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WASTEWATER RECOVERY AND UTILIZATION ON THE ISLAND OF CYPRUS

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1. Executive Summary

Cyprus is a water-scarce island where economic development and growth may ultimately be limited by the amount of water available for municipal, industrial, and agricultural use and the efficiency with which it is used. Annual average precipitation ranges from 290 mm in the west to 1,190 mm on the Troodos mountains for a total of about 4,500 million cubic meters per annum (MCM/a) of water on the entire island. Surface evaporation and evapotranspiration from forests and pastures account for about 2,520 MCM/a and from cultivated and irrigated crops about 1,030 MCM/a. It is estimated that about 175 MCM/a of surface water are utilized for agricultural and domestic uses, and the remaining 425 MCM/a are lost to the sea during floods. An estimated 350 MCM/a infiltrate into the groundwater strata.

Most of the groundwater resources have already been developed, and the prospect of further development of secondary aquifers is limited because of quantity as well as water quality. Serious overdrafts of groundwater for irrigation are already causing lowering of watertables, increasing well construction and pumping costs, seawater intrusion, and losses of crops, wells and cropland due to salinity in coastal areas.

Expedient responses by farmers include drilling additional wells and purchasing water from neighboring farmers, each of which continues to exhaust the remaining supplies. The most serious seawater intrusion problems are in Western Mesaoria, Southeastern Mesaoria and Larnaca areas. A stable though vulnerable balance of withdrawal and natural replenishment is maintained in Akrotiri area.

Since the events of 1974, irrigation technologies on the Greek Cypriot side have been implemented in many areas by high efficiency drip and sprinkler systems. Meanwhile, the need for a dynamic policy on the reuse of wastewater effluents has been recognized by all parties. The highest priority is being given to additional fresh water supplies for domestic, commercial, and industrial use. This may require reallocation of water rights presently assigned to farmers. The impacts of this reallocation can be minimized by appropriate treatment of municipal and industrial wastewater and their reutilization by agriculture. Financial viability of wastewater reuse can be assured by: (1) using the local secondary supplies rather than by expensively importing additional primary water, (2) introduction, possibly with subsidies, of efficient irrigation techniques for reusing wastewater, (3) assurance of an essentially constant supply of wastewater, and (4) savings in fertilizer costs by using the nutrients in the effluents.

It is expected that by 1990 there will be significant amounts of sewage effluent for direct irrigation and/or aquaculture or for hydrologic control of seawater intrusion by raising of ground-water levels to or above sea level in depleted aquifers. A comprehensive feasibility study to be followed by first stage demonstration projects for irrigation and possible aquaculture from effluents at Kamares and Nicosia are proposed. Preliminary estimates of the demonstration projects indicate costs of approximately $1.3 million for both sites. Detailed designs and budgets would be developed by the feasibility study.

Cyprus is a potentially important demonstration project area for the entire Middle East and Africa in integrated resource recovery concepts. Progress toward meeting goals of achieving economic and other benefits through waste recycling in developing countries could be enhanced by demonstrating cooperative activities in modern wastewater utilization on Cyprus. Ongoing project activities in evaluating health effects and economic benefits of wastewater utilization in irrigation and aquaculture can support the lead agency role for UNDP/GLO/80/004.

2. Introduction

2.1 Goals, and Objectives of the Resource Recovery Project

The goals of the research and development in Integrated Resource Recovery Project (UNDP/GLO/80/004) are (i) to achieve health, environmental, employment, energy, economic, social, and financial benefits through resource recovery and utilization projects in developing countries; and (ii) to assemble, assess, and disseminate technological, economic, and financial information to developing countries embarking on resource recovery.

Specific objectives stated in the original project document were: (i) to conduct and document state-of-the-art reviews of resource recovery technologies; (ii) to conduct and document case studies of the technological, environmental, institutional, employment, social, financial, and economic aspects of entrepreneurial and community systems for waste collection, and refuse and resource recovery projects adapted to specific conditions of urban and rural areas of lower- as well as higher-income developing countries; (iii) to design, install, monitor, and evaluate the initial operations of demonstration projects and to prepare terms of reference for full-scale investment projects in integrated resource recovery and utilization which will result in reduced costs of community sanitation and waste management; and (iv) to identify policy options consistent with initiating or improving productivity in sustainable resource recovery systems.

The principal categories of research and development undertaken under GLO/80/004 include (i) inorganic materials recovery; (ii) organic materials utilization; (iii) wastewater reclamation; (iv) energy savings and production; and (v) land reclamation.

2.2 Wastewater Reclamation

A priority research and development project of the Resource Recovery Project is wastewater reclamation and utilization. Among the technological and economic factors to be considered in planning and implementing of wastewater reclamation systems, particular attention should be given to existing land and water use, climate, and health profiles of rural, urban fringe, and urban areas; existing and alternative schemes for sanitation, drainage, and waste treatment; alternative agronomic, irrigation, aquaculture, and institutional interventions; and requirements for seasonal storage or disposal of surplus wastewater (11).

2.2.1 Wastewater Reclamation for Irrigation

Ancient and current systems for using human excreta in the production of food have evolved in response to economic and environmental imperatives. Other systems have evolved in areas of permanent or seasonal drought where the development of community water supply and sewer systems has introduced an additional resource, water. It is estimated that at least 80 percent of the wastewater from developing country cities is used for permanent or seasonal irrigation. Official concern over health effects ranges from minimal in the countries of south and southeast Asia to considerable in the policies of California which applies drinking water standards to sewage treatment plant effluent to be used for irrigating vegetables, or in private decisions that go further and reject even this water for irrigation.

In order to provide policy guidance for developing countries concerned with wastewater irrigation, the Resource Recovery Project commissioned a study on health effects (actual increased incidence of infection) from wastewater irrigation and to evaluate remedial measures. Data from sites in Chile, China, Egypt, India, Jordan, Mexico, Morocco, Peru, the Philippines, Sudan, and Tunisia were compared with information from Australia, Cyprus, Denmark, France, Germany, Israel, Italy, Japan, Singapore, and the United States.

The study revealed that although bacteria, protozoans, and helminths endemic in the community occur in wastewater and persist on soil and on crops, only a few cause a degree of measurable infection and disease. Four factors intervene: (i) maximum persistence of pathogens in the environment, (ii) the minimum infective doses, (iii) host immunity, and (iv) the importance of concurrent routes of infection. Available information on the first two factors indicates that helminths constitute the greatest probable source of infection from wastewater irrigation of vegetables because their infective dose is low and they persist in the environment for relatively long periods of time. This conclusion is supported by highly credible epidemiological studies that clearly relate excess helminth infection in exposed farmers in India and in consumers in Israel to raw sewage irrigation. The Jerusalem observation coincided with an outbreak of cholera, the causes of which included an exogenous source and persistence of the cholera vibrio in the environment, and sufficient inoculation of vegetables to provide an infective dose in a population with zero immunity. These and other data obtained during the study are summarized in the following list of health effects of wastewater irrigation in developing countries:

I. Low risk (low excess incidence) - viruses

Medium persistence (maximum of weeks), low infective dose, life-long immunity acquired by the very young, main route of infection in the home or by personal contacts.

II. Medium risk (medium excess incidence) - bacteria and protozoa

Medium persistence (maximum of weeks to months), medium infective dose (10^2 to 10^6 organisms), immunity is variable and transient, and main routes of infection are personal contact, food, water, and only occasionally wastewater irrigation (cholera, typhoid, Shigella).

III. High risk (high excess incidence) - helminths (hookworm, tapeworm, Ascaris, Trichuria)

High persistence (months), very low infective dose (one egg), no immunity, and main routes of infection outside the home (occupational and consumer health effects of sewage-irrigated vegetables eaten raw).

Some remedial measures for the control of health effects include:

(1) Crop regulation and monitoring. These are effective where land tenure and/or water rights are effectively administered, as in Khartoum and parts of Mexico City.

(2) Selection and scheduling of irrigation technology. Drip irrigation systems ensure the least contact between people and pathogens in the water, followed by sprinkler, basin, and ridge and furrow systems. Effects can be reduced by suspending irrigation during the last month before harvesting.

(3) Disinfection of produce at the household level. This measure is probably effective only at low levels of contamination.

(4) Improvement of occupational hygiene. This option may provide temporary control.

(5) Prophylaxis or chemotherapy. For carefully targeted and motivated groups of people, this may be effective.

(6) Wastewater treatment. Properly planned and operated waste treatment systems that are designed primarily for pathogen removal rather than BOD removal provide cost-effective options.

(7) Combinations of the above.

From the incidence of infection attributable to wastewater irrigation, it can be concluded that (i) wastewater treatment provides simultaneous protection to sewage farm workers and to the general public without the need for programs to change the personal behavior of masses of people, and (ii) combinations of treatment technologies and/or other remedial options may be equally effective in specific cases. Table 1 lists removal effectiveness of wastewater treatment processes in $\log_{10}$ units or successive 90 percent removals (for example, one unit equals 90 percent removal, two units equals 99 percent removal, etc.).

Table 1: Generalized Estimated Enteric Pathogen Removal Effectiveness of Wastewater Treatment Processes (in $\log_{10}$ units)

Treatment	Viruses	Bacteria	Protozoans	Helminths
Primary sedimentation	0-1	0-1	0-1	0-2
Trickling filters	0-1	0-2	0-2	0-1
Septic tanks or anaerobic ponds (1 to 2 days)	0-1	1-2	2-3	3-4
Activated sludge	1-3	1-3	1-3	1-3
Stabilization ponds (20 days - 4 cells)	2-4	4-6	4-6	4-6

Chlorination has been excluded from Table 1 because it is inapplicable in most developing countries. In industrial countries chlorination is effective against infection from bacteria and protozoa in secondary effluent when there are few, if any, other routes of infection. It is not particularly effective against viruses or helminths.

For developing countries, stabilization ponds are clearly a preferred means of dealing with the health effects of wastewater irrigation, particulary where vegetables are eaten raw. Associated land costs in urban fringe areas where services are lacking and where sewage treatment and farming take place typically range from about 5,000 to 20,000 USD per hectare. The tradeoff between land costs and the cost of transmission to more distant sites is influenced by alternative land uses, soil fertility, climate, and numbers of crops per year, and may favor higher yielding aquaculture systems over irrigated agriculture.

Design criteria for wastewater treatment facilities can be classified as follows:

Operational

Priority 1. Removal of high-risk helminths.
Priority 2. Significant reduction of medium-risk bacteria and protozoa, and of low-risk viruses.
Priority 3. Nuisance-free effluent.

Technical

Priority 1. Close matching of capacity to demand. Interim technical solutions (these should be robust, easily upgradable, and capable of extension).

Financial and economic

Priority 1. Comparable economic costing, maximizing of benefits from each alternative through proper design and operation, and involvement of the users in making the interim and final cost-benefit determinations. Consideration of alternative technologies and service standards during the early phases of project identification and preparaton.

The costs and benefits of meeting the above priorities are presented in Figure 1. Cost ratios of conventional sewage treatment to stabilization pond facilities depend upon land and sewage transmission costs. Total cost include those for storage, disposal, and other system components. Ponds are demonstrably more cost effective than conventional treatment, and 20-day pond systems are recommended for Mediterranean climates with due regard for closely matching capacity to demand.

2.3 Purpose and Scope of this Report

This report summarizes the findings of consultants commissioned by the Resource Recovery Project to investigate existing and potential utilization of wastewater on the Island of Cyprus. It concludes with recommendations for feasibility and related studies demonstration projects, and cost estimates for implementing them. This report constitutes a technical basis for a potential project for wastewater recovery and utilization on the Island of Cyprus.

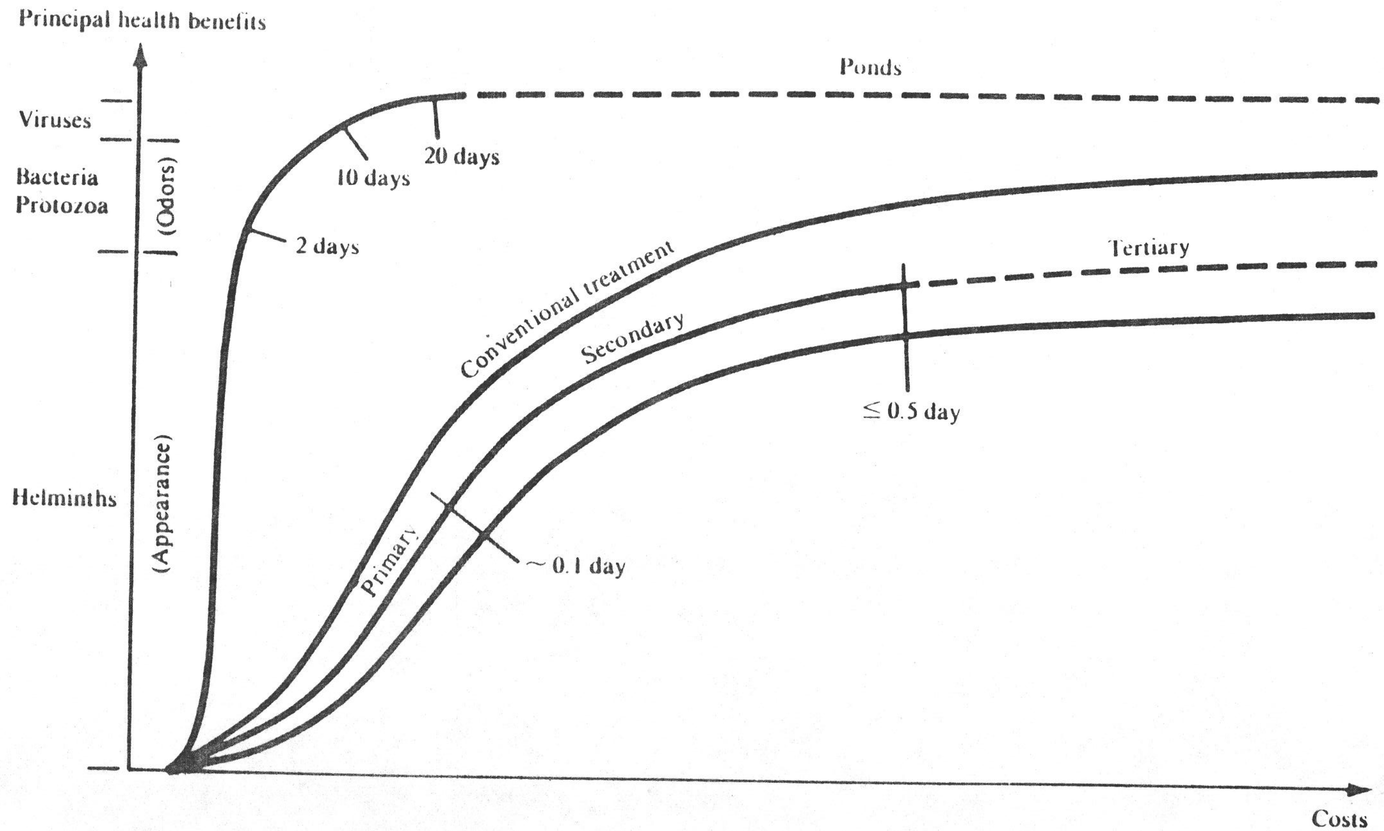
3. Background

3.1 Physical Setting

Cyprus, an island with 9250 km^2 in area and a total coast line of 780 km, is situated in the northeastern end of the Mediterranean Sea, centered on latitude 35° 00' N and longitude 35° 15' E. (Plate I) It is dominated in its topography by the Mountains of the Kyrenia Range in the north with its highest point at 1000 m above sea level and the Troodos Mountains in the southwest and Mesaoria Plain lying between these two mountains. The highest teak of the island attaining an altitude of 1950 m is the top of the Troodos Mountains.

Cyprus has a semi-arid climate of hot dry summer from mid-May to mid-September and cool, wet, rather changeable winters from November to mid-March, separated by short spring and autumn. The mountain temperatures fall below zero in the winter while the mean air temperature of the central

Figure 1. Health Benefits or Investments in Waste Treatment for Irrigating Vegetable Eaten Raw in Developing Countries



Note: Actual ratio of cost of conventional treatment to cost of stabilization pond depends mostly on costs of land and transmission.

lowlands remains 10° - 11° C and coast areas 12° - 13° C in January and in the summer the temperatures rise occasionally to above 40° C. With an average of 340 days of bright sunshine annually, the rainfall, confined to the months from October to April, averages 500 mm per year in the mountains and 250 mm in the central lowlands which represents about 4600 mcm of water in an average year over the whole area of the island. The total surface flow in an average year is about 600 mcm with a loss to the sea of about 450 mcm. Many intermittent streams drain Cyprus Island, which are active during wet periods, except in their upper reaches. There are two major lakes in the island which are salt lakes at Larnaca and Limassol and about 20 percent of the mountainous regions are covered by forests. The potential mean evaporation in Nicosia varies from 1.2 mm per day in January up to 10.3 mm per day in July with a mean evapo-transpitation of 1,500 mm/year.

3.2 Geology

Groundwater resources in the Island of Cyprus derive from rainfall (Plate II) and lithology (Plate III) of the sedimentary formations and the geologic structure of the island. Cyprus can be divided geologically into four main categories each building tectonically one belt but trending approximately east-west. These four (Fig. 2) belts are:

- The Troodos Mountain is an igneous massif with a core of harzburgite with peripheral gabbro, diabase and pillow lavas and the highest peak reaching 1950 meters.

- The Mesaoria Plain separates the two mountain ranges.

- The Kyrenia Range in the north and Troodos in the south.

- The Coastal Plain varies in width, and is found almost everywhere between the mountains and the sea. These coastal plains have wave-cut terraces resulting from changing sea levels in the Quaternary, as do over-deepened beds of many of the rivers.

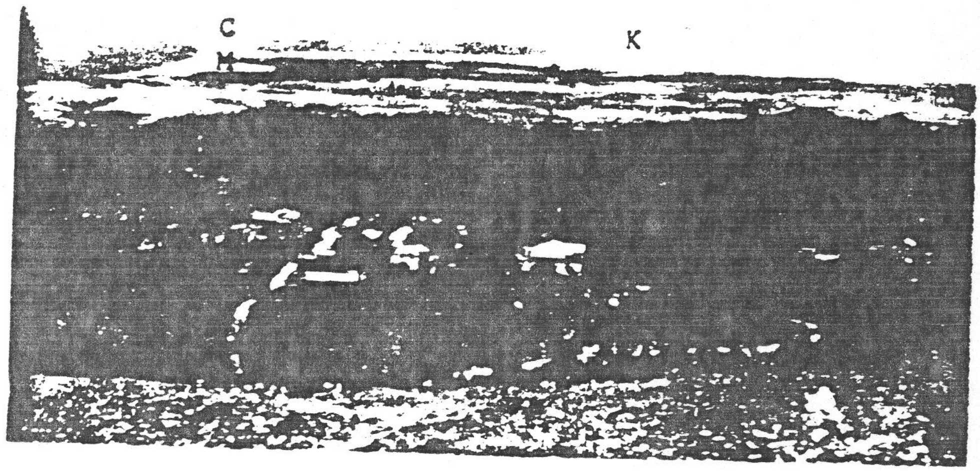


Figure 2: Four Tectonic Units of Cyprus: (T) Troodos, (K) Kyrenia, (M) Mesaoria, (C) Coastal Plain

The Troodos Mountains, a pre-Cambrian massif with a core of plutonic (ophiolitic) rocks forming the crest of the range, is built of basic igneous rocks (Harzburgites, dunites, clinopyroxnites and gabbro). The water found in shear zones, fracture zones and faults mainly in the gaebbros is of local importance and of very good quality. The ophiolitic core is surrounded by sheeted dikes and an outer peripheral belt of extrusives. The extrusives are mainly pillow lavas of basalt and olivine basalt. The Troodos pillow lavas are overlain by a thick sequence of sedimentary rocks of radiolarian mudstones, bentonitic clays, siltstones and micacceous sandstones of upper Cretaceous.

The Jurassic Hilarion limestone is found only in the Kyrenia Range, where it outcrops as upthrust slices forming a significant dramatic skyline. This karstic limestone is the most important aquifer of the consolidated rock units in Cyprus. The Hilarian formation stretches from Cape Kormakiti in the northwest of the island to Komi Kebir at the root of the Karpas Peninsula with a thickness of 100 feet in an area of up to 2.5 miles wide.

The upper Cretaceous (Maestrichtian) is the beginning of calcareous deposition all over Cyprus. It begins with Lefkara formation which consists of marls, marly chalks, chalks, and limestone. The pillow lavas occur as a fringe to the Troodos Complex, as separate outcrop in the Troulli area, and a thrust slices in the Kyrenia Range. They are submarine andesitic lavas, containing zeolites.

The Lapithos Group range in age from upper cretaceous to upper oligocene. The rocks are mainly marls and chalks often with flints. Nummulitic limestone occur in the Eocene on the east side of the island, while in the Kyrenia Range there are thin bedded flinty limestone. In the Kyrenia Range, the lapithos was exposed to the full force of the Alpine folding and is much sheared. South of the Troodos Mountains it was shielded and is gently folded. The Miocene sediments in Cyprus embraces two major facies. South of the Troodos Mountain, the Pakhna Formation consists of chalks, marls and some sandstones and gypsum lentils, not very dissimilar from the underlying lapithos beds, except for the absence of flint in the Pakhna - locally based conglomerate and at Terra reef - limestone separate the two groups.

North of the Troodos Mountains and especially along the whole line of the Kyrenia Range, the contemporaneous Kyrenia formation consists of flysch type sediments composed of material eroded from the rapidly rising Kyrenia Ranges. On the south, there existed a sinking fore deep, whose rate of sinking balanced the rate of deposition. As a result sedimentation took place in shallow lagoons, often cut off from the open sea by sandlanks, in which evaporation and salt concentration was high. There are many gypsum beds and the rocks contain much cagmate NaCl. Blue-black clays, rich in iron sulphides and carbonaceous matter are common. In clearer water to the south, the Koronia reef - limestones were formed. The Kythrea Formation was folded almost as soon as deposited on the south of the Kyrenia Range.

The Mesaoria Group consists entirely of post-tectonic formations. The Pliocene marls were built down in basins and they were followed by the Nicosia Formation, a littoral and shallow water sandstone. The interface between the pliocene and the miocene has been revealed by drilling in many areas and suggests sudden encroachments of the transgressive pliocene sea over the post miocene landscape. In turn, there was a Middle Pliocene emercenge, followed by the deposition of the Kyrenia Formation, similar in facies to the Nicosia.

The Quaternary deposits are very varied and cover large areas of eroded Miocene and Pliocene. They consist mainly of sands and gravels laid down under deltaic, fluvial, littoral and flood plain conditions, as well as sand dams and related aeolian deposits.

3.3 Soils

Most of the coastal and coastal interior lowlands are overlain by a variety of soils to moderately or strongly developed soils which, because of generally satisfactory depths up to about 10 meters and favorable physical and chemical properties, are suitable for all crops. (20).

In the Central Mesaoria plain in the immediate vicinity of the Nicosia sewage treatment plant, a soil survey carried out by Florin (10) revealed slight development to about 2 meters in depth, and generally similar surface and subsoil textures. No hardpan or caliche layers, which would restrict vertical water movement, were found.

3.4 Hydrogeology

3.4.1 Water-bearing Properties of Geological Units

An outline of the hydrogeology of Cyprus is presented in Table 2 and the island's rock units may be divided accordingly into three main categories of first class aquifers, second class aquifers and aquicludes.

Table 2: Water-bearing characteristics of major geological formations of Cyprus

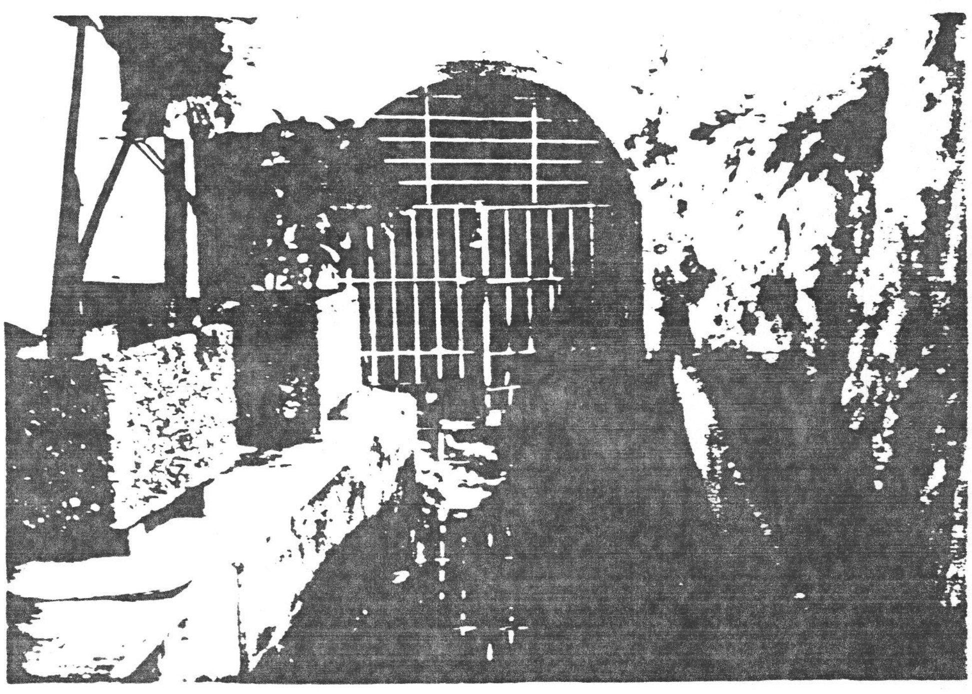
Era	Geological period	Formation	Water-bearing Characteristics
	Recent	Deltaic, fluvial littoral and flood plain alluvium	Porous aquifer, abundant water where deposits are thick.
CENEZOIC	Pleistocene	Terrace gravel	Unconfined water in marine and terresterial fanglomerate and terrace formations.
	Pliocene	Anthalassa Formation Kyrenia Formation Nicosia Formation	Porous aquifer, unconfined and confined water where deposits are thick and topography is favorable. Aquiclude in marls, marly limestones and sandy marl.
	Miocene	Kythrea Formation Pakhna Formation Koronia Formation Terra Formation	Aquiclude Groundwater in Sandy Parts Mainly impermeable, rare springs where jointed aquifers; limited extent.
MESOZOIC	Oligocene Eocene Paleocene Mastrichtian* & Lower Cretaceous	Lapithos Lefkara	Aquifers of secondary importance importance, occasionally mineralized
		Pillow Lavas	Aquiclude
	Jurasic	Hilarion limestone	The most important jointed fissured aquifer of the island
	Triassic	Sykhari Formation Mamonia Formation	Aquiclude
	Pre-Cambrian Troodos complex	Harzburgites, gabbros and serpentines	Jointed-fissured aquifer; low infiltration

The most important (Class I) aquifers of Cyprus are defined as those extending over at least 40 square kilometers with depths over 10 meters and are the extensive four coastal Plio-pleistocene aquifers of Western Mesaoria, Southeastern Mesaoria, Akrotiri and Kiti (Plate I).

