STATE OF SEAWATER INTRUSION IN CYPRUS

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ABSTRACT

The Island of Cyprus lies in the north-eastern corner of the Mediterranean Sea and covers an area of 9251 km^2. The coastal length around the island is about 800 km.

The coastal aquifers of Cyprus are of great importance to the environment, agriculture and the tourist industry. The most productive agricultural areas are along the main coastal aquifers where the greatest irrigation projects have been constructed.

The low rainfall of the last decades has caused a dramatic decrease of water inflows to the dams. The artificial recharge of the aquifers has been interrupted because of the general water deficit in the country. Over pumping and reduction of recharge led to a serious deficit in the water balance of the aquifers. The less productive parts of the coastal aquifers are depleted, the general water table along the coastal zone has stabilized below mean sea level and the inland progression of the fresh water/sea water interface has greatly increased. The most productive parts of the aquifers are already contaminated by seawater. The concentra - tion of the chlorite ions in groundwater varies from 300 to more than 1500 mg/l (April 2001) in the affected coastal aquifers.

INTRODUCTION

The Island of Cyprus lies in the north-eastern corner of the Mediterranean Sea and covers an area of 9,251 km^2. The coastal length around the island is about 800 km.

Traditionally, Cyprus is divisible into three geomorphological zones: (fig. 1)

a. *The Kyrenia Range* runs parallel to the north coast and rises to elevations of over 1000 m. Is considered as a part of the Alpine belt which extends from the Pyrenees to Himalayas. Geologically is made of a succession of mostly allochthonous sedimentary formations ranging from Permian to Middle Miocene.

b. *The Troodos Mountains* occupy the south-central part of the island and covers an area of about 3200 km^2. It rises to a maximum height of 1951 metres on Mount Olympus. Troodos is a fully developed Ophiolite or Igneous Complex and is the "foundation" on which the island was built. It is the structural and morphological backbone of Cyprus.

c. *The Mesaoria or Central plain* lies between the two ranges and it is a flat plain with mesa-type hills and Hogbacks at its borders. It is formed by a succession of Upper Cretaseous to Pleistocene sedimentary rocks.

The present population of Cyprus is about 800,000 of which 60-70% remain in the coastal areas. After 1960 the Cyprus tourism has successfully grown to 2,000,000 arrivals per year, 90% of which are staying in the coastal areas.

The most productive agricultural areas are along the main coastal aquifers where the greatest irrigation projects have been constructed.

Major problems of the coastal aquifers are:

