Management Of Groundwater Resources In Cyprus - Harmonisation With The EU Water Framework Directive.

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Abstract

Groundwater resources in Cyprus are overexploited by about forty percent of sustainable extraction. During the last 10 - 15 years many of the aquifer's water balance elements have been permanently altered. Most of the aquifers of the Island are phreatic aquifers developed in river or coastal alluvial deposits. Droughts have reduced the direct and indirect groundwater recharge. Excessive overpumping of the coastal aquifers resulted in sea water intrusion and hence quality deterioration of coastal aquifers and the depletion of inland aquifers. It is imperative for water sustainability that the adverse trend in groundwater is checked and reversed. Cyprus as new member of the European Union has to satisfy all the requirements set by EU on water quality, such as those specified in the Water Framework Directive (2000/60/EC). In this paper, we present the state of the groundwater resources in Cyprus and the measures taken on implementing the Water Framework Directive (2000/60/EC).

Keywords: Groundwater resources, Cyprus, EU Water Framework Directive (2000/60/EC)

Introduction

Groundwater resources in Cyprus are overexploited by about forty percent of sustainable extraction. During the last 10 - 15 years many of the aquifer's water balance elements have been permanently altered. Most of the aquifers in the Island are phreatic aquifers developed in river or coastal alluvial deposits. These are the biggest and the most dynamic aquifers mainly replenished from river flows and rainfall. During the last decade almost all aquifers, exhibit depleting trends. Some of the coastal aquifers show water levels below sea level. This is the result from frequent and long lasting droughts over the last decades. Droughts have reduced the direct and indirect groundwater recharge. The problem of reduced recharge to the aquifers has been exacerbated by the construction of a great number of dams on the major rivers of the country, which before were recharging the downstream aquifers. The dam construction resulted to great reductions and in many cases almost complete elimination of the natural riverbed recharge of the aquifers downstream of these dams. At the same time farmers, in their effort to maintain agricultural production levels, have continued extracting the same quantities of groundwater and in most cases have even greatly increased the extraction. All these adverse conditions resulted in saline water intrusion and hence quality deterioration of coastal aquifers and the depletion of inland aquifers.

The overpumping of the coastal aquifers and the fall of the groundwater level below critical level, lead to seawater intrusion. In order to rehabilitate these aquifers and restore their good condition in terms of quantity and quality, a lot of years of very careful management are required. During this period we will be expected to decrease the pumping and recharge the aquifer with good quantity water in order to enrich the aquifer and remove the saline water. It is important to note that in order to clean an aquifer form seawater, much more years are needed than to just replenish the aquifer. There are many examples of overpumping and seawater intrusion in coastal aquifers. Typical ones are; the aquifers of Morfou, Kokkinohoria, Kiti-Pervolia, and Akrotiri.

Groundwater resources

In the last study that carried out by the Cyprus Water Development Department (WDD) in collaboration with the United Nations Food and Agriculture Organisation of (FAO) (Cyprus Water Development Department (2002)) has been observed that the rainfall for the period 1970 – 2000, shows a serious drop in the order of 20%. Statistical analysis of the precipitation records available over the period of the hydrological years 1916/1917-1999/2000 shows a step change around 1970. The time series can be divided into two separate stationary periods. The mean precipitation of the recent period is lower than the mean precipitation of the older period a fact that had as a consequence the significant reduction in the water available on the island. The decrease in the mean annual inflow to dams, referred to as design estimates, varies between 24% and 58%, with an average of around 40%. It can be said that the island has roughly 40% less water than had been assumed based on pre-1970 records. Whether in the future the water resources will continue decreasing or will return to the pre-1970 level is an open question. Meanwhile, it is prudent to assume that the future annual water availability will continue oscillating around the 1970 – 2000 average values.