Secondary aquifers consist mainly of those rock units which store and transmit water through their joints, fractures and solution channels. The harzburgites and gabbros of the Troodox complex are the most extensive of jointed aquifers. Infiltration, movement and storage of groundwater is directly related to the degree of rocks fracturing in the Troodos Massif and in general, more groundwater will be found in higher elevations where rainfall is higher.

The Hilarion Karstic limestone which covers 1.75 percent of the island is the most important Class II aquifer. This limestone is fringed with springs mostly with small yields, but also some major springs (Fig. 3) with very significant discharge.

Figure 3. Kythera Spring, September 1983



To the south, the Koronia reef limestone of Miocene age outcrops along the northern flank of the Troodos massif and to the south of Famagusta is also one of second class but less significant aquifer of Cyprus. In the area of Kyrenia, there is an aquifer in a number of Quaternary terraces, which are second class aquifers of local importance. Thickness of these terraces vary from 3 to 30 m with 2 saturated zones of up to 5 m.

Below is additional information on the four most important aquifers of Cyprus. Other details of the hydrogeology of the island are given in Appendix 3.

3.4.2 Western Mesaoria Aquifer

The western Mesaoria, which extends about 400 km^2 and includes vast lowland sloping to the west towards the shoreline bounded by the Kyrenia Ranges on the north and the Troodos mountains on the south, is the most important aquifer in Cyprus with a maximum depth of 100 meters. It consists mostly of sands and gravels with discontinuous intercalated beds of marly (calcareous) sands. The average annual withdrawal of this aquifer is about 85 mcm against an annual replenishment of 60 mcm so that the water table is sloping inland from the coastline (Fig. 4), and seawater is moving inland. Salinization of coastal groundwater during the last 20 years shown in Fig. 5 has resulted in the present location of isochlors.

3.4.3 Southeastern Mesaoria Aquifer

The southeastern Mesaoria aquifer covers an area of about 500 km^2. This Aquifer differs from western Mesaoria in two important aspects; it is more exposed to sea-water intrusion and is more diversified--in its lithologic and structural nature. The average annual replenishment of this aquifer is 25 mcm roughly. There are some 3,500 boreholes at the present operating in this area, 47 percent from which are illegal. The mean annual lowering of the water table (Fig. 6) is about 1.5 m. Because of about 50 mcm yearly extraction from the aquifer total reduction of 200 mcm of ground reserve has been incurred since 1963. The sea water intrusion salinized (Fig. 7) some areas of this aquifer and overpumping has depleted some other areas. In the areas of Athna and Avgorou the aquifer is practically exhausted.

3.4.4 Akrotiri Aquifer

The Akrotiri aquifer is the third largest aquifer in Cyprus extends form west of Kouris river to Phassouri and east of Zakaka and cover an area of about 42 km^2 (Plate I).

The aquifer is made of gravels, sands and boulders. Replenishment of the aquifer comes mainly from seasonal infiltration, the greatest part through inflow of Kouris river, from rainfall and return flow from irrigation. The annual replenishment is about 32 mcm and the total outflow for an average year is still similar to replenishment generally. Therefore, the water table slope and the general flow in Akrotiri aquifer is still from the north to the south.

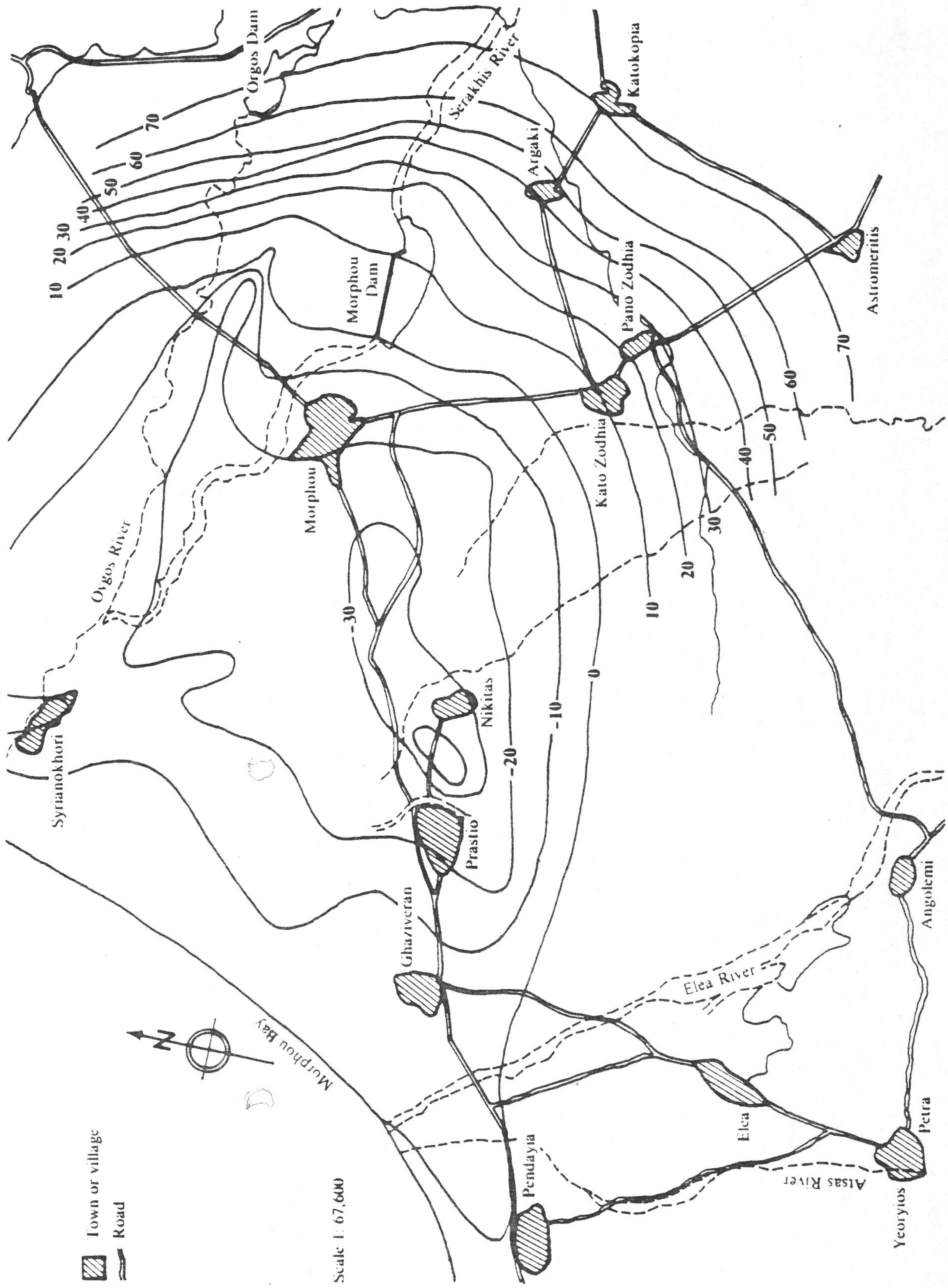


Figure 4. Groundwater Level Contours in Western Mesaoria Aquifer, February 1983

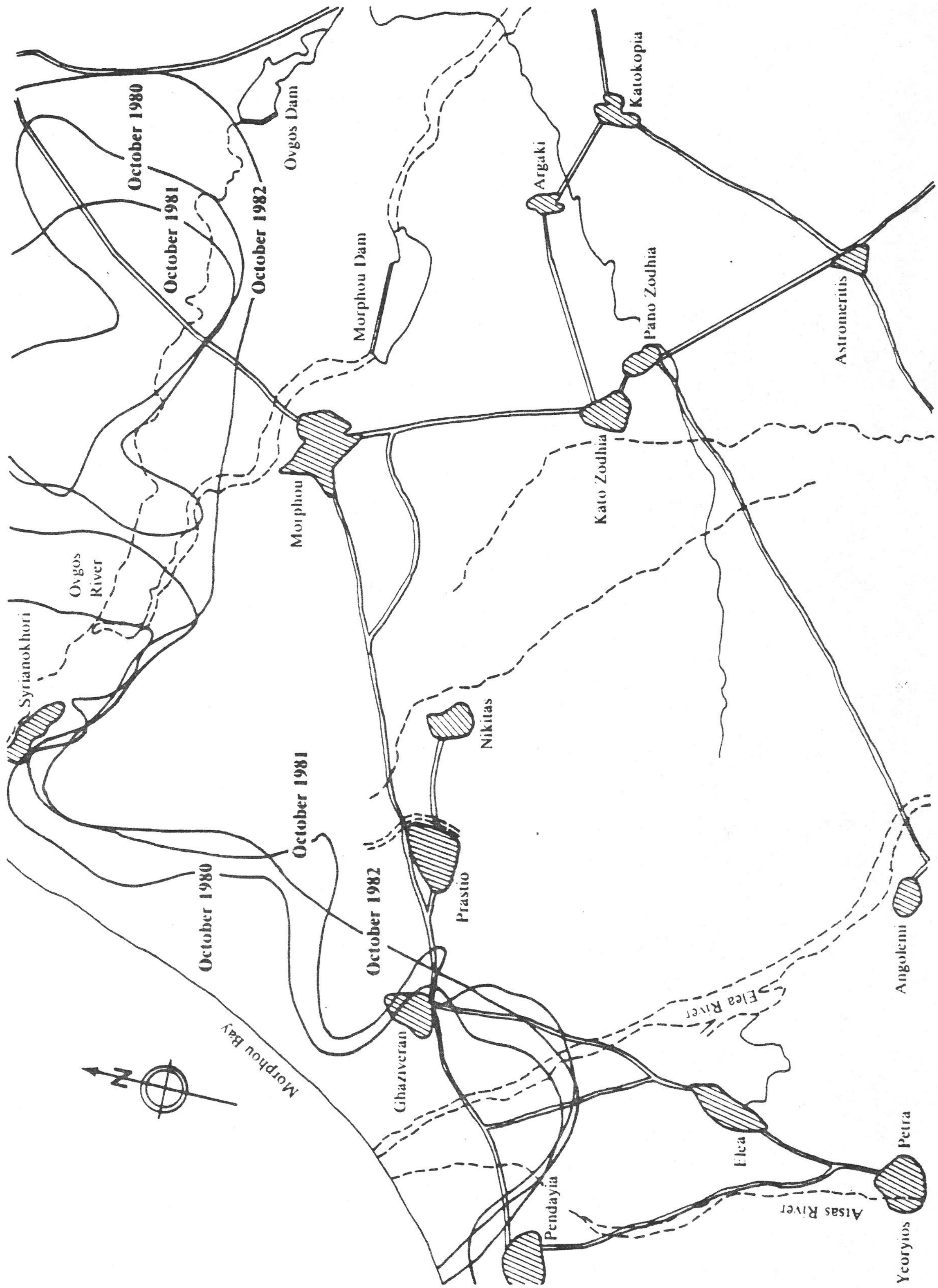


Figure 5. Landward Movement of 500 mg/l Chloride Concentrations in Western Mesaoria Aquifer, October 1980 to October 1982

Figure 6. Groundwater Level Contours at Kokkinokhoria, 1983

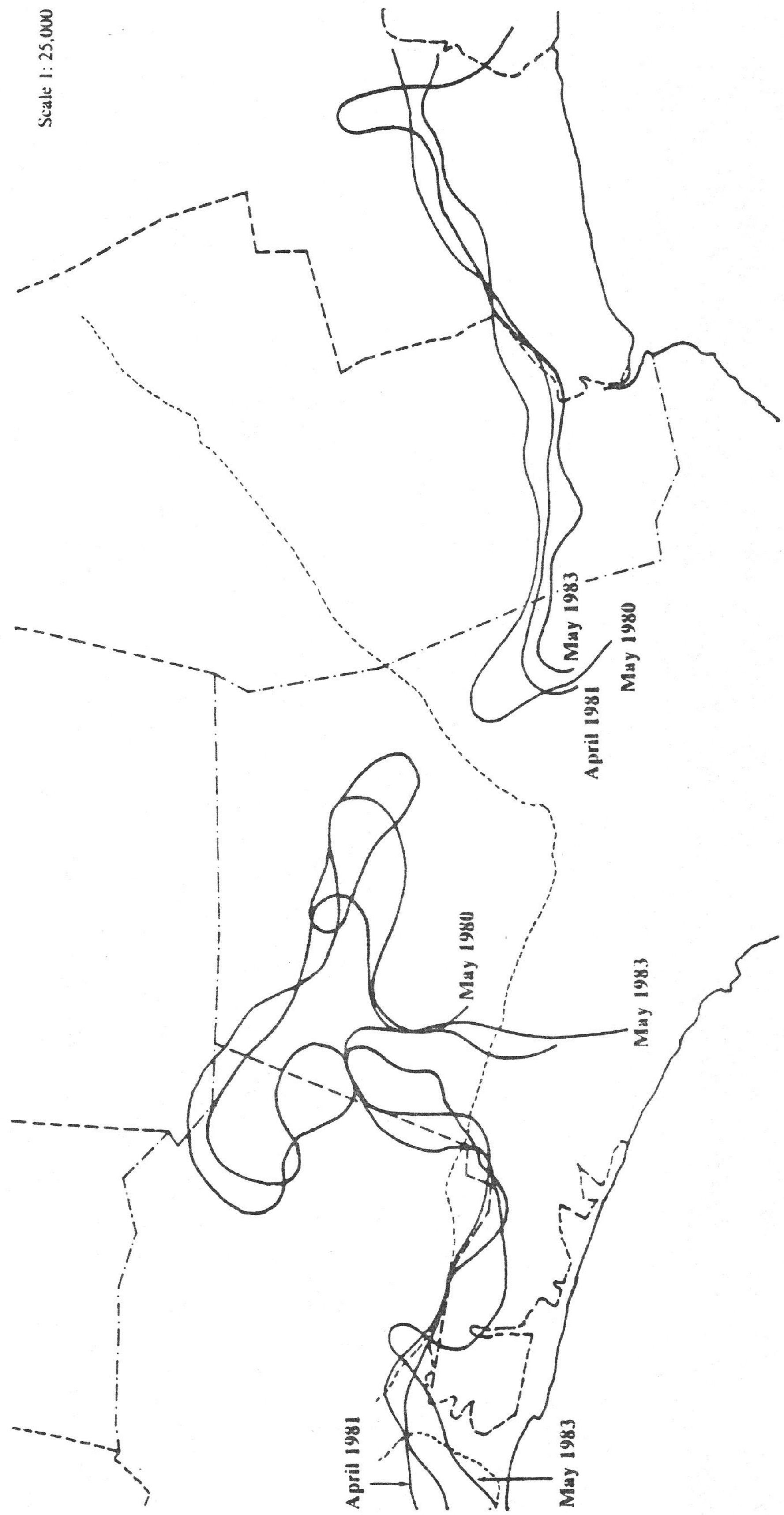


Figure 7. Locations of 500 mg/l Chloride Concentrations in the Kokkinokhoria Aquifer, 1980 to 1983

3.4.5 Larnaca (Kiti) Aquifer

The Plia-Pleistocene aquifer of Kiti which covers an area of about 30 km^2 represented by gravels, sands, silts, thin yellow marls and lenses of conglomerate. The water table is mostly 2-3 deep along the riverbed and the water is found mostly in the basal conglomerate and in the river alluvium along the riverbed.

The total recharge of the aquifer is from 2-16 mcm/yr in a relatively dry year to 7 mcm/yr in a very wet year and the estimated pumping is about 3 mcm/yr. It appears that the sediments of the river channel constitute a preferential course of groundwater flow and much of the infiltrated water flows to the sea.

3.5 Land Use

Of the total land area in Cyprus of 3,570 square miles (925,000 ha), only 424,000 ha are arable (10). Dryland field crops (mainly barley) occupy some 380,000 ha, and only 44,000 ha (about 10.4%) are under controlled irrigation (excluding spate irrigated areas) located along streams. Olive and carob orchards, cereals, and grapes have been cultivated times. Recent changes in crop patterns are in response to technological and marketing trends.

Irrigation began near rivers and springs and has expanded other areas where groundwater is found. At the begining of the 20th century, the groundwater reserves started to be exploited by the introduction of wind mills. In the 20-year period, 1904-1924, only 7 boreholes were sunk; in the next 20-year period, 1925-1945, 915 boreholes were sunk, but in the five-year period, 1946-1950, sinking was at the historical rate of 1,000 per year and these wells were all for irrigation.

Spate irrigation is the flooding of fields during the winter and early spring months with water diverted from the river. It is estimated that up to 18,000 ha of cereals, olives, carrots, and almonds can be irrigated in this way in wet years.

Potatoes, table grapes, tobacco and citrus fruits and table grapes, are the principal crops grown on irrigated lands. Table 3 (from FAO 1983 Statistics) gives summarized information about crops and other agricultural and land use statistics of Cyprus.

Citrus orchards account for 38% of the total irrigated area and are found primarily in areas where groundwater exists. Such areas are the western Mesaoria, Southeastern Mesaoria and Limassol. Irrigated table grapes is another major agricultural product of the island. The total area of some 3,000 ha is producing grape varieties mainly for export.

Potatoes earn more foreign currency for the country than any other agricultural export. Most of the vegetable crops such as potatoes, tomatoes, beans, onions, peas, cow-peas, and cabbages are grown on both the coastal

Table 3: Cyprus Agriculture (FAO)

Drescription	Unit	1961-1965	1970	1975	1980	1981	1982	1983	ANNUAL RATE OF CHANGE 1969-82	1977-75	1977-80	1978-82
Land Use	1000 HA											
Total Land			924	924	924	924						
Arable-Pers.Crops Land			432	432	432	432						
Irrigated Land			94	94	94	94						
Forests & Woodland			171	171	171	171						
Population	1000											
Total		585	604	609	620	623	627	630	.3	.2	.3	.5
Agricultural		240	233	221	212	210	209	207	-1.0	-1.1	-1.0	-.7
Labor Force	1000											
Total		243	253	262	271	274	277	279	.8	.8	.8	.8
Agricultural		100	98	95	93	92	92	92	-.5	-.5	-.5	-.5
National Accounts	Million $											
Total GDP	Current	295	502	639	1970	1915						
Agricultural GDP		61	86	110	213	198						
Production												
Agric. Production	1000 HT											
Total Cereals		150	100	118	123	121	101	104	-.3	-7.6	2.7	-2.4
Root Crops		124	213	121	211	223	223	229	1.6	-9.3	1.9	7.6
Total Pulses		13	10	8	8	7	7	7	-4.2	-12.4	-3.5	-3.7
Oil Crops		16	8	21	31	19	31	21	7.5	2.3	11.0	14.1
Livestock (Number)	1000											
Cattle		33	34	32	41	42	43	43	2.1	-.9	2.2	3.8
Sheep		418	418	440	515	525	530	53	2.0	-.6	1.7	1.1
Goats		164	335	320	360	360	360	360	.4	-3.1	-.3	.6
Pigs		37	113	121	173	186	194	200	5.3	.1	4.2	5.8
Fishery Production	1000 HT											
Freshwater & Diadron									-1.1	-24.4	-3.0	4.6
Saline Fish			1	1	1	1			-.8	-8.0	-.6	4.7
Shellfish									.7	-10.2	-1.9	1.2
Aquatic Plants												
Forestry Production												
Fuelwood & Charcoal	1000CH	14	28	20	20	20	20		-3.2	-9.5	-4.1	-.2
Industrial Rosenwood	1000CH	54	52	61	60	56	62		1.9	.1	1.7	- 1.3
Sandwood & Panels	1000CH	22	16	38	60	50	60		14.6	17.9	20.1	-1.3
Paper	1000CH											
Major Commodities												
(AG+FI+FO Production)												
Potatoes	1000 HT	175	208	117	208	220	220	226				
Grapes	1000 HT	110	183	173	208	213	210	221				
Olives	1000 HT	15	7	20	30	18	30	20				
Ind Pigheat	1000 HT	2	12	12	15	18	18	18				
Ind Chckheat		2	9	9	14	14	15	16				
Ind Sheetheat	1000 HT	3	4	5	6	6	6	6				
Barley	1000 HT	86	56	69	101	101	80	84				
Oranges	1000 HT	59	89	83	120	123	123	123				
Sheep Milk	1000 HT	12	19	20	25	26	26	27				
Goat Milk	1000 HT	11	27	32	38	38	39	40				

NOTE: AG = Agriculture
FI = Fishery
FO = Forrestry
HT = MT = Metric ton
IND = Indigenous

plains, as well as in the hilly and mountainous areas of Cyprus. For example, potatoes are mainly grown in the Kokkinokhoria and artichokes in the Kiti area.

Private ownership accounts for 93% of the agricultural lands. Some eighty percent of private land is farmed by the owners while rental contracts account for about one-quarter of the total farm area. The average farm size is about 4.5 ha.

4. Water Resources and Utilization

4.1 Surface Water

Cyprus has a typical Mediterranean climate with light winter rainfall and hot, dry summers. The average annual precipitation in Cyprus ranges from 290 mm in the west to 1190 mm in the Troodos mountains, for a total of about 4,500 million cubic meters per annum of water on the entire island. Surface evaporation and transpiration from forests and pastures account for about 2,520 mcm/yr and from cultivated and irrigated crops about 1,030 mcm/yr. An estimated 350 mcm/yr infiltrate the ground, resulting in about 600 mcm/yr net surface runoff.

Cyprus is divided into 39 watersheds but there are no perennial rivers. The largest run-off is that of the Kouris watershed at 50 mcm in an average year. In the lower reaches the larger rivers flow until June only.

Storage sites for development of surface water are relatively few and expensive to develop. Public water supply for domestic and industrial use is the second largest (next to agriculture) user of the water resources.

The total storage capacity of reservoirs in Cyprus, mostly for irrigation, including the recently completed Asprokremmos dam near Paphos, is 116 mcm. These provide an average water yield of 86.7 mcm/yr of which about 5 mcm/yr is being used for domestic water supply. The Vasilikos-Pendaskinos Project, which is presently under construction, will add about 32 mcm of storage capacity and provide 7 mcm/yr for domestic use and 7.4 mcm/yr for irrigation of about 1,600 ha. The Khrysokhou Irrigation Project will provide 23 mcm storage capacity at the Evretou dam to serve 2,000 ha of irrigation area. Full implementation of the US$254 million Southern Conveyor Project will add another 115 mcm of surface storage for surplus water from the southern catchments of the Troodos mountains, and provide conveyance of this water to areas of demand in the east for both irrigation and domestic water supply.

4.2 Groundwater

Groundwater is of extreme importance in Cyprus. Major aquifers (see Plate I) are the Western Messaoria, Southeastern Messaoria, Akrotiri and the Kyrenia limestone range. The water from these aquifers is extracted through about 10,000 boreholes and several thousand shallow wells. The total annual extraction is about 400 million cubic meters for irrigation, domestic and industrial purposes.

Small local groundwater bodies occur in the Hilarion reef limestones. The borehole yield in the limestone aquifers is dependent on the severity of fissuration and karstification. They usually range from 5 to 150 cubic meters per hour (0.04 to 1.3 mcm/yr). A recent comprehensive drilling programme has revealed a number of locally important groundwater sources in faulted or jointed igneous rocks of the Troodos. Infiltration, movement and storage of groundwater is directly related to the degree of fracturing and, in general, more groundwater will be found in higher elevation where rainfall is higher. Most of groundwater resources have already been developed, and the prospect of further development is limited because of quantity, as well as quality.

All the major acquifers except the Akrotiri and Kyrenia (Hilarion) limestone are overpumped, resulting in a constant decline of the water table. This problem has arisen because of numerous illegal boreholes and uncontrolled extraction. The water balance of several of the aquifers is currently rather precarious, with sea-water intrusion gradually increasing, particularly in the Kokkinokhoria area of the Southeastern Mesaoria aquifer and the Western Messaoria aquifer.

4.2.1 Groundwater Overdraft

The expansion of agriculture and the unsustainable extraction of groundwater from the aquifers by farmers due in part to inadequate legislation but more to ineffective enforcement of existing water laws, resulted in over-exploitation of the major aquifers such as Morphou, Southeastern Mesaoria, Akrotiri and Kiti. Pumping more water from these aquifers than their annual replenishment is resulting in the continuous lowering of the water table with the consequent intrusion by seawater and deterioration of water quality.

The average annual replenishment of the Western Messaoria (Morphou) aquifer, which is the most important aquifer in Cyprus in terms of annual replenishment and extractions, is 60 mcm. Current information reveals that annual pumpage of the aquifer is about 85 mcm. The overdraft and continuous decline of the water table since 1962 near Morphou continues even during wet years. By 1965, the landward gradient of the water table began at the shoreline, and has increased since then.

