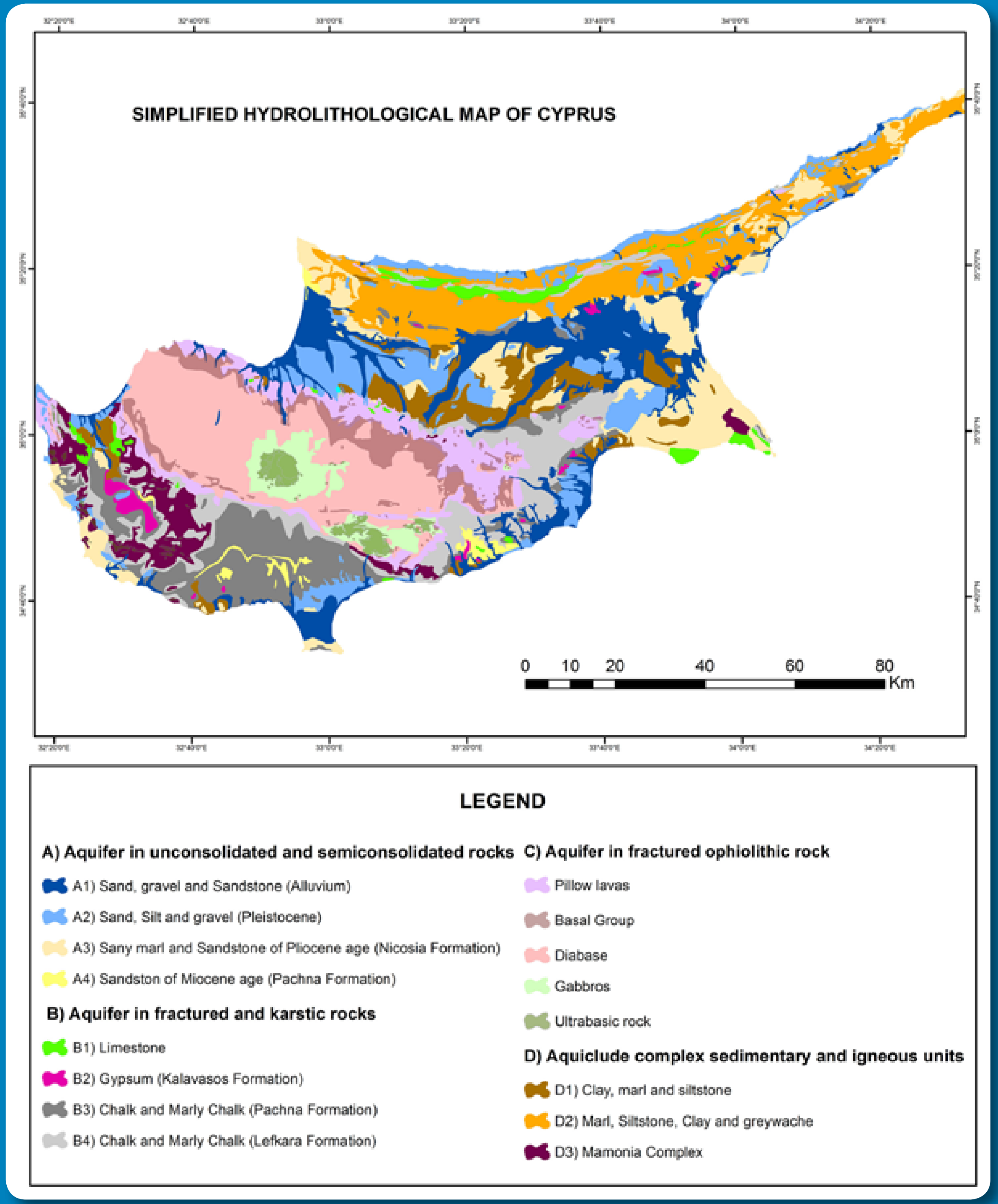
CYPRUS GEOLOGICAL SURVEY DEPARTMENT

Ministry of Agriculture, Rural Development and Environment

GROUNDWATER RESOURCES OF CYPRUS

“Water is the beginning of everything”