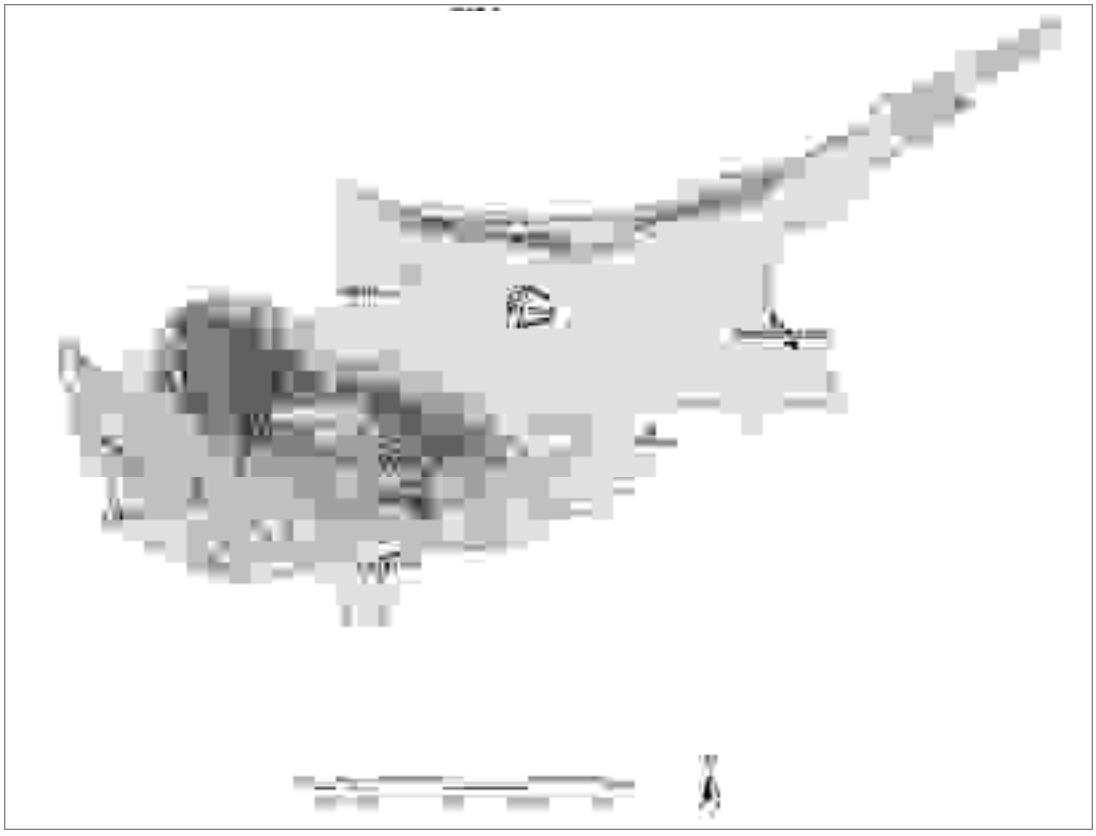

Figure 1. Topographic map of Cyprus.

The deterioration of the groundwater quality caused by the fast urbanization and tourist development and

(i) The dramatic reduction of recharge in combination with overexploitation which caused a serious deficit in the water balance of the aquifers and later on the deterioration of the groundwater quality by seawater intrusion.

GEOLOGICAL CONTEXT

The coastal plain around the island is very narrow (0.5-5 km wide). Elevated marine terraces are found bordering along the coastal plain. At least 6 levels of old marine terraces can be distinguished. The Plio-Pleistocene calcarenites and the beach depositsgravel and sand - form along the coastal plain, thin (0.5-10 m) discontinuous groundwater bodies of local importance. Their extent and thickness is controlled by the configuration of the underlying impermeable base (Palaeogene to Miocene sediments consist of marls, chalks and chalky marls). (Fig. 2)

The largest rivers in the island have their sources in the Troodos Mountains and they drain radically in all directions. All of them are non-perennial and they usually flow from December to the end of May. They formed river alluvial aquifers and in the coastal zone lead to deltaic alluvial deposits consisting of gravels, sands, sandy gravels and silts. The marine terrace deposits consist of calcarenites, sand and gravels.

CHARACTERIZATION OF COASTAL AQUIFERS

The Cyprus coastal aquifers are unconfined phreatic aquifers with some semi confined parts and their maximum thickness varies between 10 and 140 metres. The average K is about 40 m/day (varies between 5 and 130 m/day) and the average S is about 8% (varies between 2 and 18%).

Figure 2. Geologic map of Cyprus.

The total annual extraction from the coastal aquifers varies from 0.5 to 14 Mm^3, and the average yield of the protective boreholes and wells varies between 2-3 m^3/hour at the depleted parts of the aquifers and 50 to 150 m^3/h at the deepest part.

Recent Water Balances give numbers from zero to 6 Mm^3/year. The recommended extraction under the present conditions is zero or very limited and should take place mostly during spring until the aquifers recover.

The coastal aquifers of Cyprus are of great importance to the environment, agriculture and the tourist industry.

The methods of study and applied techniques are:

(i) *The Hydrological Surveys* including the registration and plotting on Land Registry maps of all existing wells and boreholes, together with other information like the owner, the pumping pland used, the area and type of crop irrigated the irrigation method etc.

(ii) *Water level observation network:* the water level measurements are carried out monthly or twice a year.

(iii) *Hydrochemical observation network:* the sampling for full ionic analysis is carried out monthly or twice a year..

(iv) *Isotupe investigations* using $\delta^{18}O$, ^{14}C and ^{3}H analysis, and

(v) *Geophysical investigations* using the resistivity survey.

The result of the hydrological surveys, the hydrologic observations and hydrogeological evaluation of the main coastal aquifers has resulted to water balance studies and safe yield definition. This led to the performance of groundwater mathematical models which allow the study of the performance of the aquifer to various stresses of pumping or recharge, including the seawater intrusion control.