The Southeastern Mesaoria aquifer is only replenished from rainfall at an annual rate of approximately 25 mcm. Irrigation has been practiced for many years at an ever-increasing rate (Figure 8). Although this aquifer has deteriorated badly since 1960, the abstraction and the number of wells continue to increase in an uncontrolled manner (Figure 9). The aquifer seems therefore to be exploited everywhere in excess of replenishment. The most severe problems are in Kokkinokhoria area, which covers the main part of the southeastern Mesaoria aquifer and accounts for about 85% of the present groundwater withdrawal. The mean annual lowering of the water table is 1.5 m and a total reduction of 200 mcm of the groundwater reserve has been incurred since 1963. Pumping concentrations are very heavy in areas of Phrenaros, Liopetri-sotira and Xylophagou-Ormidhia, where wells can still provide 10-20

Figure 8. Windmill-driven pumps at Kokkinokhoria

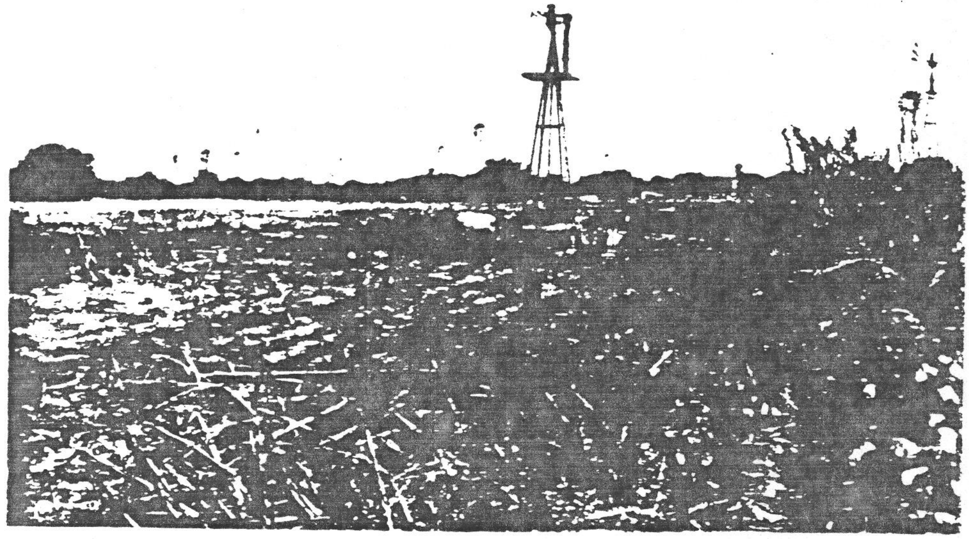
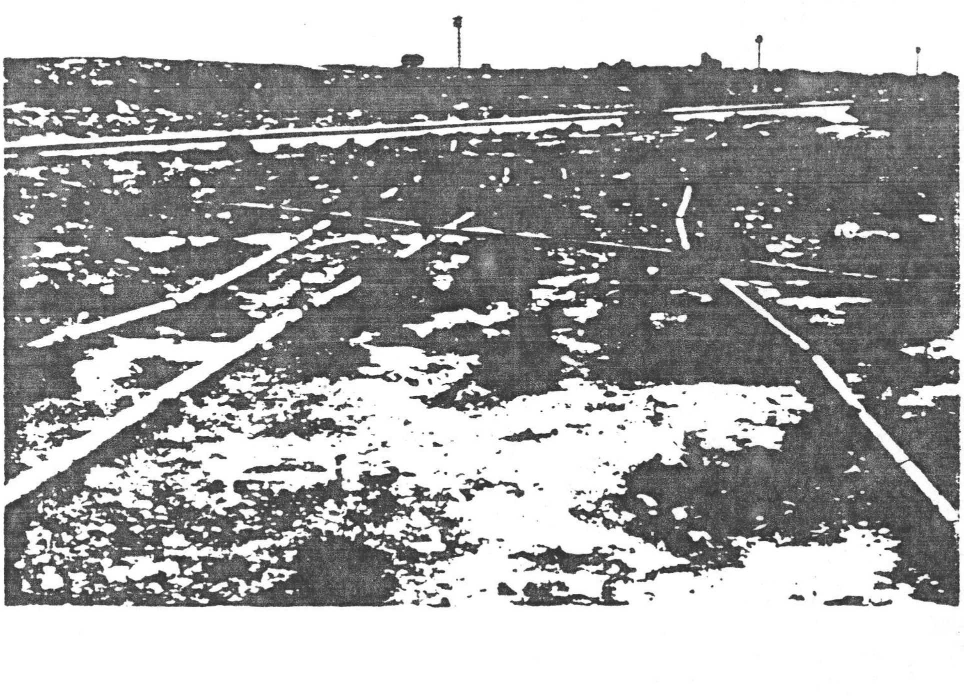


Figure 9. Numerous Pipeline Crossings Indicate Uncoordinated Development of Kokkinokhoria Aquifer



m^3/h. In large areas of the aquifer depletion is already well advanced. Yields of some of the wells are very low, and even include unacceptable concentrations of sand and silt.

In Akrotiri, replenishment of the aquifer comes mainly from seasonal infiltration. The annual replenishment is about 32 mcm and at present the total outflow for an average year is generally nearly equal to replenishment. The aquifer is, however, sensitive in the eastern part. In unusually wet years, recharge exceeds withdrawal but most of the time withdrawals exceed recharge and the aquifer continues to deteriorate. The increasing rate of groundwater extraction in the period 1960-66 led to significant increases in salinity in, among others, the Zakaki village area (personal communication, Water Development Department, 1983). During the exceptionally wet year of 1968-69 the water table level was above mean sea level throughout the area. This was followed in the early 1970s by a decrease in the level of the water table to as much as 6 meters below msl near Zakhaki. Thus, while the water balance of the Akrotiri aquifer is presently generally not negative, there are local seasonal problems.

The recharge of the Kiti aquifer was 2.2 mcm/year in a dry year and up to 7 mcm/year in a very wet year. The Southern portion of the aquifer has been heavily exploited and saltwater has been induced from the sea and the neighboring salt lake and as a result pumping from many of wells in this area is now discontinued.

4.2.2 Impacts of Seawater Intrusion, Present and Future

Since 1962, seawater has advanced progressively inland in major aquifers of Cyprus, owning to a lowering of the fresh water head into almost all Plio-Pleistocene aquifers. It has reached a distance of about 2.5 km inland near Morphou, causing many wells to be abandoned.

In the Kokkinokhoria area, seawater intrusion is proceeding inland at an increasing pace. Near Xylophahous, boreholes within 2.5 km of the cost have been abandoned, while contamination from seawater dispersion has been noted up to 4 km from the coast. Near Ormidhia and Lispertri increased groundwater salinity has been observed up to 5 km inland. Seawater intrusion began in 1965 in Western Mesaoria aquifer and Morphou, and the water-table has remained below mean sea level since then. The velocity of propagation is estimated at 30 to 100 meters per year.

In Kiti, the deterioration of ground-water quality has been observed throughout the last decade. Almost all wells in the southern portion of this aquifer are now abandoned.

The above three aquifers have played a dominant role in the agricultural sector of Cyprus economy for two decades. Although only about 10% of the total agricultural land is irrigated, it generates nearly 80% of the value added in crop production.

Agricultural exports play an important role in Cyprus foreign exchange earning. In 1982 they accounted directly and indirectly for nearly 25% of all commodity export earnings (IBRD appraisal report, SCP). The most important export commodities are potatoes from the Greek Cypriot side and citrus from the Turkish Cypriot side of the island. Future exports may include avocados from Kiti. Increasing financial yields of irrigated areas even with seawater intrusion are due to increasing prices, improved irrigation efficiencies, and better marketing institutions.

The climatic conditions along the coast south of Cyprus are well suited for off-season fruit, vegetables and flower production. A large number of days with uninterrupted sunshine, low frost hazard and absence of any serious soil problems place the area in a highly competitive position vis-a-vis other Medditeranean countries. The Kokkinokhoria area is the most productive section of the coastal zone. It has about 10,000 ha of very fertile land mostly planted to potatoes. The area, however, is beginning to lose its productivity because of seawater intrusion and soil salinization. Severe additional deterioration of the acquifer will continue and the obliteration of agriculture in a significant part of the area will be unavoidable. The observed rates of seawater intrusion and lowering of the water table compared with scheduled implementation of the Southern Conveyor Project indicate that the situation will continue to deteriorate during the near term. The water table is dropping 1.5 m per year continuously, and about 7 mcm of the seawater has already intruded the coastal aquifer so that the saturated layer is now 15 to 20 percent of its original thickness. These factors justify immediate action to maintain this very profitable but overtaxed aquifer.

The condition in the Morphou area is equally critical. A contaminated area up to 3 km wide along the coast from Pendayia to Gazivera has groundwater containing up to 4,000 ppm salinity, although it is some of the most fertile agricultural land of this area. The salinity of the Kythrea formation north of the Ovgas river is also increasing. Many boreholes in the area have been abandoned, while others have reduced yields and deterioration of groundwater quality. Significant numbers of citrus trees have died and others are under-irrigated, resulting in gradual reductions of yields. This trend is a continuous process, and the losses are serious. Morphou is the main citrus producing area of the island with 2,000 families on 8,000 ha of irrigated agricultural land which provide 80 percent of the foreign exchange for the Turkish Cypriot side. The combination of underirrigation of some trees and death of trees in other areas is estimated to have resulted in a loss of at least 10 percent of the potential citrus production particularly during the past decade.

The technological and institutional measures taken to protect the aquifers during the last two decades have had limited success throughout. The expansion of agriculture and the haphazard extraction of groundwater from the aquifers by private individuals continue to result in overexploitation of the major aquifers such as Morphou, Southeastern Mesaoria and Kiti, and deterioration of water quality and agricultural soil quality. Although no new wells are being drilled in the Morphou area, the irrigation systems in the north of the island are those of inefficient flooding and furrow methods. On the Greek-Cypriot side, the efficiencies in water application have been essentially maximized by subsidizing installation of sprinkler, mini-sprinkler and drip systems. Even so, there is overpumping and illegal drilling of new boreholes in the most severely affected area of Kokkinokhoria.

It is certain that overpumping of major aquifers and seawater intrusion has constrained growth in agricultural production during the last few years, during which the ratio between agricultural and non-agricultural labor productivity on the Greek Cypriot side declined from 42.1% in 1975 to 36% in 1982. Seawater intrusion will play an increasing role in reducing the productivity of irrigated land unless strict enforcement of the laws and regulations on well-drilling and pumping rates and the closing of significant numbers of boreholes start immediately. If pumping from the Kokkinokhoria and Morphou aquifers is not reduced, damage will be so great that even the Southern Conveyor Project and Morphou Development Project may be ineffective in maintaining present high levels of agricultural production.

4.3 Irrigation Efficiencies

The scarcity of the water resources imposed by the arid climate, and the ever-increasing competitive demand by industrial and commercial sectors on the Greek Cypriot side, prescribes to a large measure the limits within which irrigated agriculture can development.

Thus, the existing controlled water resources (groundwater and surface water) must be planned and used efficiently. In domestic water utilization on the Greek Cypriot side, essentially maximum efficiency is realized by flow-limiting devices and low-demand ornamental planting. On the Turkish Cypriot side, increasing block tariffs are in effect.

For domestic and industrial water, piped supplies are used everywhere throughout the island. Efficient irrigation practices are more advanced on the Greek Cypriot side. Irrigation technology research is being carried out by the Agricultural Research Institute and the Cyprus Department of Agriculture to determine the irrigation efficiencies of different systems of irrigation under the climatic conditions of this island. Data from the Department of Agriculture on irrigation efficiencies of various systems as applied to different crops are shown in Table 4.

As mentioned above, the efficiency of water application on the Greek Cypriot side has almost been maximized by subsidizing high efficiency sprinkler and trickle irrigation systems (Fig. 10). Implementation of irrigation improvements includes land levelling wherever required. In all cases, the Government grants 15% of the total project cost and provides long-term loans at 4.5% interest for the balance. The role of government in promoting improved irrigation is reflected in the proportion of development expenditure devoted to this sector. Water development and use receive about 63% of the total expenditure devoted to the agricultural sector. Close cooperation of farmers and government agencies in the Greek Cypriot community

Table 4: Irrigation Efficiencies with Different Technologies and Crops (A)

Ser. No.	System of Irrigation	Young Citrus and Deciduous 5 Years	Nature Citrus and Deciduous 5 Years	Bananas	Lucerne	Potatoes	Vegetables	Beans	Water-Melons Melon
1.	Wild Flooding		25-40	27					
2.	Flooding	15	45					25	
3.	Furrow					45-50	50		60
4.	Furrow Basin	30-55							
5.	Long Border (> 3 trees)	35	40	34					
6.	Short Border (≤ 3 trees)		60						
7.	Border				50			40-50	40
8.	Pipe Basin (3 in dia. pipes)		67-75						
9.	Hose Basin (1 1/4 in dia. hoses)	75-80	75-80						
10.	Sprinkler		70-75	70	70-75	70			
11.	Trickle Irrigation						85-90	85-90	85-90

(A) From "Irrigation Efficiencies", published by the Cyprus Department of Agriculture, 1973.

has resulted in improved efficiencies in water conveyance, distribution and application systems. However, this cooperation has not extended to control of illegal overpumping and illegal drilling of new boreholes by farmers.

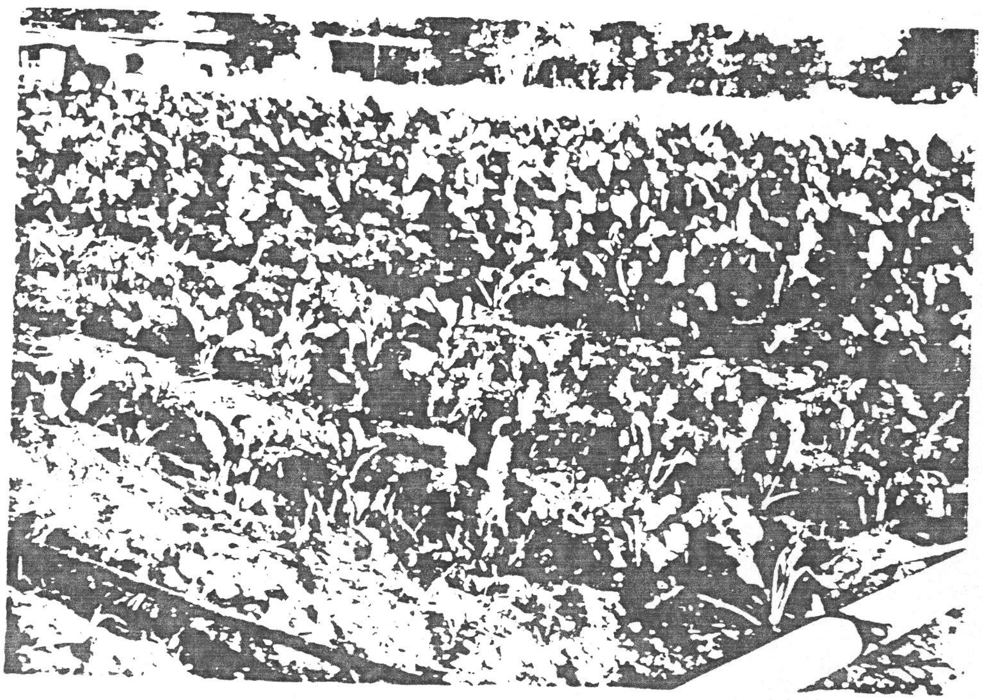


Figure 10. Efficient Use of On-Farm Water at Paralimni

On the Turkish Cypriot side, high priority has also been given to increasing irrigation efficiencies. The Department of Agriculture has assumed ownership of well-drilling rigs so that illegal drilling throughout the Western Messaoria aquifer has been stopped. Wells which become saline are not replaced. Farmer response to the latter has been to purchase water from neighbors at US$ 0.027 to 0.054 per cubic meter. Nevertheless, low efficiency flooding, furrow basin and long borders systems are common means of irrigation. Installation of sprinkler and trickle irrigation systems on the Turkish Cypriot side of the island call for investments of about US$2,500 per hectare, but long and broad experiences on the Greek Cypriot side reveal that these kinds of improvements are cost-effective. It has been shown in south Cyprus that the cost of water saved by the application of efficient systems is half of the cost for importing additional water.

4.4 Cyprus Wastewater Recovery Activities

Small-scale wastewater irrigation has been practiced on Cyprus for about 30 years and numerous studies have been made of the feasibility of reclaiming sewage for irrigation use (see Appendix 1). More recently, larger installations have been introduced or are being considered. The most important of these are described below:

4.4.1 Akrotiri

The 1450 m^3/d sewage treatment plant at the British Sovereign military base at Akrotiri is a conventional trickling filter plant with primary settling, trickling filters, final settling, digestion, and sludge drying beds (Figure 11). It was put into operation in 1962. After chlorination, the treated effluent is pumped to an elevated tank for gravity irrigation of the sports fields using a mobile sprinkler system (Figure 12). Small amounts of vegetables are also irrigated. The total area irrigated by sprinklers is approximately 10 ha. Another 2 ha of roundabout and road-borderland are also irrigated by standpipes. The available daily quantity of 1450 cu.m. of treated effluent is enough to irrigate about 15 ha. The surplus is discharged to a nearly large reservoir which belongs to the Bishoprics of Limassol and Kitium. Here, it is mixed with water from the Yermasoyia Dam and used for the irrigation of vines and citrus trees. For vines the irrigation method is ridge-and-furrow (Figure 13), and for the citrus trees a mini-sprinkler system is used (Figure 14). The dried sludge yields about 50 cu.m. of fertilizer per week, which is sold and delivered to the Bishops farm at a nominal price of 500 Cypriot pounds (USD 1000) per year, essentially the cost of removal. In the Bishopric's pond, carp are successfully grown.

A tertiary treatment works is now being planned by the municipality of Limassol. The treated sewage effluent of this plant will be used in conjunction with Southern Conveyor Project Water for irrigation on the existing Yermasoyia-Polemidhia irrigation scheme and part of the new Akrotiri irrigation area. It has been assumed that the storage and distribution works will be completed by 1992 but the sewerage system throughout Limassol will be constructed more slowly, with 85% of properties connected by 2017. A feasibility study on sewerage and sewage treatment for Limassol (3), recommended that the effluent be used for irrigation. Conventional tertiary treatment has been proposed to render the effluent suitable for all crops and with any type of irrigation equipment. Following treatment in aeration lagoons the proposed tertiary treatment standard is 10/10 (ppm BOD/suspended solids) to be achieved by (dissolved) air flotation, microscreening and disinfection processes. The tertiary processes will operate in accordance with the demand for irrigation and will have a capacity of 47,000 m^3/day, whereas the aeration lagoons will have to operate in accordance with the flow in the sewerage system. Balancing storage of 3mcm capacity is therefore proposed.

4.4.2 Nicosia

The first stage Nicosia municipal sewage collection and treatment system serving the southerly portion of the citrus was put into operation in 1980. Treatment is based on aerated and facultative sewage lagoons. A second stage funded by EEC to serve the northern area of the city is scheduled to be completed by the end of 1986. In its initial phase the treatment plant for sanitary water has the following installations at its disposal.

Figure 11. Akrotiri 1450 cubic meter per day sewage treatment plant

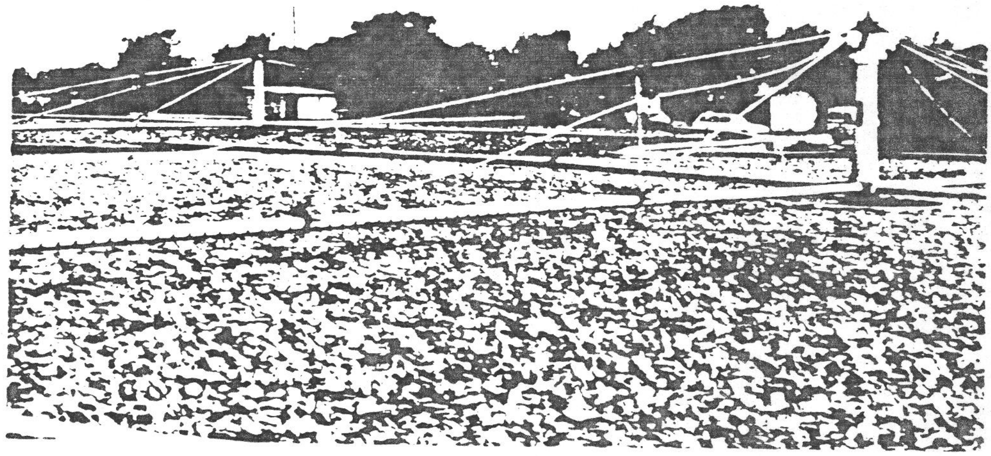


Figure 12. Sprinkler irrigation of Akrotiri sports field

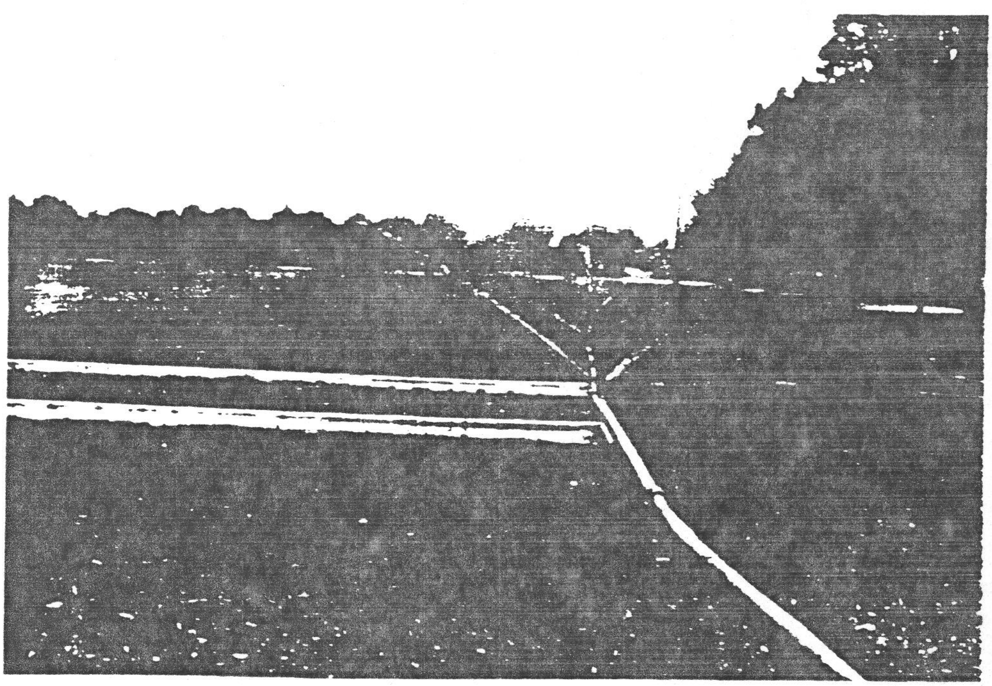


Figure 13. Ridge and furrow irrigation with Akrotiri effluent of Bishopric vineyard

Figure 14. Mini-sprinkler irrigation with Akrotiri effluent and Yermasoyia Reservoir water of Bishopric citrus

- 2 aerated lagoons--each one 0.4 ha surface area by 5 feet deep
- 4 unlined facultative lagoons in series-each of 1.42 ha surface area by 8 feet deep
- a chlorination works at the river outfall.

The present flows are 30% of the ultimate design capacity. Working capacities are 5,600 m^3/day for stage I, 10,000 m^3/day for stage II, and 14,000 m^3/day for stage III to be completed in 1989. The quality and quantity of treated sewage water is reported by Florin to be suitable for irrigation of salt and boron-tolerant fodder and seed crops.

Utilization of sewage water of Nicosia treatment plant for irrigation serves the objective of increasing agricultural production of the area, for which Florin has proposed:

- development of a pilot area with minimum investment costs under professionally qualified management.

- choice of appropriate crops to be grown in the pilot area based on salinity and boron tolerance, public health considerations, farm technology and marketing potential.

- development of full potential without storage, in accordance with the availability of sewage water.

- development of feasible storage lagoons for surplus water for further irrigation.

It is proposed that initial development of the test area will provide gravity flow to a border and furrow irrigation system. It should be noted that farmers have been using most of the dry weather flow of the Pedicos River downstream from the Nicosia sewage plant since the start of its operation in 1981 to irrigate market vegetables, orchards, and wheat.

On a smaller scale, the Central Prisons trickling filter treatment plant has been operating since 1955. Here, effluent is used to irrigate lucerne (Figure 15) and vegetables (Figure 16).

