas and pumice beds, debris and breccias appear to be quite permeable;

(c) The horizontal permiability (along individual rock units-lava flows) is expected to be much higher than vertical permiability (in various lava flows);

(d) The rainfall on Nisyros is of the order of 700 mm/annum with rainfalls moderately intensive;

(e) Runoff appears to be very small while the infiltration of rainfall is expected to be very high (30 to 40 per cent). Evaotranspiration is also expected to be high.

(f) Infiltrated water does not appear as spring flow (even as temporary springs after rainfalls) on the slopes of the island which indicates deep penetration of the recharge;

(g) In view of the above, a fresh water lens is expected to exist at about sea level and hopefully, sufficiently higher;

(h) The salt/fresh water interface and transition zone of brackish water is expected to be present under the island and generally throughout, and therefore extraction of water without disturbing this salt/fresh water condition will be difficult;

(i) The well-sortedpumice is very permeable but it is useful only when extending below sea level, underlaid by impervious pyroclastics and protected from sea intrusion. The limited extent of this formation is a constraint.

(j) The underground catchments could be larger than the surface catchments as suggested by the topography. An example is the "dry valley" which may recharge the flank towards the coast rather than the caldera area;

(k) The Dacites or post-caldera rocks are less permeable than pre-caldera rocks which have been affected by tectonics, the caldera formation and post-caldera activity;

(l) Both the quality and quantity of groudwater is expected to be better and more abundant on the flanks of the vulcano rather than in the caldera. This is due to the finer, altered rocks in the caldera coupled with the "fumarles" and higher temperature compared to the through flow and more fissured rocks on the flanks;

(m) Faults may provide selected flow paths and are worth investigating for their water potential.

(ii) Required investigations and data for developing the groundwater resource

From the above remarks, the hydrogeologic consideration presented earlier, and for realistic and practical aspects, the following were recommended:

(a) Detailed hydrogeologic mapping at the scale 1:5000needs to be carried out in selected areas where investigation boreholes have been proposed.

- The area between Emporio-Palli and the coast 1.5 km from Cape Katsouni.

- The area between Lutra, the Caldera rim and the cape west of Palli, including, if possible, the "dry valley" between the rim and the Dacitic zone.

- The area from the rim of the Caldera and the Monastery of Kyra Panayia - the spring and up to the coast along the contract of the Pyroclastics and the Dacitic lava.

(b) For the purpose of investigating the geologic sequence of rock formations, the hydrogeologic conditions of these rock units (permeability, lithology) the water-table elevation and the quality of groundwater, it was recommended that investigative and prospecting drilling be undertaken at the recommended locations, also shown on the attacheched geologic map.

(c) These boreholes are of investigative nature and full record should be kept of the drilling progress. The exact groung elevation should be determined. Full lithogic records should be kept with rock samples every 3 metres and every time there is a change in lithology. Rate of penetration, loss of circulation and any water-table horizon met should be noted and sampled for chemical analysis.

Geophysical logging of the borehole could be carried out if the variation of rocks and hydrogeologic conditions is considerable. Finally, pumping-tests could be carried out if a water-table is mer after the wells are developed by bailer. These investigative boreholes could allow and be used as index and reference points for a geophysical survey along a cross-section line from the coast to define the lateral extent of the various rock units and the sea-water profile. If these boreholes (besides their investigative role) prove that they can provide water at a satisfactory rate, they can then be turned into production boreholes without any major additional cost.

The detailed hydrogeologic map, together with the results from the investigation borehols drilling programme and any geophysical survey undertaken, will provide sufficient data for concluding an assessment of the groundwater potential with good degree of certitude. The possibility of having the problem of water supply already resolved has been considered in locating the proposed drilling programme in the order presented.

The spring at Kyra Panayia should be tested to determine its yield. The possibility for developing this spring should be considered after careful study of the conditions of occurence of this spring.

3. THE REGIONAL IMPORTANCE OF THE EXERCISE

Small island hydrogeology contains in an accentuated form all the elements that are encountered in the hydrogeology of large continental areas and especially coastal ones. The problems encountered are generally created by the scale factor, like the limited catchments and the normally low elevations precluding the establishment of sizeable fresh groundwater bodies. Also the extent of coastal area relative to the total size of the island creates particular problems of groundwater quality. Other problems are:

- The seasonality of rainfall;
- The lack of suitable storage facilities and catchment sizes;

- The geologic variation within a small island which is likely to be of a bigger significance than in a large area;
- The seasonality of demand due to tourism;
- The change in the pattern of demand and the means for water supply, rendering the traditional methods of water collection and rain harvesting rather unacceptable, etc.;
- The highly dynamic groundwater conditions influencing the relationship between the fresh water body and the underlying saline waters, accentuating mixing and reducing the quantity of fresh water available.

Additional problems are created by the reduced availability of data, the distance from mainland centres of water development and management, and the lack of locally trained staff.

For the above reasons, concentrated efforts by missions like the one for Nisyros, besides promoting interchange of information among the Mediterranean countries and encouraging technical co-operation among them, allows the establishment of renewed interest and effort in solving practical and long existing water supply problems.

In the case of the volcanic island of Nisyros, no serious effort had been made in evaluating its hydrogeologic potentials and not a single borehole had been drilled for investigating the lithology, the water potential, or the existence of a fresh water lens.

As a result of the mission's work, an investigation programme is in progress which hopefully will provide suffifient information for an assessment of the island's water potential. The general lack of data has caused the programme to be established on the basis of field reconnaissance and on cretain hypotheses regarding the water balance and relative sequence of geologic formations and their respective permeability and water yielding potential.

The results of these investigations will constitute a basis for similar work elsewhere where similar conditions exist. The operation and management of the groundwater, if available, will also provide feedback for similar practices elsewhere especially in regard to the fresh/sea water relationship. From studies like this one, complete with investigations programme and consequent assessment of water resources and evaluation of operation, suggestions for the solution of sililar problems could be formulated for use by other countries in the region.

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APPENDIX I

FRESH/SALT WATER RELATIONS

A typical section through a small island (schematic and distorted for clarity) is shown in Figure B1. The freshwater lens is a dynamic system maintained by recharge with a net flow from the water table towards the coast. The contact point between fresh and sea water, the interface, is not sharp; rather, a transition zone of salinity exists.

The width of this transition zone depends on factors like:

(i) the geology affecting the branching nature of flow paths in the rock which gives rise to the mixing of waters with different salinities. This dispersion process depends on the granular nature or rocks and the layering of fissues.

(ii) the continuous change of flow rates, springflow, tides, changes in recharge.

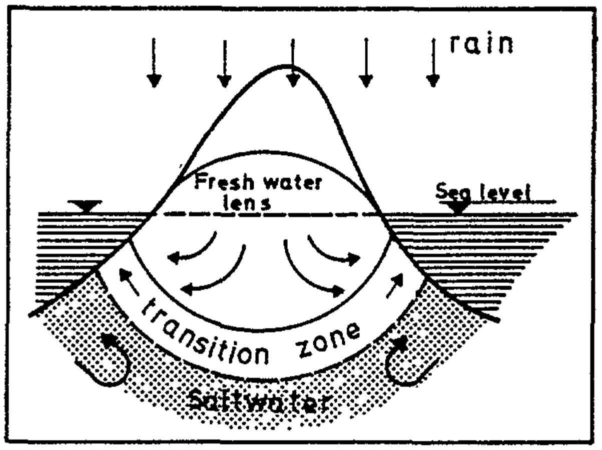

Fig. B1 Freshwater lens

In the Ghyben-Herzberg approximation, assuming a sharp interface between fresh water (density P_f = 1000 kg/m^3) and salt water, (P_s = 1025 kg/m^3) then in the case of hydrostatic equibilibrium, (as shown in Fig.B2) the pressure P at point A and B must be equal.

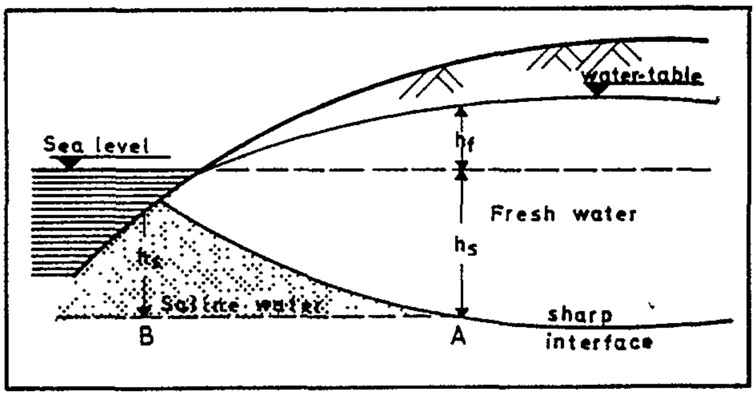

Fig.B2 Hydrostatic equilibrium

$P_A = P_f g\ (h_s + h_f) = P_B = P_s ghs$
(where g is the acceleration due to gravity)

This equation can be rearranged to give:

$h_s = \delta h_f$ and $\delta = P_f \; (P_s - P_f) \approx 40$, and for the Mediterranean, which is saltier, it is about 35 to 38.

Thus, the interface according to the Ghyben-Herzberg approximation below sea level should be about 38 times the height of the water table above mean sea level. This could be applied in the case of a thick transition zone if the 10000 ppm chloride level of quality (50 per cent sea water isochlor can be identified).

SOME STANDARD SITUATIONS

Saltwater wedge

In Fig.B3, it is assumed that a confining layer at some depth below sea level does not allow the full lens to develop. The interface intrudes inland a distance L intersecting the top of the impervious layer forming a wedge.

Assuming an unconfined, homogeneous aquifer and using the G-H approximation and Darcy's law, an estimate of the length of the wedge is given by:

$$L = \frac{K.B^2}{80Q}$$

where:
"K" is the permeability
"Q" is the discharge rate of freshwater to unit length of the coast

It is obvious that if Q decreases (lack of rainfall or increase extraction) the sea intrusion moves further inland. Also the higher the permeability of the aquifer the greater the extent of intrusion.

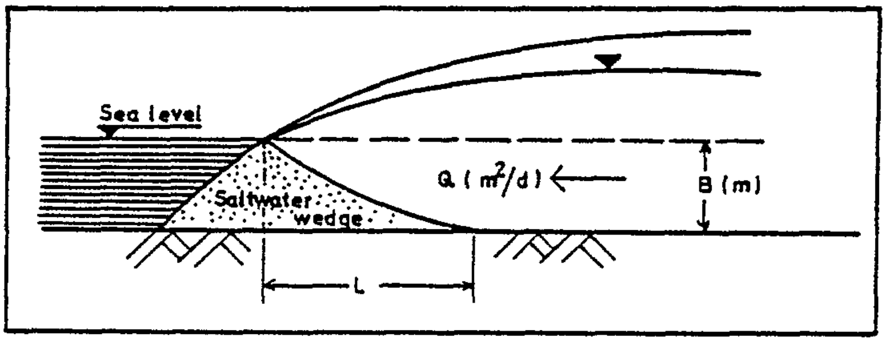

Fig.B3

Upconing beneath a skimming well

With a skimming well that abstracts freshwater from above a saline interface, the harder it is pumped the higher the salinity of the abstracted water.

In Fig.B4 a sketch for upconing below a skimming well in (a) confined and (b) unconfined aquifer is shown.

In case (a) the Q_c, critical pumping rate, which if exceeded, rises the interface to the bottom of the well, is approximated by:

$Q_c = \pi D^2K/40$ and the rise of the interface at this rate is $z = D/2$.

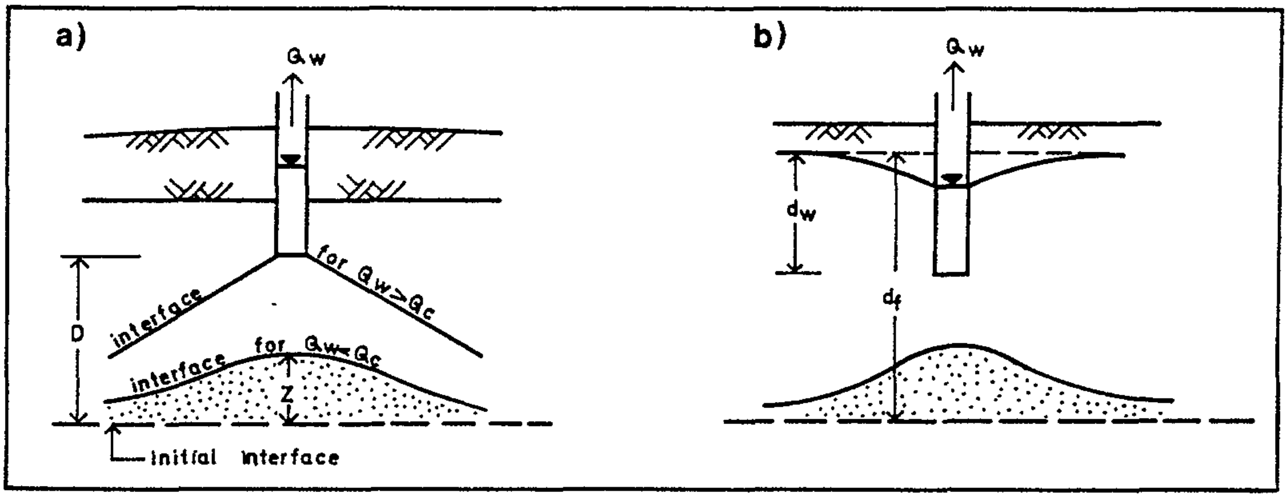

Fig.B4

These results rarely apply with great accuracy because of the heterogeneity of the aquifer, the flow to the coast and the existence of the transition zone. However, they suggest that the skimming well should be made as shallow as possible (due to the D^2 factor in Q_c) and that the salinity will rise quickly if a certain pumping rate Q_c is exceeded. This rate can be estimated using the Q_c formula given above.

In the case of unconfined aquifer for very small drawn-downs, the behaviour will be similar to the case of a confined aquifer with an impermeable surface coincident with the water table. However, because of the dewatering of the well with increasing draw-down, such a well has a limited production capacity. Thus:

the well depth dw should be chosen so that upconing into the well is impossible (above mean sea level) or $dw < df/3$ for a homegeneous isotropic aquifer (Chandler and McWorter (1975)).

General lens base density relationship

In practice, attempts to determine the approximate size and shape of lenses, density relationships of the Ghyben-Herzberg approximation as given above are difficult. In practice, the delineation of potable lens resources is found at 1 to 20 relationship (Vacher 1974, Lloyd 1980) while the classical 1 to 40 relationship occurs within the brackish water transition zone.

The 1 to 20 relationship holds reasonably well for the thicker lenses (say 20 m but may not be applicable in thin lenses.

Electrical conductivity logging and other geophysical surveys can provide useful information on this subject.

The dynamics of upconing depend more on the specific yield rather than the G-H approximation relationship.

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APPENDIX II

SINGLE WELL PUMPING TESTS

Although not entirely suitable for long term predictions, single well pumping tests can be used as a rough guide to future performance of boreholes (14).

Selection of drill sites

- proximity of village
- geology
- height above sea level
- distance from shore

Target depth is the sea level or slightly below.

Test procedure

- Standing water level is measured before the test
- Pump should be capable of delivering up to 5 to 10 m^3/hr
- Test usually is run for 24 hrs with usually a longer period for recovery

Constant discharge test

This test involves pumping the borehole at a constant discharge rate measuring the varying drawndown throughout the test.

Drawdown measurements are taken during the test at the following time intervals after pumping has commenced:

1,2,3,4,5,6,7,8,9,10,15,20,30,45,60,75,90,100,120 minutes then each 30 minutes to six hours and then every 60 minutes until the end of the test.

Pumping rate measurements are taken at the start of the test, after 15 minutes, 30 minutes and every half hour thereafter. The discharge rate must be maintained constant. Orifice meter, orifice bucket or water meter can be used.

Recovery measurements are taken at the end of the test as follows:

1,2,3,4,5,6,7,8,9,10,15,20,25,30,45,60,75,90,100,120, then hourly until the water level has recovered to within 15 cm of the standing water level.

It is more important to know the time when the drawdown or recovery was measured than to have the drawdown measured at the exact times indicated above.

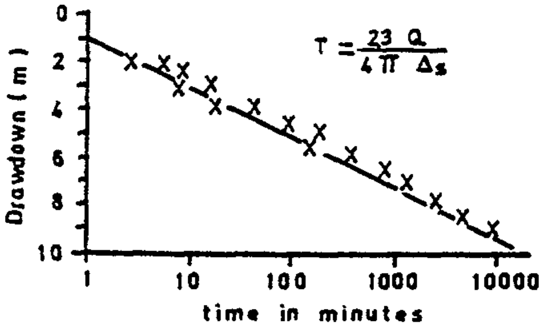
Constant drawdown test

In this type of variable discharge test, the drawdown is held at a constant depth and the variations in discharge are measured. This test is suitable when drawdown cannot be measured.

The drawdown is held constant by making sure that the pump breaks suction soon after the test begins and the water level is maintained at the pump section throughout the test.