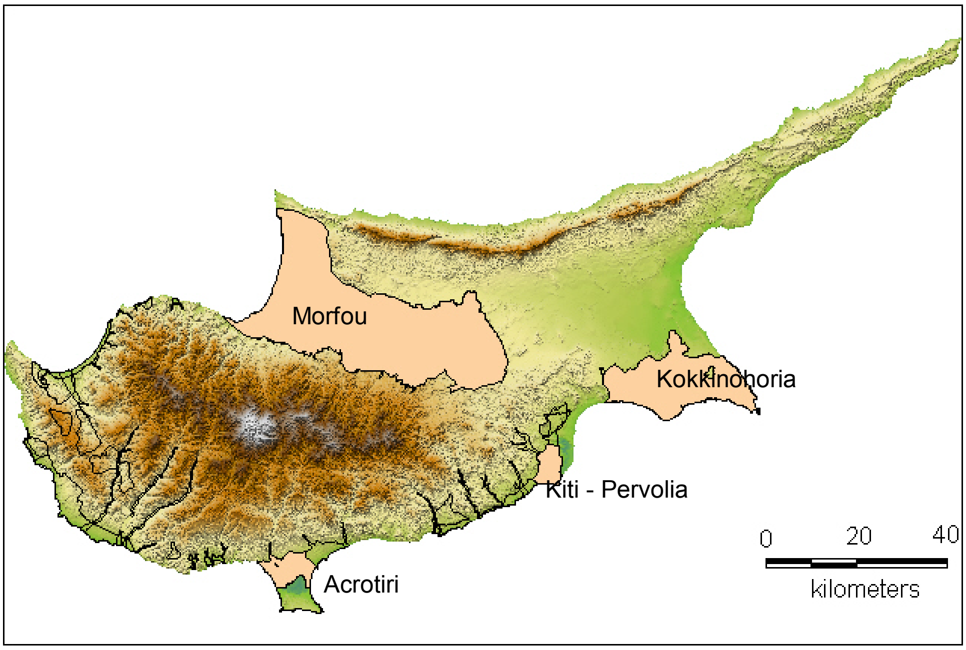

Figure 1: Cyprus shaded relief map depicting the most important aquifers.

The decreased rainfall has caused reduction in the flow of rivers, and naturally in the surge of water in our dams, the order 40%. This reduction of rainfall and the flow of rivers caused also the reduction of recharge of the aquifer. This reduction of recharge, in combination with the overpumping, which was caused by the attempt to overcome the water balance shortfall, they have negatively influenced and stretched to the limit our underground water resources.

Fortunately the last two years the hydro-meteorological conditions were good and resulted to an improvement of the water resources in Cyprus. The rainfall for the last three years amounted to 120% of average rainfall. Indicative of these good rainfall years, is the increase in storage in our dams. At the beginning of March 2004 the storage in the dams reached 98% of the total capacity, which is 315 Mm^3.

As a result from the above the average rainfall we observe an improvement of the groundwater conditions. We can see a general reversal of the downward trend on water table levels and a steady rise can be observed also. However, in many aquifers the water level continues being lower than the safety level. In our main aquifers, such as those of Kokkinohoria, Akrotiri, Kiti-Pervolia the water level continues being lower than the mean sea level.

The water balance in Cyprus is summarised in Table 1. The present level of extraction is estimated close to 130 Mm^3/year. Artificial recharge contributes 10 Mm^3/year. The amount of extracted groundwater originating from natural recharge is therefore in the order of 120 m^3/year. The aquifers show an overall annual negative balance (net extraction) of 15.3 Mm^3/year.

Table 1: Annual groundwater balance of Cyprus averaged over period 1991-2000 (Water Development Department, 2002).

Replenishment of the aquifers

Natural Recharge from:	(Mm^3/year)	(Mm^3/year)
Rainfall	205.1	
River flows	44.8	
Return from irrigation/domestic	22.1	
Groundwater inflow	8.8	
Dam losses	1.7	
Total natural recharge	**282.5**	**282.5**
Artificial recharge		**9.8**
Sea intrusion		**12.8**
REPLENISHMENT (TOTAL RECHARGE)		**305.1**

Outflow from the aquifers

Extractions from aquifer for:		
Domestic water supply	-24.7	
Irrigation	-101.7	
Industry	-2.7	
Total extraction	**-129.1**	**-129.1**
Groundwater outflow		**-166.7**
Sea outflow		**-24.6**
TOTAL OUTFLOW		**-320.4**

The average extraction for domestic water supply over the period 1991 - 2000 is estimated to be 24.7 Mm^3/year; for irrigation it is estimated to be around 101.7 Mm^3/year and for industrial use it is estimated to be around 2.7 Mm^3/year. Owing to its gradual replacement by desalinated water, the use of groundwater for domestic water supply has been significantly reduced in recent years. At present, the demand of groundwater for domestic supply is 18 to 20 Mm^3/year.

For sustainable aquifer management and protection of groundwater resources, it is estimated that extraction from all aquifers should not exceed 81.3 Mm^3/year (Water Development Department, 2002). This estimated figure brings the water balance equation "out of balance", and therefore, once the drought crisis is over, aquifers should be left to recover. Year by year water management must be based on the prevailing hydrogeological conditions of each aquifer at the time of study. At present, there is a major gap between actual and recommended water extraction from the aquifers. Groundwater resources in Cyprus are overexploited by about 40% of their sustainable yield. The existing conditions have resulted in saline water intrusion and consequent quality deterioration in coastal aquifers and depletion of inland aquifers. Saline water intrusion in aquifers results also in destroying our valuable underground water storage reservoirs.

Besides its growing scarcity, groundwater is also being abandoned for use in the domestic supply because of quality problems. Intensive agriculture and excessive use of fertilisers have resulted in nitrate pollution of many aquifers. Similar nitrate pollution problems appear in aquifers developed in inhabited areas because of direct sewage disposal in adsorption pits.