4.4.3 Larnaca Master Plan for Sewage Treatment

A master plan and feasibility report for water drainage and sanitary sewerage commissioned by Larnaca Municipality and prepared by Reid Crowther and Partners, Limited (19) has been recently presented to the Government of Cyprus. The proposed sewerage system will serve an area of 7,000 ha, including the city of Larnaca, the village of Livadhia, a coastal strip to the north extending from the city boundary, the Larnaca International Airport and the salt lake. Although no data are provided, the consultant assumes that potential high boron and sodium concentrations in the treated sewage would make it unsuitable for use in citrus trees. The plan justifies ocean disposal during the four winter months of 21,000 m^3 per day of effluent as follows:

Figure 15. Lucern irrigation with effluent from Nicosia Central Prisons treatment plant

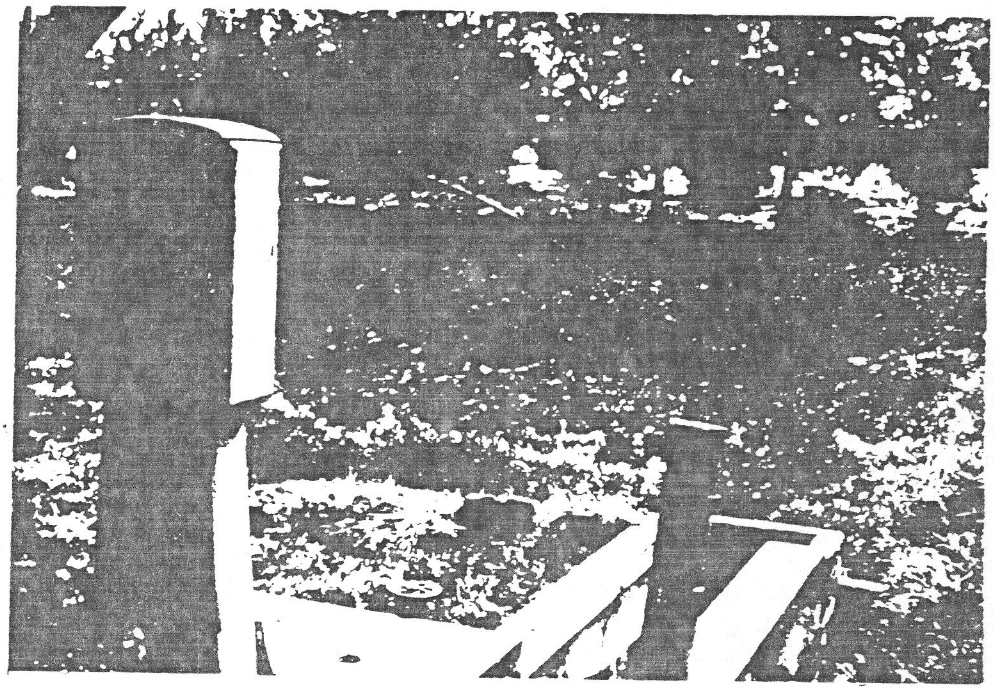


Figure 16. Vegetables and trees irrigated with effluent from Nicosia Central Prisons treatment plant

"Although outside the term of reference, attention should be paid to the possibility of disposing of treated effluent to the sea during the winter months when little or no bathing is taking place; since bathing is not the only problem, this proposal for a place like Cyprus and especially Larnaca part of that is not reasonable at all because of many reasons discussed in other part of this report."

4.4.4 Ayia Napa

In hotels of Ayia Napa, recycling is usual for wastewater. Town officials require collection of commercial and domestic wastes. Oxidization pond effluents are used for irrigation of lawns and gardens.

4.4.5 The Episkopi Sewage Plant

The Episkopi Sewage Plant produces 500 m^3/day of pond effluent. The chlorinated effluent serves as a source of water for sprinkler irrigation of 10 playgrounds.

4.4.6 The Dhekelia Sewage Plant

The Dhekelia Sewage Plant produces about 500 m^3/day of pond effluent which at one time was reported to contain 1.04 ppm boron and 438 ppm chloride. The effluent is used for the irrigation of grass on the sport grounds.

4.4.7 The Pergamos Sewage Plant

The Pergamos Sewage Plant produces about 500 m^3/day of pond effluent which again at one time was reported to contain 1.64 ppm of boron and 540 ppm of chloride. The effluent has been used for irrigating maize. Some burns caused by boron have been observed. The source of the boron is believed mostly due to detergents, as the water supply contains only small concentrations.

4.4.8 Kamares II Sewage Treatment and Reuse

A sewage treatment plant has been constructed by the Water Development Department for the Kamares Housing Estates (Figure 17). The 625 m^3/d project was completed in 1983 and serves the community of 2,600 people. The sewage flow was estimated at 250 l/cap/day and the BOD loading at 68 gr/cap/day. The contact stabilization process of activated sludge treatment is designed to deliver effluent meeting the Royal Commission Standards of 20 mg/l BOD and 20 mg/l SS. Tertiary treatment is provided by an upward flow clarifier, designed to achieve 15 mg/l BOD and 15 mg/l SS.

The final effluent will be chlorinated and conveyed to the new Larnaca sports stadium for lawn irrigation. The excess treated effluent is to be pumped to a small reservoir located 4 km west of the treatment plant, where it will be impounded for recharging the underlying gypsum aquifer (Figure 18).

Figure 17. Kamares contact stabilization sewage treatment plant under construction

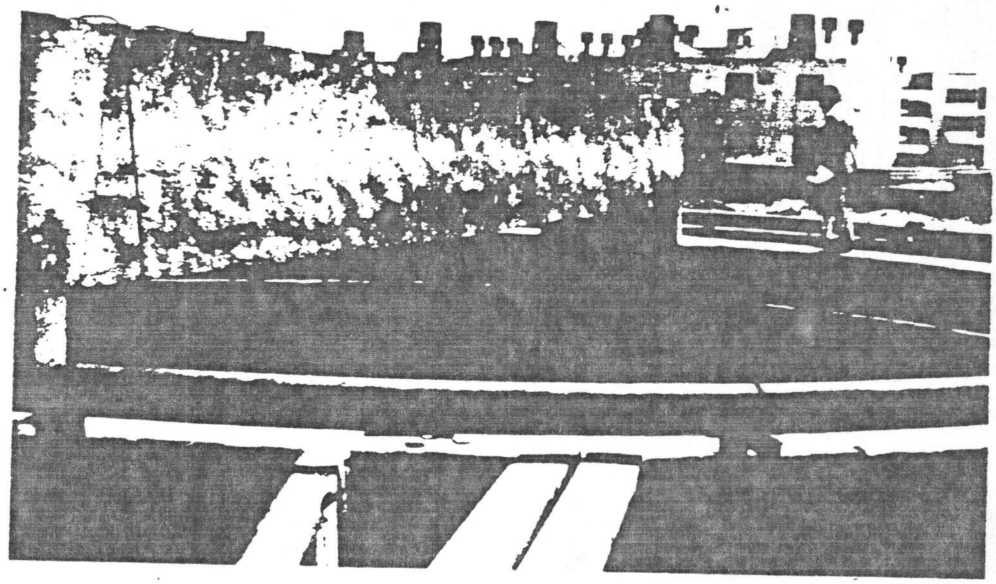
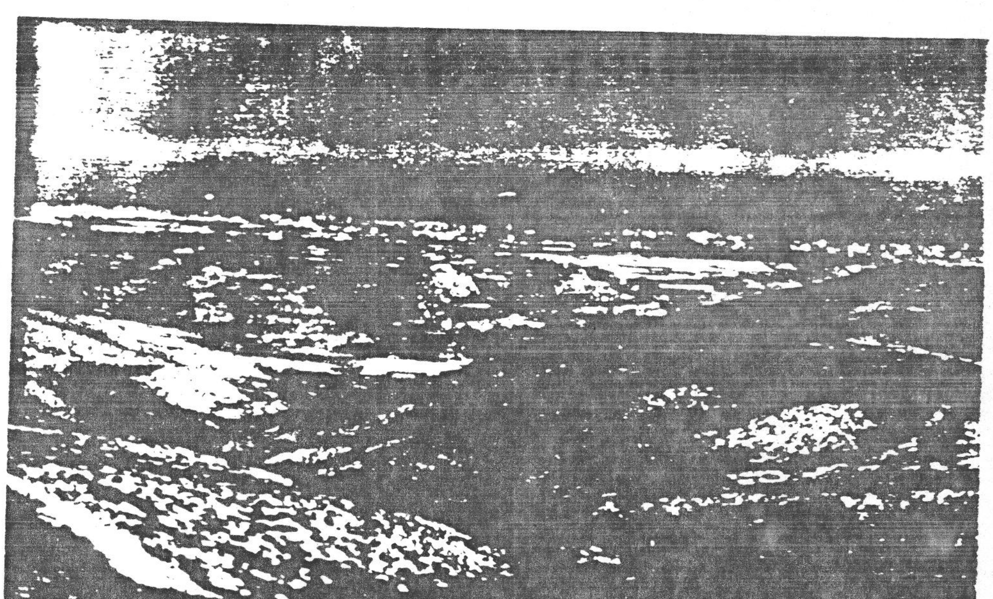


Figure 18. Site of Rizoelia dam and reservoir for groundwater recharge with Kamares effluent



4.4.9 Ayios Ioannis Housing Estate Sewage Treatment Plant

The Government Housing Estate, Ayios Ioannis, was constructed by the Government of Cyprus within the municipal boundaries of Larnaca for displaced persons. The central sewage treatment plant for Ayios Ioannis was designed to treat the sewage of 700 people. The plant is a package contact stabilization unit and was constructed below because it is near the main road. (Figure 19).

The plant was put into operation in 1982 and effluent pumped to a site 3.4 km from the plant where a trench was constructed for groundwater recharge. The infiltration trench is in a well indurated conglomerate, so very little infiltration can be achieved. Farmers in the region have informally installed a siphon in the balancing tank and are irrigating an olive grove which apparently is thriving (Figure 20).

5. Potential for Wastewater Utilization

Traditionally throughout most of Cyprus, land owners may drill wells whenever they desire and extract as much water as they can. This has been a factor of development of this country and as long as wells were shallow and hand-dug and yielded only small quantities with hand, wind or animal traction, aquifers were stable sources of water. Since the 1950s, however, deep boreholes in thick aquifers of Cyprus have become equipped with powerful pumps that yield large quantities of water. There is therefore increasing recognition of the need for improved regulations and institutions for water management. As previouly discussed, surface water resources to replenish groundwater are very limited. High efficiencies for the utilization of the available water resources are accordingly of the utmost importance.

Reuse of treated sewage effluents from small communities has been practised throughout Cyprus for decades. As sewage treatment plants for larger towns become constructed, effluent reuse will become correspondingly more important. Diversion of surplus waters from rivers and their conveyance to areas of water deficiency will also increase the efficiency of total water use.

5.1 Existing Wastewater Treatment Plants

As discussed in Par. 4.4, a substantial number of sewage treatment plants on Cyprus provide effluents suitable for water reuse for irrigation purposes. These facilities have provided operating experience and data which not only lend credibility to the acceptance of wastewater reclamation and reuse, but also inspire confidence that sewage can become a valuable resource to mitigate water shortage in the future.

5.2. Future Sources

In recent years the introduction of central sewage schemes has become a policy for all municipalities and is becoming of interest to all

Figure 19. Ayios Ioannis Underground contact stabilization treatment plant

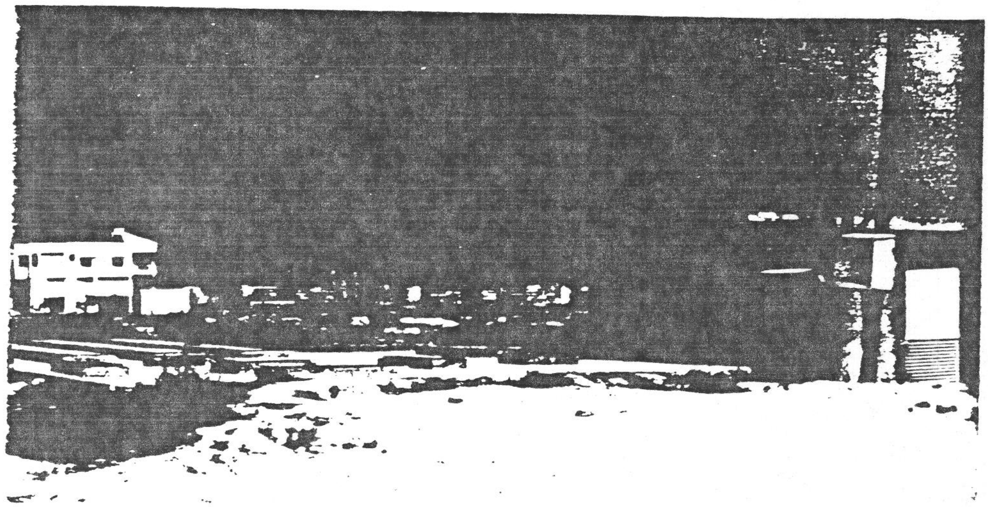
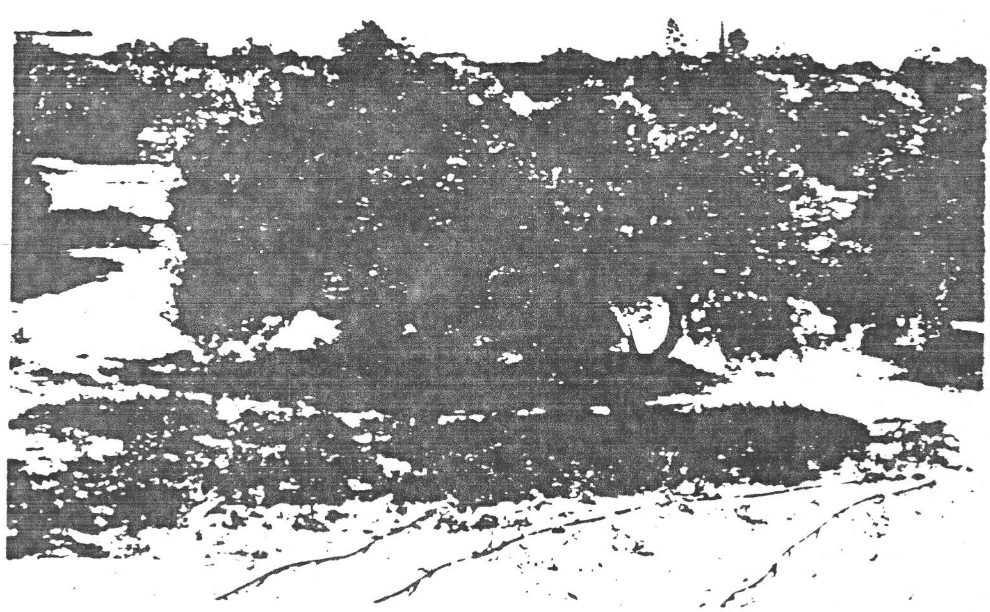


Figure 20. Private irrigation of olive groves with Ayios Ioannis effluent



major rural communities. Meanwhile limited supplies and increasing demands for domestic and irrigation uses require wastewater utilization for direct irrigation and groundwater recharge of aquifers. Significant sources of reclaimed wastewater are available from Nicosia, Limassol, Famagusta, Larnaca, and Kamares.

The Nicosia sewage treatment plant inflow of 5,600 m^3/day during the first stage, 10,000 m^3/day during the second stage, and 14,000 m^3/day in the third stage will be reduced by evaporation and seepage losses from the treatment lagoons. It is estimated that without storage the irrigation water availability during peak requirements therefore will be 1000 m^3/day during the first stage, 6800 m^3/day during the second stage and 9800 m^3/day from the year 1989.

The Limassol tertiary treatment plant includes dissolved air flotation, filtration and disinfection to yield an effluent suitable for unlimited irrigation and groundwater recharge. An earlier estimate (3) of 10 mcm/year has been increased to 20 mcm/year by 2010 (personal communication, Louis Berger International, 1983). The proposed Larnaca Sewerage Project will provide daily flows ranging from 3,400 cu.m in summer to 16,000 in winter. The treated effluent is to be used for irrigation. Effluent storage during the four winter months will require a volume of 3.2 mcm capacity. Alternatively, the excess 0.2 m^3/s winter flows could be discharged to sea. Benefits of infiltration of 2.5 mcm/year of treated effluent into the Kiti aquifer are discussed in Par. 5.3.1.4.

5.2.1 Morphou Development Project

The Morphou Development Project, scheduled to be completed in 1984, provides diversion dams on the Xeros, Marathasa and Karyotis Rivers. They will divert 8 mcm/year from the Xeros River, 8 mcm/year from the Marathasa River and 9 mcm/year from the Karyotis River to a partly lined conveyor which leads to the Morphou dam. About 5 mcm/year are estimated to infiltrate from Morphou reservoir while much of the remaining 20 mcm/year can infiltrate along the 13 km unlined sections of the aqueduct into the Morphou aquifer or be diverted by irrigation (see also Par. 5.3.2.1).

5.2.2 Southern Conveyor Project

The Southern Conveyor Project (SCP), described in Appendix 1, will collect, store, and transmit surplus waters from catchment areas in portions of southern Cyprus to other areas of water deficiency. As seen in Plate II, the conveyor system will transfer the water in a generally easterly direction, from the Dhiarizos River area to Nicosia, Famagusta, and intermediate areas along the conveyor route. Primary objectives of the 10-year project are to provide an adequate drinking water supplies to the four major areas of Nicosia, Limassol, Larnaca, and Famagusta, with utilization of surplus waters for irrigation and groundwater recharge purposes.

During the early years of operation excess capacity of the Southern Conveyor Project can provide artificial recharge into the Kokkinokhoria groundwater basin. The quantity of water supply and water use of SCP is given in the table 5 (World Bank data 1984):

Table 5: Comparison of Southern Conveyor Project Water Supply and Demand

Year	SCP Water Supply (MCM)	SCP Demand (MCM)
1989	16.5	13.3
1990	32.2	28.1
1991	32.2	32.2
1992	32.2	33.4
1993	59.5	43.1
1994	59.5	47.2
1995	59.5	51.0
1996	59.5	54.9
1997	59.5	58.9
(1993-97)	(297.5)	(255.1)

This surplus of SCP water during early years of operation and availability of effluent from the Limassol Sewerage Scheme from 1994 with an extension of the project area to Amathus tourist area can provide a total of some 7 mcm/y for artificial recharge of the Kokkinokhoria aquifer. For this, local recharge wells and/or spreading basins can be employed.

Upon full development of the Southern Conveyor Project and wastewater reclamation plants at Limassol, Larnaca, and Kamares, there will be substantial improvement in the water supply available in the SCP project area for irrigation and groundwater recharge purposes. Estimated annual quantities available and their distribution between irrigation and aquifer recharge from 1984 through 1997 are given in Table 6.

Table 6: Estimated Potential Southern Conveyor Project Area Water Utilization, mcm/y

	Excess SCP Flows	Limmassol Effluent	Larnaca Effluent	Kamares*	Direct Irrigation	Recharge
1984	0	0	0	0.1	0.06	0
1985	0	0	0	0.1	0.06	0
1986	0	0	0	0.1	0.07	0
1987	0	0	0	0.12	0.07	0.05
1988	0	0	0	0.13	0.07	0.05
1989	3.2	0	0	0.14	0.07	1.5
1990	4.1	0	0	0.14	0.08	2
1991	0	0	0.5	0.14	0.08	2
1992	(1.2)	0.5	1	0.14	0.08	0.5
1993	16.4	1.5	2	0.15	2.5	8
1994	12.3	2	3	0.16	4	9
1995	8.5	2.5	4	0.16	4	9
1996	4.6	4	4.5	0.16	4.5	7
1997	0.6	5	6	0.16	4.5	6

*Mostly local supplies 1984-1988.

5.3 Potential Utilization of Wastewater

5.3.1 Irrigation

As stated previously, wastewater has been successfully reused on a small scale for irrigation over the past 30 years. Potential utilization of additional treated wastewater from Nicosia, Limassol, Larnaca and Kamares is discussed below, with emphasis on pilot operations.

5.3.1.1 Nicosia

The approximately 400 ha of arable land available for irrigation with sewage effluent from the Nicosia sewage treatment plant lies downstream of the treatment plant. Except for the northern part, where slopes of 1 percent are predominant, the project area is nearly flat with general slopes of about 0.2 percent in both north-south and west-east direction. Most of the arable area is now dry-farmed to winter cereals with a high percentage of fallow land used as pasture. Small areas near the river bed are under surface irrigation and are planted with cereals. During the dry season, the flow in the Pedicos River consists of effluent from the Nicosia treatment plant. Within the irrigable area nearest the plant, soil surveys show a soil profile to 1.5 meters depth with surface and subsoil generally of similar textures. No restrictive layers have been observed, except in one test hole at a higher elevation. The irrigation water available during peak requirements is estimated at 1,000 m^3/d in 1981, 3,500 m^3/d in 1982, 6,850 m^3/d in 1984, and 9,800 m^3/d in 1989. R.S. Ayers (2) estimated average water quality as follows:

Table 7: Nicosia Water Characteristics

	Influent water to Nicosia Municipal System	Effluent water from Sewage Treatment Plant
Boron, milligrams/liter	0.3	1.0
Nitrate-nitrogen mg/l	7.5	5.0
Chloride milliequivalents per liter	8.3	8.3
pH	7.65	7.65

Ayers suggested that initial agricultural use of the effluent be restricted to the irrigation of salt-and-boron tolerant fodder and seed crops, and to those crops in which the harvested part does not come into contact with water or ground. A two-step pilot study was proposed.

Phase I: Development of an initial pilot area with minimum investment costs. Most suitable for this purpose are 250 donums (2.5 ha) of arable land immediately downstream from the sewage plant, sought of the Pedicos River.

Phase II: Development of the full irrigation potential by adding to the pilot area the remaining 450 donums (4.5 ha) along the north bank of the river and a small terminal storage reservoir, providing for irrigation of winter cereals.

5.3.1.2 Limassol

As noted above, surplus Akrotiri Sovereign Base treatment plant effluent is discharged to a nearby large reservoir which belongs to the Bishoprics of Limassol and Kitirum. Here it is mixed with water from the Yermasoyia Dam, and is used for the irrigation of vines and citrus trees. The Yermasoyia-Polemidhia Irrigation Project includes about 1900 ha of Akrotiri land. Water sources include 8.7 mcm/y from the Yermasoyia and Polemidhia reservoirs, 8 to 10mcm/ygroundwater, and spate diversions averaging 2-3 mcm/y from the Kouris River. After completion of the Kouris Dam, the spate diversions will be eliminated and groundwater abstraction will be reduced to around 6 mcm/y. The Yermasoyia Reservoir will be progressively switched from irrigation to domestic water supply as demand increases in the Limassol area. To partially compensate for these losses, irrigation supplies will be met partially from treated Limassol sewage effluent. The demand at this stage will be supplied from four terminal reservoirs, located to provide adequate pressure and to enable conveyor water or treated effluent to be economically used. Conveyor water will flow by gravity to the storage reservoir but treated effluent will have to be pumped.

The proposed treatment standard for Limassol tertiary effluent of 10/10 (mg/l BOD/mg/l suspended solids) is considered suitable for unrestricted irrigation of crops and for infiltration into the aquifer (Louis Berger, International, personal communication, 1983). The yield of Limassol sewage effluent is expected to reach 10 or more MCM/year resulting in a net reduction of 4 mcm/y.

5.3.1.3 Larnaca

The potential area to be irrigated with Larnaca plant effluent if the effluent is stored is 500 ha, reducing to 250 ha if the effluent is discharged to sea or used for other purposes during the wet period. Because of the expected quality of the effluent, only crops tolerant to salinity and boron, including fodder crops, are considered suitable (Reid Grother and Partners, 1983). Accordingly, agronomic and aquaculture studies are needed to determine the optimum use of the effluent.

5.3.1.4 Kamares

The Kamares Central Sewage Plant has been designed as a demonstration project for effluent utilization in Cyprus. The present average daily yield of the effluent is 258 m^3/day, enough to irrigate 3.5 ha of lawn during July when the maximum amount of water is needed. Surplus water can be utilized in a number of ways, including simultaneous irrigation of other crops, storage for subsequent irrigation of other crops, fish culture, ground water recharge or wasteage (see Table 8).

Table 8: Kamares Monthly Effluent Yields and Potential Utilization

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Total
Average Yield													
1983, KCM*	6.0	5.7	6.3	7.0	8.4	8.9	9.1	10.1	9.2	8.7	6.8	6.6	92,940
2003, KCM	11.0	10.3	11.5	12.7	15.2	16.2	16.5	18.4	16.7	15.8	12.3	12.0	168,410
Lawn Requirements													
Consumptive use, mm	30	33	55	85	130	171	619	180	133	95	56	34	1,198
Effective Rainfall, mm	-	-	-	56	19	0	0	0	0	24	29	-	-
Irrigation at 60 %													
100 mm	-	-	-	29	111	171	619	180	133	71	27	-	918
60 mm	-	-	-	39	148	228	126	240	177	95	36	-	1,224
60 m³/ha	-	-	-	390	1,480	2,280	2,610	2,400	1,770	950	360	-	12,240
Maximum ha	-	-	-	18.1	5.7	3.9	3.5	4.2	5.2	9.2	18.8	-	-
Winter Wheat													
Irrigation at 60% m³/ha	RF	375	125	1,500	--------	--------	--------	--------	--------	--------	RF	RF	3,000
Berseem													
Irrigation at 60% m³/ha	RF	RF	980	870	930	850	370	--------	--------	--------	--------	RF	4,000
Olives													
Irrigation at 60% m³/ha	--------	--------	--------	225	300	450	525	625	375	--------	RF	RF	2,500
Eucalyptus													
at 100%, m³/ha	-	-	-	800	1,200	1,600	2,400	2,850	2,400	2,100	1,350	300	15,000

*Note: KMC = Thousand cubic meters.

With free flow effluent for 3.5 ha of sports grounds irrigation and surplus for irrigation of other crops, only a balancing reservoir with 24 hours capacity is required. Crop selection is to be based on marketability, soil characteristics, climate, effluent availability, potential health effects, and local practices. Alternative crops include wheat, berseem (a forage crop), olives, and eucalyptus which are tolerant to potential boron and dissolved salt levels in the effluent.

From antiquity, wheat has been Cyprus' main agricultural crop. About 20 years ago it provided about 70 percent of the island's demand. Before 1974, about 133,000 ha of land were planted to winter wheat and barley under rainfed conditions. There were 70,000 ha of barley and 63,000 ha of wheat, mostly in the area of the Turkish Cypriot side.

Rainfed wheat is planted between mid November to mid December. Irrigated wheat can be planted by mid November with harvesting in May. Assuming sufficient rainfall during November through January, irrigation requirements at 60% efficiency are 375 m^3/ha in February, 1125 m^3/ha in March, and 1,500 m^3/ha in April.

Irrigation during the late autumn and winter can increase yields from 2.5 to 5.0 tons/ha/year of capacity as Kamares soils are deep and have a good holding capacity. Potential effects of over-irrigation during the early season vegetative period can be prevented by using the Dwarf Mesaoria Durum wheat developed for Cyprus.

The range of pilot studies revealed by Table 8 is shown by the example of 10 ha of wheat whose demands would leave a surplus of 8,875 cu.m. during four months, May through September, when no irrigation of wheat is required.

Berseem is fodder crop growing between September and April and can be used in rotation with wheat. Irrigation requirement at 60 percent efficiency for berseem averages about 900 m^3/ha/month during September and October, decreasing to zero during December through February and returning to about 900 m^3/ha during March and April (Table 8).