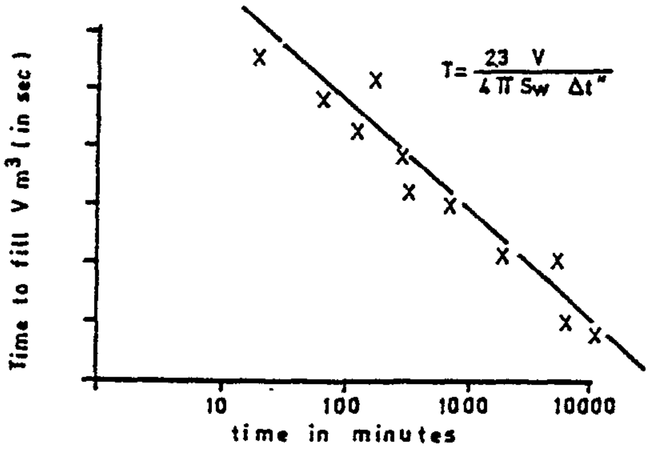
A container of known volume or orifice bucket could be used for measuring the discharge rate.

Discharge measurements should be taken at the time intervals shown for drawdown during the constant discharge test if an orifice bucket is used or at 5,15,30,45,60 and every half hour if a container of known volume is used.



T - transmissivity m²/d
Δs - slope of the drawdown over one log cycle
Q - discharge (m³/d)

Fig. E1 Typical analysis of test



V - volume of water collected in container (m³)
Sw - drawdown, amount of lowering the water level in pumping hole (m)
Δt" - slope of the time required to fill the same container over one log cycle (days)

Fig. E2 Constant discharge test

EVALUATION OF THE WATER RESERVES AND OPERATION OF THE KARSTIC AQUIFER

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1. INTRODUCTION

1.1 Preface

Within the framework of the Priority Actions Programme (PAP) of the Mediterranean Action Plan (MAP), a project dealing with the evaluation of the water reserves and operation of the Maroni gypsum karstic aquifer in Cyprus was carried out by a mission formed for this purpose.

The consultants spent two weeks in Cyprus, together with local experts from the Division of Hydrology, Department of Water Development, Ministry of Agriculture and Natural Resources, working to solve the existing hydrogeological problems.

After completion of the work, the present report was produced with a global dimension to if so that it could serve as well, other Mediterranean areas with similar conditions.

1.2 Background of the project

The Maroni Gypsum Aquifer is located in the Vassilikos-Maroni area within the Vasilikos-Pendaskinos Irrigation Project, on the southeast coast of Cyprus.

The Karstic aquifer is not hydrologically nor hydrogeologically fully defined. Furthermore, data are required to define the morphology of the aquifer.

The water balance and the sources of recharge have already been determined but new developments are expected. The Cyprus water Authorities proposed to PAP/RAC and WHO/EURO the recruitment of consultants to work in Cyprus in order to evaluate the water reserves and to determine the means for diverting the operation of the aquifer.

2. GENERAL INFORMATION FOR THE GYPSUM AQUIFER

2.1 Physical aspects

Location:

The area of the Maroni gypsum aquifer extends to the southern coast of Cyprus between the towns of Larnaca and Limassol (Fig.1).

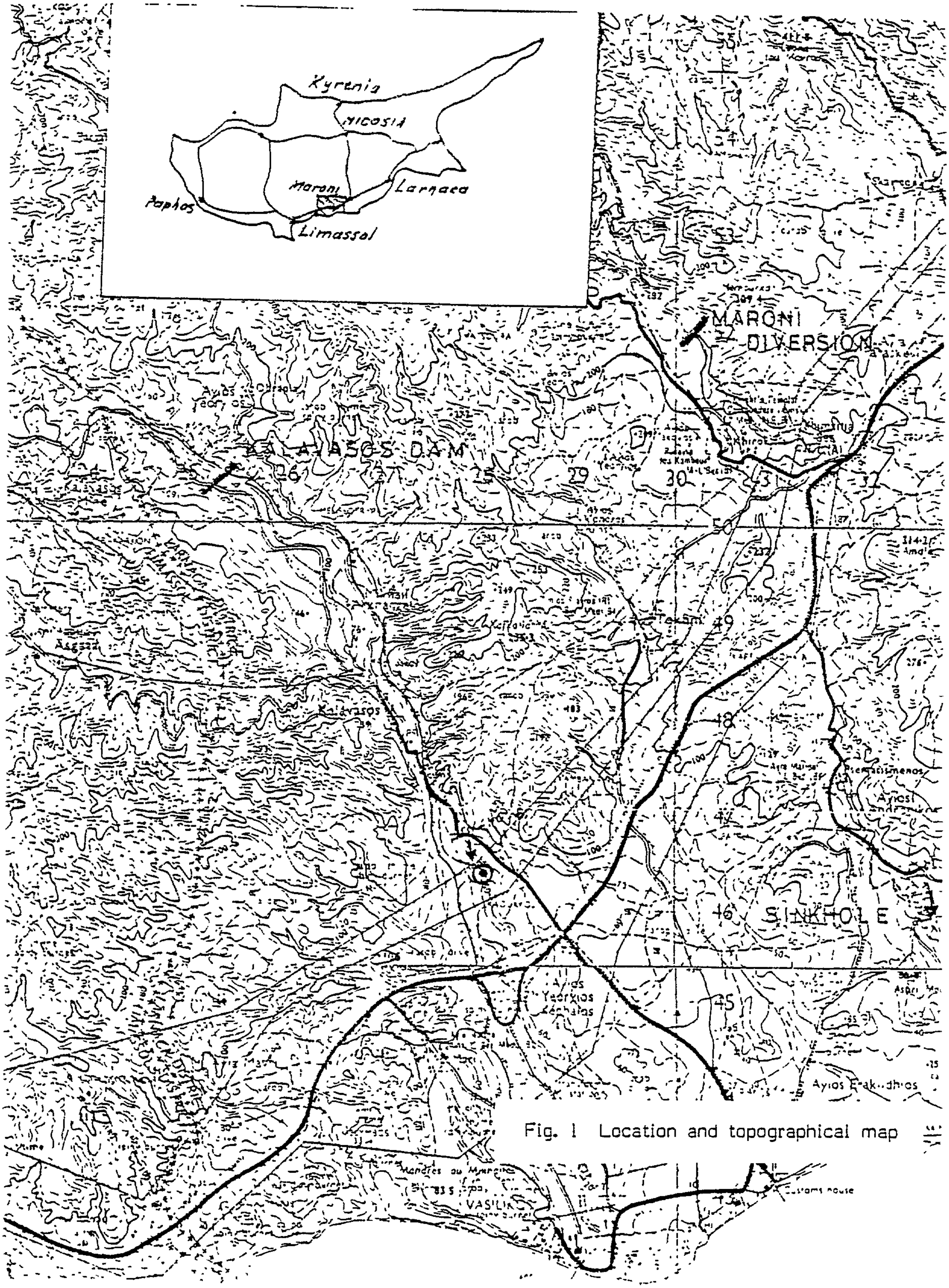

Fig. 1 Location and topographical map

Topography:

The area is traversed by two rivers (torrents) with a general direction of north to south (Vasilikos and Maroni Rivers).

The northern boundary of the Maroni gypsum aquifer essentially coincides with the outcrops of gypsum at an elevation of 75 m. From this elevation to the sea, the land surface declines fairly rapidly.

The terrain higher than the 75 m contour is dissected by the Vasilikos and Maroni rivers.

From the Vasilikos river, wide coastal plains of alluvium and river valley deposits have built up. In contrast, the Maroni river shows less developed valley deposits.

The area holding the villages of Maroni, Zyyi, Mari and Vasilikos, is traversed by the Nicosia-Limassol highway.

2.2 Climate

The climate of Cyprus, typically Mediterranean, features two seasons:

Winter, between November and March. In this season the weather is changeable and temperate.

Summer, between April and October. In this season the weather is consistently hot, dry and subtropical with occasional short periods of fluctuating temperatures.

The transition between these two seasons is sometimes very abrupt with no marked spring or autumn.

Air temperature in this coastal area is on the average 12 °C during the coldest month, January, while the temperature in summer is normally quite high; in August, normally between 25 to 30 °C.

The average annual rainfall over this area is 400 to 450 mm, increasing with higher elevation.

Surface water hydrology

About half of the drainage area is on the flanks of the Troodos igneous Complex. The remaining part of the drainage area downstream is on sedimentary rocks, first on the lapithos formation (chalks and marls) and then on Pakhna and recent deposits (chalks, marls, gypsum, calcarenite, etc.). The valleys are V-shaped and narrow in the upper reaches of the watersheds, becoming wider and flat 4-5 km from the coast.

Almost all of the annual runoff occurs during the winter and early spring. Usually runoff appears in late October or early November and a continuous base flow occurs through late spring. The base flow ceases at the end of May and the rivers are dry during the summer. Summer precipitation does not usually influence runoff.

The Maroni River maximum monthly discharge during the period of 1965 to 1967 was about 1.6 MCM. The mean simulated annual runoff of the Maroni River has been about 4.6 MCM using rainfall data from 1916 to 1982. The maximum flow observed on the Vasilikos River was from 1968-69, while the maximum monthly discharge for this period equalled 12 MCM. This value is near the mean simulated annual runoff.

2.3 Geology

Synoptic summary

The area consists geologically of sediments of the Miocène, Pliocène and Pleistocène periods, as well as recent deposits. Underlying all these formations, are older sediments from cretaceous to Jurassic age while at even deeper levels there are rocks.

Below we give a synoptic summary of the succession of the geological formations found in this part of Cyprus and their maximum thickness according to the existing bibliography.

Age	Lithology	Average thickness (m)
Recent to Pleistocène	Gravel and sands of river-bed and coastal plain	15
Pliocène	Marls and calcereous silt-stones (Masaoria Group)	40
Upper Miocène Pliocène	Marls	250
	Unconformity	
Miocène (Dhali Group)	- Gypsum deposits - Koronia Reef limestone - Pakhna formation	40 20 300
	Unconformity	
Lower Miocène to upper Cretaceons (Lapithos Group)	- upper unit (Chert free) - lower unit (Chert bearing)	500 270
Jurassic ? Campanien ?	- Perapedhi and oni formations	80
	Unconformity	
Igneous complex (Troodos igneous complex)	Lavas, basalts	

2.4 Hydrogeology

Aquifers:

Past hydrogeological investigations in the area of our study have revealed the identification of three sedimentary aquifers. The stratigraphic order of the three aquifers from top to bottom is as follows:

(a) Coastal and river gravel aquifer
(b) Gypsum aquifer
(c) Pakhna sandstone aquifer

(a) Coastal and river gravel aquifer

This is a phreatic aquifer of small thickness composed of gravel, sand and silt from Pleistocene to recent age. It extends over an area of about 30 km^2 with a thickness of 15 m.

The yields of the boreholes and wells vary from 5 to 10 m^3/h. Water table gradients are generally about 1-1,5 and the direction of the groundwater flow is in conformity with the configuration of the impervious base. The aquifer is replenished mainly by the surface flow of rivers and by direct rainfall on the outcrops.

Water salinity increases from north to south towards the sea. The relatively high salinity near the coast is due to sea water intrusion.

Two river gravel aquifers are defined in the area:

The Pendaskinos gravel aquifer, which extends to the east of Maroni village. Some 120 wells and boreholes tap this gravel aquifer. The estimated extraction is about 1.2 MCM/a. In late summer, on the northern fringes of the aquifer, many wells dry out.

The Vasilikos riverbed aquifer. This aquifer is located in the Vasilikos riverbed, south of Kalavasis village. The estimated extraction is about 0.7 MCM/a from 100 wells and boreholes.

(b) Gypsum aquifer

The outcrop of gypsum aquifer is to the northeast of Maroni village. From there on, southwards, it dips beneath the Pliocène marls at a slope of 0.1 to 0.15. The extent of the outcrop area is about 10 km^2. The top of the gypsum aquifer near the coastline is about 300 to 350 m below sea level (see Fig.2).

The lower part of this aquifer (below + 40 m elevation) is a confine aquifer under heavy exploitation by a number of boreholes yielding about 1 MCM (see Table I).

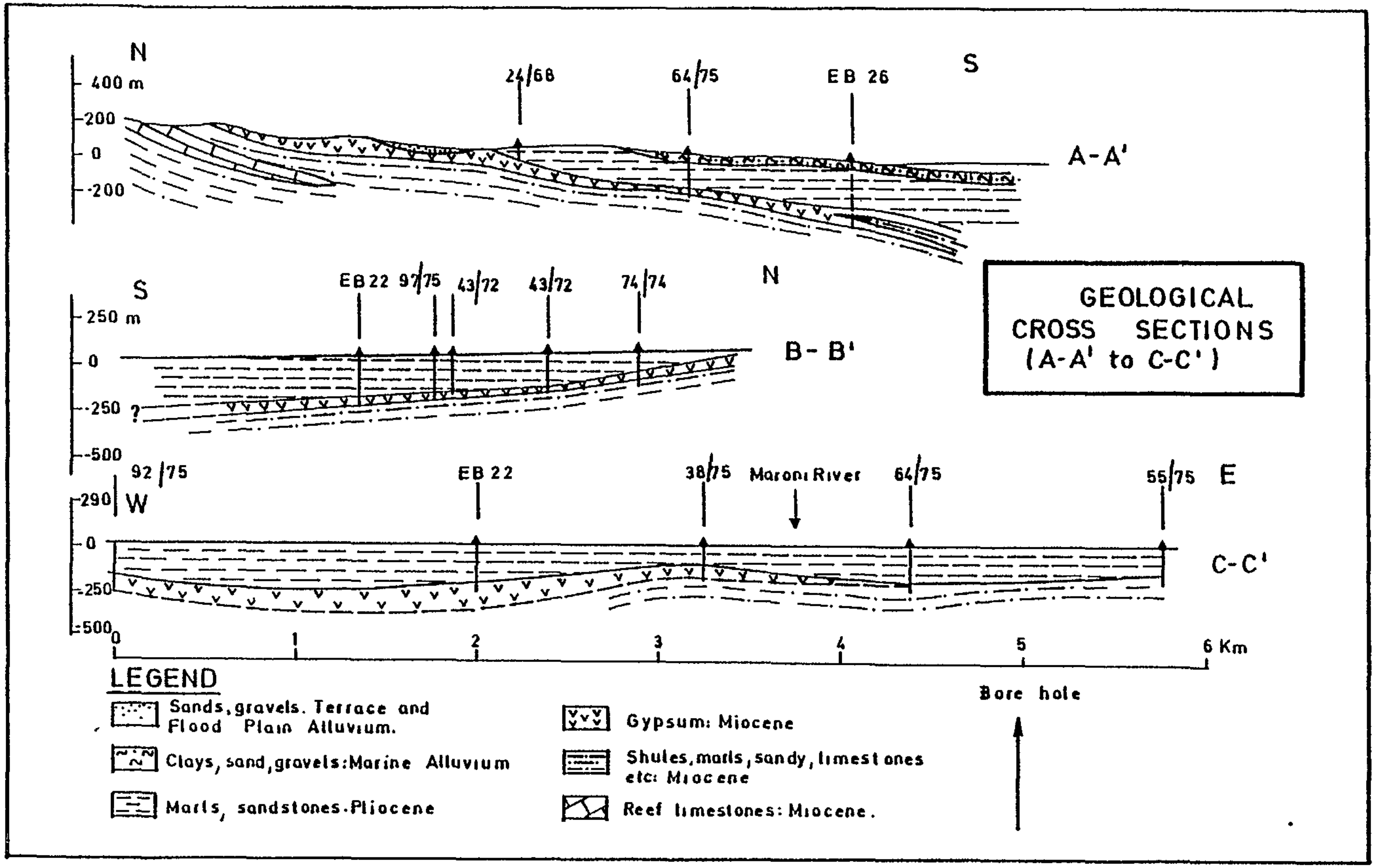

Fig.2 Geological cross sections (A-A to C-C)

Table I

Groundwater abstraction (MCM) from gypsum aquifer (*)
1980

Purpose	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.'	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Irrigation	0,001	0,002	0,020	0,059	0,088	0,105	0,109	0,094	0,094	0,095	0,091	0,055	0.813
Industrial	0,018	0,18	0,18	0,18	0,15	0,18	0,18	0,18	0,18	0,18	0,18	0,18	0,216
Total	0,019	0,020	0,038	0,077	0,106	0,123	0,127	0,112	0,112	0,113	0,109	0,073	1,029

* J. Jacovides *et al.*, July 1982
(Details are given below in a separate chapter)

(c) Pakhna sandstone aquifer

This aquifer is partly phreatic and partly artesian, and is composed of sandstone and conglomerate interbedded with marly layers. The outcrop covers about 40 km^2. The maximum thickness of the aquifer near the coast exceeds 300 m. The southern part of the aquifer is artesian.

The general water table gradient is about 3 per cent towards the south. Transmissivity values range from 13 km^2/day to 79 km^2/day. Isovhloride and water table contours show a similar configuration. The estimated extraction from the Pakhna sandstone aquifer is about 0.1 MCM/a.