According to European Union directives, aquifers in a country should be managed in ways that guarantee adequate quantities of good quality water. Intense pressure on the island's water resources, and the current state of quantitative and qualitative degradation of groundwater in the most important aquifers in Cyprus, point to the need for the establishment of an island-wide groundwater monitoring system.

The effects from overpumping in Cyprus.

It is known that almost all the aquifer of our country overpumped for decades. This overpumping, in the free region of Cyprus, amounts in the 31 Mm^3/year. During the last 40 years, which is the period were the intensive exploitation of aquifer took place, have been extracted roughly 1240 Mm^3 (Water Development Department, 2002).

In order to conceive the size of overpumping, we consider the estimated average natural recharge of our aquifers, which should not exceed the 100 Mm^3/year. In order to fully replenish the water lost from the aquifers it is expected to take at least 12 years assuming that no water is being extracted from the aquifer during that period. This period is increased dramatically when we try to restore the water quality as well for the aquifers, which became saline due to seawater intrusion. The replenishment of the water deficit in the aquifers is a very slow process and sometimes almost impossible.

These enormous deficits cannot be fixed with the a few good rainy seasons like those of the last three years. We should not be misled with the appearance of a few good rainy years. In Cyprus the appearance of periods low rainfall is rule and not the exception. Consequently we should get ready to face these critical periods without causing deficits in our water systems. We should store and wisely manage our reserves so as to accommodate for the low rain seasons.

The state of the major aquifers

For the rest of this chapter we will see the condition of the most important aquifers in Cyprus. Figure 2 presents a contour map of water levels of the Kokkinohoria aquifer for September 2003. The areas with the shades of red colour are the parts of the aquifer where the water level is below mean sea level. The darker the red colour, the lower the water level is with respect to the mean sea level. In the area of the Xylofagou, Liopetri and Ormidia villages, the water level reaches up to 45 meters below mean sea level. With blue colour are presented the regions with levels above the mean sea level. Around the Paralimni town one can see water level up to 99 meters above mean sea level. This is misleading because the thickness of the water-bearing stratum is very thin there and also, being a small lens, is not connected with the rest of the aquifer. The blue line depicts the region that has been influenced by seawater intrusion.

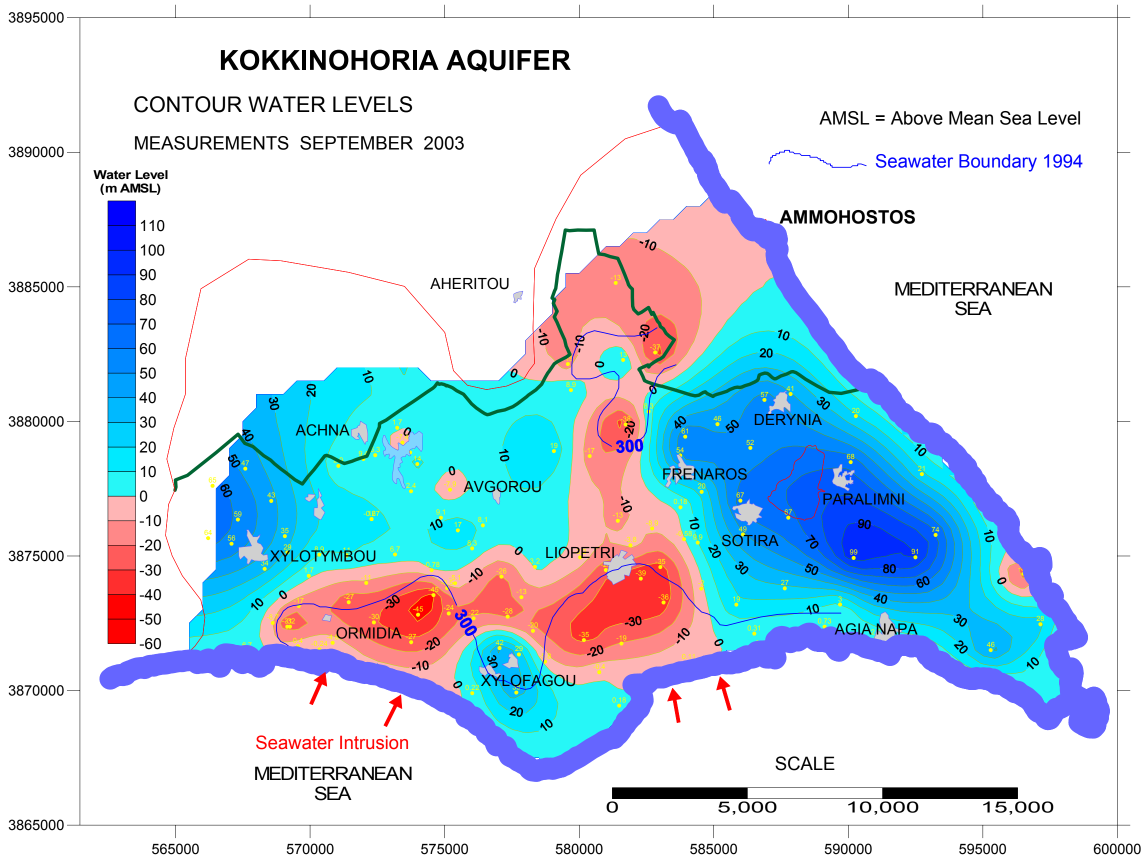

Figure 2. Groundwater contours at the Kokkinohoria aquifer on September 2003

Line A–A is a vertical hydrogeological section of the aquifer in the region Xylofagou and it was drawn in order to explain the mechanism of infiltration of sea water.