CURRENT STATE OF SEAWATER INTRUSION

Cyprus is a semiarid country and water scarcity is one of its major problems. The average annual rainfall is about 500 mm. Water demand in the island has always been much higher than the available water resources. This was manifested mainly by the construction of over 100 dams on almost all rivers of the country. With the dams built not far from the coast, the groundwater replenishing regime in most areas has been modified and downstream coastal aquifers depend more and more on artificial groundwater recharge through controlled releases from the dams directly into the downstream riverbeds.

The low rainfall of the last decades has caused a dramatic decrease of water inflows to the dams. The artificial recharge of the aquifers has been interrupted because of the general water deficit in the country. Over pumping and reduction of recharge led to a serious deficit in the water balance of the aquifers. The less productive parts of the coastal aquifers are depleted, the general water table along the coastal zone has stabilized below mean sea level and the inland progression of the fresh water/sea water interface has greatly increased. The most productive parts of the aquifers are already contaminated by seawater. The concentration of the chlorite ions in groundwater varies from 300 to more than 1500 mg/l (April 2001) in the affected coastal aquifers. Extensive over pumping has started in the island from early 50s.

MANAGEMENT

The Water Development Department together with the Hydrogeological section of the Geological Survey Department of the Ministry of Agriculture, National Resources and Environment are responsible for the overall policy on water resources including Hydrogeological, Hydrological and Hydrochemical investigations, planning, design and construction of water projects and the management and control of all surfaces and groundwater bodies.

Recently has been decided to established a Water Authority.

Groundwater in Cyprus is conserved through legislative measures and it is by the con-

stitution the property of the State. The water resources management of coastal aquifers is undoubtedly one of the key priority issues not only because of the actual challenges of limited resources, but also because of the increasingly stringent quality standards and environmental sensitivities arising from the European legislation.

Management tools to monitoring and control of seawater intrusion are among others the following:

(i) *Artificial recharge:* As mentioned before, quantities of stored water in reservoirs have to be released in a controlled manner for artificial recharge to maintain continuing activities relying on groundwater from downstream riverbed and coastal aquifers.

(ii) *Reforme of agricultural crops:* The cropping pattern envisaged by the planners on the basis of soil surveys, water availability and marked studies has proved to be not fully in accordance to the users selection which is fully controlled by market forces and other economic reasons or even traditional practice. As a result the irrigation demands has being higher and a reform of less water-demand crops must been carried out in cooperation with the farmers.

(iii) *The re-use of treated sewage effluent:* This anticipated to cover part of the irrigation needs of certain coastal aquifers whose recharge has been reduced by upstream high dams. Sometime this is being looked upon by farmers with scepticism and there is an apparent reluctance to accept this potential source of water which could allow high quality freshwater to be used for other purposes.

(iv) *The groundwater demand management*: Includes among others the controlling of demand through technical and prising mechanisms, the public (tourist and farmers) awareness campaigns for water conservation measures, the mechanisms for rationing and allocation priorities in times of scarcity (drought periods) and the implementation of the groundwater "special measures" low to reduce and control pumping according to the available groundwater storage.

CASE STUDIES

Kiti Coastal Aquifer

Introdution

The Kiti area situates to the southwest of Larnaca Town and is limited by the cost line between Larnaca airport, Cape Kiti and the Tremithos river valley up to the Kiti Dam to the north. The elevation of this plain varies between 0 and 50 m.a.s.l. (Fig. 3)

The Kiti aquifer is a small phreatic main unconfined coastal aquifer. Despite its size it is of great importance because its the basic aquifer in Larnaca District and most of irrigation water is drawn out from this aquifer. However over-development and over-pumping of the aquifer since the late seventies caused seawater intrusion in its coastal zone. Problems of increasing salinity in groundwater are experienced of distances of up to 3,5 km from the sea coast or the salt lakes bordering the aquifer to the east (near the airport). (Fig. 4).

The aquifer at its western part is in hydraulic connection with the Tremithos river alluvial deposits. In 1964 Kiti dam was constructed on this river for recharge purposes, at the north-western corner of the aquifer. Kiti dam has a capacity of 1.6 Mm^3. The Southern Conveyor Project covers some of the irrigation demand, by import surface water from the west part of the island. The coastal zone of the aquifer is a rapidly developing tourist area.

Geology

The impervious base of the aquifer consists mainly of Palaeogene marls, chalks and chalky marls. The sediments of the aquifer are 20 to 30 metres thick and they consist of Pleistocene

Figure 3. The kiti pervolia aquifer.

marine terrace deposits such as silts, gravel and sands. Aquifer sediments along the Tremithos riverbed consist of 20 to 45 m thick river alluvial deposits.