Gypsum aquifer problems

Four main problems of investigation exist:

1. The problem of recharge:

Because of the increasing groundwater abstraction, a high draw-down in the water table appears, causing the drying of the upper part of the gypsum aquifer starting from an elevation of +45 m to -32 m (m.s.l).

With this, a problem of replenishment of the aquifer arises. This situation imposes on the evaluation of the aquifer volume and the way for its recharge.

2. The problem with the stability of Maroni village:

This problem appeared after 1976 when the spring of Maroni river dried up and river water started flowing into the gypsum layers through the existing karstic openings located near Maroni village. With the inflowing water, the openings of the gypsum became too large, creating problems for the stability of Maroni village.

3. The problem of water quality:

This problem is connected with the high sulphate content of the gypsum water and the potential danger of using it for irrigation over a long period of time.

4. The problem of sea intrusion:

Because of the depression of the water table to a level of about 32 m below sea level, a danger of sea intrusion exists. If the gypsum aquifer is not well protected by impervious layers, the connection of the gypsum aquifer to the sea is not clear, as losses appear to be very small.

3. THE VASILIKOS-MARONI GYPSUM AQUIFER

3.1 History

The Vasilikos-Maroni gypsum aquifer is located between the Vasilikos and Maroni Rivers.

Until 1967, on the southeast border of the Maroni village, a spring flowed at an elevation of 45 m (m.s.l.). This spring was acting as an overflowing spring at an annual discharge of some 0,35 MCM. Another small spring in the same condition was flowing along the eastern boundary of the Vasilikos river, extending to points 2 km southeast of Kalavasos village. These two springs were the only exurgences rising from the gypsum aquifer. Their discharge declined towards the end of the dry season and increased with the beginning of the winter rains. The appearance of this overflow spring indicates that the gypsum aquifer below the elevation of 45 m is confined.

With the drilling of boreholes between Maroni village and the coast, flowing to the surface, the piezometric pressure in the aquifer was being gradually lost, with the result that by 1970 the springs had dried up. Further drilling in 1974 and 1975 and the discharge of a considerable quantity of water, reduced the piezometric pressure even further. Today the piezometric surface is many metres below sea level.

With the decrease of the piezometric surface of the gypsum aquifer and the activity of the surface water of the Maroni River, some sinkholes appeared near the location of the old spring. Similar phenomena occurred on the Vasilicos River.

Measurements of the river runoff and water table levels indicate a direct relation between the inflow of the river water through the sinkholes and the fluctuations of the piezometric surface in the Vasilikos-Maroni aquifer.

The appearance of the above described sinkholes that are located at the foot of a small hill where Maroni village is built, created some slope stability problems.

The Vasilikos-Maroni aquifer is included in a bigger project of the Vasilikos-Pendaskinos Project for development of surface and groundwater resources. In this project, the Vasilikos-Maroni aquifer is being used as a complement to the surface water needs.

Within the frame of the Vasilikos-Pendaskinos Project, three dams are constructed on the rivers of Vasilikos and Pendaskinos. The first one is located on the Vasilikos River about 2 km NW of Kalavasos village with a storage capacity of 17,1 MCM.

The second is constructed on the Pendaskinos river with a diversion weir on the Maroni River 1,5 km upstream to Khirokitia village and is a diversion dam to divert 2,3 MCM to Dhypotamos Dam 13,0 MCM built on the Pendaskinos River.

After the construction of Kalavasos dam and the Maroni diversion weir, the runoff of the Vasilikos and Maroni Rivers, downstream of the structures, decreased considerably.

The possibility of replenishment of the gypsum aquifer from the Vasilikos and Maroni rivers is now very limited because of the above description of the water works. With this situation, the need to replenish the water of the gypsum aquifer is becoming more important. The most suitable way to increase the recharge of the gypsum aquifer is to use the existing sinkholes in both Vasilikos and Maroni Rivers, using as much as possible surface water runoff after a proper construction and preparation of the sites.

3.2 Physical characteristics

The gypsum layer is limited by two systems of impermeable formations. Below the gypsum, layers of marls, marchale, etc., are developed as an aquiclude. Above the gypsum, a system of marly layers exists forming an impervious cover. In this way, the gypsum aquifer is confined between two aquiclude systems. The thickness of this gypsum layer is not constant. The mean thickness is estimated to be 40 m.

According to the data taken from the boreholes, the general slope at the top of the gypsum aquifer is about 10 - 15 per cent dipping to the south (see Fig.3).

The outcrop of the gypsym aquifer extension is about 10 km^2 and is located in a triangular area formed by Khirokitia, Maroni and Kalavasos villages.

The dimensions of the confined part of the aquifer are not well known, especially south of the coastal line. Inshore these dimensions are about 20 km^2.

Fig.2 shows the configuration of the gypsum aquifer through boreholes and outcrops data.

3.3 Hydrogeological characteristics

Conditions of occurrence of groundwater

The water table contour map for 1967 shows that the general direction of flow from the replenishment area is southward, fanning out towards the southeast and southwest. The general water table gradient at that time was 1%. Between 1976 and 1986, the general direction of flow was from the north to the south with a very small general water table gradient. The piezometric surface of the water table is very flat and the limit of the art sianism is placed near the coastal line.

Pumping tests in the confined area gave values of transmissivity of about 3000 m^2/d. The yields of the boreholes are greater than 100 m^3/h and the free flow is in the range of 5 m^3/h to more than 45 m^3/h.

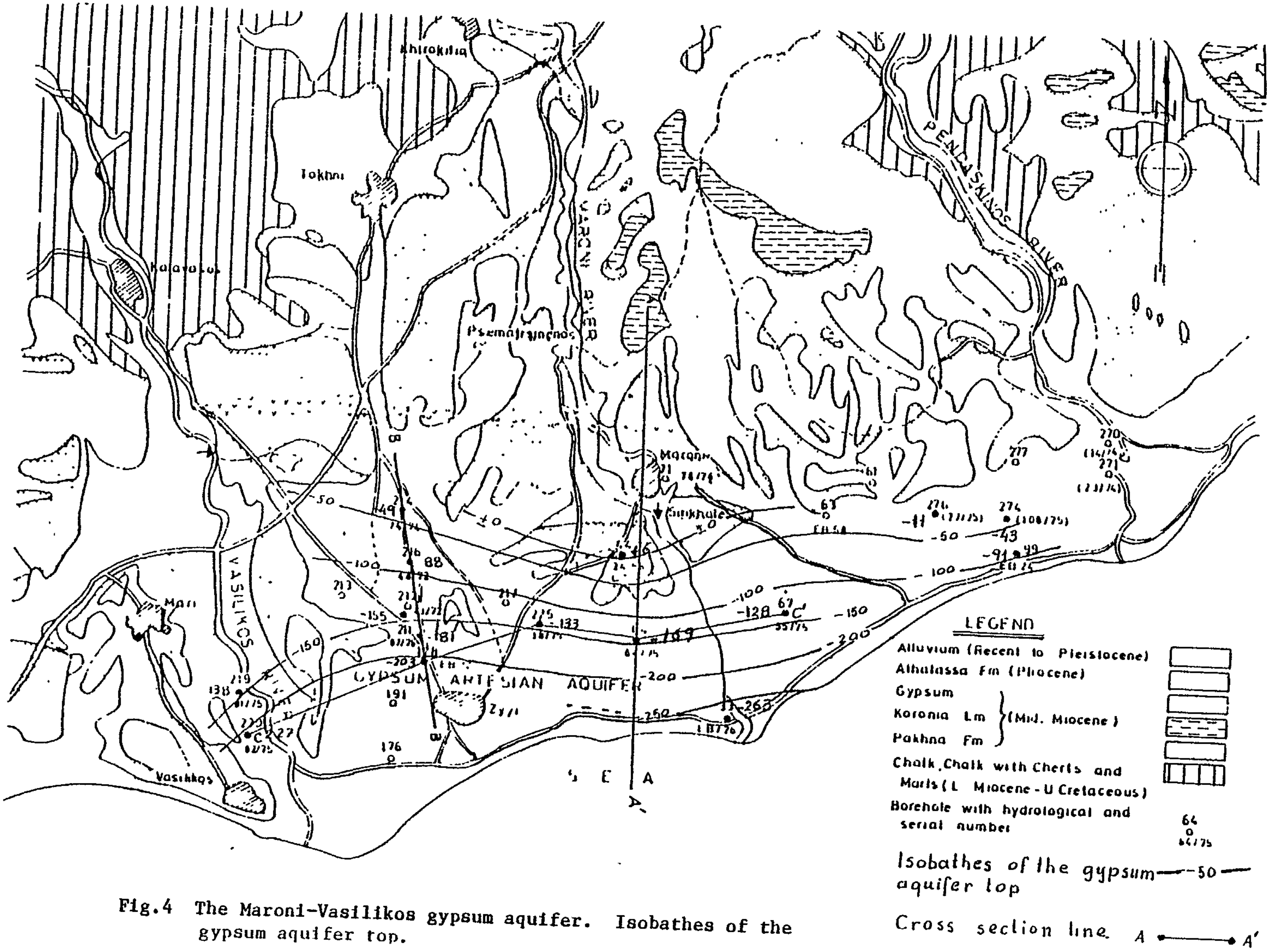

Fig.4 The Maroni-Vasilikos gypsum aquifer. Isobathes of the gypsum aquifer top.

Before drilling in the confined part of the aquifer in recent years, the area above the elevation of 45 was under phreatic conditions. The part below this level was under artesian conditions. At this time the most important source of recharge in the system was the rainfall which percolated through the out cop area. Taking into consideration the historical information about the annual flow of the spring, we can estimate that the recharge of the aquifer from rainfall at 0,5 MCM was equal to the annual recharge of the spring.

The loss of pressure in the system due to the flow of large volumes of water to the surface through artesian boreholes, resulted in the decrease of the water table level and consequently Maroni and Vasilikos river springs dried out.

Following this, two new sources of replenishment attained importance: the runoff of Vasilikos and Maroni Rivers which can flow directly into the gypsum aquifer through very well-developed sinkholes close to the riverbeds near the location of the dried up spring at an elevation of about 45 m (m.s.l.).

In both places, these sinkhole zones were always there but because the system is under full pressure, they were not operating as an inlet, but rather working as outlets of excess pressure as springs.

After the decrease of the water table due to the abstraction from the boreholes located in the artesian part, the gypsum aquifer appears to be a uniform system (Fig.4(b)) and through its developed karstification, is an immediately responding subsurface reservoir which corresponds evenly to any recharge or discharge condition (Fig.5). The fluctuation of the piezometric head is even throughout the aquifer, having a very small hydraulic gradient (Fig.4(a)).

Water balance

As it is mentioned above, the outcrop of the aquifer is about 10 km^3. Taking into consideration that the mean thickness of the aquifer is 40 m, the volume of the part of the aquifer line above the elevation of 40 m is:

$$V_1 = 40 \times 10^7 = 4.10^8 \text{ m}^3$$

The volume of the aquifer below the elevation of 40 m until the coastal line is calculated as follows:

$$V_2 = 3,5 \times 7.10^6 \times 40 = 980.10^6 \text{ m}^3$$

With: - The length of the aquifer : 7 km
- The width of the aquifer . 3,5 km
- The thickness of the aquifer : 40 m