Here we see a hydrogeological cross section. The horizontal axis gives distances and the vertical the altitude above mean sea level. The zero on the axis represents the mean sea level (MSL). On the left with blue colour is the sea. The green line defines the surface of ground. We see also here the groundwater level, which reaches 50 meters below mean sea level. Graduating colour shades from rose to blue depict regions in the aquifer that has saline water due to seawater intrusion and finally, with light blue colour is presented the fresh water. Brown colour represents the base of the aquifer, which is considered impervious. The arrows show the direction of flow of seawater, which due to the low level of the groundwater being at this instance at 50 meters below sea, moves continuously from the sea inland. As long as there is a negative piezometric difference in the levels of sea and groundwater, water from the sea will continuously flow into the aquifer and fill these areas.

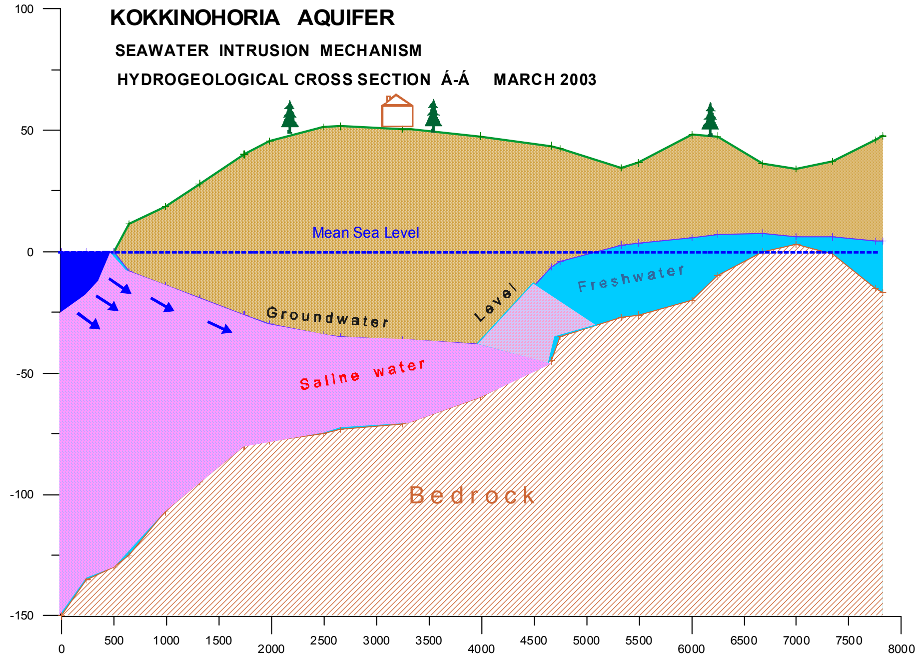

Figure 3 Vertical section at the Kokkinohoria aquifer March 2003. Mechanism of seawater intrusion.

In Figure 4, we see a contour map of the water level of aquifer Kiti-Pervolia aquifer for the months March and April 2003. As one can see, the water level reaches up to 6 meters below mean sea level.

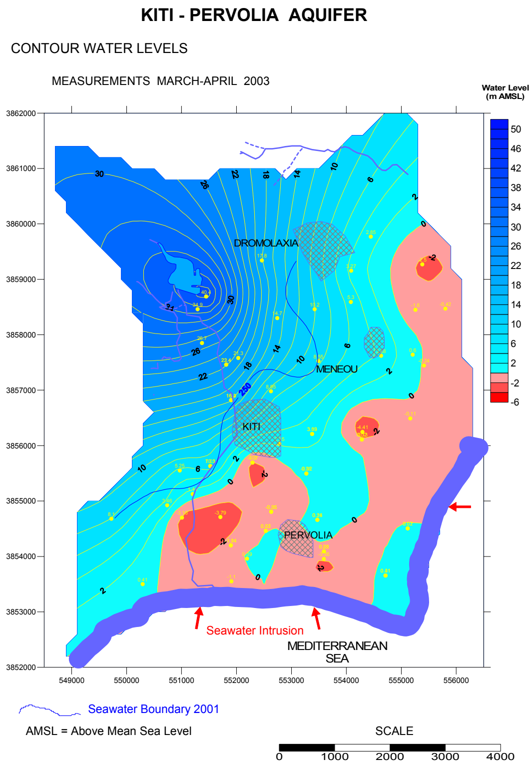

Figure 4. Groundwater contours at the Kiti-Pervolia aquifer on March-April 2003

Figure 5 presents contour map of the water level of aquifer Akrotiri aquifer for September 2003. The blue line delimits the region of the aquifer, which has saline water. The biggest part of aquifer has become saline. Line A–A is a vertical hydrogeological cross section of the aquifer.