General Information/Aquifer characteristics

A groundwater level observation network was established by water Development Department (WDD) since 1975 with 52 boreholes measured every 3 months (figure 5). Also there is a groundwater quality observation network with 20 boreholes sampled twice a year for full ionic analysis. Last sampling was carried out in 1998. All boreholes in the aquifer up to the period 1974-76 were plotted and the last Hydrological Survey was carried out by W.D.D. in 1996.

The Kiti aquifer has an area of 38 km^2 (5.5 km width, 7 km length). The outcrop area is 38 km^2.

The average rainfall for the period 1990-2000 was 320 mm, but for the period 1970-2000 was 350 mm.

The hydrogeological parameters of this aquifer are:

Average K= 4 m/day (from 2 to 8 m/day)

Average S= 8% (from 2 to 14).

Hydrogeological Conditions Today

The most productive parts are located in the areas of Kiti, Perivolia and Meneou villages (southeast part of the aquifer) where the aquifer thickness ranges between 20 and 45 m. These most productive parts have been sea intruded and consequently abandoned as early as the early 80s. The less productive parts are depleted and borehole yields have dropped dramatically. It is estimated that around 300 boreholes operate in the area today. An amount of about 2 Mm^3/year is extracted from these boreholes. Yields of the production wells varies between 2 and 10 m^3/h depending on the year's recharge. This recharge comes directly from rainfall, from riverbed infiltration when the dam spills and through underground leakages from the Kiti dam.

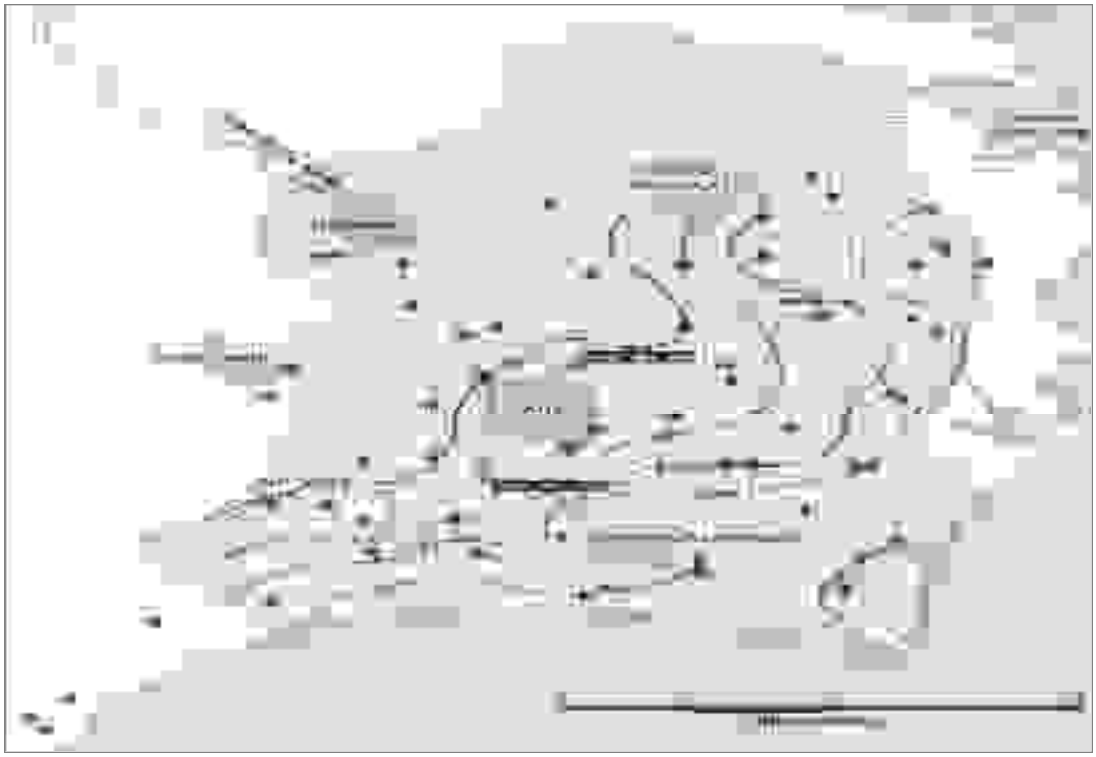

Figure 4. The kiti pervolia aquifer - Isochlorides (ppm) contour map April/May 2001.