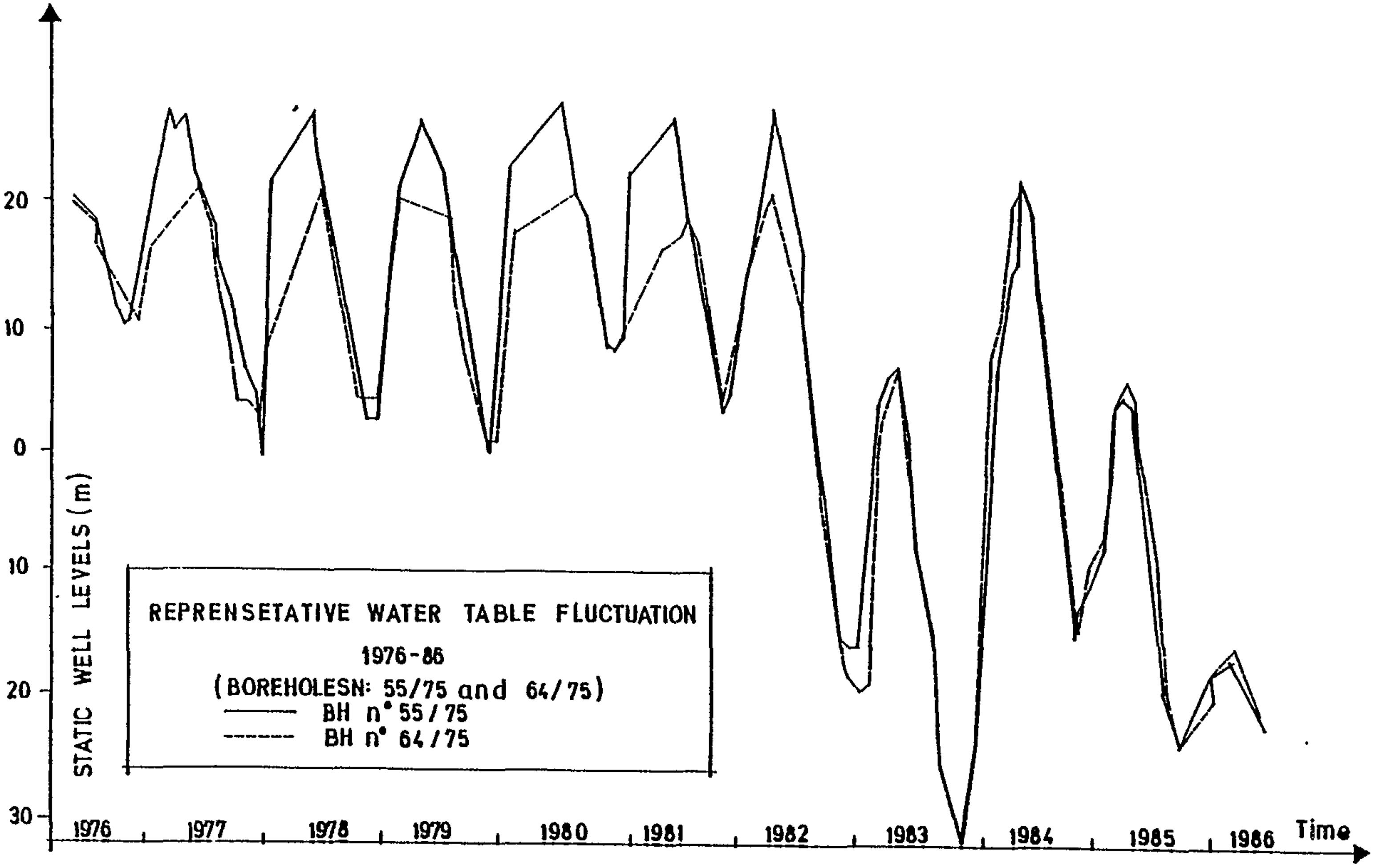

Fig.4(a) Representative water table fluctuation

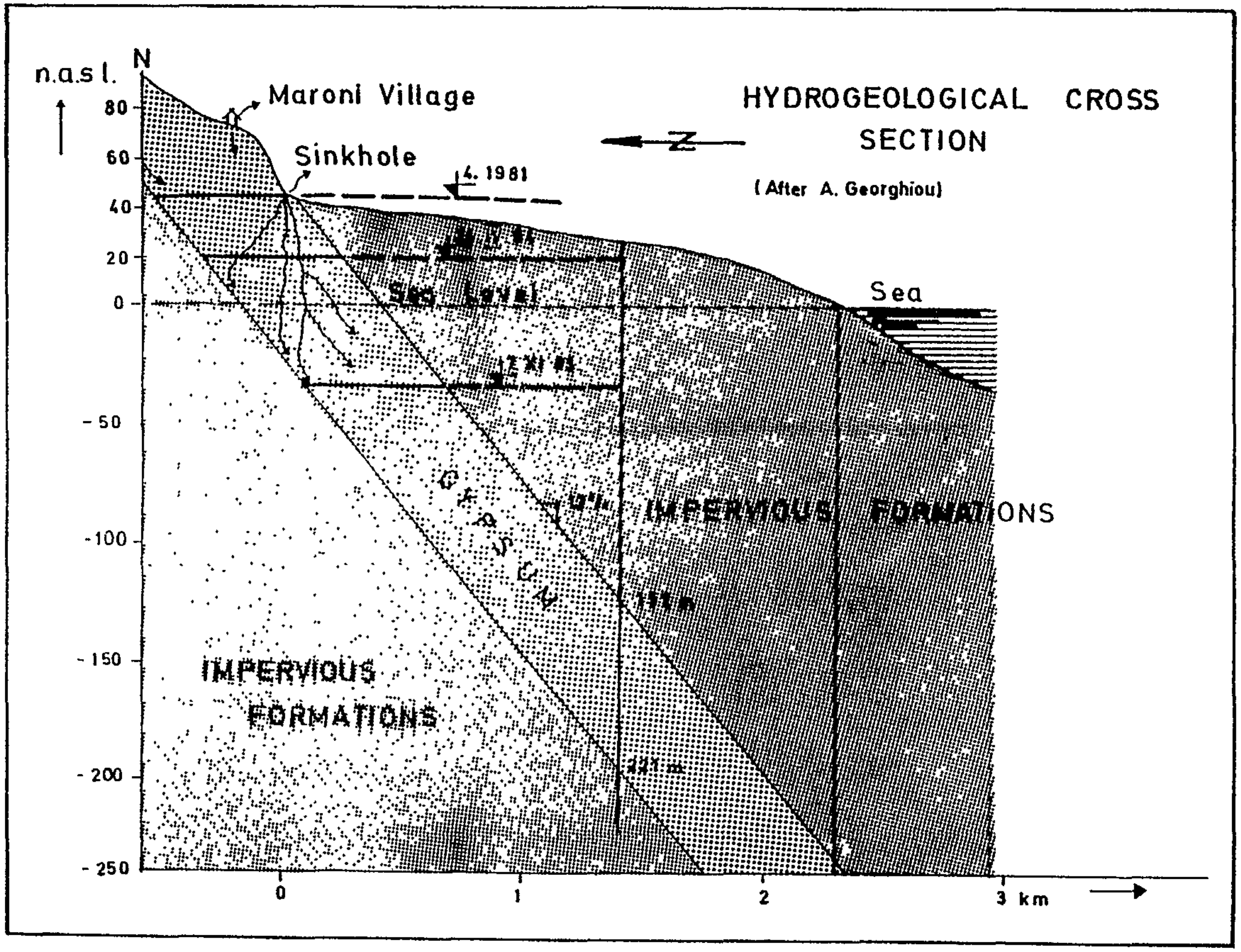

Fig.4(b) Hydrogeological cross section

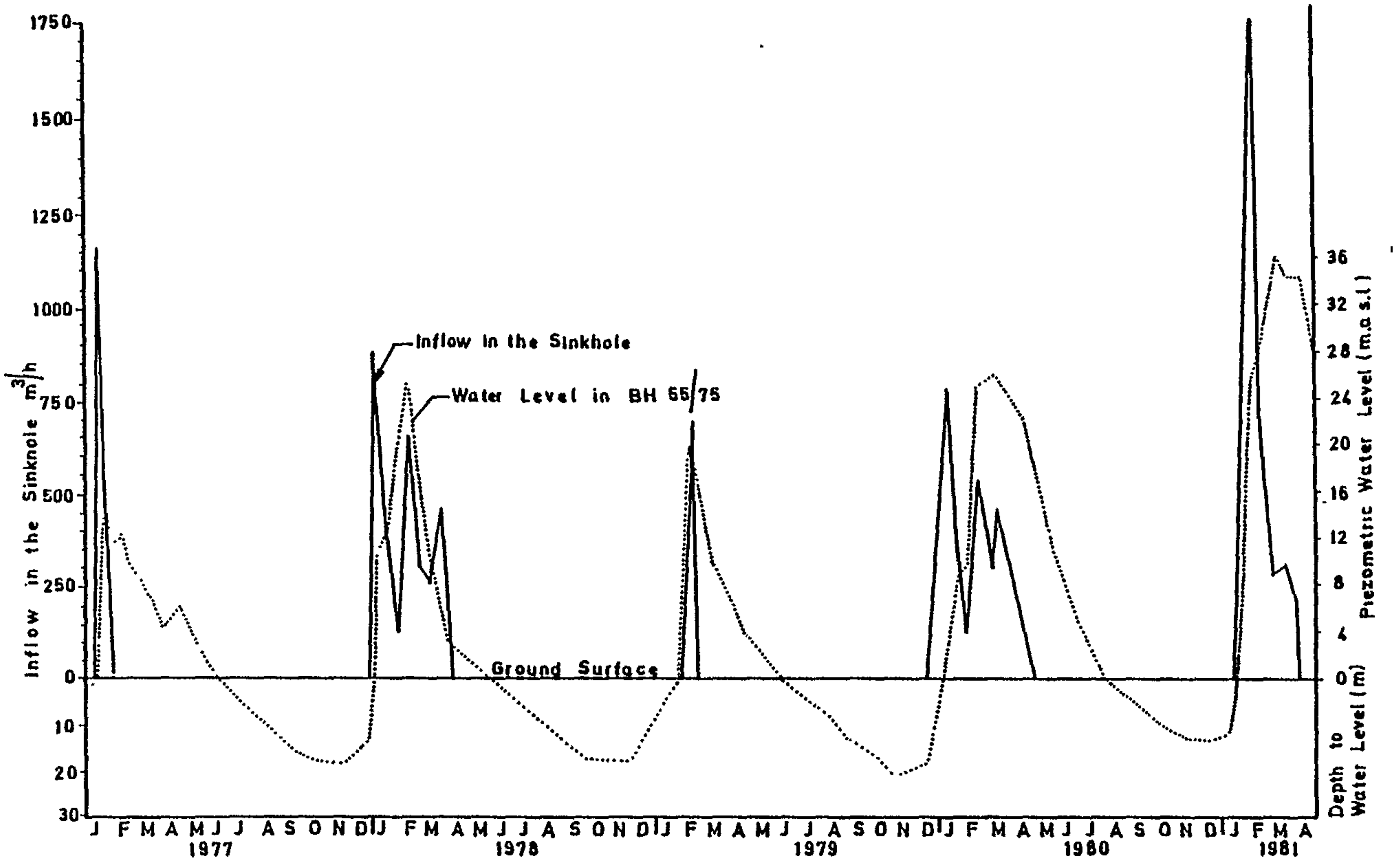

Fig.5 Relationship between sinkhole and water level in the gypsum aquifer

Where S = Storage coefficient

Q = Net recharge from the systems (total volume inflow through the Maroni sinkhole)

Fig.5 shows the direct relationship between inflow in the sinkhole and water level in the borehole No.55/755. This signifies that the biggest part of the recharge of the aquifer is coming from the sinkholes inflow showing the importance of using the sinkhole as the main means of replenishment. This recharge is evaluated to be about 1,5 MCM under present conditions.

V_3 : Total volume of the aquifer between the two levels

$V_3 = 53 \times 490 \times 7000 = 181.8 \times 10^6 \text{ m}^3$

Therefore:

$$S = \frac{1{,}5 \text{ MCM}}{181{,}2 \text{ MCM}} = 8.3 \times 10^{-3} = 0{,}008$$

We have to note that:

1. The volume of the aquifer from below the level of 40 m to the coastal line is about 7 MCM. The greater part of this volume (85 per cent) is formed below sea level. Storage capacity of the part above sea level is about 1,3 MCM.

After the construction of the boreholes and with heavy abstraction of the water, the level of the aquifer declined more than 1,3 MCM/a. That is, the abstraction exceeded the recharge and a part of the abstraction represented geological reserve taken by the pumping.

It is in this way in recent years, that the water level of the aquifer has declined many metres below sea level, with a maximum decline of 53 m in autumn of 1983.

It is clear that if more than 1,5 MCM/a is needed to be pumped in, making it necessary to provide a source of water to make up for and replace the extra water that is pumped (above the value of 1,5 MCM).

2. It is possible to extend the storage reserves to the depth of about 230 m but it is not known what will happen to the quality of water in the case of a hydraulic connection with the sea.

The importance of the upper part of the aquifer is only as a recharge area from local rainfall.

This recharge is estimated to be below $R_1 = P \times S \times Ki$ where:

R : Recharge (MCM)
P : Precipitation (mm) = 450 mm
S : Infiltration area (km^2) = 10 km^2
Ki: Coefficient of infiltration (%) = 10%

Than $R = 0,45 \times 0,10 \times 10^7 = 0,45$ MCM $\neq$ 0,5 MCM

This value is equal to the past mean annual discharge of the springs flowing into the Maroni and Vasilikos Rivers.

The lower part of the aquifer is of particular interest because it is the part that bears water and can be used as a reservoir for groundwater by increasing the value of recharge.

Using the existing data, we calculated that the storage coefficient is about 0,006.

According to this and the total volume of the aquifer, we calculate that the total storage capacity of the aquifer until the coastal line is:

$$R_2 = V_2 \times S.C.$$

Where:

R_2 = Total storage capacity (MCM)
V_2 = Volume of the confined part of the aquifer = 980.10^6 m^3
S.C. = Storage coefficient = 6.10^{-3}

Then: $R_2 = 980.10^6 \times 6.10^{-3} = 5.9$ MCM $\neq$ 6 MCM

The determination of the storage coefficient of the gypsum aquifer can be calculated in two ways:

(a) By using the results of a representative borehole No. 64/75 in the confined aquifer giving a value of S = 0.004 to 0,007 (data came from the Division of Hydrology of the Department of Water Development).

(b) By using the fluctuation of the water table of the aquifer for the period between 7 Nov.83 and 24 Apr.84 (from -32,6 m to + 20,8 m), in accordance with the dimensions of this part of the aquifer (between the above levels (Fig.4(b)) and the measurement of the mean inflow through the Maroni sinkhole during the same period in the year thus:

$$S = \frac{Q}{V_3}$$

Indications for such a connection are non-existent, although some boreholes of the aquifer have reached a depth of about 200 m below surface level.

The only possibilities of increasing the recharge of the aquifer are:

(a) To use the water coming from the overflow of the diversion dam in the Maroni River;

(b) To use the water coming from the overflow of the Kalavasos dam and some downstream tributaries of the river;

(c) To use part of the Kalavasos dam surface water. The best way for such recharge is to use the existing sinkholes on the Vasilikos and Maroni Rivers.

Quality of groundwater

Table II shows the result of chemical analyses of the water of some boreholes drilled in the gypsum aquifer for different periods between the years 1967 and 1984. In the same table, the chemical characteristics of the surface water of the Maroni River used as recharge of the aquifer are given.

The improvement in quality of the boreholes EB22, 48/72 and 55/75 is remarkable, although all boreholes show some improvement.

The results of the analysis for borehole 64/75 do not conform with the rest of the boreholes and should be treated carefully in the evaluation of the quality of the gypsum aquifer.

This change seems to be the result of fresh water recharge compared with water which had a long contact with lithologic units, allowing it to collect soluble minerals and to change composition.

The chemical polarity is represented by Ca^{++} for the cations and $SO4^{--}$ for the anions. This polarity indicates that the origin of water is the gypsum aquifer.

When there is a change of polarity from Ca^{++} to Na^{+}, the origin could be from another evaporite included in the gypsum deposits. Probably this evaporite is the mineral "Mirabilite" (Na_2 S04, 10H20).

Fig.6 shows that this chemical facies is characteristic of the water of the boreholes 64/75 and 176. In this case it is clear that the values of Na^{+} are not in correspondance to the values of Cl^{-} but to the values of $SO4^{--}$.

Generally, the values of Cl^{-} are high but not too much, except for the borehole 64/75. In all other cases, the values of Cl^{-} are below the upper limit of the standard of drinking water (Table III).

It is remarkable that the values of Cl^{-} do not change after the discharge and lowering of the level of the water table many metres below sea level.

Probably, this means that there is an original concentration of chloride in the water table and it is not coming from the sea by intrusion.

The SAR (sodium adsorption ratio) is low and does not exceed 3,5 except from the water of the borehole 64/75.

Fig.7 shows the relationship between SAR, salinity and reduction of infiltration in soils. The samples of water from the gypsum aquifer represented in this figure are all in the zone of "no reduction of the rate of infiltration". That is why it can be said that the use of the gypsum aquifer water in irrigation should not cause a reduction in the rate of infiltration in the soil.

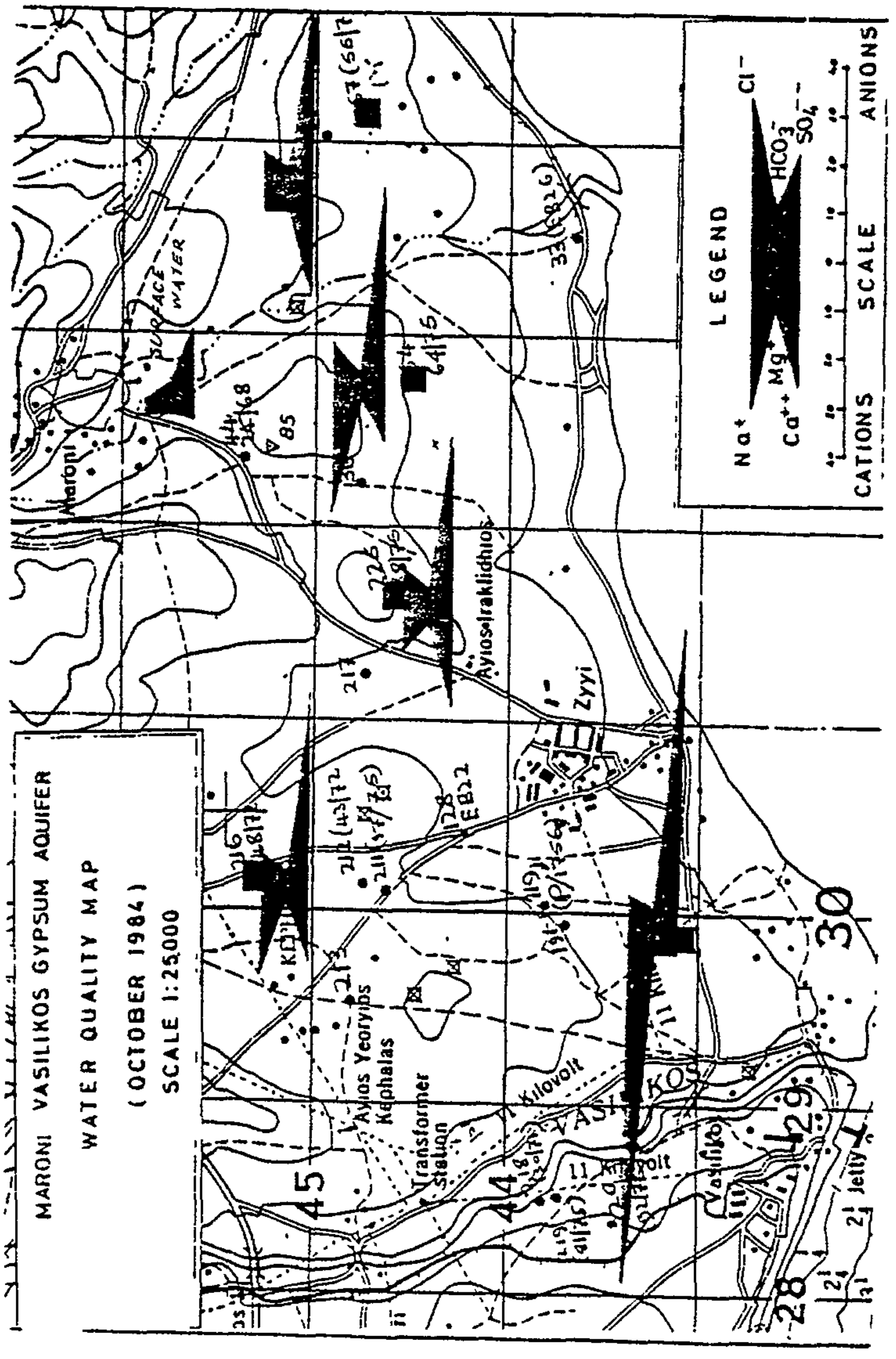

Fig. 6 Maroni-Vasilikos Gypsum Aquifer - Water quality map

Table II

Chemical composition of Maroni-Vasilikon aquifer, Maroni River surface water and sinkhole area

	Date of sampling	Dissolved solids ppm	pH	Concentration (mcg/1)							Concentration (mg/1)							SAR	Mg Ratio	Cations meg/1	Conductivity
				Ca	Hg	Ha	K	HCO3	SO4	Cl	Ca	Hg	Na	K	HCO3	SO4	Cl				
EB22	26.05.67	-	7,7	32,73	7,56	6,87	0,05	4,32	36,06	5,64	656	92	158	2	264	1732	200	1,53	0,19	47,21	3100
	08.04.76	3090	7,3	31,14	9,05	5,66	0,13	4,72	36,02	5,61	623	109	130	5	288	1729	199	1,26	0,23	45,98	3100
	16.03.78	2940	6,7	32,0	7,16	4,60	0,17	4,64	34,48	4,60	640	86	106	7	283	1655	163				2900
48/72	1975	-	-	31,34	7,05	5,92	-	4,56	34,22	5,81	627	85	136	-	278	1643	206	1,35	0,18	-	-
	16.03.78	2095	6,8	16, 3	3,41	10,86	0,45	0,47	26,56	4,39	326	41	250	18	29	1275	156	3,45	0,17		2500
	02.09.80	2135	6,4	....	5,83	2,74	0,10	0,49	29,48	2,31	465	70	63	4	30	1415	82	0,72	0,20		2150
	12.03.84	2900	7,3	30,14	5,59	7,05	0,10	3,34	35,68	3,09	604	68	162	4	204	1714	138	1,67	0,16		3500
64/75	29.12.75	-	-	33,43	4,11	5,22	0,15	3,77	35,39	3,70	669	49	120	6	230	1699	130	1,20	0,11	42,91	-
	10.06.76	3795	8,1	10,4	1,0	43,48	0,60	0,80	44,27	10,59	208	12	1000	24	49	2125	376	18,19	0,08	-	4800
	12.03.84	3340	7,0	9,18	4,77	48,72	0,59	2,0	31,15	9,25	184	58	1120	23	122	1496	328	18,45	0,34	42,40	4100
55/75	08.11.75		-	31,2	6,17	8,96	0,23	3,64	36,85	5,92	624	74	206	9	222	1769	210	2,07	0,16	46,56	-
	04.05.78	2740	7,0	33,2	4,08	2,96	0,10	3,36	34,37	2,81	664	49	68	4	205	1650	100	0,68	0,11		2700
	18.05.81	2590	7,9	31,0	4,17	2,74	0,12	1,64	34,37	2,81	620	50	63	5	100	1650	100	1,70	0,12		2400
	12.03.85	3070	7,5	25,15	12,01	7,14	0,13	2,0	39,97	4,37	504	146	210	5	122	1920	155	11,65	0,32	46,34	3600
Maroni sink-hole	12.03.84	440	8,1	2,5	1,89	1,48	0,02	3,59	16,0	1,02	50	23	34	1	207	77	36	1,00	0,43	6,2	520

Table III

Chlorite contents of groundwater in the gypsum aquifer

Borehole No.	Time	Cl^-	Time	Cl^-
176	12/3/84	497	13/11/84	302
48/72	12/3/84	138	13/11/84	177
38/75	12/3/84	177	13/11/84	177
64/75	12/3/84	328	13/11/84	218
55/75	12/3/84	155	13/11/84	133

The Mg ration is well below the 0,5 mark thus presenting no magnesium hazard (Table II).