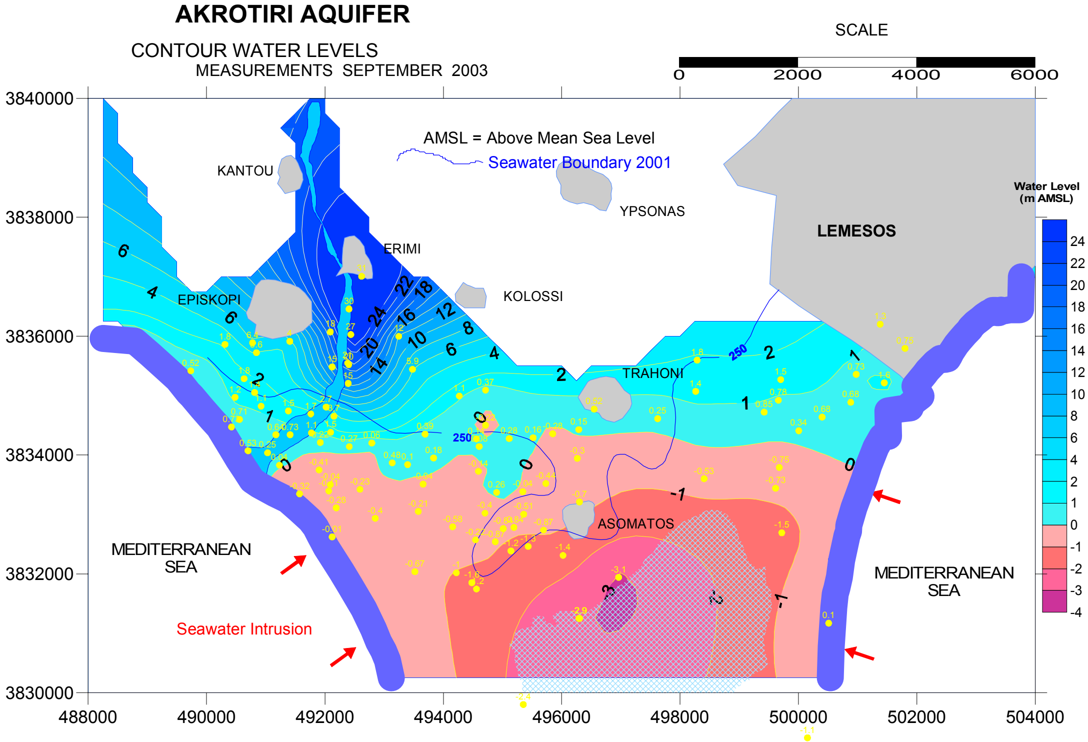

Figure 5. Groundwater contours at the Akrotiri aquifer on September 2003

Figure 6 presents a vertical cross section at the Akrotiri aquifer on March 2003. In this cross section we see the mechanism of seawater intrusion. Graduating colour shades from rose to blue depict regions in the aquifer that has saline water due to seawater intrusion and finally, with light blue colour is presented the fresh water. Brown colour represents the base of the aquifer, which is considered impervious. As we see from this cross section, the amount of fresh water remained stored in the aquifer is very small.