Thales of Miletus (624 - 546 BC)



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Spring located at Foini village (2015)

Karkotis river flow during the winter period (2013)

Krios river flow (waterfall) at Mesa Potamos village (1997)

Aquifers of Cyprus

In Cyprus there are three **classes of aquifers**. The first one is that of the clastic aquifers which are mainly developed in river and deltaic deposits as well as in marine terraces. In these aquifers, groundwater fills the pore space between the sand and gravel grains. In the second class belong the **karstic and pseudo karstic aquifers**. The former are developed in carbonated rocks such as limestones, dolomites and marbles while the latter mainly in gypsum. In this type of aquifers, groundwater takes up the voids (caves) which are created from the dissolution of such rocks. The **fractured aquifers** represent the third class of aquifers in which water fills up the space created by the fracturing of the sound bedrock-mass (fractured zones). The productivity of these aquifers depends mainly on the lithology, the extent of tectonic fracturing and the presence of (secondary) clay minerals.

Clastic Aquifers: The most important clastic aquifer is that of Western Mesaoria (Morfou area) which is mainly developed in the alluvial deposits of the torrential river Serrahis. Its recharge results mainly from the flow of Serrahis's tributaries which originate from the northwestern part of Troodos (the torrential rivers of Peristerona, Akaki and Palaiometocho). However, overpumping of the aquifer has resulted to a negative water balance and consequently to seawater intruding to a substantial part of it. Other notable clastic aquifers are those of South-Eastern Mesaoria (Kokkinochoria), that of Akrotiri, Germasogia and the Pafos coastal zone.

Karstic and Pseudo karstic Aquifers: The most important karstic aquifer is that of the Pendadaktilos range, which develops in limestones, dolomites and marbles. Due to tectonism, the aquifer is compartmentalised in distinct sections which, prior to its exploitation through boreholes, recharged through overflow karstic springs known as “Kefalovrisa”, like the ones at the communities of Lapithos, Karavas, Kythrea and Akanthou. Less important karstic aquifers have also developed in the limestones of Terra and Koronia formations, at various parts of Cyprus such as the ones in the communities of Pegeia and Androlikou. Pseudokarstic aquifers occur in gypsum of the Kalavasos formation such as the ones in the areas of the communities Maroni and Aradippou in Larnaka District as well as in Giolou-Letymvou in Pafos District.

Fractured Aquifers: Fractured aquifers are mainly developed in the Troodos ophiolites. The most promising hydrogeological conditions are observed in tectonically faulted and fractured gabbros, while in the lavas they are the poorest mostly due to the low permeability of these rocks. Fair prospecting conditions are also observed in faulted diabase, where mostly local aquifers develop. Similar types of aquifers develop in the massive chalks of the Lefkara formation as well.

Historical Retrospection

Water resources, both surface and underground, constitute a vital commodity for the growth and progress of human kind. Thus, their availability has always governed the foundation of new settlements from ancient times to the recent years.

The foundation of the first settlements in Cyprus was based on the exploitation of spring and river flows. Since the Neolithic times, Cypriots have realised the vulnerability of surface waters during dry seasons and therefore, initiated groundwater exploration. Compelling evidence of this constitutes the existence of a well at the community of Kissonerga in Pafos district, which dates back to 6500 BC.

Extensive copper exploitation (3rd millennium BC) resulted in the overall development of the island, giving also rise to population growth and consequently, water demand. These demands were at first covered by springs and later on by dug wells, a practice which continued through the Hellenistic period. During the Roman and Byzantine periods, great aqueducts were also constructed such as the one of Salamis, which supplied the city with water from the Kythrea springs. During the Ottoman period the construction of "lagoumia" was developed, namely a chain of wells interconnected through a tunnel via which groundwater was driven to the surface.

The systematic pumping of aquifers, however, commenced towards the end of 19th century with the importation of windmills, and continued later on with the drilling of boreholes. The very first percussion rig was imported in 1920. By 1950 the practice of borehole drilling had already been established, thus intensifying the exploitation of the then known aquifers. Gradually, thousands of irrigation boreholes have been drilled, unfortunately most of them without any control.