4. OBJECTIVES AND CRITERIA ADOPTED IN RESOLVING THE PROBLEMS INVOLVED WITH THE GYPSUM AQUIFER

As mentioned earlier (gypsum aquifer problems) the main problems are:

- Recharge of the aquifer and the stability of Maroni village
- Connection of the aquifer with the sea and probability of sea intrusion
- Water quality

4.1 Recharge of the aquifer and the stability of Maroni village

After the high abstraction of the aquifer, a significant draw-down in the piezometric surface appeared. This caused in the aquifer a net empty volume equal to 1,5 MCM. If abstraction by pumping in the boreholes is not carried out it will create a larger empty volume in the aquifer. This is calculated to the coastal line limit, about 5,9 MCM. The recharge of the aquifer before the construction of the Maroni and Kalavasos weir and dams was about 1,5 MCM (0,5 MCM coming from the direct infiltration in the outcrops and 1,0 MCM coming by inflow through the existing sinkholes).

After the construction of the above weir and dams, the possibilities for inflow through the sinkholes and, generally for the river beds to recharge the aquifer, are seriously limited.

According to our opinion, the way to recharge the aquifer is to use the physical ways, meaning the existing sinkholes in the two rivers. The water for this recharge, with the exception of the water infiltrated directly into the gypsum outcrops, can be obtained:

1. From the overflow of the diversion weir in the Maroni River and the part of the drainage area of the Maroni valley between the diversion weir and the sinkhole area.

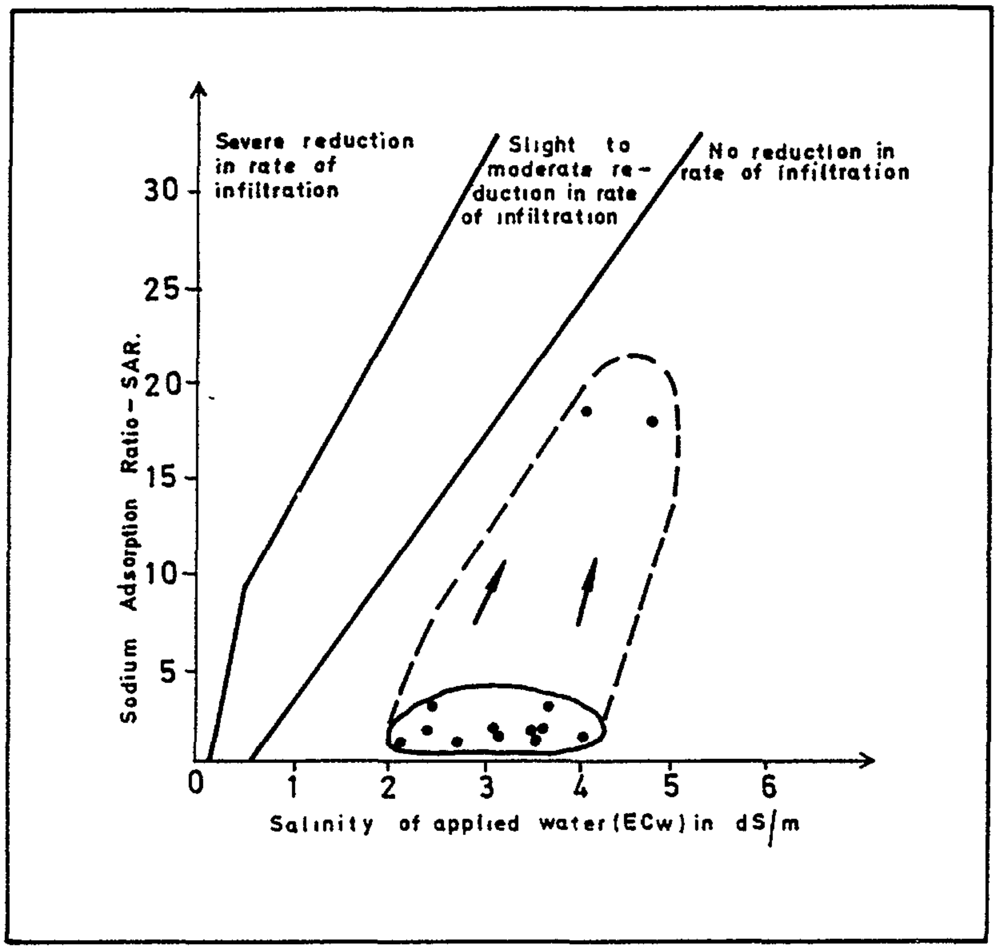

Fig.7 Relative rate of water infiltration as effected by salinity and sodium absorption ratio.

2. From the overflow of the Kalavasos dam (if there is any) and the part of Vasilikos River valley between the Kalavasos dam and the sinkholes area at this river.

3. From the water reserves of the Kalavasos dam.

4. By diversion of surface water from other rivers.

The more important areas of recharge are the Vasilikos and Maroni existing sinkhole areas.

4.2 Connection with the sea and probability of sea intrusion

According to the existing data on the geological-hydrogeological conditions, the fluctuation of water table levels in relation to the abstraction made through the boreholes and the results of the water chemical analysis, no indication exists that sea intrusion has happened up until now.

The fact that the aquifer is under artesian pressure (confined aquifer) with a very thick impervious cover, signifies that no suitable conditions of sea intrusion exist.

The significant draw-down of the water table (1976-86) to a depth of about 32 m below sea level without the occurrence of any change in the quality of water and especially in the chlorite content, reinforces the opinion that no sea intrusion has occurred under the present conditions.

Tables II and III show the chlorite value contents for two periods 1967 and 1984.

In comparing the two periods it can be concluded that no significant change was caused after such long period (1967-84) and after such a heavy amount of water abstraction.

The other available chemical analysis data for water, present no increase of salt over time.

4.3 Water quality

At the beginning, the abstracted water from boreholes appears to be "fossil water" with characteristics of gypsum waters with polarity in Ca^{++} and $SO4^{--}$ contents.

After 10 years of abstraction with numerous boreholes, the change in the quality of water was in relation to the seasons of the year. The quality was better in the recharge period until the beginning of the irrigation period. Later, the quality of the water deteriorated depending on the amount of the quantity abstracted, happening by the end of the irrigation period and before the wet period of the year's start.

All the above means that the recharge improves not only the reserves of the groundwater but also its quality.

5. CONCLUSIONS AND RECOMMENDATIONS

After completion of the investigation, the most important conclusions and recommendations are the following:

1. The storage capacity of the gypsum aquifer is limited. According to the calculations made, the used storage capacity up to the present is about 1,5 MCM. There is a possibility for increasing the active storage by the intensification of the exploitation through the existing boreholes or some additional boreholes located closer to the coastal zone. In this way, it is possible to increase the exploitable capacity up to about 6 MCM.

2. The recharge of the aquifer poses the biggest problem because available water is limited (about 1,5 MCM/a). Additionally needed water could be obtained from the Kalavasos dam reserves or by diversion of water from other hydrologic basins.

   The most suitable places for this recharge are the sinkhole areas in the Vasilikos and Maroni rivers. In these areas some works have been suggested to improve the recharge conditions.

3. Historical and present data on the water quality of the aquifer shows that the groundwater is typical gypsum water and no deterioration of the quality during the last ten years has been observed. This is an indication that up until the present, no sea intrusion has occurred.

   In contrast, some improvement of the water quality has been observed due to the replenishment by fresher water (surface water). The quality of the water is not appropriate for drinking but it can be used for irrigation, without causing any reduction in the rate of soil infiltration.

4. <u>Recommendations</u>

   (a) Special constructions on the mouths of the existing sinkholes in the Vasilikos and Maroni rivers to secure and protect the recharge of the aquifer;

   (b) Three boreholes should be drilled.

All the proposed boreholes could be used as production boreholes. In constructing these boreholes the proper material for oasing should be used (PRC etc.).

In view of the erosive quality of the gypsum water, care should also be paid to the high artesian pressures that occasionally may be available; boreholes should be constructed so that regulation of the pressure can be implemented.

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REUSE OF WASTEWATER FOR IRRIGATION

By

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1. INTRODUCTION

The use of municipal wastewater for irrigation of agricultural crops is one of the most attractive and populat reuse options in many regions of the world, for the following reasons:

(a) Irrigation is usually needed in areas where water tends to be scarce and wastewater reuse is necessary for supplementing available fresh water sources.

(b) Agriculture requires large amounts of water, which are used only once, since irrigation is a consumptive use. Thus, there is no danger of gradual accumulation of undesirable substances in the water by continuous recycling.

(c) Agriculture can use not only the water, but also additional resources found in wastewater, such as organic matter or nutrients (nitrogen and phosphorus), which are thus converted from being an environmental nuisance to being an asset.

(d) Irrigation is relatively flexible with respect of water quality requirements. Some crops can be irrigated with low quality water, and some water quality problems can be overcome by suitable agricultural practices.

(e) Use of wastewater for irrigation prevents its discharge to receiving water bodies and consequently avoiding pollution of water resources.

The Mediterranean coasts and islands suffer from limited water resources and present a case in which municipal wastewater should be regarded as an unconventional source of supply that can be developed and integrated within existing regional water supply schemes. Utilisation of treated wastewater for irrigation will decrease the demand for fresh water from groundwater sources and thus result in reduction of salinity of the water extracted from aquifers. In addition, wastewater resuse will prevent the pollution of the Mediterranean coastal water and encourage tourism which comprises an important source of income in the Mediterranean zone.

2. FACTORS RELATED TO IRRIGATION WITH EFFLUENTS

When considering irrigation with treated wastewater, several related factors and terms should be recognised. Some of these are presented below:

- Restricted and unrestricted irrigation: "restricted irrigation" refers to the use of low quality effluent in specific areas, where only certain crops should be cultivated. The restrictions imposed usually refer to the type of crops to be cultivated, the irrigation methods, the harvesting method, fertilizer application rates, distance of irrigated fields from houses and distance between non-potable and potable water supply mains. "Unrestricted irrigation" refers to the use of high quality effluents for irrigation of all crops on any soil type, without any adverse environmental effect on the soil, crops, animals, persons involved in the production process or persons consuming agricultural products.

- Effluent quality: the effluent quality is the main factor that dictates the type of reuse (i.e. restricted or unrestricted irrigation), types of crops and irrigation methods. The effluent quality should be considered regarding two aspects: public health and agronomics. Most existing standards for wastewater reuse deal only with public health aspects and prescribe the treatment processes or quality parameters that the effluent must meet before it can be used to irrigate a certain category of crops. These include mostly bacteria, viruses and other pathogens and sometimes also organic matter (BOD, COD, S.S) pH and residual chlorine. However, agronomic aspectes related to crops and soils must also be taken into account. These include salinity, sodium absorption ratio of the water, nitrogen, phosphorus, chloride, bicarbonate, heavy metals, boron and other trace elements, pH and synthetic organics (including pesticides).

  Considering the agronomic aspect of effluent quality, water quality standards established for crop irrigation with fresh water are, at present, also the best available criteria for effluent reuse. However, there are additional constituents in wastewater, usually absent from or unimportant in fresh water. For such constituents, specific reuse standards will have to be developed in the future. At present, only preliminary guidelines can be established based on available knowledge.

  Additional information about effluent quality for irrigation can be found in Ref.1.

- Irrigation methods: the effluent quality has an effect on the irrigation method to be used. Surface irrigation methods can utilise low quality effluents, whereas sprinkler and mainly drip irrigation require higher quality effluents, because of the danger of clogging orifices of the irrigation equipment by suspended solids. This problem can be overcome by utilising filters at the head of the irrigation system.

- Seasonal storage: while municipal wastewater is available at a relatively constant flow, irrigation water is required mainly during the dry season. In order to compensate between the constant supply and variable demand, seasonal storage is required. There are two possibilities for storage: surface storage and groundwater storage. In both cases, storage acts as an additional treatment stage.

- Treatment in relation to project size: for small wastewater flows, the effluent can be used on special, well supervised "sewage farms" where forage, fibre, or seed crops are grown, that can be irrigated with standard primary or secondary effluent. Large scale use of effluent require additional treatment so that the effluent meets the public health, agronomic and aesthetic requirements for unrestricted use (no adverse effects on crops, soils, humans and animals).

- Economic aspects: the economy of a reuse project depends on many factors, most of which are specific to each project and include the distance of reuse area from the source of wastewater, soil types and climatic conditions. The closer the reuse area to the sewage source, the more profitable can a project be. A reuse project can be economically feasible if alternative disposal costs are deducted from the project cost. Such a deduction is justified because sewage disposal should be provided in any case. Similar to other irrigation projects, the irrigation method has a marked effect on the economics of a reuse project. Irrigation methods with a high efficiency use are preferable.

3. PUBLIC HEALTH EFFECTS AND IMPLICATIONS REGARDING WASTEWATER TREATMENT AND CLASSIFICATION OF IRRIGATED CROPS

Public health effects present the greatest concern when considering wastewater reuse for irrigation. Pathogenic organisms (bacteria, viruses and parasites) are the parameter of significance when considering health effects.

Recent publications (2, 3, 4) conclude that previous public health orthodoxy, which held that every excreted pathogen that can persist in the environment, in soil or on crops irrigated with wastewater, is a potential cause of serious disease in humans, is basically overly conservative because human infection is not dependent solely on the presence of pathogens on soils and crops. It depends also on the minimum dose of a pathogen necessary to cause infection (which varies greatly for various types of organisms), on the persistence time of the pathogens in the environment and on the level of immunity to endemic diseases.

Combination of the above factors led to the conclusion that the amount of excess infection and diseases caused by various classes of pathogens, when irrigating with untreated wastewater, is in the following order of descending magnitude:

- Intestinal nematode infections (Ascaris, Trichuris and the hookworms);
- Excreted bacterial infection (bacterial diarrhoeas and typhoid);
- Excreted viral infections (rotavirus diarrhoea and hepatitis A).

According to Ref.2 the first quality criterion for wastewater use in agriculture is the complete, or almost complete removal of the eggs of intestinal nematodes (to a geometric mean of less than 1 viable nematode egg per litre). In addition, a major reduction (to a geometric mean of less than 1,000 faecal coliforms per 100 ml) in the concentration of excreted bacteria is recommended for unrestricted use of wastewater in agriculture. If these standards are met, other pathogens such as trematode eggs and protozoal cysts are also reduced to undetectable levels.

The priority for effective wastewater treatment for the specific purpose of pretreatment for agricultural irrigation, as based on the recent publications (2, 3, 4) are in the order:

- Maximum removal of helminths and protozoa;
- Effective reduction in bacterial and vireal pathogens;
- Freedom from odour and appearance (i.e. effective reduction of BOD).

These specific design criteria and their order of priority differ from those for reducing surface water pollution from BOD to COD, and thus result in different optimal treatment strategies.

Remedial measures based on conventional wastewater treatment practices developed in industrial countries were not designed for, nor are they particularly effective in removing pathogens.

Based on the recent findings, a series of practical alternative remedial measures for controlling negative health effects may be considered as follows:

- Restrictions on type of crops irrigated so as to prevent consumers from being exposed directly to infection through contaminated vegetables or salad crops eaten raw;
- Selection of irrigation techniques and procedures so as to minimise direct contact between wastewater and crops;
- Wastewater treatment and/or storage practice, aimed at effectively reducing first the concentrations of priority pathogens to low levels, and in subsequent stages to levels below which the incidence of excess infection is essentially controlled.