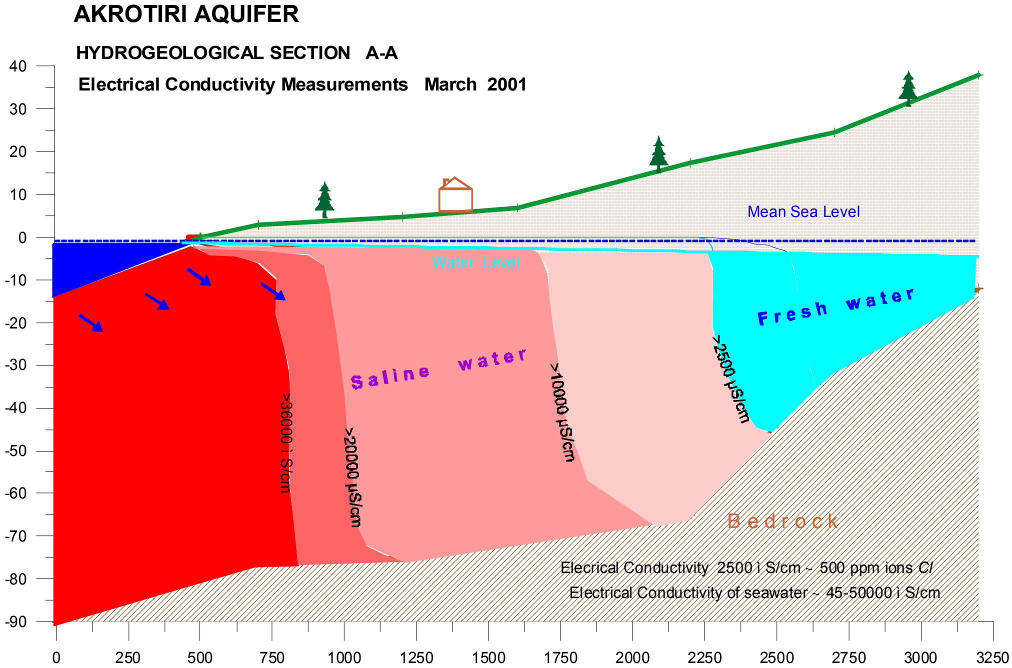

Figure 6. Vertical cross section at the Akrotiri aquifer March 2003. Mechanism of seawater intrusion.

Figure 7 presents a hydrograph of a bore number 719 at the Akrotiri aquifer. In the hydrograph one can observe the fluctuation of the groundwater level since 1965. Also a negative trend of the water table rise can be seen. For the last three years one can see the rise of the water level but it is still below mean sea level (MSL), which means that seawater intrusion still occurs in this region.

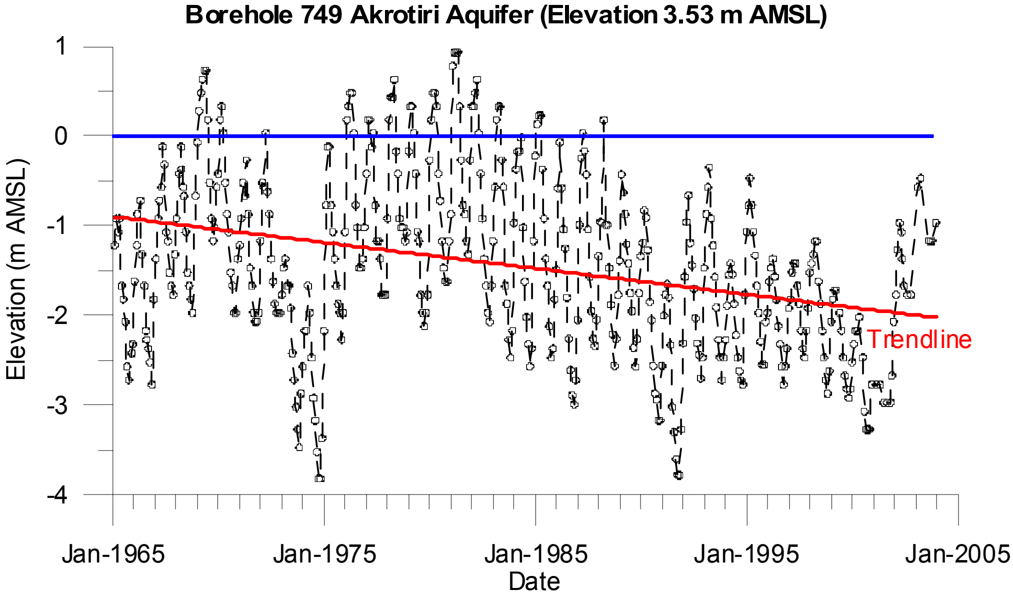

Figure 7. Hydrograph of the borehole 749 in the Akrotiri aquifer

The last completed study on the water resources of Cyprus concluded that from the 61 aquifers in the free region of Cyprus the 44 are overpumped. In this study the authors make recommendations on the rehabilitation of the aquifers, such as the annual extraction should not exceed the 81 Mm^3. In the future when our aquifers are restored, the safe extraction rate could increase to 100 Mm^3. The current total groundwater extraction from our aquifers amounts to 129 Mm^3. It is obvious from these numbers that reduction of the extraction is needed. Also, Cyprus as a Member State of the European Union we are required through the Water Framework Directive, to implement measures for reduction of pumping from the aquifers to sustainable levels.

Due to rainfalls falling below the yearly average during the last decades, the recharge of the aquifers ha been dramatically decreased. The deficits in the general water balance had also serious repercussions in the programs of aquifer recharge. Fortunately, the hydrometeorological conditions of last three years improved our water balance, allowed the intensifying of artificial recharge measures. This is achieved by diverting, and releasing water from rivers and dams, into the aquifers. Also, for aims of increase of natural recharge, the last years has been intensified the construction of artificial recharge works along the length of almost all rivers in Cyprus.