Decrease in the rainfall during the last ten years resulted in reduced direct natural recharge of the aquifer and diminished river flows. This in turn resulted in diminished inflows to the dam and consequently diminished recharge from dam leakages and spills. (Fig. 6).

Carried out studies

(i) An average water balance between 1978-1980 (2 years) was carried out during the southern conveyor project (SCP). Is a result of a mathematical model applied in an area of 29.25 km^2. The average rainfall was 350 mm.

Replenishment (Mm^3/year)							
	Rainfall	Riverbed	Subsurf. Inflow	Sea intrusion (sea/s.lake)	Return from irrigation	Artificial recharge	Total
Average	1.5	0.42	0.35	0.1	0.57	0.21	3.1

Outflow (Mm^3/year)			
	Abstraction	Subs. Outflow (sea/s. lake)	Total
Average	2.83	0.11	2.94
Balance: + 0.2 Mm^3/year			

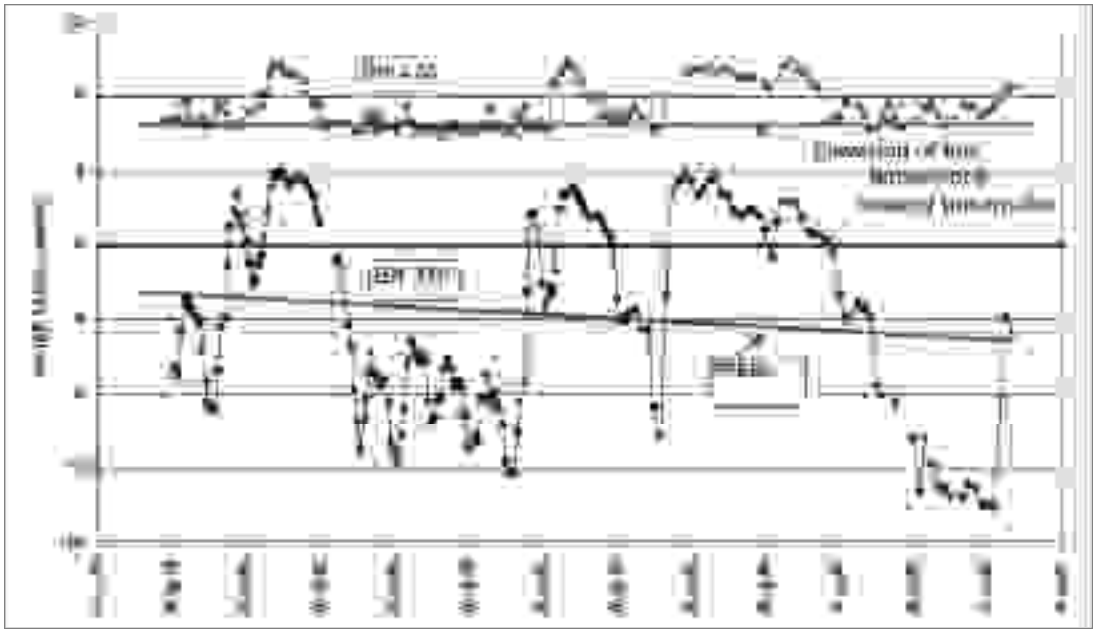

Figure 5. Hydrograph of boreholes kiti 370 and 424 (Elev. 16.59 m and 25.9 m amsl).

(ii) A water balance was carried out today in cooperation between the W.D.D. and F.A.O. in the frame of the "Re-assessment of the Water Resources and Demand of the island of Cyprus" Project.

The period of the study is 1991-2000. The accuracy of estimates is good, the aquifer area is 38 km^2 and the average rainfall was 320 mm.

(iii) A study of the Kiti aquifer was carried out between 1980-1985 in the framework of the "Cyprus – German Geological and Pedological Project" in cooperation between the Geological Survey Department (GSD) and the Institute of Geosciences and Natural Resources (BGR) of Hanover..