Olive trees are resistant to water shortages and have been cultivated in Cyprus under rainfed conditions up to 1,000m elevation since antiquity. It has been estimated that in Cyprus there are about 2,400,000 olive trees mainly of the traditional local variety Olea europea var. silverstris, although modern table olive varieties are now being introduced. Olive trees can grow well on all soil classes, but with increased yields on more fertile soils. Annual yields usually vary from year to year; those under irrigation are between 30 to 50 kg/tree. Irrigation water requirements at 60 percent efficiency are estimated at as much as 625 m^3/ha/month in July (Konteatis, 1983). Irrigation scheduling can vary from values shown in Table 8 because the heavy soils of the area and also because the lateral roots of the olives reach up to 12 m and can utilize stored moisture from a large area.

Eucalyptus camaldulensis is a boron and salt tolerant tree resistant to water shortages in summer, especially after an excess rainfall or irrigation. Eucalyptus have been extensively used in marshy, high water table areas with clay soils to reduce soil moisture. They flourish near soakpits in Nicosia and other areas. The maximum monthly water requirements for eucalyptus may be taken as those of pan evaporation less rainfall. The trees are fast growing and can be cut for timber every ten years producing about 350 cu.m of wood per ha.

All of the crops listed, wheat-berseem rotation, olive and eucalyptus are of interest under Cyprus conditions because their adaptability to wide ranges of soil, water quality and quantity, and market conditions. They have low labor demand requirements, particularly olives and eucalyptus, and have long been produced throughout Cyprus. Tables 8 and 9 reveal that many combinations of cropping patterns can take advantage of the available Kamares wastewater. For example, the initial effluent flows would provide 61 percent of the annual requirement for 2 ha of wheat-berseem, 6 ha olives, and 4 ha eucalyptus. There would be seven months of water shortage which would decrease as more effluent becomes available.

Groundwater storage and conjunctive use or surface storage would decrease the months of shortage as shown on Table 9.

Table 9: Allocation of Irrigation Water for 2 ha Wheat-Berseem, 4 ha of Eucalyptus and 6 ha of olives using surface or groundwater storage*

Month	Monthly Surplus cu.m	2 Ha Berseem cu.m	4 Ha Eucalyptus cu.m	6 Ha Olive cu.m	Total Actual Requirements cu.m	% Meeting of Water Demand
January	6,030	-	-	-	0	100
February	5,670	-	-	-	0	100
March	6,330	1,026	2,067	2,067	5,160	100
April	5,685	1,576	3,142	3,142	7,860	100
May	3,190	-	3,280	4,920	8,200	100
June	930	-	5,040	7,560	12,600	100
July	-	1,039	2,078	2,078	13,730	38
August	1,740	348	696	696	13,350	13
September	3,015	605	1,204	1,204	12,510	24
October	5,405	1,085	2,160	2,160	7,100	76
November	5,520	1,104	2,208	2,208	1,940	284
December	6,600	1,320	-	-	0	100
TOTAL	50,115	9,202	20,043	20,860	82,450	

*Note: Values are uncorrected for evaporation from surface storage.

The Department of Water Development has identified a potential recharge project at a gypsum aquifer at Rizoelia in the village of Aradhippou about 41 km from the Kamares Treatment Plant. Appropriate geological, geophysical, drilling and hydrogeological baseline and operational studies are needed to optimize present and future schemes.

Fish culture using effluents from treatment systems designed for pathogen removal provide greater yields of protein per hectare than any irrigated crop yield. Carp, tilapia, gray mullet and possibly giant prawns are potential alternatives. Carp raised extensively in Cyprus reservoirs have not been found to be marketable. Preliminary results have shown that tilapia and gray mullet have been marketed successfully. There has been no experience with prawns. Productivity levels of about 2.5 tons/ha/years have all routinely achieved in many areas of the world, and 10 to 20 tons/ha/year are achievable in ponds of, say, 1.5 m depth which provide for efficient harvesting (Gunnerson, 1984).

The final disposal alternative of coastal or submarine disposal of excess effluent has not been shown to be viable. Desalination of irrigation return water, natural brackish water or sea water also may be studied sufficiently for its applicability to local conditions.

5.3.2 Control of Seawater Intrusion

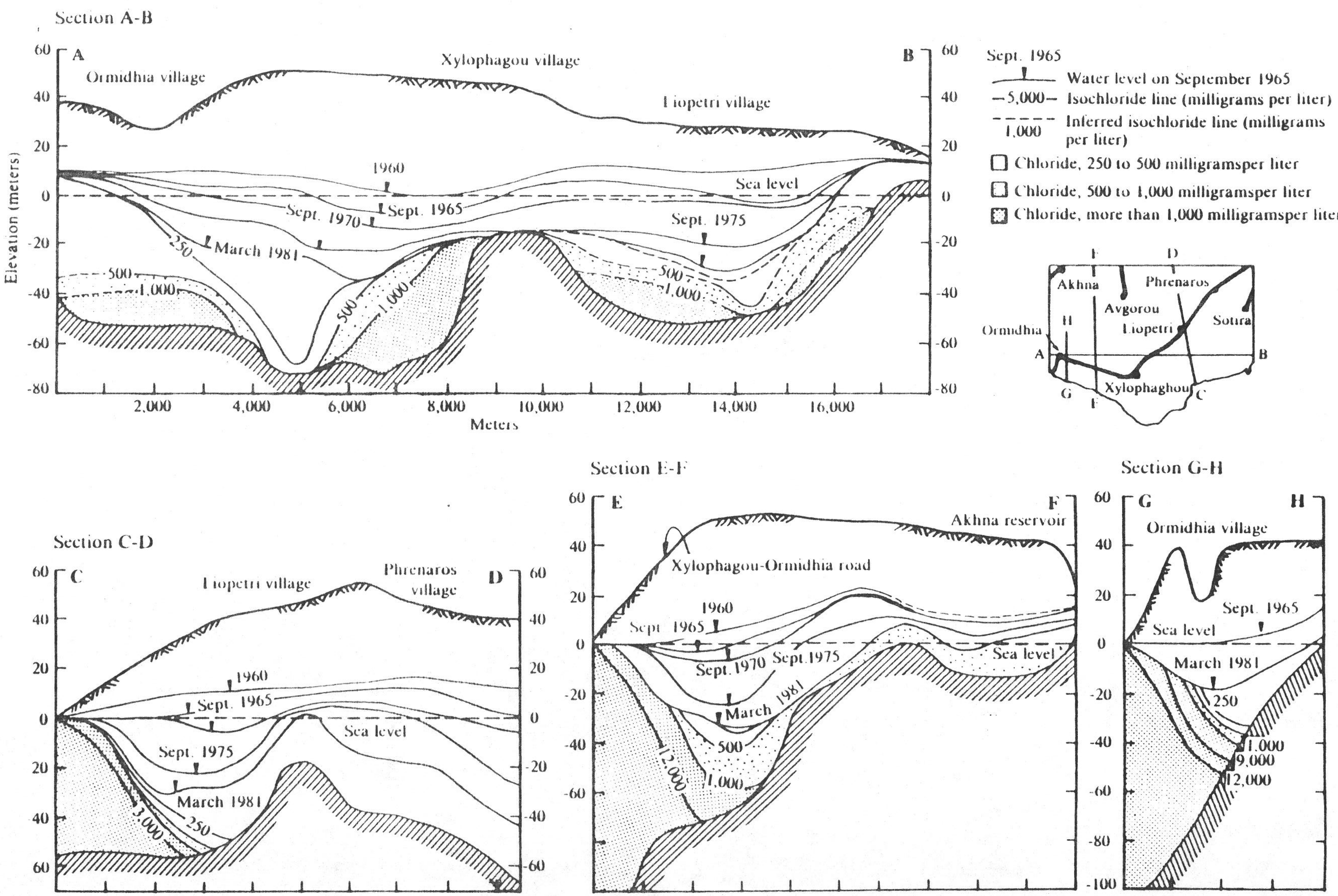
Seawater intrusion is controlled only by raising groundwater levels above sea level. This can be done by reduction or rearrangement of patterns of pumping draft, maintenance of a fresh water ridge above sea level along the coast by artifical recharge, construction of artificial subsurface barriers, or marginally by development of a pumping trough adjacent to the coast and artificial recharge. Three requirements for artificial recharge are (i) an adequate source of recharge water of suitable quality, (ii) suitable hydrogeological and ground water conditions exist, and (iii) costs of the proposed recharge system are less than those of the least cost alternative. The extent to which recharge schemes using wastewater treatment plant effluents can support seawater intrusion control on Cyprus is presented below for critical areas.

5.3.2.1 Southeastern Mesaoria (Kokkinokhoria) Aquifer

The Southeastern Mesaoria plain extends over about 500 square kilometers from Famagusta to Kondea-Pergamos-Dhekelia and the sea, and has a rather low relief with few points higher than 100 m above sea level. This aquifer is almost completely covered by a weathered secondary limestone crust and a deep soil which obscures the geological features. This aquifer has been heavily overexploited during the last 20 years. The mean lowering of the water table is as much as 1.5 m per year and it is estimated that only 15 to 20% of the original groundwater reserve of 1960 remains before the aquifer is exhausted.

The economy of the area is based on irrigated agriculture which in turn is dependent on a reliable water supply. Essential irrigation demands are being met by an estimated 4000 boreholes of which about 47% of which have been drilled illegally. Withdrawals amount to about 30 mcm/year which

Figure 21. Development of the Groundwater Depression at the Kokkinokhoria Aquifer, 1960 to 1981



exceeds the estimated annual replenishment of 14 mcm/year by about 16 mcm/year. The Kokkinokhoria area covers about 180 sq. km. and includes the villages of Xylophagou, Liopetri, Athna, Phrenaros, Ormidhia and Avogrou. The area accounts for about 85% of present pumping of the Southeastern Mesaoria Aquifer and for the greatest lowering of the water level. Groundwater movement, originally towards the coastlines to the northeast and the south, has been reversed during the past 20 years. The greatest depressions are near Phrenaros in the north, near Liopetri in the southeast, and Xylophaghou in the southwest (Fig. 21). Annual withdrawals have increased steadily since 1963. In the north, the 1963 water level of 12m above mean sea level (msl) has been lowered to about 40m below and there are only a few meters of water remaining above bedrock. During the same period, by 1983 water levels dropped from 2m above to 30m below msl in the southeastern depression from 2m above to 40m below msl in the southwestern depression.

The 500 ppm isochlorides line shown in Figure 8 indicates the extent and progression of current seawater intrusion and aquifer loss. Some artificial recharge in the southeastern Messaoria is provided by the multi-purpose Kouklia dam and reservoir built in 1900 near Famagusta (Fig. 22).

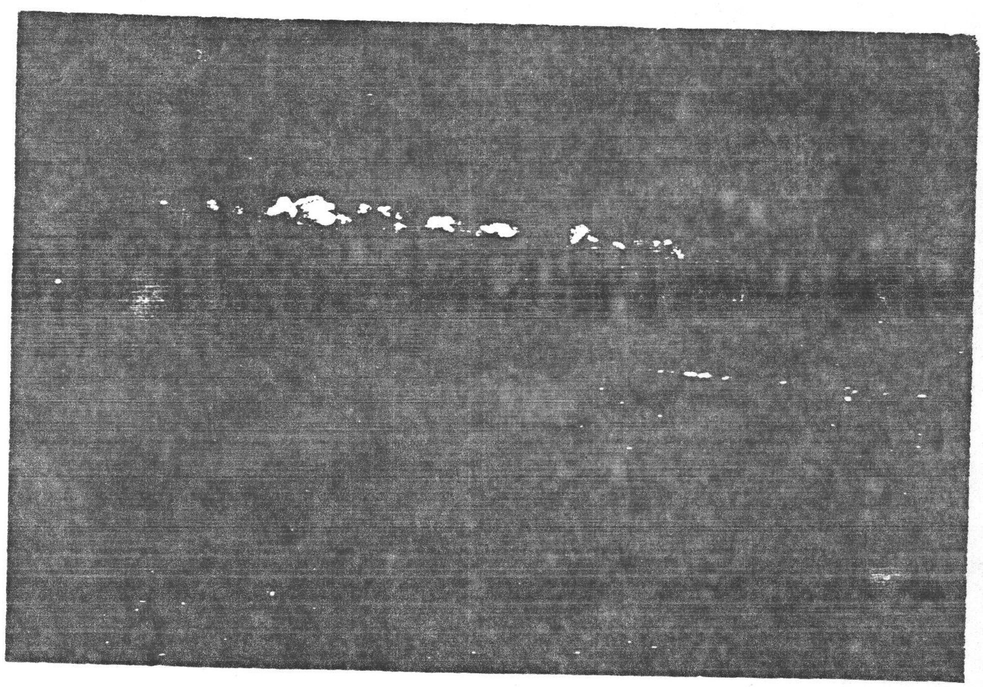


Figure 22. Kouklia dam

This has led to a number of small dams with a total capacity of 3 MCM built since 1950 for artificial recharge by surface spreading. These works have failed because of near-surface, semi-pervious soils and intervening lenses, infrequent filling, evaporation and unsaturated zones above the water table which prevent water from reaching the saturated zones.

Alternatively, early establishment of a fresh water barrier in the Kokkinokhoria by injection wells using surplus water availing during the early years of the Southern Conveyor Project followed by subsequent maintenance of that barrier using both SCP water and wastewater and appears feasible. Both especially constructed injection wells and conventional boreholes can be used for injection, providing the latter are operated so as to avoid entrapment of air into the injected water. "Free fall" into the borehole doesn't work. Use of extraction wells for intermittent recharge controls clogging of the aquifer by suspended solids in the recharge water. This flow reversal can also be used to restore the injection capacity of the wells. The following determinants are relevant:

(a) the treated Limassol sewage effluent is expected to yield around 10 MCM/year. It is planned in conjunction with Southern Conveyor Project that this treated effluent will be used on the existing Yermasoyia-Polemidhia irrigation scheme as well as Akrotiri irrigation. No need during the winter months is anticipated for this water. Injection of the winter months' portion of this treated sewage effluent will improve the ground water conditions at Akrotiri. A corresponding portion of the storage capacity of Kouris reservoir will be reserved for other allocation.

(b) The Southern Conveyor Project demand is less than supply during the early years of its operation so that a surplus is available for artificial recharge during the summer.

(c) The Southern Conveyor can provide substantial quantities of water for recharge in Kokkinokhoria during the winter months.

Reduction of the net discharge from the aquifer and reversing the trend toward further seawater intrusion can be attained by a combination of injection into the ground water level depressions along a line parallel to the coastline. This will create a fresh water barrier to further seawater intrusion between Ormidhia and Ayia Thekla Church. The next few years will provide an opportunity to study the response of the aquifer to artificial recharge, using existing facilities and supplies before Southern Conveyor Project Water and Limassol treated sewage effluent become available.

The Liopetri reservoir with 0.325 mcm of capacity can also serve as a source of water. The dam was completed in 1965 to provide groundwater recharge through the bottom of Liopetri reservoir. It was found that infiltration rates are so low that most of the water evaporates. It is considered probable that the significant runoff from the Potomus River during wet years can provide the necessary water for demonstrating injection into experimental recharge wells at minimum cost and large potential benefits to future major artificial recharge works.

5.3.2.2 Akrotiri Aquifer

As previously noted, the water balance of Akrotiri aquifer under present conditions is marginally neutral. However, seasonal problems with water level depressions in isolated areas are a matter for concern and planning. Ground water levels near Episkopi and other coastal areas have been below sea level for sometime. Near Zakaki, earlier seawater intrusion has been reversed by importation of Yermasoyia and Polenidhia waters since 1975 which reduced the need for groundwater. However, completion of the Southern Conveyor Project's Kouris dam will reduce flows to the recharge reaches of the Kouris river which provide about 60 percent of the infiltration to the Akrotiri aquifer. Other changes will follow scheduled reallocation of Yermasoyia reservoir water from 6 mcm/year for irrigation of Akrotiri Peninsula to municipal supplies for Limassol. Since it is less expensive for farmers to pump from their own wells, abstraction may exceed replenishment and seawater intrusion will occur unless appropriate pricing and institutional measures are implemented. Alternatively, local recharge of Limassol effluent not scheduled for transmission to Kokkinokhoria may be applied, especially during the winter months. Recharge of treated sewage effluent will also meet two other specific objectives: (i) it will make possible the transfer of more water to Kokkinokhoria for artificial recharge of that troubled aquifer, and (ii) inland disposal of treated sewage reduces transmission costs to irrigated areas and may avoid problems of surface water eutrophication.

The proposed treatment standard of Limassol tertiary treatment work is 10/10 (BOD/suspended solids) which can be achieved by dissolved air flotation, filtration and disinfection processes following treatment in eration. The yield of tertiary treated Limassol sewage effluent is expected to reach up to 10 MCM/year.

The western part of Akrotiri aquifer consists of sands and gravel and is particularly suitable for artificial recharge. The land is readily available for spreading grounds and monitoring wells, geologic conditions are favorable, the distance from proposed Limassol water-reclamation facilities is not prohibitive, and the water table is sufficiently deep.

5.3.2.3 Larnaca (Kiti) Aquifer

The Kiti aquifer serves irrigated agriculture of the Larnaca area. Increasing rates of development since 1960 has caused the deterioration of the groundwater quality and the abandoning of wells, especially in the main wellfield south of Larnaca--Mazotos. During the same time, construction of Kiti dam deprived the downstream aquifer in some annual recharge occuring through the base flow and underflow in the riverbed alluvium.

Future seawater intrusion can be controlled by injection wells during the winter months using Larnaca sewage effluent. This would be an alternative to storage during the four winter months of 21,000 m^3 per day and to consultants' speculation that "although outside the term of reference, attention should be paid to the possibility of disposing of treated effluent

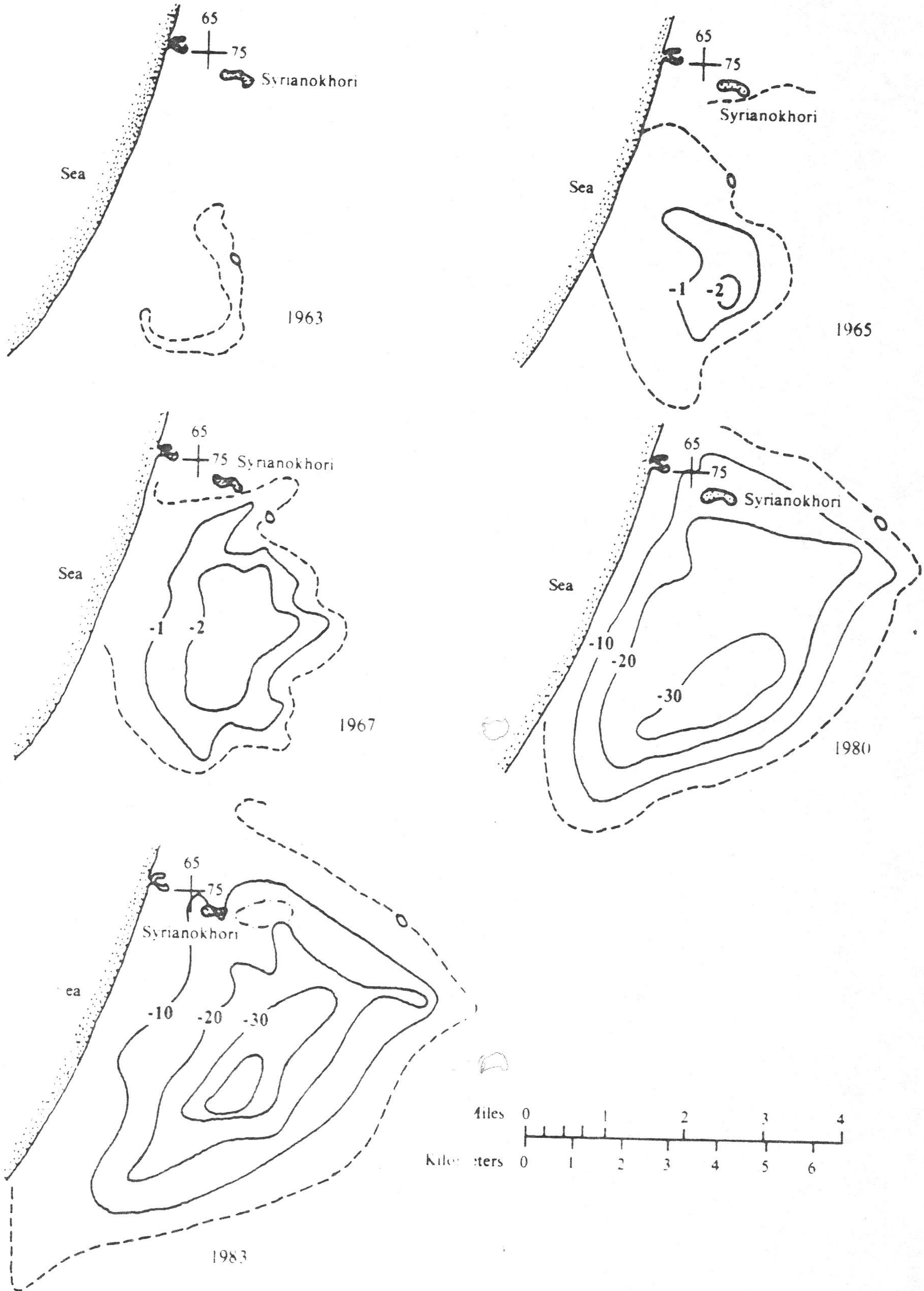


Figure 23. Development of the Groundwater Depression at Morphou, Western Mesaoria, 1963 to 1983

to the sea during the winter months when little or no bathing is taking place" (19).

5.3.2.4 Western Mesaoria (Morphou) Aquifer

Since the 1950s the most productive and important agricultural area of Cyprus in western Mesaoria has been developed by Government programs to increase yields of Morphou aquifer from 58 MCM to 182 MCM per year. This development has long since exceeded the sustained yield of the aquifers. In 1952, groundwater levels along the coastline varied from about 30cm to 3 meters above msl. Recently increasing rates of degradation of the aquifer are revealed by Figure 23.

The groundwater table was 6 meters below mean sea level in 1970 and 10 meters below msl in 1973 in the central part of the depression where it is now 40 meters below msl. This has been accompanied by reductions in well yields, crop yields, deterioration of groundwater quality due to the seawater intrusion, and death of citrus plantations over the western part of the aquifer (Fig. 24).

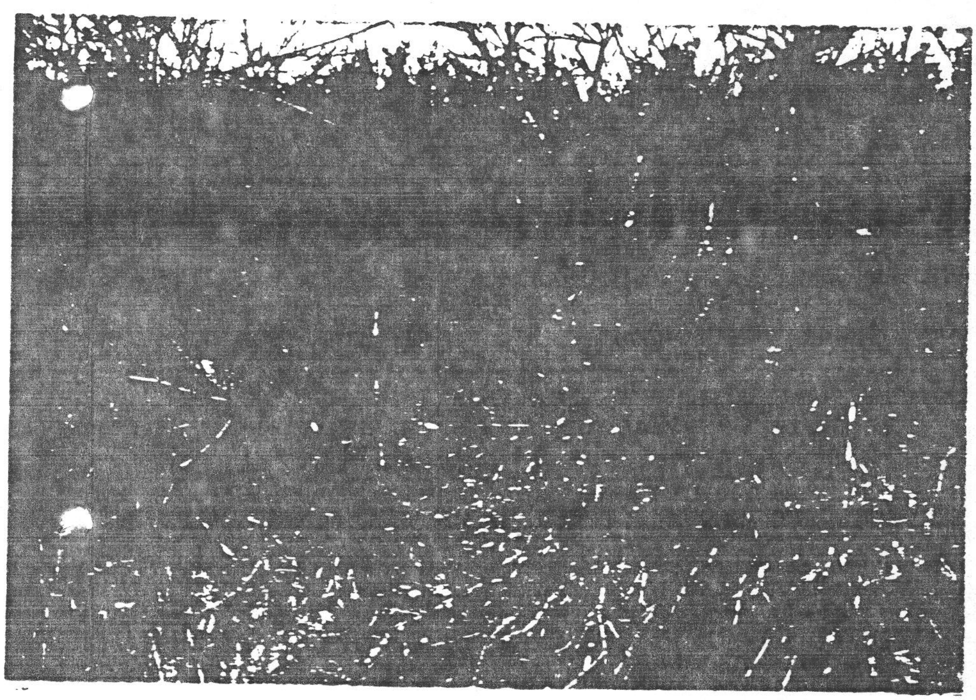


Figure 24. Dying of citrus trees in Morhpou as a result of seawater intrusion

The effects and intensity of seawater intrusion in the last few years is demonstrated by the 500 PPM isochloride map (Fig. 6) especially near Pandyia. Remedial measures to deal with the consequences of groundwater overdraft include construction of the Morphou Development Project beginning in 1982. The project is designed to divert 25 MCM/year during the winter months from the nearby rivers, Xeros, Marathasa and Karyotis which run otherwise to the sea. This project is essentially the first stage implementation of the comprehensive project prepared in 1974 by Electro-Watt Engineering Services, Ltd., Zurich. The origianl project was planned to feature an off-channel terminal storage reservoir on the Morphou coastal plain near Prastio, main river storage reservoir on the Xeros and Pyrgos river; and diversion works on the Karyotis, Marathasa and Limnitis river all to be linked by a main conveyor. Some 20 MCM per year the Prastio reservoir were to be distributed to about 3300 ha of perenially irrigated land in the area of maximum overdevelopment of the Morphou acquifer.

The Morphou Development Project provides for regulators on each river. The Karyotis and Marathara regulators and conveyor were placed in operation during the winters of 1982-83 and 1983-84, respectively. The Xeros regulator and channel are scheduled for construction in 1984. It is planned also to use the Morphou dam as a storage infiltration reservoir, supplemented by additional infiltration galleries along the canal.