Another big point which we should mention is the use of recycled water which is produced in increasing rate and occupies a vital place in our water resources budget. It is a new alternative source of water, with very reliable degree in terms of quantity. Beginning of next decade is expected that they will be available up to 30 Mm^3 per year. A big part of these quantities will be utilized in artificial recharge of the aquifers, which will improve the condition of the aquifer and also protect them from seawater intrusion.

Another source of water in Cyprus is desalinated water, which at present has a capacity of 33 Mm^3 per year.

The Water Framework Directive 2000/60/ec and Cyprus

One of the obligations that Cyprus undertakes by joining the European Union is to stop further deterioration of the quality and quantity of all the water systems and their constant improvement up to the final goal, which is good condition of all waters in terms of quality and quality. The implementation of this directive is obligatory to all member states and aims at the viability of the water resources. Delay or unjustifiable failure on achieving this objective involves serious penalties. All Member States are obliged to protect, restore and upgrade their water systems. The citizens of the European Union, with this directive seek to ensure so much their own survival, prosperity and quality of life but also that of the future generations.

The water framework directive covers the following:

- It protects all waters: rivers, lakes, coastal and underground waters.
- It places ambitious targets all waters will achieve "good condition" by 2015.
- It develops a management plan on river basin level.
- It requires cross-border collaboration between countries and all the involved parts, (in the case of international regions of river basins).
- It ensures active participation of all institutions, in the activities of water management.
- It ensures reduction and control of all pollution sources.
- It requires development policies on pricing of water and ensures that the polluter pays.
- It counterbalances the interests of environment with the interests of what depends from it.
- It ensures reduction and control of pollution from all sources.
- For each river basin district, there are defined actions, which need to be finalised within certain timeframe.
- For certain water systems, provided they fulfil certain conditions, the Directive permits:
- Extension of the deadline further to 2015
- Relaxation of the environmental targets than those required normally

For Surface waters the directive specifies that "good condition" is considered "good ecological" and "good chemical status".

For Underground waters the directive specifies "good condition" is considered "good quantitative" and the "good chemical status"

Legal and institutional framework.

The Cyprus pre-European Union legislation was dividing the responsibility for water management between several ministries exercising overlapping jurisdictions, often resulting in instances where there was duplication of efforts and other instances where no action was taken at all. These and other weaknesses and deficiencies were identified and targeted for correction through the new legislation. The new legislation is based on a unified water code and the establishment of a new Water Entity while abolishing a number of dispersed bills of law, and harmonised Cyprus legislation with the EU Directive 2000/60/EC. The new Water Entity is proposed to develop and manage water resources within the framework of the national water policy. It will, deal with the difference between water demand and supply. The new Water Entity would be based on the existing Water Development Department, which will continue to be under the Ministry of Agriculture, Natural Resources and Environment.

Important deadlines set on the implementation of the 2000/60/EC

Key activities and their importance as they are related to different phases of the implementation process determined by the deadlines as they have been laid down in the Water Framework Directive. These phases may be presented in Table 2.

Priority was given to all projects for which the outcome is needed to fulfill the requirements of Phases 1 and 2 and in particular on the development of guidance documents on the key requirements of the Directive. However, the priorities are identified as issues in their own right. It is not the intention to develop a hierarchy of importance. Moreover, contribution to the work on individual priorities is based on a principle of voluntary participation depending on national prioritisation of resources and national interests. Preparation for making the classification system operational through the identification of reference sites and specification of reference conditions need to be initiated already during Phase 2 in order to meet the deadlines. Likewise, all guidance documents needed for the analyses of the characteristics of the river basin, of pressures and impacts and for the economic analysis should also be developed over the next 2 years to be of real use for the Member States. Great importance is given in the information and participation of the public.

Table 2. Important deadlines set on the implementation of the 2000/60/EC

Phase 1:	- Transposition - Identification of River Basin Districts	Deadline: Dec. 2003
Phase 2:	- Establishment of reference conditions and reference sites for the inter-calibration network	Deadline:

	- Preparation for specification of values for the ecological status classification systems	Dec. 2004
	- Analyses of the characteristics of the river basin, of pressures and impacts and the economics of water use	
Phase 2a:	- Establishment of Community criteria for assessing groundwater (Commission proposals)	Deadline: Dec. 2002
	- Individual Member State action in absence of adoption criteria	Deadline: Dec. 2005
Phase 3:	- Operational monitoring program	Deadline: Dec. 2006
Phase 4:	- Publication of River Basin Management Plans	Deadline: Dec. 2009
Phase 5:	- Establish water pricing policies to promote efficient water use and to recover the costs of water services by economic sector	Deadline: Dec. 2010
	- Make operational all measures established under the program of measures	Deadline: Dec. 2012
	- All waters are in “good condition”	Deadline: Dec. 2015

Common strategy

The Directive presents many difficulties in the implementation. For harmonised implementation of the Directive, it was decided to setup a common implementation strategy. The aim of this strategy is the identification of the important problems and design of common methodological approaches, the common confrontation of the problems and the exchange of information and experiences. Were constituted eleven workgroups aiming at the development of guidance documents for the important topics of the Directive. Most of the workgroups have completed their work. The final guidance documents can be accessed from the web (http://forum.europa.eu.int/Public/irc/env/wfd/home).