In addition, improved occupational health and hygiene conditions are necessary.

The reuse systems for irrigation may be classified in three categories (A, B and C) according to the crop type, the restrictions imposed on the irrigation system and the risk to public health. These categories depend on the effluent quality (5).

Categories A and B correspond to restricted irrigation while category C corresponds to unrestricted irrigation for all types of crops including ones consumed raw (Table I).

As a consequence of the limitations, irrigation of categories A and B is generally applicable in limited, well controlled zones, while irrigation of category C is adequate for large-scale projects which may include crops that demand water of high quality.

Table I

Categories of crops irrigated with treated effluents

Category of Crop	Category "A"	Category "B"	Category "C"
Definition of crop and restrictions.	1. Crops not for human consumption (for example cotton). 2. Crops normally processed by heat or drying before human consumption (grains, oil seeds, sugar beets). 3. Vegetables and fruit grown exclusively for canning or other processing that effectively destroys pathogens. 4. Fodder crops and other animal feed crops sun-dried and harvested before consumption by animals. 5. *Landscape irrigation in fenced areas* without public access (nurseries, forests, green belts).	1. Pasture lands, green fodder crops. 2. Crops for human consumption that do *not come into* direct contact with wastewater on condition that no windfall be marketed (orchards, stalked vine and hung crops - tomatoes, cucumbers, etc. and vineyards irrigated by surface and drip irrigation) 3. Crops for human consumption normally eaten only after cooking (potatoes, eggplant, beet roots). 4. Crops for human consumption, uncooked whose peel is not eaten (melon, citrus, bananas, nuts, groundnuts).	1. Any crops for human consumption normally consumed uncooked, and grown in direct contact with wastewater effluent (fresh garden vegetables such as tomatoes, carrots, fruits, etc.). 2. Landscape irrigation in areas with free public access immediately after irrigation on condition that during spray irrigation, areas are fenced so that there is no public access within 15 metres of wetted irrigation zones.
Required effluent	Low	Intermediate	High

Source: TAHAL - Reuse of the wastewater of Lima, Peru (5)

4. WASTEWATER TREATMENT SCHEMES FOR REUSE

The development of planned effluent reuse schemes, which took place in the last two decades came, in most cases, after wastewater treatment plants designed for discharge purposes were already in operation. The conventional approach to wastewater reuse starts with a municipal effluent, which is usually available after conventional primary-secondary treatment is carried out for the purpose of discharge to a water body (Fig.1). Such effluent is normally suitable only for restricted irrigation and limited industrial use. In order to produce a higher quality effluent, which is suitable for unrestricted agricultural reuse, for numerous industrial uses and for potable aquifer replenishment, additional treatment has to be provided. Tertiary treatment by physico-chemical processes, in addition to primary-secondary treatment by mechanical and biological processes, is usually included in reuse schemes where a higher water quality is required.

Conventional treatment processes generally used for wastewater treatment for restricted irrigation include biological treatment of any type, sometimes followed by chlorination. In Fig.2, some conventional treatment schemes for restricted irrigation are presented. These include primary treatment, oxidation ponds of various types, aerated lagoons, trickling filters, activated sludge and oxidation ditches.

During the last years, some additional low cost innovative treatment methods have been developed. These can be used as treatment processes for restricted irrigation and sometimes as additional treatment processes after conventional biological treatment, to produce effluents for unrestricted irrigation. These processes include:

- overland flow with collection of the effluent by surface drains;
- aquaculture by means of water hyacinth, duckweed or other plants of similar properties;
- aquaculture by wetlands, using plants, trees, fish, birds and biological purification chains in general.

An attractive process which was developed in Israel and is in widespread use there, is the Deep Reservoir Treatment (DRT). Information on this process will be presented further on.

Conventional additional treatment for production of effluent for unrestricted irrigation usually consists of coagulation-sedimentation with alum and polyelectrolytes, followed by filtration and chlorination. This process is standard practice for treatment of turbid surface waters. A newer development related to tertiary wastewater treatment, which is also "borrowed" from the surface water treatment industry, is the "direct" or "contact" filtration process. Another tertiary process is the high lime treatment process followed by polishing ponds for recarbonation and ammonia stripping. The above additional schemes for unrestricted irrigation are presented in Fig.3.

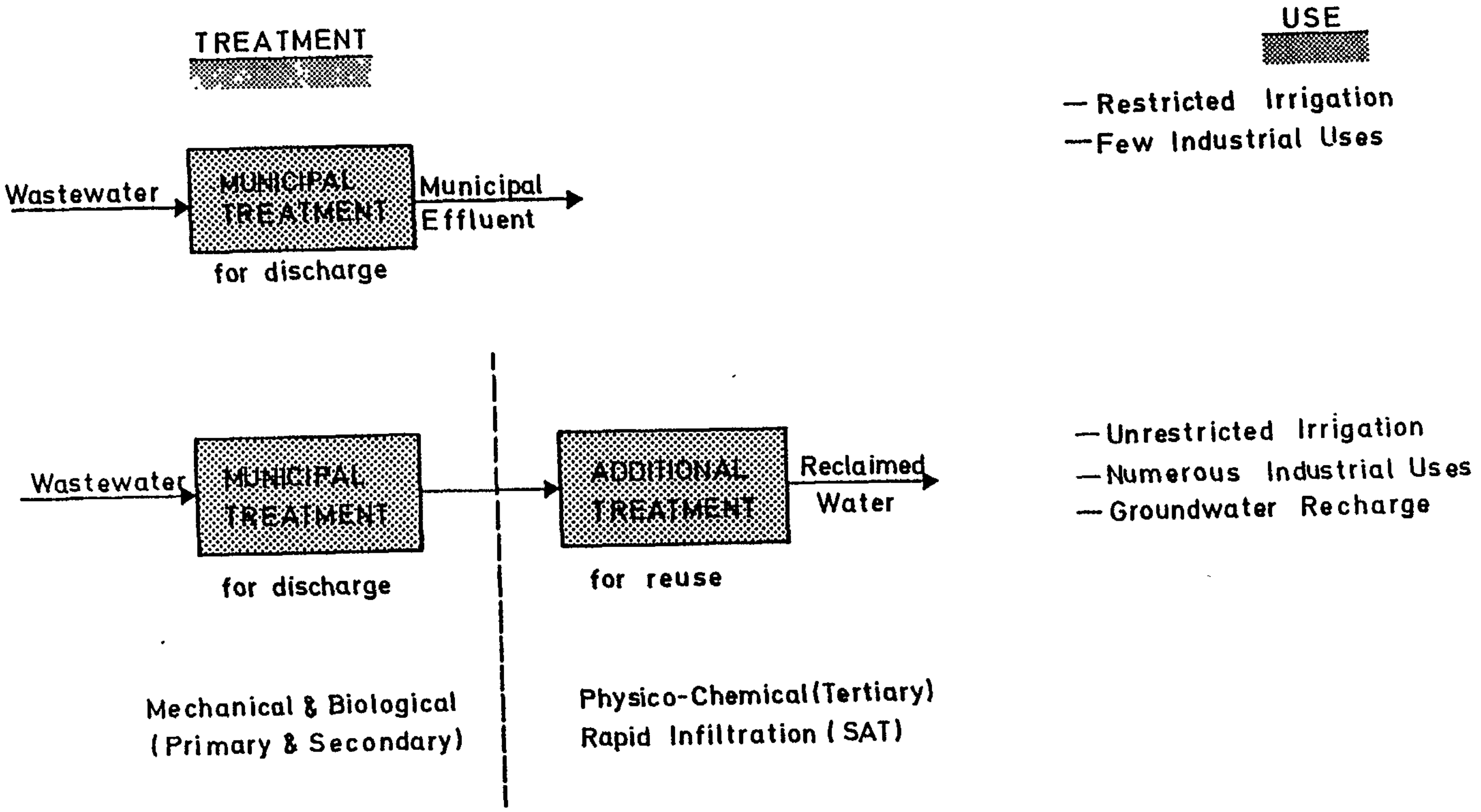

Fig. 1 General approach to wastewater treatment for reuse

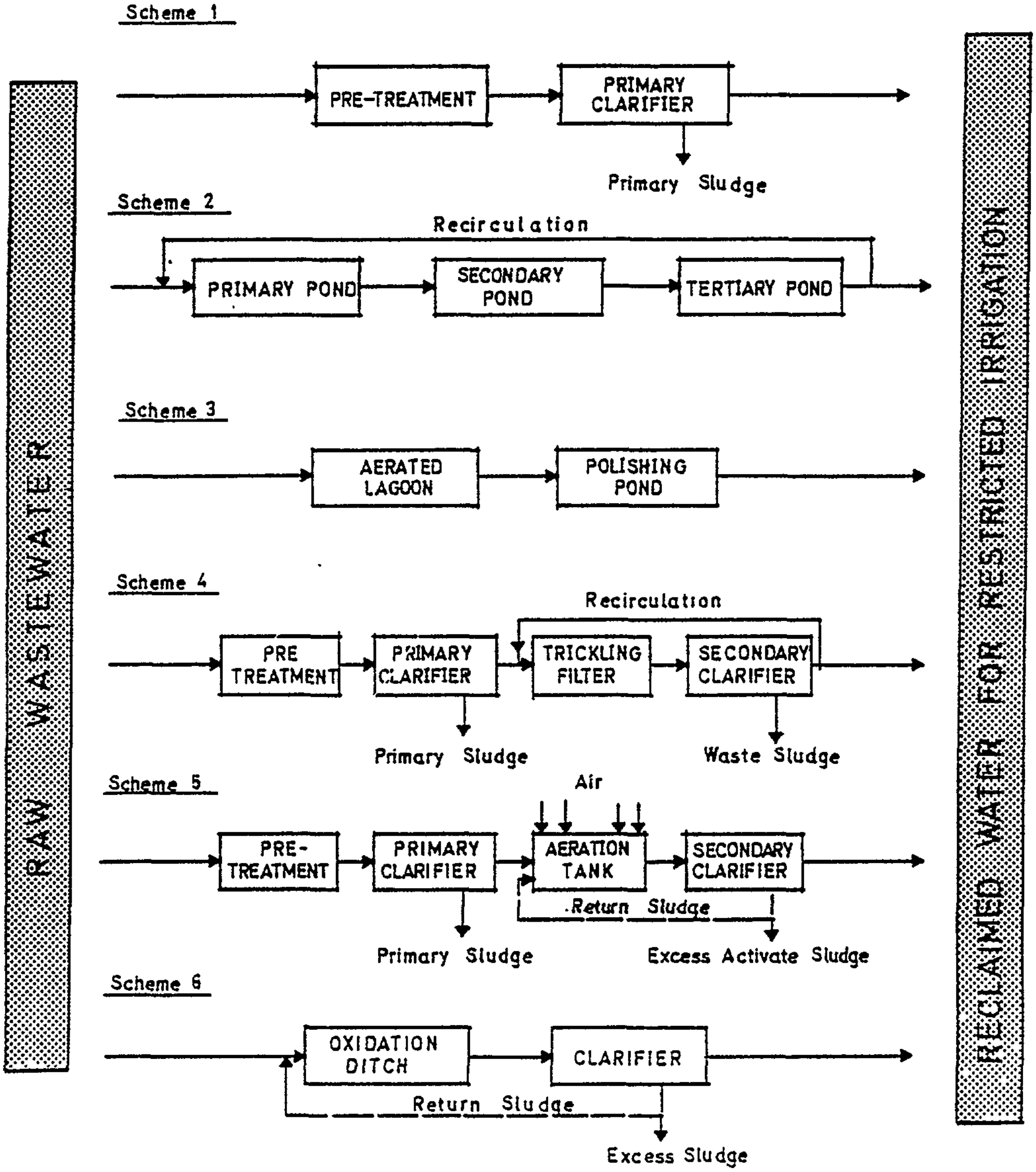

Fig.2 Treatment schemes for restricted irrigation.

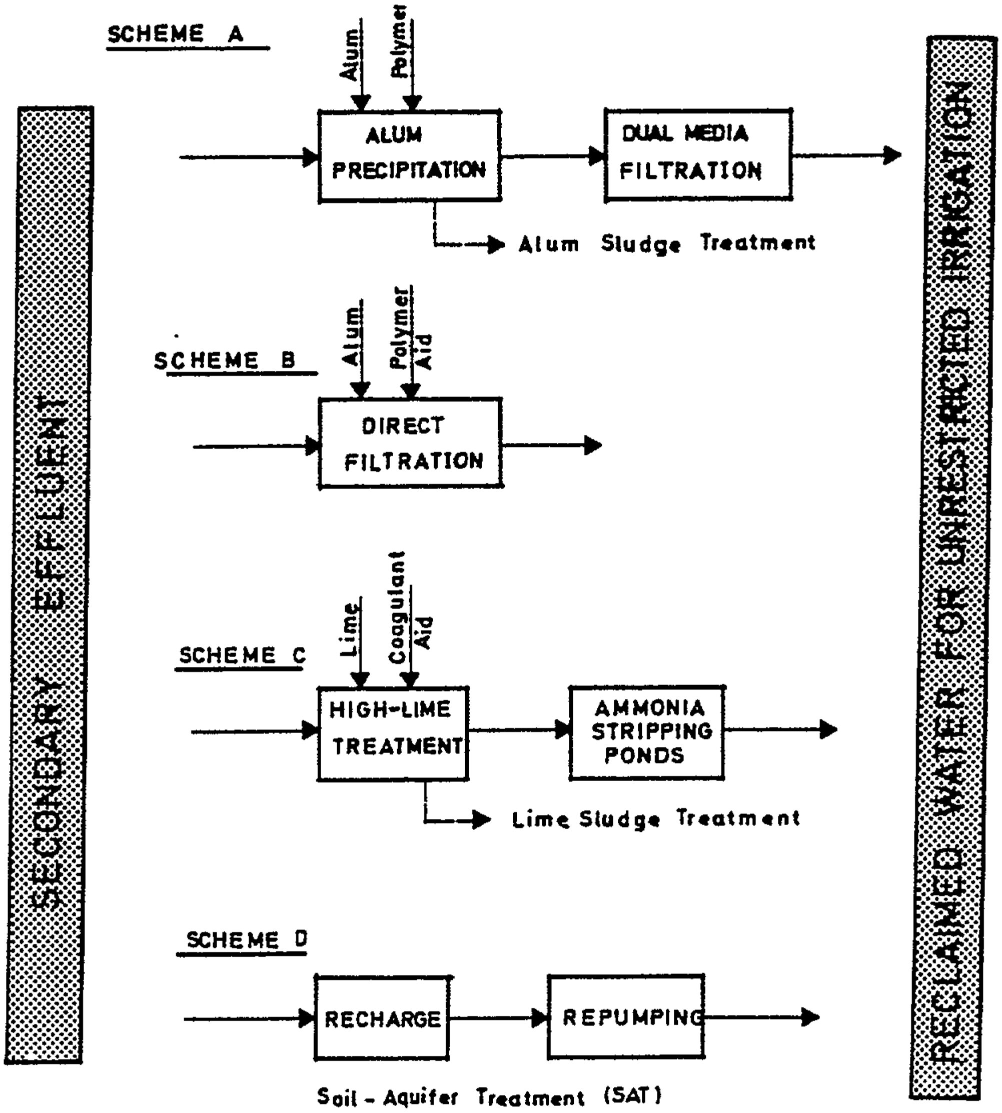

Fig.3 Additional treatment schemes for unrestricted irrigation.

Also in the case of additional treatment processes, for high quality effluent production, some alternative innovative low cost treatment methods have been developed. Some of these are mentioned before (aquacultures, overland flow and Deep Reservoir Treatment). Others are land application methods (in addition to overland flow which is also a land application method). These include:

- slow-rate infiltration;
- rapid infiltration by spreading basins to a low depth and collection of the percolated water by underdrains;
- rapid infiltration by spreading basins to the groundwater and pumping of the effluents by wells.

The last process is also known as the Soil Aquifer Treatment process (SAT). This process is practised in Israel and will be discussed in continuation. The combination of primary-secondary and tertiary treatment is, in some cases, so expensive that the production of effluent for irrigation becomes prohibitive from an economic point of view. The use of innovative low cost treatment processes instead of more sophisticated and expensive processes has considerable advantages.

As a consequence of the water shortage in Israel, a country in which agriculture depends almost totally on irrigation, municipal wastewaters in this country are considered as an important source of water, mainly for irrigation. At present, about 40 per cent of the total volume of the wastewater of Israel is utilised for irrigation. This number will increase to 65 per cent during 1986-1987, when the second stage of the Dan Region Project (reuse of the wastewater of Tel Aviv Metropolitan Area) will go into operation. The importance assigned to reuse of wastewater in Israel stimulated the development of innovative treatment systems. Two of these are briefly described below:

D.R.T. (Deep Reservoir Treatment): A deep reservoir is in fact a deep facultative lagoon (7 to 10 m), with a variable water level during the year. The reservoir provides the detention time necessary for seasonal storage of the effluent and combines seasonal storage with additional treatment. Purification is affected by aerobic bacteria and algae in the upper layer, as well as by anaerobic bacteria at the bottom of the reservoir. The design of such reservoirs is governed by the criterion of maximum organic loading per reservoir surface unit in order to minimise the environmental nuisances. The most critical period is at the end of the irrigation season, when the water level in the reservoir is at its lowest, and thus its surface area is at its smallest. Deep reservoirs are very effective in the removal of helminths, protozoa and bacteria.