The Morphou dam and reservoir were constructed in 1962 with a capacity of 1.8 mcm. The reservoir was designed to retain a significant portion of the 14 mcm average annual flow of the Serakhis River. Initial operation of the Karyotis River diversion provided maximum inflows of less than one m^3/s to the reservoir, the balance having infiltrated from the estimated 25,000 square meter unlined area of the conveyor. A reconnaissance survey of surface sediments along the 13 km unlined section of the conveyor revealed that these areas are permeable and suitable for constructing spreading basins. Other recharge areas include the bed of Serakhis river between Massari dam through Morphou reservoir and the town of Morphou. The area between Morphou dam and Ovgos river is a potential site for creation of a ground water barrier against further seawater intrusion.

No sewerage system is presently planned for the small (or 4000 people) population of Morphou. The only additional source for artificial recharge of this aquifer is that the Morphou Development Project.

6. Costs

Artificial groundwater recharge with treated wastewater and wasted winter stormwater can provide important economical benefits for Cyprus. The combination in many places of water shortages, increasing pumping costs due to the lowering of the water table, and increasing salinity of coastal groundwater support water conservation and reuse proposals. The costs and benefits of previously discussed project elements are summarized below. Details of the Kamares and Nicosia demonstration projects and artificial recharge works are presented in separate reports of R. Florin (10) and the authors.

The initial (1982) construction costs for the Kamares sewage treatment plant were about £65,000 ($130,000). Additional costs for demonstration of wastewater reclamation include those for storage, pumping transmission, distribution, sprinklers, soil preparation and planting at the stadium; these have been estimated at £9,000 ($18,000) for capital recovery, operation, and maintenance. Estimated total annual net benefits equals to £11,000 yielding a benefit: cost ratio of about 1.22 for this initial activity.

The estimated investment costs of the irrigation project in Nicosia are based on those by Florin (10). At 1984 prices, these are estimated at $250,000 for the first phase and $480,000 for the second phase. This project will irrigate about 700 donums (94 ha) in its final stage and generate an estimated additional $76,000 net income for farmers.

Cost figures presented above are provisional estimates based mostly on previous studies. They need to be confirmed by additional reviews of existing data, site investigations, and demonstrations. Estimated costs for feasibility studies of these and other selected activities, based on similar US, Israeli, and other investigations are listed in Table 10.

Table 10: Preliminary Identification of Cyprus Wastewater Utilization and Associated Irrigation Projects and Estimated Costs of Feasibility Study Components (Provisional)

	Feasibility Study	
	1st Year	2nd Year
Further review of existing data	$ 100,000	100,000
Implementation of Nicosia demonstration	50,000	100,000
Implementation of expanded Kamares demonstration	100,000	50,000
Preliminary geohydrological studies (Western Mesaoria aquifer; Central Mesaori aquifer; Southeastern Mesaoria aquifer; Kyrenia aquifer; South coastal aquifer)	100,000	200,000
Feasibility studies and demonstration (seawater and brackish water desalinization; brackish water irrigation)	-	50,000
Diagnostic and predictive water and salt balance models for Cyprus	100,000	200,000
Recharge Demonstration Projects (Kokkinokhoria injection; Morphou spreading; Kiti injection; Akrotiri spreading)	-	100,000
Irrigation Technology Demonstration Projects Nicosia/Morphou	-	50,000
Aquaculture Technology Demonstration Projects Kamares	-	100,000
Implementation Projects (including feasibility studies, etc.)		
Wastewater Reuse (Nicosia irrigation; Famagusta-Larnaca irrigation; Famagusta-Larnaca recharge; Limassol -Akrotiri irrigation and recharge)	-	-
Irrigation (Morphou Recharge; Morphou Irrigation Technology; Paphos; Kyrenia; Limmasol-Famagusta)	-	-
Total Feasibility Study Costs	500,000	1,000,000

7. Policy Issues

Efficient wastewater reclamation and utilization and irrigation on the Island of Cyprus requires conjunctive use of groundwater, surface water, and sewage effluent systems and integrated appropriate institutional measures to make them work. Proposals for wastewater treatment and permanent or seasonal disposal of treated effluent to the sea have yet to be shown to be appropriate for Cyprus, although salt-balance requirements for some areas may justify exceptions.

Water laws and regulations in Cyprus are numerous, repetitive, and complex and have been extended from time to time to meet specific problems. Water use efficiency is emphasized in the Greek Cypriot side by a special measures law which gives wide powers for the control of extraction and utilization. However a correspondingly strong mechanism for implementation of some of these laws is not presently in effect to meet such serious problems as illegal drilling and overpumping of aquifers in the south. Similar regulations on the Turkish Cypriot side are enforced by agency ownership of drill rigs. There are needs to update and rationalize the laws, regulations, and agencies on both the Greek and Turkish Cypriot sides, and to ensure their coordination and information exchange by means of an appropriate compact or other legal instrument.

8. Information needs

Optimum efficiency in wastewater reclamation and utilization requires conjunctive use of all supply and utilization systems. Among the information needs are those discussed in earlier sections of this report, together with with clarification of the following specific technical issues (ordered according to priorities):

- sewage flows and final location of the Larnaca sewer system and treatment plant, proximity of alternative recharge and irrigation sites to the plants, and locations of suitable producing wells which can be used for recharge purpose.

- monitoring of surface streams of the Morphou Development Project to determine changes in stream flow and in water quality.

- the Balasha Jalon feasibility study on sewerage and sewage treatment for Limassol (3), recommended the use of effluent for irrigation. The Southern Conveyor project includes the use of the effluent from the Limassol sewerage scheme beginning 1994 (25,26). The conventional tertiary treatment originally proposed by Balasha Jalon Consultants to achieve European and North American stream standards of 10 mg/l levels for BOD and suspended solids would not be a cost-effective way to meet bacteriological standards for unrestricted agricultural use.Shuval, et al., (11) have convincingly demonstrated that a series of oxidation ponds with no moving parts can provide safe effluent at much lower costs. Their work is summarized in Par.

2.2. A new consulting firm (15) is updating (1983) the sewage project. Major changes including extension of the project area to Amathus tourist area to the east of Limmasol are under consideration. Service areas,effluent flows, and treatment plant location of the revised Limassol wastewater treatment project are to be fixed.

- physical, biological, chemical and institutional aspects of wastewater reclamation and utilization for irrigation, aquaculture, and/or artificial recharge.

- an exploratory well drilling program is needed in areas where there are not enough detailed logs available to provide a reasonable interpretation of the island's geology and hydrogeology.

- the depth and thickness of permeable and impermeable layers in potential recharge boreholes.

- exact number, locations, and corresponding annual extraction rates of boreholes (specially in major areas of stress) in the Western Mesaoria, Southeastern Mesaoria, Akrotiri, and Kiti aquifers.

- a pilot scheme in each of four above mentioned aquifer is required to determine and to demonstrate the behavior of these aquifers, regional and local hydraulic gradient, effectiveness of recharge and to enable planning the locations and the numbers of recharge wells and/or spreading basins, their characteristics, performance requirements and costs.

- costs and benefits of alternative methods of injection well operation to be initially studied in the area of Kokkinokhoria.

- information on construction, operation, and maintenance costs and problems from demonstration infiltration basins in the Morphou aquifer for design of full-scale schemes.

9. References and Bibliography

(1) Ayers, R.S. and Westcot, D.W., Water Quality for Agriculture, Irrigation and Drainage Paper 29, FAO, Rome, 1976.

(2) Ayers, R.S., Use of Sewage Effluent for Irrigation in Cyprus, FAO, Rome, 1979

(3) Balasha-Jalon, Limassol City Master Plan for Drainage and Sewerage, Municipal Corporation of Limassol, 1974.

(4) Bowering, B., Grover, B., and Smith, R., Appraisal of the Nicosia Sewerage Project, Cyrpus. World Bank data, 1971.

(5) Brankov M., Improvement of Morphou Aquifer, W.D.D. 1964.

(6) Bundesantalt fur Geowissenshaften und Rohstoffe, Technical Cooperation Project No. 75.2019.0, Groundwater Exploration and Protection in Cyprus, Hannover, W. Germarny, 1981.

(7) Cramer and Warner, Consulting Engineers, Report on the Possible Use of Nicosia Sewage Effluent for Irrigation Purposes, Nicosia, 1973.

(8) Department of Agriculture, Views and Comments on Consultancy Report, "Use of Sewage Effluent for Irrigation in Cyrpus," Nicosia, 1979.

(9) Electro-Watt Engineering Services, Ltd., Feasibility Studies for Irrigation Development in the Morphou-Tylliria Area, Zurich, 1974.

(10) Florin, R, Optimum Utilization Study of Sewage Water for Irrigation in Nicosia, FAO, Rome, 1980.

(11) Gunnerson, C.G., Research and Development in Integrated Resource Recovery (an interim technical assessment). Proceedings, International Resource Recovery and Utilization Seminar, Shanghai, China, November, 1984.

(12) Hadjistavrinou Y., Groundwater Resources of the Karstic Regions of Cyprus, G.S.D. Buletin No. 5, Nicosia, 1972.

(13) Hadjistavrinou Y. and Afrodisis, S., Geology and Hydrogeology of the Paphos Region, Geological Survey Department, Bulletin No. 7, Nocosia, 1977.

(14) Kutrafali, Z., Report on "Guzelyurt Ovasinin Yeralti Sulari Yo Nunder Kurtarilmas," 1977.

(15) Louis Berger International, A Preliminary Comparison of Sewage Treatment, Aerated Lagoons Versus Extended Aeration, The Sewerage Board of Limassol, 1983.

(16) Maclaren International, Ltd., Report to the Municipality of Nicosia. Master Plan and Feasibility Study on Sewerage and Drainage, Toronto, 1982.

(17) Mantis, M., Upper Eocene Radiolaria in Cyprus, Geological Survey Department Bulletin No. 7, Nicosia 1977.

(18) Ministry of Agriculture, Natural Resources and Energy (Turkish Federated State of Kibris), Irrigation and Development of Morphou Area, 1980.

(19) Reid, Crowther, and Partners, Ltd., Master Plan and Feasibility Report of Stormwater and Sanitary Sewerage of Larna, Cyprus, London, 1982.

(20) Savvides, I., Land Use in Cyprus, Water Develoment Department, Nicosia, 1976.

(21) Tahal Consulting Eng. Interim Assessment of the Water Resources of the Island of Cyprus, Tel Aviv, 1967.

(22) UNDP, Survey of Groundwater and Mineral Resources of Cyprus, U.N., New York, 1970.

(23) UNESCO, Groundwater Storage and Artificial Recharge, U.N., New York, 1975.

(24) Ustun, O., The Present Groundwater Resources of the Western Mesaoria in Cyprus, P.G. Diploma, Middlesex Polytechnic, 1978.

(25) Water Development Department, Feasibility Study, Southern Conveyor Project (SCP), Nicosia, 1982 (19 volumes).

(26) World Bank. The Southern Conveyor Project. World Bank data, 1984.

APPENDIX 1 - RELATED INVESTIGATION, REPORTS AND PROJECTS

Throughout the history of water deficiencies on Cyprus numerous studies and projects have been undertaken to reclaim and conserve this previous resource. Some of the most important of these, which relate to reclamation of valuable water from sewage, water diversion, and coveyance are summarized below.

1. Use of Sewage Effluent for Irrigation in Cyprus, R.S. Ayers (2)

The report refers to the system of treatment of the sewage of Nicosia, and describes the land and soil characteristics within the area to be irrigated. Three alternative irrigation demonstration schemes were studied. Case 1 assumes that no effluent is discharged to the Pedicos River. Water will be stored and be used as necessary. Water use for irrigation of different crops and storage volume for one hectare of crop land are calculated at 65% irrigation efficiency.

The report includes a table where the monthly irrigation requirements and the possible irrigated areas are calculated with a total quantity of 10,500 cu.m/ha/year. At 65% efficiency, the storage required per hectare of land irrigated is 7000 cu.m. At different flows per day the following land area can be irrigated.

Flow per day cu.m.	Land area (ha) at 20,000 cu.m/ha/year at 65% Irrigation Efficiency
5,000	93
10,000	197
15,000	280
20,000	374

In case 2, the effluent will be discharged to the Pedicos River during the winter months, December, January, and February. Using the same assumptions as for case 1, the land which can be irrigated is as follows:

Flow per day cu.m.	Land area at 20,000 cu.m/ha/year 65% efficiency
5,000	70.5
10,000	141.0
15,000	271.5
20,000	282.0

In case 3 it is assumed that the effluent will be used for irrigation during the winter months. With no storage available, the planted area would need to be adjusted so that peak water demand for summer crops could be supplied completely from the daily flow of effluent. The cropped area that could be served is calculated to be as follows:

Flow per day cu.m	Land area (ha) at ETo=8mm/d and 65% efficiency
5,000	40.6 ha
10,000	81.2
15,000	121.8
20,000	162.4

This procedure reduces the volume of effluent available for agricultural purposes but is recommended as an emergency measure. The author states that the sewage effluent quality is suitable for irrigation of selected crops based on his analysis of data in FAO Irrigation and Drainage Paper Ni. 29.

The main irrigation problems include salinity (affects crop water application), permeability (affects infiltration rate into soil), and specific ion exchange (affects sensitive crops). In addition, there was boron reported in the sewage effluent. However, since 1979, no licenses have been issued by the Ministry of Industry and Commerce for importing boron containing detergents.

Health regulations presently proscribe irrigation with raw or partially treated sewage on vegetable crops which are eaten raw and which are in contact with the sewage or the ground.

2. The Nicosia Sewerage Project, Cyprus, World Bank (4)

In response to a request originated by the Sewage Board of Nicosia, application was made to the International Bank of Reconstruction and Development for a loan of US$3.5 million. The loan was to provide for the first stage of the sewerage system, covering an area of 425 hectares serving 32,000 residents occupying about 6,000 properties, and eliminating the need for vacuum truck removal of septage. Cost recovery is to be provided by sewer service charges, two-thirds based on property assessments and one-third on water sales. The financial projections assume charges of 50 mils/cu.m on water consumed, 36 mils/£ of assessed property value in the project area and 12 mils/£ of assessed value of property in areas which will be connected later. Projected rates of return on net plant were reported to increase from 7.6% in 1976, increasing into nearly 10% in 1979.

3. Possible Use of Nicosia Sewage Effluent for Irrigation Purposes, Cramer and Warner (7)

The report discusses the quality of sewage effluent and its interrelationships with soil, climate, and crops to be irrigated. The authors concluded that there was a lack of sufficient information on the physical and chemical parameters associated with the use of sewage effluent; that effluent water quality can be controlled by dilution, alternating with other irrigation supplies, and by banning boron-containing detergents.

4. Optimum Utilization Study of Sewage water for irrigation in Nicosia, R. Florin (10)

The author proposed a demonstration project with the following objectives:

i) to minimize waste of useful water
ii) to minimize the discharge of raw or inadequately treated sewage into the Pedicos River since its natural water is used further down for irrigation of market vegetables
iii) to gain experience with sewage irrigation under local climatic and agricultural conditions
iv) to raise the agricultural production and income of the areas farmers.

The proposed demonostration area is 95 ha of irrigable land east of Nicosia and downstream the sewage treatment plant along the Pedicos River. Crop selection criteria include public health protection, salinity and boron tolerance, feasibility of farm technology, and marketing potential. Salt and boron tolerant fodder was recommended for the fattening of calves and he-goats. The proposed cropping pattern includes lucern, barley, maize, and sudan grass together with eucalyptus to serve as a shelter belt. Because of the high installation cost of drip or sprinkler irrigation systems, Florin proposed border and furrow irrigation.

Due to the uncertainties in effluent quality and crop response, the project provides for staged development. The first stage will be for development of a 35 ha pilot area and project center immediately downstream of the sewage treatment plant on the southerly bank of Pedicos river. Second stage development of up to 50 ha of the remaining area will be according to water availability and may include construction of a reservoir for additional winter irrigation outside the project area.

Florin proposed to form a "Cooperative Committee" for the management and monitoring of the project. Committee members will include participating farmers and members of the staff, administrative authorities who will manage and monitor the project farms.

The estimated project costs based on optimum wastewater utilization are US$170,000 for the pilot project area and US$490,000 for full development (both in 1978 dollars; multiply by 1.5 for 1984 costs). It was estimated that at full development, the annual crop value of the project area would be US$80,000 requiring an annual input of US$60,000.

An alternative scheme which would utilize all of the wastewater would be development of a 20 ha eucalyptus plantations under gravity surface irrigation. The investment and planting costs were estimated to be US$30,000. Annual crop revenues were estimated at US$10,500 with costs of US$1,800.

5. Report to the Municipality of Nicosia Master Plan and Feasibility Study on Sewerage and Drainage, Maclaren International Ltd. (16)

The report provides for a separate sewerage system throughout the Greater Nicosia area of 6,250 ha of which the municipality occupies 4,000 ha.

The system was designed for the year 2000 population of 312,750 with an average daily sewage flow of 143,000 cu.m. This flow includes also the industrial and commercial wastes and an allowance of groundwater infiltration of 34,100 cu.m (24%). Pre-existing combined sewers are to be used where feasible.

The treatment plant location is along the south bank of the Pedicos river south of Mia Milea village. Maclaren International recommended aerated and facultative sewage lagoons for first stage construction.

Effluent irrigation

For the disposal of the treated effluent, the following methods groundwater recharge, discharge direct to the Pedicos River, and crop irrigation were considered. From these, the consultants recommended the latter because it provides a satisfactory method of disposal; it contributes to the productivity of the community; and will provide the Municipality with a source of income. it was further proposed to use the treated effluent on a newly established centralized irrigation demonstration under the direct control and management of the Government.

Cost recovery

To obtain sufficient revenue to cover the annual operation and maintenance costs incurred by the municipality, a combination of ad valorem taxes and user service charges were recommended.

The first three stages, in order or priority, are

Stage I: 425 ha in the southern half of the area within the walls and the clay area south of the walls.

Stage II: 180 ha in the northern half of the area within the walls.

Stage III: 195 ha located in heavily populated and industrial areas of Engomi and Ayios Andreas Area in Nicosia.

6. Views and Comments on Consultancy Report "Use of Sewage Effluent for Irrigation in Cyprus", Cyprus Department of Agriculture (8)

This is a letter report to the Director General of the Ministry of Agriculture and Natural Resources from the Director of the Department of Agriculture which addresses the report of Mr. R. S. Ayers. He generally concurs with Ayer's findings.

Recommended crops to be irrigated include alfalfa, beets, corn, berseem and cereals.

7. Master Plan and Feasibility Report of Stormwater and Sanitary Sewerage of Larnaca, Cyprus, Reid, Grother and Partners, Ltd. (19)

The Municipal Corporation of Larnaca invited international tenders for the preparation of a scheme for the collection and disposal of the sanitary sewerage and stormwater drainage of the Larnaca area. The terms of reference required that a separate system should be studied and the treated effluent from sanitary sewage should be suitable for the irrigation of fruit trees and annual fodders. The area to be served includes 7000 hectares in the city of Larnaca, the village of Livadhia (north west of Larnaca), the Larnaca International Airport, the Salt Lake and a coastal strip to the north, up to the boundaries of the Sovereign Base Area of Dhekelia. The 54,100 estimated population to be served by the year 2000 is 54,000.

Sewage flows predicted for the year 2000 following flows were predicted on the basis of 225 liters/c/d (domestic); 20 liters/c/d (commercial); 28,500 liters/hectare/day (industrial); and 360 liters/bed/d (hotels).

Low-lying of the city along the coastal plain are expected to have high levels of infiltration of groundwater into the sewerage system. These are assumed at 2,000 l/ha/d during the winter in areas above the five meter contour and zero during the summer. Below the five meter contour winter infiltration of 10,000 liters/ha is assumed. Daily flows will range from a maximum of 34,300 cu.m. in summer to a minimum of 16,000 in winter.

The expected quality of the treated effluent predicted with due regard for infiltration was estimated at 6,150 micromhos in the suburbs and 2,500 in the city equivalent to about 4,000 and 1,500 mg/l total solids, respectively.

The treated effluent is to be used for irrigation with winter storage volume of 3.2 x 10^6 cu.m. The irrigated area with effluent storage will be 560 hectares or 250 hectares if the effluent during the rainy season is not stored. Since the quality of the effluent may be marginal for irrigation use, an agricultural study is needed to establish which crops are most suitable.

The selected site for the construction of the treatment plant is located north-east of the village of Kelia. Based on a comparison of capital, operation and maintenance costs, the consultant recommended treatment by oxidation ditch. Treated effluent would be stored near the plant where there is suitable land for irrigation of animal fodder.

The estimated cost for the construction of the sanitary sewerage scheme has been estimated as follows:

Collection......................	C£ 18,200,000	
Treatment........................	2,789,000	
Storage and Disposal.............	6,913,000	
Total	C£ 27,902,000	(USD 14 million)

First stage construction includes the sea front and the central portion of the developed part of the city the cost is estimated as follows:

Collection......................	C£ 5,652,000	
Treatment........................	1,392,000	
Storage and Disposal.............	3,456,000	
Total	C£ 10,500,000	(USD 5.2 million)

8. Southern Conveyor Project for Water Resources Development (25,26)

The project is a two phase development to utilize the remaining surface water resources on the Greek Cypriot side. Different supply options, phasing, technical alternatives and details were examined and are described in 19 volumes of a Water Development Department feasibility study published in 1982 and updated in 1983, and summarized in World Bank data in 1984.

The Southern Conveyor Project for Water Resources Development (SCP), when fully developed, will collect and store surplus water from the south catchments of the island and convey this water to areas of demand for both domestic water supply and irrigation. An additional source of water for irrigation could be at a later stage the effluents from a tertiary sewage treatment plant for Limassol proposed by Balasha-Jalon Consultants in 1974. In total, SCP will provide an incremental water supply of about 70 MCM/y which ultimately will be allocated to domestic supply and irrigation in varying proportions. The main SCP objectives at full development are:

- to secure a safe domestic water supply until at least the year 2010 to the four major areas (Nicosia, Limassol, Larnaca, and Famagusta), with a combined population of 435,000. Water will continue to be provided to the Turkish Cypriot sides in Nicosia and Famagusta whose consumption is estimated at 12% of total domestic consumption in the project area.

- to provide irrigation water in order to maintain present agricultural production in 5,125 ha in Kokkinokhoria and to expand irrigated agriculture totalling about 3,000 ha in four other areas along the southern coast of the island.

- to implement policies and take institutional measures in order to improve overall cost recovery through increased revenues and to further enhance the efficient use of both domestic and irrigation water and to establish an integrated institutional framework so as to ensure the efficient use of water resources and the uniform application of policy measures.

The SCP components at full development include:

a) Kouris reservoir, with a gross capacity of 115 MCM behind the 103 m high earthfill Kouris dam;

b) Main conveyor, a 110 km long pipeline, ranging in diameter from 1400 mm to 800 mm, running from Kouris reservoir to Akhna reservoir;

c) Akhna terminal reservoir, with a gross capacity of 5.8 MCM behind the 16 m high Akhna dam;

d) Dhiarizon diversion, conveying water from Dhializos river through a 16 km long, pressurized pipeline and tunnel to kouris reservoir, collecting water from Khapotami river en route;

e) tertiary sewage treatment plant at Limassol, as a source of additional water supply for irrigation;

f) pressurized irrigation distribution networks on about 8125 ha;

g) domestic water supply works, for urban and rural areas, consisting of water treatment works, river aquifer development, pumping stations transmission mains, and storage tanks;

h) central control system and project administration, buildings, equipment, workshops and study to determine the appropriate structure for the establishment of the water entity.

The full SCP requires an implementation period of an estimated ten years. The 1983 cost of the full project including physical contingencies, is US$254 million of which US$86 million are local cost and US$168 million foreign cost (the World Bank loan is US$27 million).

9. Morphou Development Project (9)

The Morphou Development Project is designed to divert 25 mcm/y winter flow of the Xeros, Marathasa and Karyotis Rivers. Implementation began in 1981 with the Karyotis diversion. The project is a portion of the more comprehensive project prepared in 1974 by Electro-Watt Engineering Services, Ltd., Zurich. The first stage of the original project included an off-channel terminal storage reservoir on the Xeros and Pyrgos rivers; and diversion works on the Karyotis, Marathasa and Limnitis Rivers. Storage and diversion works were to be linked by a main conveyor. Some 20 mcm per year would be diverted from the Karyotis, Marathasa and Xeros rivers to the Prastio off-channel reservoir. Distribution of irrigation supplies to about 3300 ha of perenially-irrigated land in the area of maximum over-development of the Morphou aquifer would reduce some of the overdraft on the aquifer.

The project under construction includes regulators on each of the three rivers of Xeros, Marathasa and Karyotis in order to divert 8 mcm/year from the Xeros river, 8 mcm/year from the Marathasa river and 9 mcm/year from Karyotis river to a conveyor (Figure A-1) which links these regulators to the Morphou dam.