This study included the following immediate objectives:

- to determine the state of the distribution of groundwater salinity and hydrochemistry,
- to define the sources of groundwater salinity,
- to investigate the hydrogeological conditions of the area with a particular view to the hydrogeological aspects of possible

Replenishment (Mm^3/year)

	Rainfall	Riverbed	Subsurf. Inflow	Sea intrusion (sea/s.lake)	Return from irrigation	Artificial recharge	Total
Average	1.2	0.1	0.2	0.3	0.2	0	2.0

Outflow (Mm^3/year)

	Abstraction	Subs. Outflow (sea/s. lake)	Total
Average	1.9	0.1	2.0

Balance: 0 Mm^3/year

Change in storage (1991-2000): 0 Mm^3/year

Recommended average extraction from the aquifer (sea intruded areas excluded): 0.7 Mm^3/year

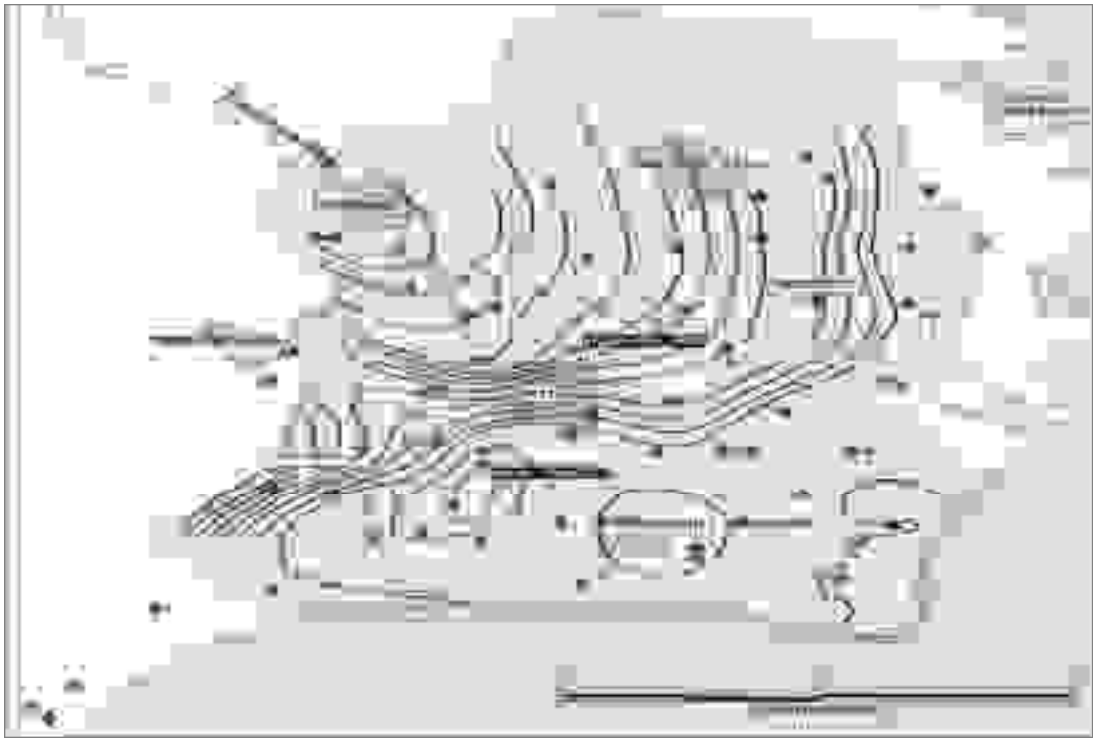

Figure 6. The kiti pervolia aquifer - water level (m amsl) contour map January 2001.

measures to improve the groundwater quality,

Investigations carried out during the period of the project included among other an extensive Hydrochemical and isotope surveys.

Two main alternatives are possible to remedy the present deterioration of groundwater quality in Kiti aquifer:

(i) To reduce the groundwater abstraction quantity drastically. This measure would have to comprise at least the entire zone affected by seawater intrusion. Since production wells may be endangered by localized upconing of brackish groundwater, an individual maximum yield for each well would have to be established.

(ii) To import water in order to reduce the demand on groundwater to be abstracted in the Kiti plain or to increase the groundwater recharge. Two sources for import of water may be envisaged for the future:
   - The southern Conveyor Project
   - The Larnaca Sewage Treatment Plant

The exclusive implementation of alternative (i) would involve a substantial decrease of agricultural activities in the area, Alternative (i) is therefore discussed only in combination with measures proposed under alternative (ii).

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