When effective secondary treatment is applied as pretreatment before the reservoir, the reservoir effluent may be used for unrestricted irrigation. When lower pretreatment is applied, the reservoir effluent is appropriate only for restricted irrigation. Treatment in deep reservoirs is included in numerous small reuse schemes in Israel, and also in large-scale projects such as those of the wastewater reuse schemes of the cities of Haifa and Jerusalem.

A typical scheme that includes Deep Reservoir Treatment is presented in Fig.4. Typical effluent quality of DRT is presented in Table II. These results refer to the wastewater reuse project of the city of Haifa, Israel, which includes activated sludge treatment followed by DRT.

Table II

Haifa wastewater reuse project - water quality at various points along the treatment process

Parameter	Concentration mg l^{-1}		
	Raw wastewater	Activated sludge effluent	Seasonal storage reservoir effluent
Suspended solids	704	35	18
BOD_5	600	39	12
BOD_5 Filtered	117	9	3.8
COD	1307	105	46
COD Filtered	264	66	40
Detergents	7.1	0.5	0.4
NKT as Nitrogen	89	41	11.3
Ammonia as Nitrogen	48	36	8.4
Nitrate as Nitrogen	0.5	2	1.3
Phosphorous	12.4	6.9	4.2
pH (Units)	7.7	7.9	7.8
Total Coliform (MPN/100 ml)		10^7	3×10^2
Faecal Coliform (MPN/100 ml)		10^6	2×10^1
		Pre-treatment	Deep reservoir treatment

S.A.T. (Soil-Aquifer Treatment): This innovative process which produces a high quality effluent for unrestricted reuses involves the use of the soil and the aquifer as a treatment system, by controlled passage of effluent through the unsaturated and saturated soil zones, and subsequent pumping from the aquifers. The effluent is allowed to percolate through the unsaturated soil zone and then, to flow into the aquifer. The system consists of spreading basins on permeable soils, surrounded by a series of pumping wells. Observation wells located between the spreading basins and the pumping wells permit the continuous monitoring of the process. The spreading basins are flooded intermittently in order to maintain high infiltration rates and allow oxygen to penetrate into the soil. The high purification capacity of the system is the result of a unique combination of physical, chemical and biological processes occurring in the soil and the aquifer (6).

Incorporation of the SAT process in a reuse scheme has to include appropriate pretreatment and may include post-treatment. The pretreatment has to remove organic load and separate solids which may clog the spreading basins. Post-treatment may be used in the case where the effluent is to be supplied for potable uses. Appropriate processes for post-treatment may be carbon absorption, ion exchange, reverse osmosis and disinfection. A general reuse scheme which incorporates the SAT process, both for non-potable purposes (unrestricted irrigation) and potable purposes, is presented in Fig.5. A schematic diagram of the SAT process is presented in Fig.6.

The concept of SAT has been applied on a large scale in the Phoenix area in Arizona (7) and in the Dan Region Project (reuse of the wastewater of Tel Aviv Metropolitan Area) in Israel (8, 9). This project consists of two stages which differ in the pretreatment provided before the SAT unit. The treatment scheme flow diagrams of both stages of the Dan Region projects are presented in Fig.7. Water quality data at various points of the Dan Region treatment plant stage one are presented in Table III.

Table III

Dan region project stage one - water quality at various points along the treatment process

Parameters	Concentration mg l^{-1}				
	Raw wastewater	Oxidation ponds effluent	Lime treatment effluent	Polishing ponds effluent	Reclaimed well water
Suspended solids	240	305	140	20	0
BOD_5	285	135	40	14	0.5
BOD_5 filtered	115	15	15	4	0.5
COD	590	435	150	65	12
COD filtered	225	90	55	40	12
TOC	175	125	55	20	3.5
Detergents	12	4	3	1.1	0.2
Ammonia, as N	35	25	25	5	0.02
Total Nitrogen	60	60	38	11	6
Phosphorus	12	11	4	1.5	0.03
pH (units)	7.6	7.8	11.5	9.2	7.8
Total coliform (MPN/100 ml)	10^8	10^6	2×10^1	10^1	0
Fecal coliform (MPN/100 ml)	10^7	$6.3x10^5$	6.3	$1.2x10^1$	0
		Faculative Lagoons with recirculation	Lime-Magnesium treatment	Polishing ponds	Soil-aquifer treatment

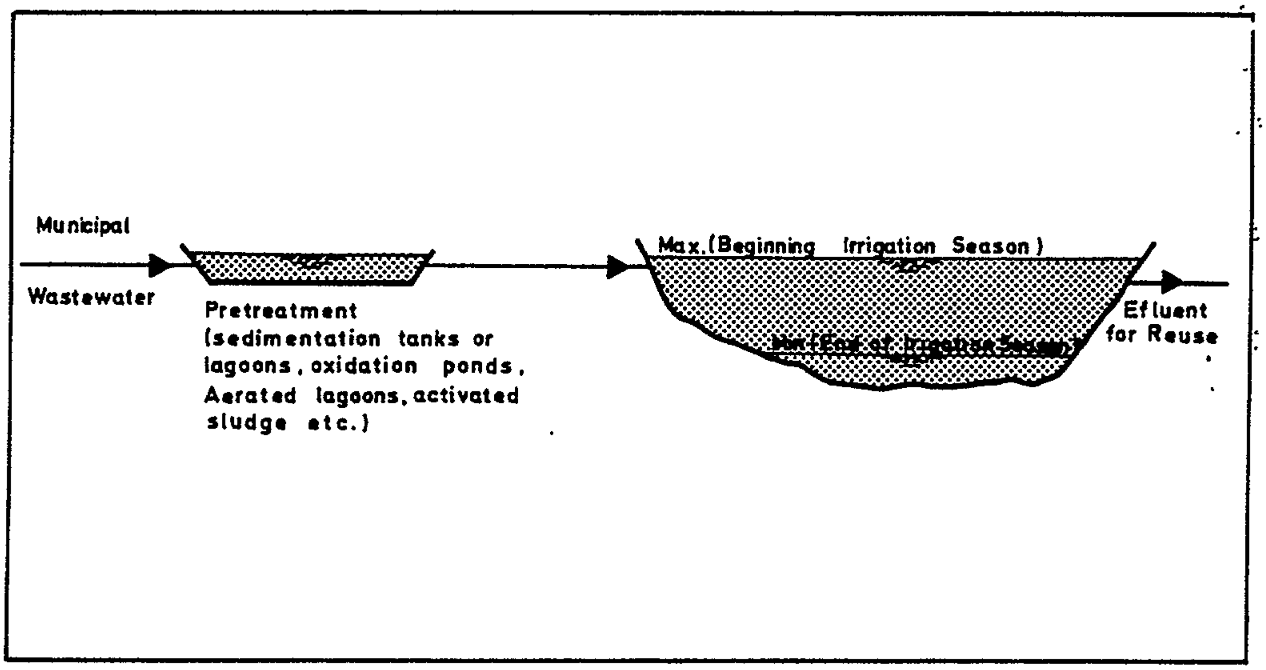

Fig.4 Scheme of deep reservoir treatment (DRT)

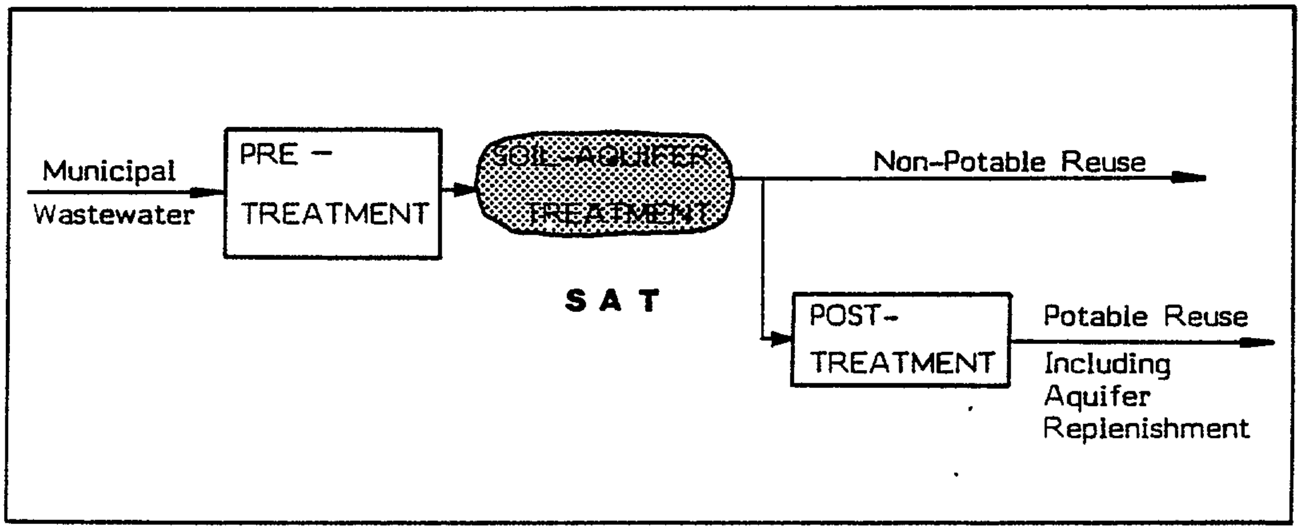

Fig.5 SAT schemes for non-potable and potable reuse

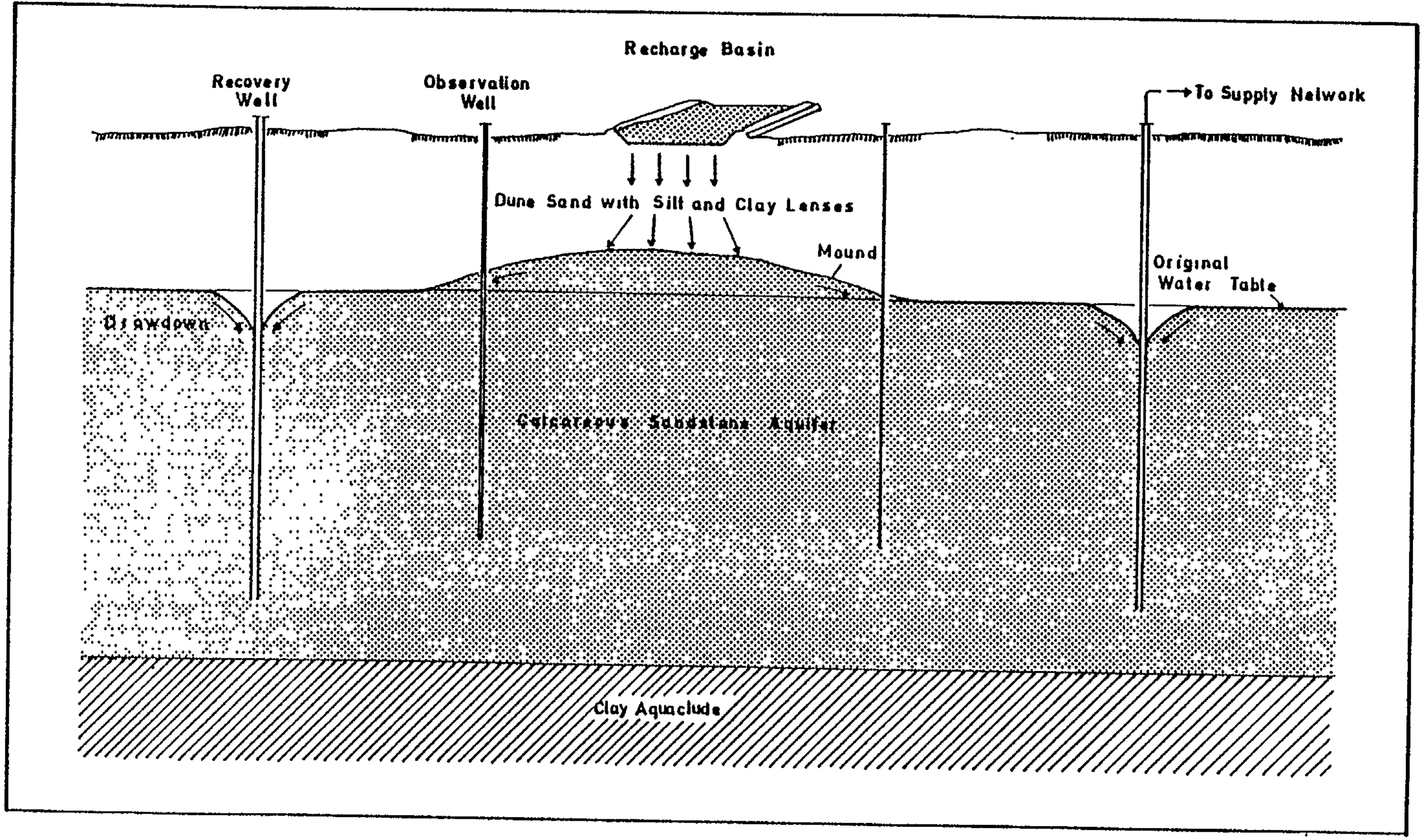

Fig. 6 Diagram of recharge recovery system by the SAT process

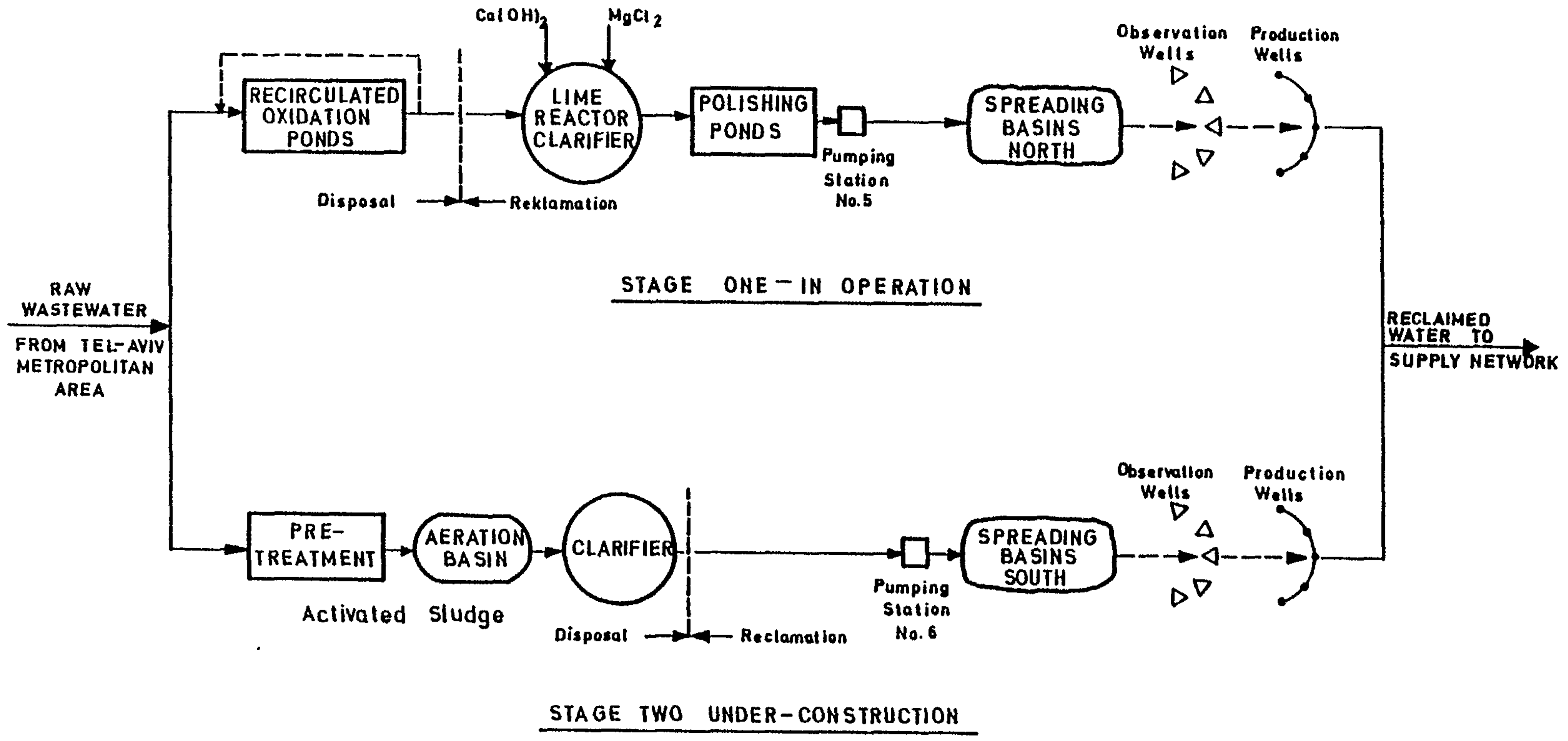

Fig. 7 Dan region project: Treatment schemes of the two project stages

5. REUSE OF WASTEWATER FOR IRRIGATION ON THE ISLAND OF MALLORCA

5.1 Introduction

In October 1985, a mission of two experts spent some days on Mallorca in order to revise and propose reuse schemes for municipal wastewater for irrigation on the island of Mallorca (10). A summary of the mission's work is presented below.