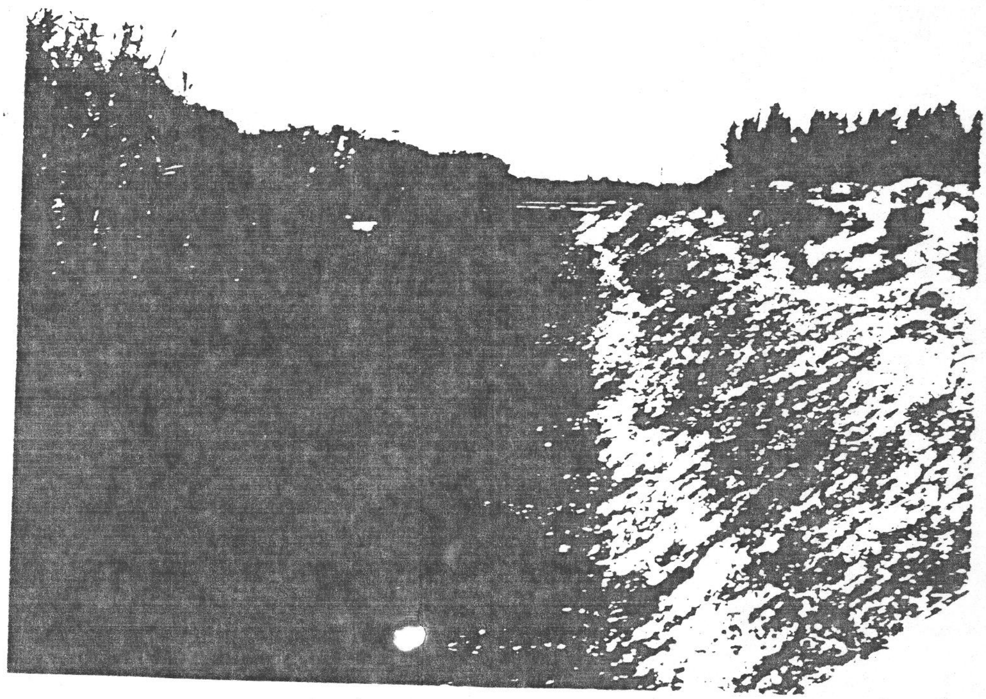


Figure A-1. Morphou Development Project Conveyor

The main conveyor canal is 21 km long. The first 8 km of the open channel northerly from the Karyotis regulator are lined with reinforced concrete and the remaining 13 km are earth channel. The capacity of the canal will vary from 3 m^3/sec at the Xeros River to 8 m^3/sec. in the north.

First stage of the project (Karyotis regulator and conveyor) was placed in operation in 1982. Diversion of Marathasa Riverwater was scheduled for 1983. The Xeros regulators and Xeros channel to the main canal is planned for construction in 1984. Water in the existing 3 million MCM Morphou reservoir on the Serakhis River infiltrates into the aquifer or is distributed for irrigation.

An estimated half of the capacity of Morphou Reservoir is used by flows from the Serakhis River. The additional 25 mcm/y flows from the three southerly rivers will exceed the capacity of the reservoir, with any excess which has not infiltrated into the aquifer (see Par. 5.3.2.4) being lost to sea.

APPENDIX 2 - GEOLOGY

Groundwater resources on the Island of Cyprus are expressions of the lithology of the sedimentary formations and the geological structure of the island. Cyprus can be divided geologically into four east-west trending categories (see Fig. 2 in text). These are:

- The Troodos Mountains consisting of an igneous massif with a core harzburgite with peripheral gabbro, diabase and pillow lavas. The maximum elevation is 1951 meters.

- The Mesaoria plain which consists of a series of sediments and which separates the two mountain ranges, Kyrenia in the north and Troodos in the south.

- The Kyrenia range along the north coast notable mostly for its karstic limestone topography and aquifer.

- The coastal plains which vary in width, but are found almost everywhere between the mountains and the sea. These coastal plains show evidence of quarternary changes in sea levels in both general sea levels in over-deepened beds of many of the rivers.

The Pre-Cambrian Troodos Mountain is an igneous massif comprise of a core of plutonic rocks (Harzburgites, dunites, clinopyroxinites and gabbros) forming the crest of the range. The water found in shear zone, fracture zone and faults within gabbro is of local importance and of very good quality. The ophiolitic coreis surrounded by a sheeted dike complex with an outer peripheral belt of extrusives. The extrusives are mainly pillow lavas which represent the extrusive phase of the igneous complex and consist mainly of basalt and olivine basalt. Troodos pillow lavas are followed by a thick sequence of sedimentary rocks of radiolarian mudstones, bentonite clays, siltstones, and micaceous sandstones of cambrian to early Mastrichitian.

The Jurassic Hilarion limestone is found only in the Kyrenia Range, where it outcrops as upthrust slices forming a dramatic skyline. This karstic limestone is the most important aquifer of the consolidated rock units in Cyprus. The Hilarion formation stretches from Cape Kormakiti in the northwest of the island to Komi Kebir at the root of the Karpar Peninsula with a thickness of 300 meters and width up to 4 kilometers.

The Upper Maestrichtian marks the beginning of calcareous deposition all over Cyprus. It begins with Lefkara formation which consists of marls, marly chalks, chalks, and limestone. The pillow lavas occur as a fringe to the Troodos Complex, a separate outcrop in the Troulli area, and as thrust slices in the Kyrenia Range. They are submarine andesitic lavas, containing zeolites.

The Lapithos Group ranges in age from upper cretaceous to Upper Oligocene. The rocks are mainly marls and chalks with flint concretions. The Eocene Nummulitic Limestone occurs on the east side of the island, while in the Kyrenia Range there are thin-bedded flinty limestones. In the Kyrenia Range, the lapithos was exposed to the full force of the Alpine folding and is much sheared. South of the Troodos Complex it was shielded and gently folded.

The Miocene sediments in Cyprus embrace two major facies. South of the Troodos Mountains, the Pakhna Formation consists of chalks, marls and some sandstones and gypsum lenses, generally similar to the underlying Lapithos beds, except for the absence of flint. Locally a basal conglomerate and at Terra a limestone-reef separate the two facies. North of the Troodos Mountains and especially along the whole line of the Kyrenia Range, the contemporaneous Kyrenia formation consists of flysch type sediments composed of material eroded from the rapidly rising Kyrenia Ranges. On the south, there was a sinking fore deep whose rate of sinking balanced the rate of deposition. As a result, sedimentation took place in shallow lagoons, often cut off from the open sea by sandbanks, in which evaporation and salt-concentration was high. There are many gypsum beds and the rocks contain much cognate $NaCl$. Blue-black clays, rich in iron sulfides and carbonaceous matter are common. In clearer water to the south, the Koronia reef-limestones were formed. The Kythrea Formation was folded almost as soon as deposited along the south of the Kyrenia Range.

The Mesaoria Group consists entirely of post-tectonic formations. The Pliocene marls were laid down in basins and were followed by the Nicosia Formation, a littorial and shallow water sandstone. The interface between the Pliocene and the Miocene has been revealed by drilling in many areas and suggests sudden encroachment of a transgressive Pliocene sea over a Post Miocene landscape. In turn, there was a Middle Pliocene emergence, followed by the deposition of the Kyrenia Formation, similar in facies to the Nicosia.

The Quaternary deposits are varied and cover large areas of eroded Miocene and Pliocene surfaces. They consist mainly of sands and gravels laid down under deltaic, fluvial, littoral and flood plain conditions, as well as sand dunes dams and related aeolian deposits.

APPENDIX 3 - HYDROGEOLOGY

Determinants of the groundwater hydrology of the Island of Cyprus include precipitation (Plate III) and the locations and characteristics of infiltration zones (Plate IV).

A. Water-Bearing Properties of Geological Units

A hydrogeological classification of rock units of Cyprus consists of first class aquifers, second class aquifers and aquicludes.

Pliocene and Quarternary sediments form the first class aquifers in western and southeastern Mesaoria, Akrotiri and Kiti, and are developed by infiltration galleries, wells and boreholes.

The second class aquifers include those rock units which store and transmit water through joints and give rise to almost all the springs of this island. The Harzburgites and gabbros of the Troodos Complex are the most extensive of the jointed igneous aquifers. Except along fissures, joints and shattered zones, these rocks are impermeable in both their fresh or weathered states. Infiltration, movement and storage of ground water is directly related to the degree of fracturing of the rocks and in general, more ground water will be found in higher elevation where rainfall is higher. Many springs and over 90 drillings have proven a number of small, local aquifer's are promising sources for local use. The quick response of springs to rainfall indicates that Troodos aquifers are local and that there is no movement of water for long distance through these rocks.

The Hilarion karstic limestone covers 1.75% of the island and is the most important second class aquifer. The formation is a good retainer and transmitter of water with the large springs of the island. The limestone is fissured, faulted and in places has an almost vertical dip. The topography is extremely rugged and there is every indication that infiltration is very high. Where the contact of limestone and underlying bed is lowest, the water spills out of the limestone. The limestone is fringed with springs, mostly with small yields, but also some with very significant discharge. Kythrea spring in Kythrea Village is the greatest spring of the island with a recorded average yield of 120 to 130 l/s but the yield of the spring measured by the writer of this report on September 22, 1983 was only 20 l/s which is most probably the result of low precipitation during the last three years.

Other jointed or fissured aquifers are small and of minor importance. The Lapithos chalks are folded and jointed. A few drillings near Ktima in southwest Cyprus has shown that this aquifer is very localized and that successful boreholders are on the banks of streams which usually follow faults and other planes of weakness. Larnaca gets part of its water supply from boreholes drilled in Lapithos chalks. The Koronia limestone is a shallow water deposit of Miocene reef limestone which is well exposed all along the northern fringes of the Troodos massif and south of Famagusta at Cape Greco and Plya. The water of this formation is usually highly mineralized but it is acceptable for the irrigation purpose.

The Plio - Pleistocene Mesaoria Group embraces all the major aquifers of Cyprus. Its main outcrop extends across the Mesaoria Plain from Morphou Bay to Famagusta with an extension southwards to Larnaca Bay. Along the coasts, Pleistocene deposits predominate but the location and the level of the lighter sweet groundwater table is influenced by the heavier salt water of the Mediterranean.

At Kyrenia there is an aquifer in a number of quaternary terraces which is exploited by hand dug wells of local importance. The aquifer, whose base is above sea-level is producing some 6 mcm of water for local use and discharges another 5 mcm to the sea. Terraces of the Kyrenia consist of buff, fossiliferous calcarenites, gravels and sands which form aquifer of 3 to 30 m thickness with a usual thickness of up to 5 m which extends inland to about 2 km.

The identification of the aquicludes of Cyprus is also important in avoiding profitless attempts to tap water in these rocks, and in identifying studying their controls on downward movement of ground water. The Pillow lavas surrounding the Troodox Complex are aquicludes and no water penetrates below the weathered surface of the lavas. The marls and chalks of the Lapithos Group retard the downward movement of groundwater and are very good aquicludes. The Pakhna Formation is generally an aquiclude since it is mostly of marls, marly chalks and laminated organic shales facies. The Kythrea Formation is more of an aquiclude than an aquifer since the blue-black clay is the typical representative of the formation. Around the Kyrenia Range the Kythrea forms the impermeable bed enclosing the water-filled Hilarion limestone joints and caves. Beneath most of the Mesaoria and coastal plains, the impermeable rocks of Miocene hold up the underground water in the overlying Pliocene and Pleistocene beds and at the base of the Pliocene occur the impermeable Myrtou marl of Miocene. These rocks outcrop east of Mesaoria Group.

B. Major Aquifers

There are four major aquifers in Cyprus which generally extend over in excess of 40 square kilometers, and three of which are first-class aquifers. Under this definition first-class aquifers include the western Mesaoria (Morphou) aquifer, the southeastern Mesaoiria (Kokkinokhoria, Kiti) aquifer, and the Akrotiri peninsula aquifer. The fourth of these major aquifers is Kiti which belongs to the second-class aquifers. All four are severely depleted and damaged by overexploitation and seawater intrusion.

C. Western Mesaoria Aquifer

The Western Mesaoria Aquifer extends over about 400 sq km and includes vast lowlands sloping to the west towards the shoreland bounded by the Kyrenia Range in the north and the Troodos Mountains in the south.

The Western Mesaoria upper aquifer is the most important aquifer in Cyprus in terms of annual replenishment. It consists of gravel, sand and calcarenites with interbedding of relatively extensive lenses of silt and clay and is underlain by thick Plio-Pleistocene clays and marls. Its shape is approximately that of a half-bowl with a maximum depth of over 100 meters at Morphou Bay.

The base of this aquifer has been penetrated by several boreholes of up to about 300 meters deep. The complexity of the aquifer is expressed by many lenses and layers of different permeability. The average annual replenishment of the Western Mesaoria is 60 mcm. They estimated that annual pumpage from the aquifer is about 85 mcm, 25 million cubic meters per year of which are not replaced resulting in a continuous decline of the water-table.

The groundwater depression of Western Mesaoria, even during wet years, has been below mean sea level since 1962. With continued enlargement of the depression, its western boundary reached the shoreline by 1964. Since then seawater has been flowing into the watertable depression, which reached a maximum depth of 4 meters in 1968 and 40 meters below msl by 1983. (see Figure 4 in text).

The velocity of seawater intrusion is estimated at 30 to 100 meters per year. During the record dry year of 1973 the estimated deficit was of the order of 53 mcm due to the neglible recharge on one hand and the larger extraction on the other because of the prolongation of the irrigation period. It should be noted that a deficit of 10 MCM causes a drop of 0.5 meters of the groundwater level.

D. <u>Southeastern Mesaoria Aquifer</u>

The Southeastern Mesaoria covers an area of about 500 sq km bounded by the roads connecting Famagusta-Kondea-Pergamos-Dhekelia and the sea in the southeastern corner of the island. It differs from western Mesaoria in two important aspects: it is more exposed to seawater intrusion because of the longer coastline and they are still more diversified in their geological structure.

Four different aquifers can be distinguished in this area of which only the upper, sandy section of the Plio-Pleistocene sequence is of regional importance and which supplies some 99% of the ground water presently used. The aquifer consists mainly of calcarenities, sands and gravels which are covered on the surface by a weathering curst which obscures geological features. The base of the aquifer consists mainly of marly Plio-Pleistocene sequence and the marls of the Upper Miocene where the aquifer thins out. The upper sandy section up to 80 m thick comprises several lithologic types changing laterally by interfingering, and forming intercalated lenses of calcareous sands and sandstones, gravels, lumachelle, sandy marls, marly sands and clays. The bedrock has a rugged topography, with deep troughs in which the aquifer is thick, separated by ridges where the aquifer is thin. It is thin over large areas within the village boundaries of Agorou, Athana, Xylotymbou, north of Ormidhia, and between Phrenaros Village and Liopetri. The aquifer thickens to more than 80 m towards the coast in the Liopetri and Xylophaghou area. This aquifer has been divided by Tonal Consulting Engineers (1969) into four groundwater zones as:

"Zone I covers an elongated area parallel to the northeastern coast from north of Famagusta to Cape Greco, Zone 2 has the shape of a reversed L extending (from west to east) from Xylotymbou to Liopetri and hence to the north to the Four-Mile Camp; Zone 3 covers the area inside the angle formed by the L of Zone 2; and Zone 4 corresponds to a belt running along the southern coast of the regions. The groundwater is generally unconfined. Actual abstraction of groundwater is concentrated mainly in the area where the aquifer is relatively thick and has high transmissibility values and comparatively high specific yields. Since there is no major stream in the area the aquifer is replenished by rainfall. The annual average replenishment is roughly 24 mcm. There are some 3500 boreholes at the present operating in this area, forty-seven percent from which are illegal. Windmill driven pumps (Fig. 8) which were usually tapping the first water bearing formation in the ground and were used to irrigate one or two donums of land (One donum = 0.134 hectares = 0.3306) have been replaced by boreholes of several hundred feet deep equipped with big pumps of output sufficient to irrigate hundreds of donums. Although the aquifer has been increasingly damaged since 1960, total abstraction and the number of wells have also increased (see Figure 8 in text). In the Kokkinokhoria area which covers the main part of the southeastern Mesaoria aquifer and accounts for about 85% of its present ground water abstraction, the situation is worse. The mean annual lowering of the water table is 1.5 m and total reduction of 200 MCM of the ground water reserve has been incurred since 1963. Pumping is heavily concentrated in the areas of Phrenaros, Liopetri - Sotira and Xlophaghou - Ormidhia where wells can stillprovide 10-20 m^3/h. In more depleted areas of the aquifer, wells yield is very low. In Xyloghaghou-Ormidhia and Liopetri, sea intrusion is prograting inland at an increasing pace. In the first area, boreholes within 2.5 km of the coast have been abandoned, and saltwater contamination has been observed up to 4 km from the coast.

Since 1963 the water level has dropped by 55 m to the present situation of 43 m below msl at Phrenaro and by 40 m to the present situation of 35 m below msl in Liopetri and by 45 m to the present situation of 40-45 m below msl in Xylophaghou. The yields of the boreholes in these areas have dropped from 20-30 m/h in 1963 to the present 5-20 m/h. Farmers are competing for the remaining water in the aquifer and discharge lines cross each other to supply sprinkler irrigation systems throughout the Kokkinokhoria area (see Figure 9 in text). Seawater intrusion has salinized some areas of this aquifer and overpumping has essentially exhausted the aquifer in the areas of Athna and Avgorou.

The Akrotiri aquifer is made of gravels, sands and boulds intercalated with thin lense of silt and clay. These deposits extend into the aquifer from the northwest. The sediments of the aquifer varies from coarse boulders in the north and west to fine sands in the south and east. Further east and south the aquifer consists of fine gravel with fine sand interbedded with layers of silt and sandy marls. To the west the Kouris river forms an alluvial cove composed of boulders, which give way to finer material towards the southeast and to the west.

The area of the aquifer has a very flat, smooth and low topography and as a result of this low surface topography the thickness of the aquifer is a few meters in the north and increases towards the south where it attains a maximum thickness of 120 meters. The ancient and recent Kouris River courses created alluvial cones in the western part of the aquifer while in the east Gryllis river has deposited only loam and other fine materials. Therefore towards the east, where interbedding of layers consist of different material, the permeability if less and the aquifer is very sensitive.

Replenishment of the aquifer comes mainly from seasonal infiltration, the greatest part through inflow of Kouris river (70%), from rainfall and from irrigation return flow. The annual replenishment is about 32 mcm and the total outflow for an average year is similar to replenishment generally.

As mentioned earlier the aquifer is sensitive in the eastern part. This sensitivity is due to annual climatic conditions, excessive recharge or reduction of pumping, and to overpumping.

The increasing rate of ground water abstraction during 1960-66 led to an increase in salinity in wells in some locations such as the Zakaki Village area. The fresh water-saline water interface movement inland has been halted and in some area reversed by the import of water from Palenidhia and Yermasoyia reservoir and reduced pumping. East Akrotiri, where the aquifer is sensitive marsh conditions occured temporarily in some locations. This type of sensitivity has been also recognized as responding to annual precipitation. During the exceptionally wet year of 1968-69 the water table level was above msl throughout the aquifer but during dry years of the early 1970s, ground water reached its lowest level, up to 6 meters below msl so that seawater has intruded about 2 km from the coast. The water balance of the aquifer under present conditions is generally not negative but the seasonal problem due to water level depressions is present in some locations.

F. Larnaca (Kiti) Aquifer

Larnaca coastal lowlands are built up mostly of Pliocene marls, overlain by a thin cover of sandstones and conglomerates. These sandstone and conglomerate deposits are too thin to bear any significant quantity of water. The Plio-Pleistocene Kiti aquifer, covers an area of about 30 sq km consists of by gravels, sands, silts, thin yellow marls and lenses of conglomerates indicating shallow water sedimentation. The base of the aquifer rests unconformably upon the marls of Athalassa Formation. The thickness of the aquifer varies from 50 m near the mouth of the Tremithos river to about 10-20 m along the most part of the aquifer. The water table is mostly 2-3 m below the surface in the basal conglomerate and in the river alluvium along the riverbed.

The recharge of the aquifer consist mainly of rainfall, leakages from the Kiti dam and infiltration from the Tremithos riverbed when the Kiti dam overflows. The total recharge of the aquifer is from 2.2 mcm/year in a dry year to 7 mcm/year in a very wet year. The estimated pumping is about 3

MCM per year. It appears that the sediments of the river channel constitute a preferential course of ground water flow and much of the infiltrated water escapes to the sea through a narrow strip with much higher transmissivity.

APPENDIX 4

Table A-1: Soil Analysis Report of Central Mesaoria

Sample No.	Depth cm	EC x 10^3 at 25°C mmhos/cm	pH 1/5 soil/ water	$CaCO_3$ %	Organic matter %	Boron mg/1
1	0-30	0.974	8.2	19.8	2.20	0.00
	30-60	1.032	8.4	20.4	-	0.00
	60-90	0.757	8.5	-	-	0.90
	90-150	0.947	8.6	22.5	-	0.90
2	0-30	0.757	7.9	-	1.40	-
	30-60	0.757	8.1	18.1	-	-
	60-90	0.947	8.3	20.1	-	-
	90-150	0.947	8.5	23.2	0.50	-
3	0-30	0.445	8.0	-	1.40	0.28
	30-60	0.445	8.3	20.6	1.10	0.23
	60-90	0.556	8.3	-	-	0.45
	90-150	0.617	8.5	24.4	-	0.23
4	0-30	0.445	8.3	23.0	1.24	-
	30-60	0.556	8.5	25.2	1.07	-
	60-90	0.654	8.5	-	-	-
	90-150	0.741	8.8	25.6	-	-
5	0-30	0.445	8.3	17.6	1.61	-
	30-60	0.445	8.2	18.2	-	-
	60-90	0.585	8.5	-	-	-
	90-150	0.654	8.5	20.9	-	-
6A	0-30	2.471	8.0	20.4	1.67	-
	30-60	1.853	8.4	20.7	-	-
	60-90	2.021	8.4	-	-	-
	90-150	2.021	8.6	23.4	-	-
6B	0-30	0.445	8.0	-	1.67	-
	30-60	0.568	8.3	-	-	-
	60-90	0.617	8.5	23.0	-	-
	90-150	0.741	8.6	24.0	-	-
7	0-30	0.568	8.1	19.8	1.47	-
	30-60	0.741	8.3	24.4	-	-
	60-90	0.741	8.2	-	1.40	-
	90-150	1.110	8.5	-	-	-
8	0-30	0.568	7.9	21.0	1.07	-
	30-60	0.617	8.0	22.9	-	-
	60-90	0.741	8.0	-	-	-
	90-150	1.130	8.2	25.0	-	-
9	0-30	0.445	8.0	23.6	1.67	0.34
	30-60	0.445	8.2	24.9	-	0.56
	60-90	0.556	8.2	-	1.09	0.17
	90-150	0.741	8.4	26.0	-	0.28

Sample No.	Depth cm	EC x 10^3 at 25°C mmhos/cm	pH 1/5 soil/ water	$CaCO_3$ %	Organic matter %	Boron mg/1
10	0-30	0.444	7.9	25.4	1.64	-
	30-60	0.444	8.0	27.0	-	-
	60-90	0.444	8.2	-	-	-
	90-150	0.444	8.4	30.0	-	-
11	0-30	0.371	7.9	21.8	1.70	0.45
	30-60	0.372	8.0	21.8	-	0.00
	60-90	0.371	7.9	-	-	0.45
	90-150	0.444	8.2	-	-	0.00
12	0-30	0.568	8.0	-	1.88	-
	30-60	0.617	8.3	21.0	-	-
	60-90	0.874	8.4	-	0.75	-
	90-150	1.110	8.6	18.3	-	-
13	0-30	0.445	8.2	22.6	1.94	-
	30-60	0.617	8.0	23.1	-	-
	60-90	1.010	8.3	-	-	-
	90-150	1.112	8.3	-	-	-
14	0-30	0.568	8.0	24.4	1.40	0.23
	30-60	0.757	8.2	24.8	1.07	0.00
	60-90	1.032	8.4	-	-	0.23
	90-150	1.130	8.6	25.2	-	0.23
15	0-30	0.444	8.1	25.2	1.3	-
	30-60	0.444	8.3	25.3	-	-
	60-90	0.654	8.3	-	-	-
	90-150	0.654	8.4	26.7	-	-
16	0-30	0.445	8.0	-	0.75	0.00
	30-60	0.445	8.0	-	-	0.00
	60-90	0.556	8.2	26.5	-	0.00
	90-150	0.617	8.3	27.4	-	0.23
17	0-30	0.444	7.8	21.3	1.60	-
	30-60	0.654	8.2	23.4	-	-
	60-90	0.654	8.6	-	-	-
	90-150	0.784	8.4	-	-	-
18	0-30	0.741	8.2	19.3	0.8	0.23
	30-60	1.308	8.3	21.0	-	0.84
	60-90	1.110	8.4	-	-	1.13
	90-150	0.617	8.4	23.0	-	1.63
19	0-30	0.445	8.2	18.2	1.2	-
	30-60	0.556	8.2	18.6	-	-
	60-90	0.741	8.3	-	-	-
	90-150	0.793	8.5	14.6	-	-

Sample No.	Depth cm	EC x 10^3 at 25°C mmhos/cm	pH 1/5 soil/ water	$CaCO_3$ %	Organic matter %	Boron mg/l
20	0-30	0.556	8.1	21.4	1.9	0.84
	30-60	0.654	8.3	21.6	-	0.84
	60-90					
	90-150					
21	0-30	0.445	8.4	21.0	1.27	-
	30-60	0.556	8.4	23.4	-	-
	60-90	0.654	8.2	-	-	-
	90-150	0.741	8.4	-	-	-
22	0-30	0.445	7.9	23.8	1.10	-
	30-60	0.445	8.0	-	-	-
	60-90	0.654	8.3	-	-	-
	90-150	0.714	8.3	26.9	-	-
23	0-30	0.444	8.0	24.6	1.94	-
	30-60	0.556	8.0	27.4	-	-
23A	0-30	0.444	8.1	29.2	1.35	0.00
	30-60	0.444	8.1	30.0	-	0.00
	60-90	0.444	8.2	27.3	-	0.00
24	0-30	0.444	8.2	21.6	1.40	-
	30-60	0.556	8.0	23.0	-	-
	60-90	0.568	8.3	-	-	-
	90-150	0.714	8.5	26.7	-	-
25	0-30	0.445	8.1	23.0	1.30	0.56
	30-60	0.445	8.2	24.2	-	0.39
	60-90	0.855	8.3	-	-	0.51
	90-150	1.112	8.5	-	-	0.62
26	0-30	0.454	7.8	18.6	1.10	-
	30-60	0.568	7.9	-	-	-
	60-90	0.568	8.2	20.4	-	-
	90-150	0.568	8.3	-	-	-
27	0-30	0.425	8.0	21.2	1.34	0.00
	30-60	0.425	8.3	22.0	-	0.28
	60-90	0.425	8.4	-	-	0.11
	90-150	0.510	8.4	23.0	-	0.23
28	0-30	0.454	7.8	18.6	1.10	-
	30-60	0.454	7.9	19.0	-	-
	60-90	0.874	8.1	-	-	-
	90-150	1.032	8.2	21.0	-	-