Application of the directive in Cyprus

An action plan has been prepared. Teams are assigned to follow the development of all the guidance documents. More importance was given at the initial stages of the implementation plans of the Directive, which are considered critical and decisive. The Cyprus legislation was harmonised with the requirements of the Directive by enacting a new bill. The bill was passed by the parliament on February 2004. For determining the river basin districts, it was decided that the entire island of Cyprus constitutes one river basin district. The competent authority is the Minister of Agriculture, Natural Resources and Environment. The "Responsible Authorities" for the implementation and reporting to the EU about the Directive are Water Development Department and the Environment Service. By December 2004 we need to report on Articles 5 and 6 of the Directive. This involves analysis of the characteristics, review of pressures and impacts, economic analysis and creating a register of protected areas. Due to the lack of available human resources with the necessary expertise within the government sector this project was given to a consortium of international experts.

The ENVIS database

The cornerstone for achieving the implementation of the water framework directive is the utilisation of a database for warehousing all the water quantity and quality data. The database package developed is called ENVironmental Information System (ENVIS). It was designed using a widely used commercial database package.

The ENVIS database is used to input, store, and report environmental information. It is a distributed database implemented in Microsoft Access 2000 and installed on PCs. The menu-based graphical user interface (GUI) is subdivided into four data sections - ground water, surface water, meteorology, and water quality - plus an administration section. Each section includes site information, ancillary information pertinent to the type of data being stored, and the raw data. The database is adaptable and can be modified to meet other needs and requirements.

The meteorological information stored in the database includes daily, hourly, and intensity precipitation, and 24 other types of meteorological observations. The ground-water section of ENVIS is divided into site information, borehole details, water levels, and water-quality data. The borehole details include: construction, drilling, hole description, water struck, casing, packing, well development, lithology, pump test, yield, water levels, pump, and networks. The surface-water section includes information for springs, streams, and dams. Daily flow can be entered for all streams and springs. The maximum instantaneous flow and stage for weirs also can be stored in ENVIS. The water quality information stored in the database includes information about the sample collection history as well as the analytical results for physical, organic, inorganic, isotopic, biologic, and trace elements analyses and other water-quality characteristics such as toxicity. The administration section of the database is relatively simple and covers administrative functions needed by MS Access and ENVIS such as security safeguards including password protection and user restrictions on data entry and editing. The username and date of all changes are recorded automatically by ENVIS.

The water quality information, which is composed mainly from results from ionic analysis, is limited at present because the points of measurement are not georeferenced yet. It should be noted that a small database of chemical, microbiological, ecotoxocoligical, and biomonitoring data has been developed for eight major dams and ten rivers. This monitoring was curried out for the period of 1996 to 2000.

Problems on Implementing the DirectiveMany problems are encountered on the planning of the implementation of the directive. These are as follows.

- The lack of an integrated rationally organised national network for data collection.
- The database for storing and analysing information is at its initial stages with many teething problems. Much of the information collected over the years is still in paper form.
- The lack of water quality data, especially chemical analysis information other than ionic.
- The difficulty on co-ordination between the responsible authorities and all the involved institutions.
- The points of pressure were not monitored in a systematic way and also are not georeferenced.
- The lack on specialised expertise and suitable human potential. The mentality of users of water.
- The high cost of implementation.
- The division of responsibility on water management and the lack of a single authority responsible for it.
- Difficulties associated with the extended periods of low rainfalls observed in Cyprus in the last decades.
- Difficulties arising from the fact that the Directive is more focused on the big river basins of Europe.

Conclusions

Almost all the aquifers are overpumped and for many of them their water quality has deteriorated due to seawater intrusion. Drastic action is required for reducing aquifer extraction to a level, which will allow the aquifers to recover. Unless groundwater is left to recover to a reasonable level, the resource will be of limited help to mitigate future water shortages. Within the water framework directive, River basin management plans will be developed. This will ensure the rehabilitation of the aquifers as well as their protection. This can be achieved with very careful management that is focused mainly in two methods; first with the drastic reduction of pumping to sustainable levels and second with the increase of their recharge with natural and artificial methods. Also, is important to remember that the best economic way for supplying water is to save water though better water management.

Positive effects from the application of Directive in Cyprus will be that it will create the essential conditions for the support of policy that will lead in the satisfactory and effective protection of all waters and develop a rational management and exploitation of our precious water resources.

The application of the directive in Cyprus requires the creation of essential infrastructure, laborious work on behalf of all people involved, long-term planning, change of mentality, economic cost and most important of all political will.

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