5.2 Problems related to water supply and wastewater disposal on Mallorca

Mallorca is an island with limited water resources. Certain zones of the island suffer from shortage of water for potable and agricultural uses. These problems are coupled with water quality problems.

Palma, the largest city of the island, consumes about 39 million m^3 of water per year. The main water source is groundwater. During recent years salinisation occurred in several wells and the chloride concentrations reached about 2,500 mg l^{-1}. As a result, the average combined chloride concentration is about 1,000 mg l^{-1} and higher values may be reached as a consequence of dilution problems. In order to decrease the chloride concentration to acceptable values (lower than 400 mg l^{-1}) an additional source of good quality water of about 10 to 15 million m^3 per year should be supplied instead of parts of the saline water wells.

The estimated annual wastewater flow of Palma is about 30 million m^3 per year. Two wastewater treatment plants are in operation in Palma, both of them activated sludge plants.

Plant Palma I is situated in Sant Jordi and drains the Zone of Playa del Arenal. The treatment capacity is 30,000 m^3 day^{-1} but the plant treats about 18,000 m^3 day^{-1} during the summer season and about 10,000 m^3 day^{-1} during the winter season. During summer, the effluent is utilised for irrigation (after chlorination), and during winter part of the effluent is injected into groundwater by use of wells located at the treatment plant site and in farm areas.

Plant Palma II is situated at Son Puig and drains part of the wastewater of Palma including the industrial zone. Treatment capacity is about 40,000 m^3 day^{-1} but as a result of sludge treatment problems, the actual flow is about 10,000 m^3 day^{-1}. The effluent is discharged to sea (after chlorination) via a sea outfall - Emisor de Torente Gros - with a length of about 1 km.

The rest of the wastewater of Palma (40,000-50,000 m^3 day^{-1}) is discharged to sea without treatment, via two additional sea outfalls of about a 1 km length.

Additional installations of activated sludge are under construction in plant Palma II in order to increase its treatment capacity to 90,000 m^3 day^{-1}. Works are expected to terminate at the beginning of 1987. The total treatment capacity of plants I and II will be 120,000 m^3 day^{-1}.

As a result of the high salinity of water supplied to Palma, the effluent salinity is high and reaches about 1,500 mg l^{-1} chloride.

Two traditional agricultural zones on the island of Mallorca suffer a severe water shortage problem because of salinisation of well waters (chloride concentrations reaching up to 7,000 mg 1^{1}). These zones are Sant Jordi (about 8 km from Palma) and Campos (about 50 km away from Palma). Location of these zones can be identified in Fig.8. Unless new irrigation water sources are supplied to these zones, agricultural activity may collapse.

5.3 Advantages of reuse of the wastewater of Palma

In the specific case of Palma, wastewater reuse may serve as a solution to the problems presented in the former paragraph. The advantages of such a reuse are the following:

- Increase of water resources for agricultural development on Mallorca (which is an island with limited water resources);
- Possibility of direct or indirect improvement of the water supply system to Palma (direct improvement by interchange of treated wastewater with good quality water and indirect improvement by rise in groundwater levels of Llano de Palma Aquifer);
- Rehabilitation of agriculture in areas with agricultural infrastructure, suffering from groundwater salinisation and for which no other irrigation water source is available (such as Sant Jordi and Campos);
- Prevention of sea water pollution, which is of great importance on an island whose main source of income is tourism;
- Diversification of income sources on the island so that agriculture will also become a significant source in addition to tourism.

5.4 Possible reuse areas

Based on existing wastewater treatment and reuse schemes and on a field survey, the following areas were defined as potential areas to be irrigated with Palma's treated wastewater (see Fig.8):

- Sant Jordi
- Campos
- Lluchmayor
- Binisalem
- La Puebla

In the Sant Jordi area wastewater reuse is already being implemented as previously presented, but additional land is available. Reuse in this area presents important advantages:

- The area is very close to the wastewater source (6-8 km);
- Agricultural infrastructure already exists;
- There is no risk of groundwater pollution because the local aquifer is highly saline (up to 6,000 mg 1^{-1} chloride);

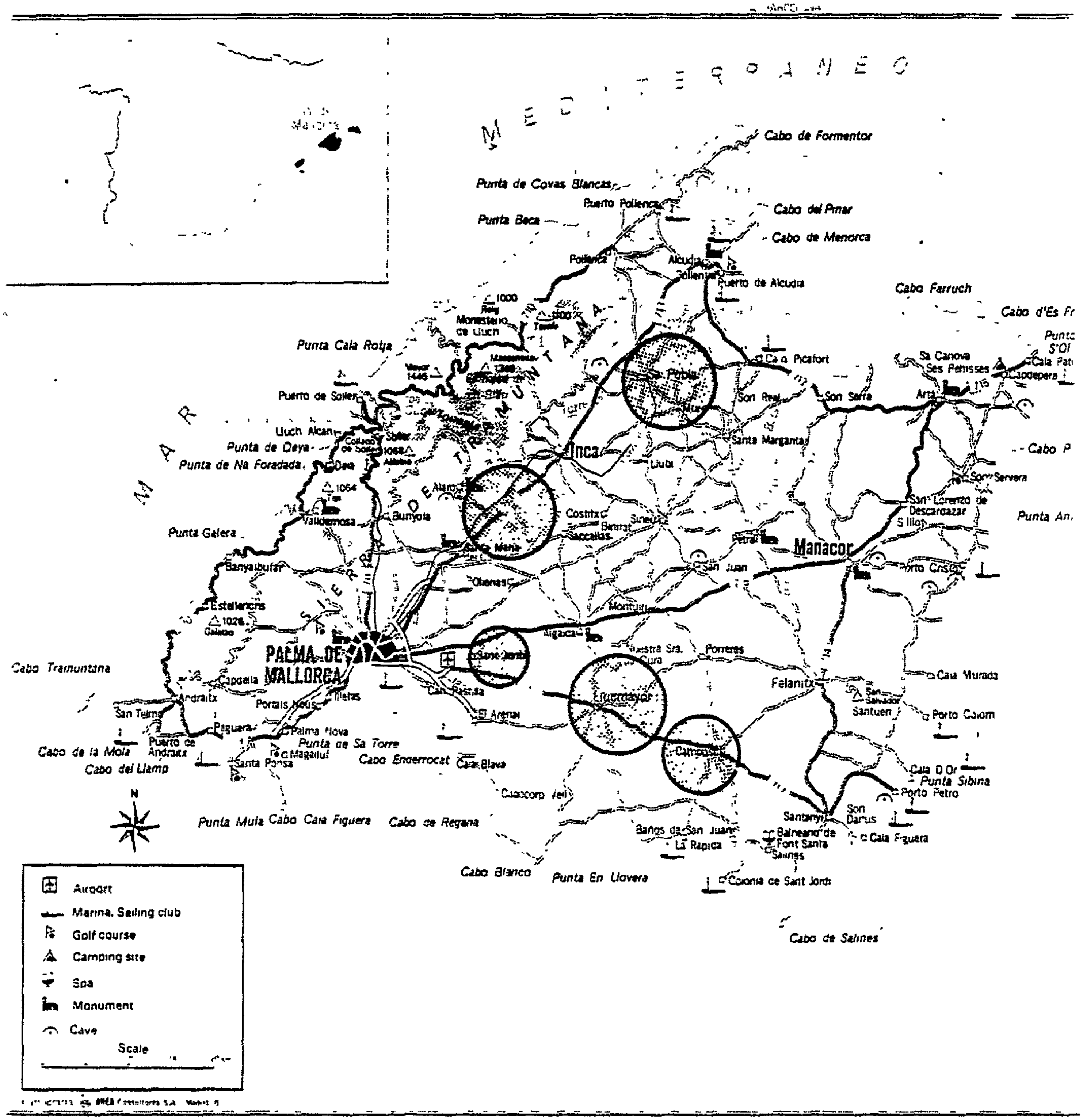

Fig.8 Location map of reuse areas related to Palma project.

- Rise of the groundwater level in the area may prevent groundwater flows from the Llano de Palma aquifer to San Jordi and thus result in a rise of groundwater levels in Pont d'Inca zone and an indirect improvement in water supply to Palma.

Considering the high salinity of groundwater in Sant Jordi, wastewater reuse is the only way to maintain agriculture in the zone.

Reuse of Palma's wastewater in Compos is the only way to maintain agriculture in this zone (which suffers from salinisation of the local aquifer with chloride concentrations of up to 7,000 mg l^{-1}). The Campos agricultural area suffers from the disadvantage of being 50 km away from Palma, a fact which is unfavourable for the economics of such a reuse system, thus an extensive agricultural practice will be preferred in order to compensate for the distance.

Luchmayor and Binisalem are situated about 20 km from Palma (see Fig.8). Both are rainfall farming zones which may be incorporated into the Palma reuse scheme and changed into more profitable and irrigated agricultural zones. Their advantage is they are relatively close to the water source.

The utilisation of the area of La Puebla for irrigation with Palma effluents presents a special case. Economically, such a reuse scheme is unfavourable because of the distance of about 50 km between the effluent source (Pala) and the reuse area. But, such a scheme may be necessary as part of a water interchange programme which will use the high quality water of the La Puebla aquifer as a water source for Palma and will supply, in exchange, effluent of Palma for irrigation in the La Puebla agricultural zone.

Another possibility for water interchange for a supply of good quality water from La Puebla aquifer to Palma is a regional reuse project based on the collection of effluents from La Puebla, Muro, Sta Margarita, Maria, Sineu, Llubi, Inca, Pollensa and Alecdia and its reuse for irrigation in La Puebla agricultural area. This may satisfy the water needs for irrigation in the zone, without the necessity for conveying effluent from Palma.

5.5 Treatment and reuse schemes for the wastewater of Palma

The proposed reuse schemes should take into consideration existing and under construction treatment facilities. Activated sludge effluent without additional treatment can be used only for restricted irrigation, because of health risks associated with this type of effluent. When considering a reuse scheme, in which water cost is high, it is preferable to provide an effluent quality for unrestricted irrigation and thus, increase project income. This is especially true in cases where effluent is distributed between a great number of consumers, as in the case under consideration, where control of adequate reuse is difficult. As a result, additional treatment is advised.

As presented in Chaper 2, seasonal storage of effluent will be necessary to compensate for the constant supply and variable demand for agriculture. It seems that in the present case, no favourable conditions for groundwater storage prevail. As a result, surface storage in deep reservoirs is proposed. Such storage acts also as an additional treatment step and will comprise additional necessary treatment by utilising the DRT treatment method, as explained in Chapter 4.

The proposed treatment scheme is the one presented in Fig.4, while the pretreatment stage comprises the existing activated sludge installations of Palma.

The combination of activated sludge treatment and seasonal storage will yield effluent which, according to new tendencies in the criteria for wastewater reuse (for example "the Engelberg Report" - Ref.2), can be utilised for unrestricted irrigation for all types of crops.

In the case of Palma II, storage volume is quite large and more than one reservoir might be needed if an adequate location for one big reservoir is not found.

As part of the proposed reuse scheme, it is recommended that drip or microsprinkler irrigation methods be adopted whenever crop types permit. These methods have two main advantages:

- They are safer from a public health point of view, of importance in the present case in which farm houses are quite close to irrigated fields;
- Water use efficiency is higher than in other irrigation methods thus permitting irrigation of larger areas and improved project benefits.

It should be noted that the application of the above methods requires effluent filtration before irrigation. The filtration should be carried out by each farmer separately, from the main supply pipe to the farm. Recent experience dictates three filtration stages: preliminary screen filtration of 40 to 60 mesh, secondary coarse sand filtration and final screen filtration of 80 to 100 mesh. All these filters are manufactured with automatic backwash.

The effluent form a seasonal reservoir may be utilised for unrestricted irrigation, provided that a long enough detention time, of at least 20 days has been maintained. Nevertheless, it is recommended that during the first stage of operation, restricted irrigation be practiced using only crops of categories "A" and "B" presented in Table I.

After a study of effluent quality and in the case it is found adequate according to reuse criteria (such as, for instance, the Engelberg criteria - faecal coliform count lower than 1,000 MPN/100 ml and intestinal nematodes less than 1 viable egg/litre - see Ref.2) it may be used for irrigation of any crop for human consumption normally consumed uncooked, and grown in direct contact with wastewater effluent (fresh garden vegetables such as tomatoes, carrots, onions, etc., or recently spray irrigated fruit). As an added precaution, it is recommended that irrigation of leafy vegetables, such as lettuce, be excluded.

In order to avoid effluent quality problems, especially towards the end of the irrigation season when detention time in the reservoir is lowest, it is recommended that an emergency chlorination installation be supplied and operated when necessary.

In addition to public health restrictions, crop selection should also be based on salinity restrictions. Considering the present high salinity of the effluent, sensitive crops should be avoided and salinity resistant crops such as cotton, alfalfa and maize should be preferred. It is expected, however, that salinity levels by EMAYA (Empresa Municipal de Aqua y Allcantarillado).

In the event that seasonal storage is not incorporated in the reuse scheme, direct irrigation with activated sludge effluent will be practiced during dry seasons while effluent disposal to the sea will be implemented during the wet season. Such a resue system suffers from two main disadvantages:

- water use efficiency is low, reduced areas cannot be irrigated, resulting in low economical feasibility;
- removal of pathogens is not complete and irrigation is restricted to certain types of crops.

Crops that may be irrigated with the activated sludge effluent are those of category "A" presented in Table I.

Adequate chlorination (using much higher chlorine doses than the ones applied at present) may remove viruses and bacteria but it is not efficient in removal of parasites. If surveys will demonstrate that parasites do not present a serious problem in chlorinated Palma effluent, this effluent can be used also for crops eaten raw.

Direct reuse of activated sludge effluent does not present a major problem from the point of view of sea water pollution, because during the bathing season (which coincides with the season of high irrigation water demand), no effluent will be discharged to the sea, similarly during the wet season, health effects of effluent discharge to the sea are minimal.

It should be emphasised that efficient use of effluent (i.e. installation of seasonal reservoir and utilisation of drip irrigation) may yield enough irrigation water to simultaneously supply some of the areas proposed in paragraph 5.4 and thus achieve the advantages presented in paragraph 5.3.

Assessment of risk associated with the various reuse schemes are discussed in Ref.10, considering public health risks, groundwater pollution risks and effects on soil and crops.

5.6 Additional reuse systems on Mallorca

In addition to reuse of the effluents of Palma, various small size reuse systems are in operation on Mallorca. These are systems that utilise effluents of small towns and villages with populations of up to 30,000 inhabitants. The reuse systems are basically the same in all cases. The raw wastewater undergoes secondary treatment in an activated sludge treatment plant. During the dry season the effluent is utilised for irrigation, mostly on fodder crops (alfalfa and maize). Seasonal storage is not included in any of the systems, and when there is no requirement for irrigation, the effluent is disposed of by other methods (such as sea disposal or groundwater infiltration).

6. IMPLICATIONS OF THE FINDINGS ON MALLORCA FOR THE ENTIRE MEDITERRANEAN REGION

Palma de Mallorca is a good example for a case in which reuse of wastewater may serve as a solution for a series of environmental and socio-economic problems. Palma may serve as a case study for the Mediterranean region, which includes numerous populated zones with similar climatic conditions and problems such as:

- Shortage of water resources for domestic supply and irrigation;
- Wastewater disposal problems and pollution of water bodies which serve as recreation sites in zones of intensive touristic activity.

An attitude similar to the one undertaken in Palma should be adopted in the entire Mediterranean zone and reuse of wastewater should be applied whenever such an approach turns out to be technically and economically feasible.

A general and brief description of wastewater treatment schemes for reuse was presented in Chapter 4 and may serve as a basis for the development of alternative reuse schemes. Considering the favourable climatic conditions prevailing in the Mediterranean region, innovative low-cost treatment methods should be sought. Such methods are based on natural purification processes, are simple and easy to operate and economically cost-effective. In Chapter 4, some of these processes were briefly presented (treatment in various types of oxidation ponds, aerated lagoons, deep reservoir treatment, soil aquifer treatment, overland flow, aquaculture, etc.).

Within the framework of PAP, wastewater reuse should be encouraged.

A demonstration project including the innovative treatment processes, reuse and agricultural systems, would be helpful for promoting the idea of wastewater reuse in the Mediterranean region and for developing design criteria for reuse systems under conditions prevailing in the region. Details of such a project are presented in Ref.10.

7. REFERENCES

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