Table A-1 (Cont'd)

Sample No.	Depth cm	EC x 10^3 at 25°C mmhos/cm	pH 1/5 soil/ water	$CaCO_3$ %	Organic matter %	Boron mg/1
29	0-30	0.408	8.0	22.0	1.47	-
	30-60	0.408	8.1	-	-	-
	60-90	0.510	8.1	-	-	-
	90-150	0.510	8.3	23.0	-	-
30	0-30	0.500	7.9	24.2	1.34	-
	30-60	0.400	8.4	-	-	-
	60-90	0.714	8.1	25.0	-	-
	90-150	0.714	8.4	-	-	-
31	0-30	0.400	8.0	20.8	1.74	-
	30-60	0.500	8.4	21.0	-	-
	60-90	0.714	8.5	-	-	-
	90-150	1.110	8.7	22.4	-	-
32	0-30	0.408	8.1	24.0	1.47	0.28
	30-60	0.444	8.4	24.2	-	0.51
	60-90	0.689	8.5	-	-	0.28
	90-150	0.714	8.4	-	-	0.28
33	0-30	0.444	7.8	22.8	1.60	-
	30-60	0.500	7.8	23.4	-	-
	60-90	0.454	8.0	-	-	-
	90-150	0.454	8.3	24.0	-	-
34	0-30	0.408	7.9	19.6	0.55	0.45
	30-60	0.408	8.1	18.4	-	0.00
	60-90	0.408	8.2	19.9	-	0.00
	90-150	0.408	8.2	19.9	-	0.45
35	0-30	2.040	8.0	21.2	1.05	-
	30-60	2.471	8.0	21.8	-	-
	60-90	3.000	8.1	-	-	-
	90-150	2.471	8.2	-	-	-
36	0-30	0.500	8.0	11.2	1.00	-
	30-90	1.538	8.1	12.6	-	-
	90-150	1.[illegible]38	8.3	14.9	-	-
37	0-30	0.400	8.1	20.4	1.38	-
	30-60	0.500	8.2	-	-	-
	60-90	0.588	8.5	22.5	-	-
	90-150	0.714	8.4	-	-	-

Sample No.	Depth cm	EC x 10^3 at 25°C mmhos/cm	pH 1/5 soil/ water	$CaCO_3$ %	Organic matter %	Boron mg/1
38	0-30	0.408	7.8	21.6	1.14	0.11
	30-60	0.408	8.0	-	-	0.00
	60-90	0.582	8.1	23.9	-	0.06
	90-150	0.784	8.3	-	-	0.00
39	0-30	0.445	7.9	25.2	0.5	-
	30-60	0.445	7.9	26.4	-	-
	60-90	0.445	8.0	-	-	-
	90-150	0.445	8.3	-	-	-
40	0-30	0.510	8.0	22.0	1.4	-
	30-60	0.600	8.0	-	-	-
	60-90	0.680	8.1	25.2	-	-
	90-150	0.741	8.3	26.4	-	-
41	0-30	0.454	7.9	20.2	1.1	-
	30-90	0.710	8.1	-	-	-
	90-150	0.874	8.3	22.0	-	-
42	0-30	0.400	8.0	26.4	1.38	-
	30-60	0.500	8.5	27.0	-	-
	60-90	1.110	8.6	-	-	-
	90-150	1.667	8.4	-	-	-
43	0-30	0.676	8.0	18.6	1.50	0.00
	30-60	0.769	8.1	24.6	-	0.00
	60-90	0.769	8.0	-	-	0.11
	90-150	0.833	8.2	25.6	-	0.11
44	0-30	0.510	7.8	20.4	1.54	-
	30-90	0.510	8.1	21.8	-	-
	90-150	0.637	8.3	-	-	-
45	0-30	0.408	7.9	19.6	1.54	0.39
	30-60	0.600	8.2	19.7	-	0.00
	60-90	0.680	8.2	19.99	-	1.69
	90-150	0.689	8.3	-	-	0.17
46	0-30	0.444	7.8	23.8	1.54	-
	30-60	0.556	7.9	25.0	-	-
	60-90	0.714	8.1	-	-	-
	90-150	1.110	8.3	26.7	-	-

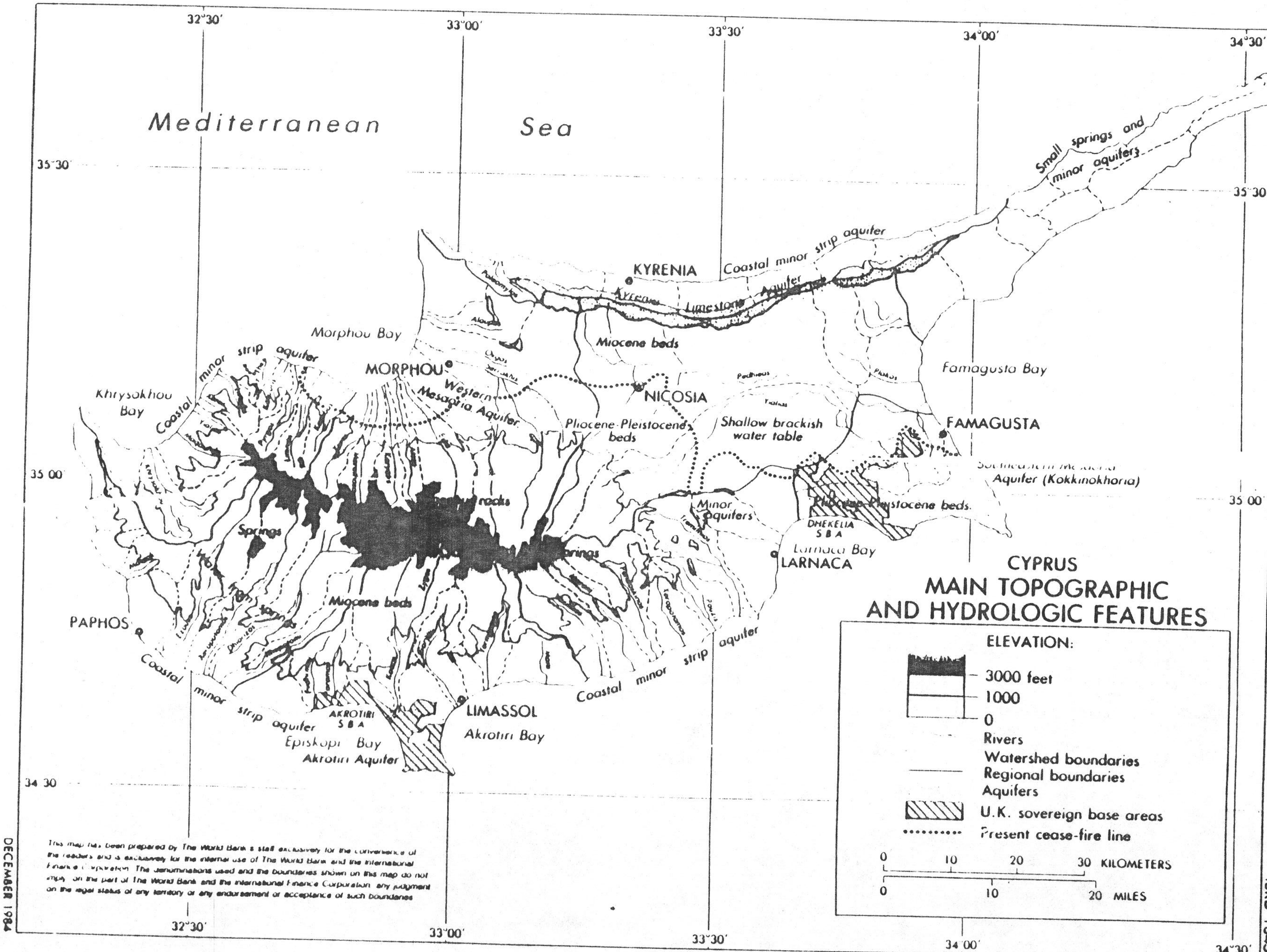
Sample No.	Depth cm	EC x 10^3 at 25°C mmhos/cm	pH 1/5 soil/ water	$CaCO_3$ %	Organic matter %	Boron mg/1
47	0-30	0.556	7.9	18.6	1.60	-
	30-60	0.568	7.9	18.8	1.45	-
	60-90	0.714	7.8	19.0	-	-
	90-150	0.874	7.9	19.8	1.08	-
48	0-30	0.556	7.8	18.5	1.70	0.31
	30-60	0.568	7.8	19.0	-	0.40
	60-90	0.714	7.9	19.8	-	0.40
	90-150	0.874	7.9	20.4	1.25	0.41
49	0-30	0.445	8.0	18.0	1.80	0.34
	30-60	0.714	8.1	18.2	1.60	-
	60-90	0.714	8.2	19.1	-	0.30
	90-150	0.874	8.1	19.4	1.07	-
50	0-30	0.408	7.9	18.4	1.51	0.44
	30-60	0.408	7.9	18.3	1.12	0.41
	60-90	0.610	8.0	19.4	-	-
	90-150	0.714	8.1	19.8	1.01	0.81

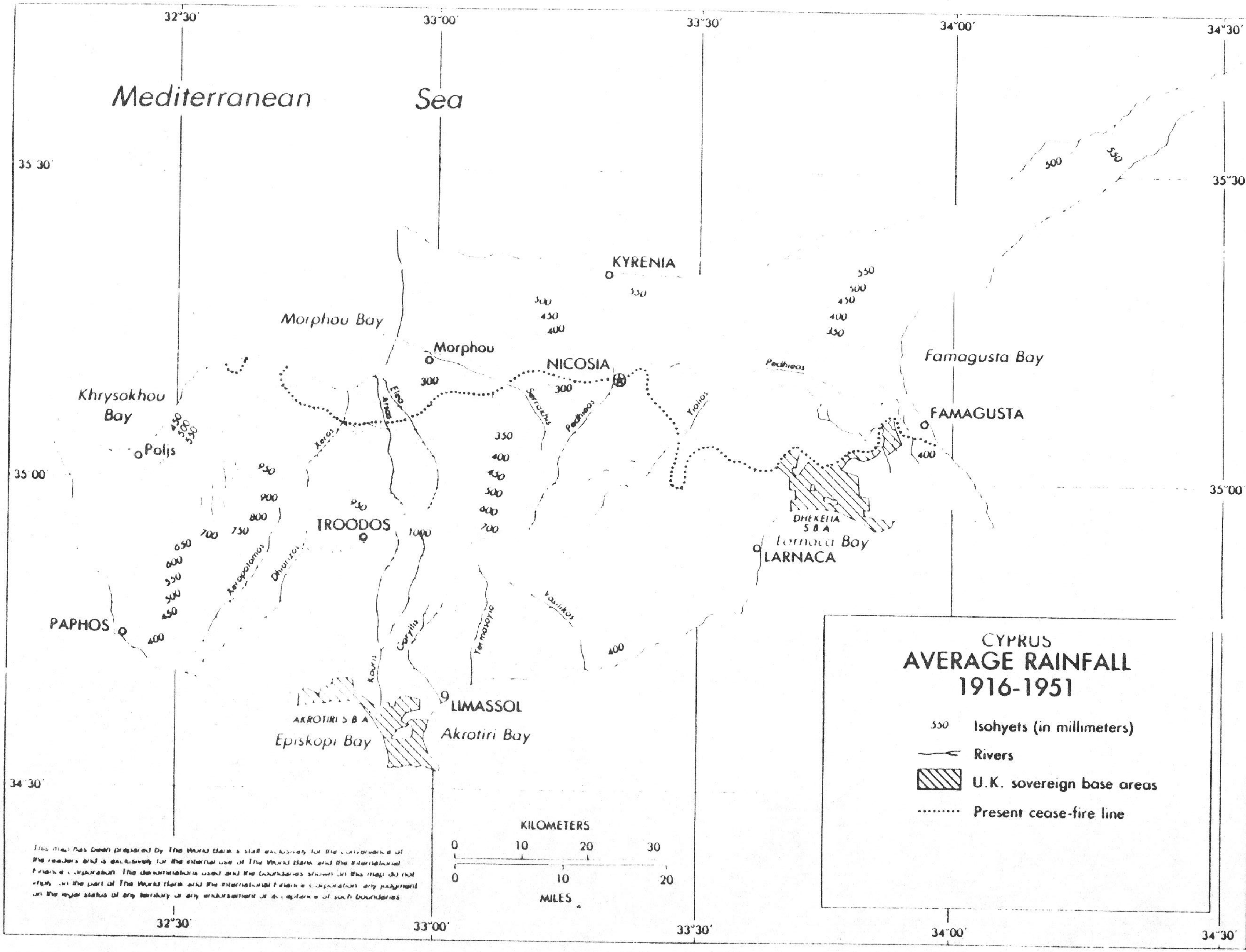
Table A-2: Permeability Tests

Test No.	Soil Classification Surface/Subsoil	Soil Texture Surface/Subsoil	Permeability cm/hour
Development Area			
1-1			1.2
1-2	Clay/Clay	Heavy/Heavy	0.1
1-3			0.2
2-1			0.2
2-2	Clay loam/Clay	Medium/Heavy	0.4
2-3			0.1
3-1			0.4
3-2	Silty clay/Silty clay	Heavy/Heavy	0.5
3-3			0.5
4-1			0.2
4-2	Silty clay/Silty clay	Medium/Medium	0.2
4-3			0.5
5-1			0.5
5-2	Clay loan/S. clay L.	Medium/Medium	0.01
5-3			0.7
Treatment Lagoon			
T-1			0.02
T-2	Clay	Heavy	0.01
T-3			0.02
Storage Lagoon			
S-1			0.05
S-2	Clay	Heavy	0.04
S-3			0.01

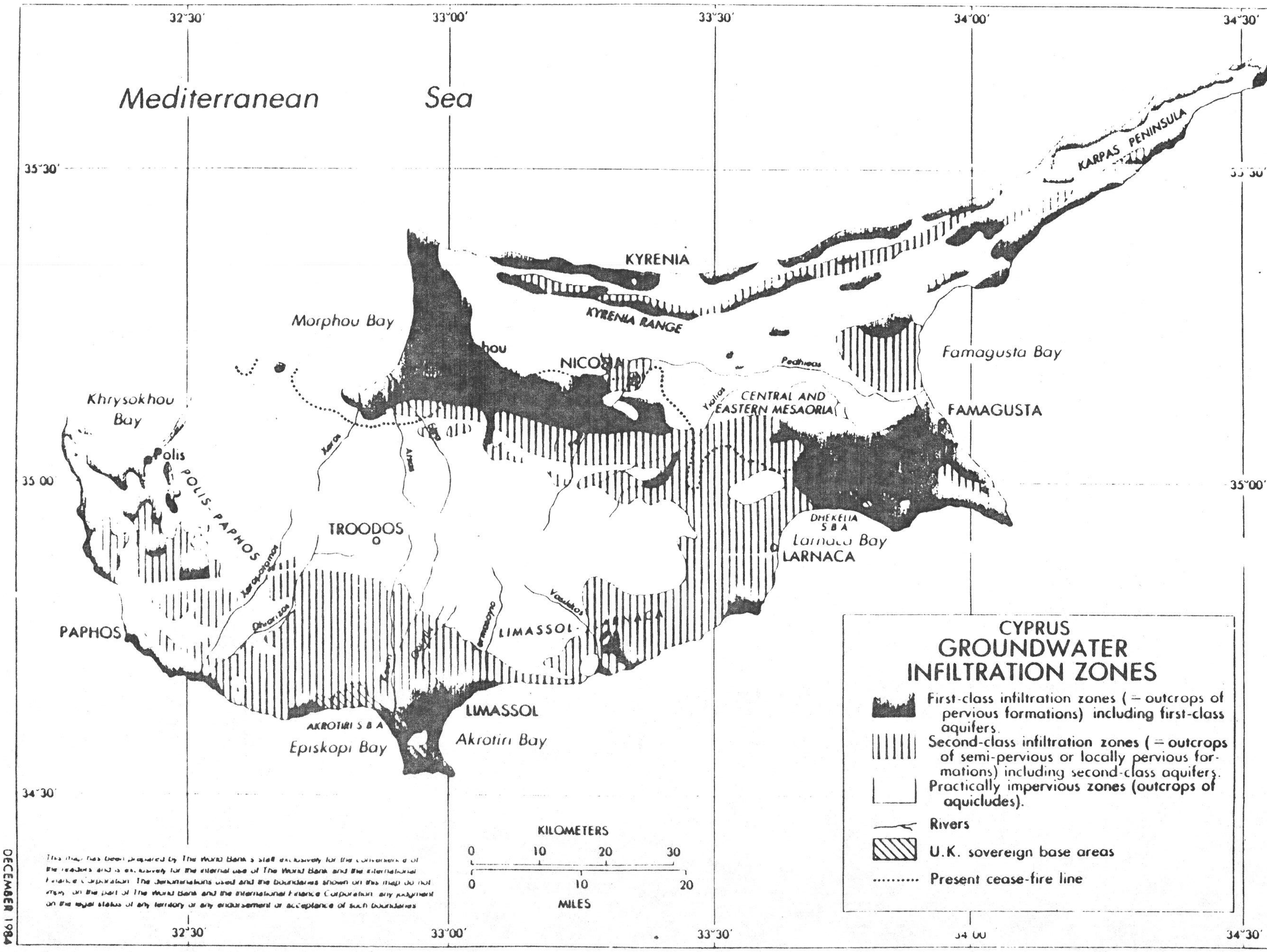
As a measuring instrument a double cylinder of 30 cm/45 cm diameter was used, driven 15 cm into the soil. The water height was 15 cm.

PLATE I


CYPRUS
MAIN TOPOGRAPHIC AND HYDROLOGIC FEATURES
Mediterranean Sea
Small springs and minor aquifers
Coastal minor strip aquifer
KYRENIA
Kyrenia Limestone Aquifer
Miocene beds
Morphou Bay
MORPHOU
Western Mesaoria Aquifer
NICOSIA
Khrysokhou Bay
Coastal minor strip aquifer
Pliocene-Pleistocene beds
Shallow brackish water table
Famagusta Bay
FAMAGUSTA
Aquifer (Kokkinokhoria)
Pliocene-Pleistocene beds
Minor aquifers
DHEKELIA S B A
Larnaca Bay
LARNACA
Springs
Miocene beds
PAPHOS
Coastal minor strip aquifer
AKROTIRI S B A
Episkopi Bay
Akrotiri Aquifer
LIMASSOL
Akrotiri Bay
Coastal minor strip aquifer
ELEVATION:
3000 feet
1000
0
Rivers
Watershed boundaries
Regional boundaries
Aquifers
U.K. sovereign base areas
Present cease-fire line
0 10 20 30 KILOMETERS
0 10 20 MILES
32°30′
33°00′
33°30′
34°00′
34°30′
35°30′
35°00′
34°30′
DECEMBER 1984
IBRD 18451
This map has been prepared by The World Bank's staff exclusively for the convenience of the readers and is exclusively for the internal use of The World Bank and the International Finance Corporation. The denominations used and the boundaries shown on this map do not imply, on the part of The World Bank and the International Finance Corporation, any judgment on the legal status of any territory or any endorsement or acceptance of such boundaries.


Mediterranean Sea
KYRENIA
Morphou Bay
Morphou
NICOSIA
Khrysokhou Bay
Polis
Famagusta Bay
FAMAGUSTA
TROODOS
PAPHOS
LARNACA
Larnaca Bay
DHEKELIA S B A
AKROTIRI S B A
LIMASSOL
Episkopi Bay
Akrotiri Bay
CYPRUS
AVERAGE RAINFALL
1916-1951
Isohyets (in millimeters)
Rivers
U.K. sovereign base areas
Present cease-fire line
KILOMETERS
MILES
DECEMBER 1984
IBRD 18551

PLATE



Mediterranean Sea
KARPAS PENINSULA
KYRENIA
KYRENIA RANGE
Morphou Bay
NICOSIA
Famagusta Bay
Pedhieos
CENTRAL AND EASTERN MESAORIA
FAMAGUSTA
Khrysokhou Bay
Polis
POLIS-PAPHOS
TROODOS
DHEKELIA S B A
Larnaca Bay
LARNACA
PAPHOS
LIMASSOL
AKROTIRI S B A
Episkopi Bay
Akrotiri Bay
32°30'
33°00'
33°30'
34°00'
34°30'
35°30'
35°00'
34°30'
KILOMETERS
0 10 20 30
0 10 20
MILES
CYPRUS
GROUNDWATER
INFILTRATION ZONES
First-class infiltration zones (= outcrops of pervious formations) including first-class aquifers.
Second-class infiltration zones (= outcrops of semi-pervious or locally pervious formations) including second-class aquifers.
Practically impervious zones (outcrops of aquicludes).
Rivers
U.K. sovereign base areas
Present cease-fire line
DECEMBER 1984
IBRD 18552

PLATE III

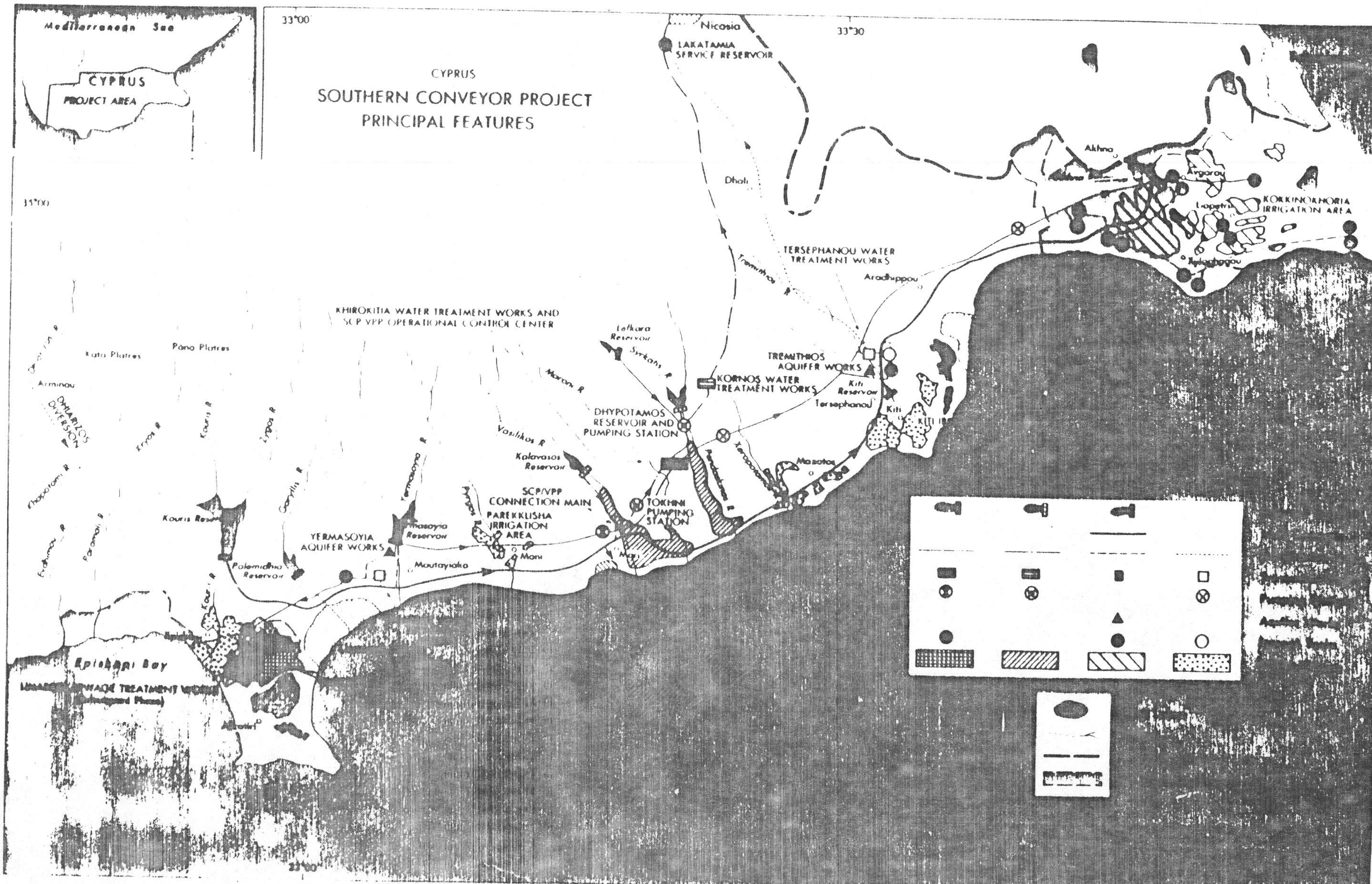

Mediterranean Sea
CYPRUS
PROJECT AREA
CYPRUS
SOUTHERN CONVEYOR PROJECT
PRINCIPAL FEATURES
33°00
33°30
35°00
Nicosia
LAKATAMIA SERVICE RESERVOIR
Dhali
TERSEPHANOU WATER TREATMENT WORKS
Akhna
Avgorou
KORKINOKHORIA IRRIGATION AREA
Liopetri
Aradhippou
KHIROKITIA WATER TREATMENT WORKS AND SCP VPP OPERATIONAL CONTROL CENTER
Kato Platres
Pano Platres
Arminou
DHIARIZOS DIVERSION
Lefkara Reservoir
Maroni R
Vasilikos R
Kalavasos Reservoir
TREMITHIOS AQUIFER WORKS
KORNOS WATER TREATMENT WORKS
Kiti Reservoir
Tersephanou
Kiti
DHYPOTAMOS RESERVOIR AND PUMPING STATION
SCP/VPP CONNECTION MAIN
PAREKKLISHA IRRIGATION AREA
TOKHNI PUMPING STATION
Masotos
Kouris R
Kouris Reservoir
Polemidhia Reservoir
YERMASOYIA AQUIFER WORKS
Yermasoyia Reservoir
Moutayiaka
Moni
Episkopi Bay
Akrotiri
FEBRUARY 1982
IBRD 18737

PLATE IV