The exploitation of groundwater for irrigation contributed to the replacement of non-irrigated with irrigated crops such as the citrus plantations in Morfou and Ammochostos. However, the growth of irrigated agriculture resulted in the gradual inversion of the water balance. Consequently, groundwater levels have been lowered, seawater intruded in the majority of coastal aquifers and borehole yields reduced.

The substantiation of the negative water balance in numerous aquifers in conjunction with increased water needs, have led the State to design and construct major waterworks such as dams, water channels, river ponds and, recently, desalination plants. Furthermore, the Troodos ophiolites aquifer was exploited with the use of contemporary drilling rigs.

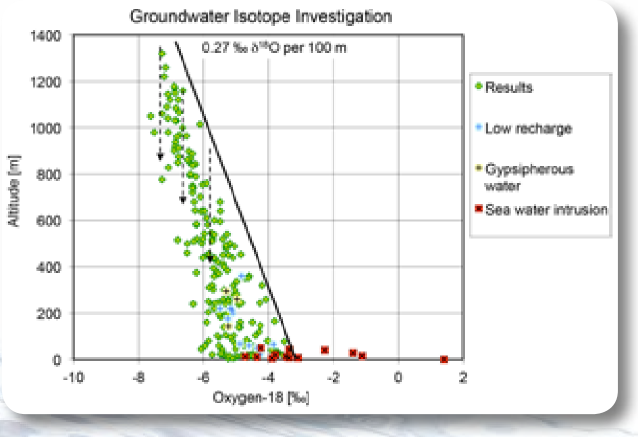
Percussion rig of the Geological Survey Department.

The contemporary rotary rig, Ingersol RD20, of the Geological Survey Department.

Pumping test worksite of the Geological Survey Department.

Research

The very first scientific research on groundwater in Cyprus was conducted at the beginning of the 20th century, during which the first major aquifers have been discovered such as the one of Pentadaktylos and later on that of Western Mesaoria. In the 1960s, the first thorough study on groundwater resources (UNDP Project) was carried out, during which the major aquifers of the island were studied. Furthermore, the existence of a negative water balance was substantiated for the first time.



In the 1980s, research focused on understanding groundwater quality, modeling selected aquifers and on exploiting the fractured aquifer of the Troodos ophiolites. Later on, research was diverted to natural radiation of groundwater, to the calculation of water balances and to the study of aquifer pollution resulting from various human activities. In early 2000, a study on the reevaluation of the island's groundwater resources was completed, while contemporary research focuses on issuing an updated hydrogeological map with the use of new technologies such as water isotope analysis.

Groundwater Quality

The natural composition of the groundwater depends mostly on the susceptibility of the hosting rocks to chemical weathering, to groundwater-rock contact time and to a lesser extent to rainwater composition which constitutes the main source of groundwater. In many cases, groundwater composition is influenced by various human activities such as agriculture, husbandry and industry.

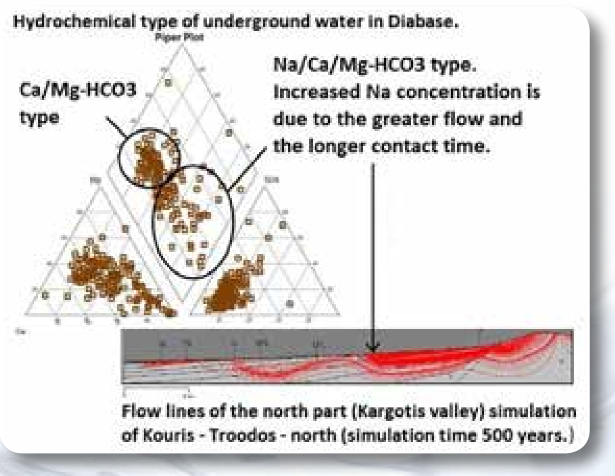
Bedrock weathering and concurrent enrichment of groundwater with various ions depends on the mineralogical composition of the hosting rock and consequently, to the solubility of these minerals, to groundwater-rock contact time and to the water pH and temperature. More specifically, water's mineral dissolving capacity increases with temperature rise and pH decrease. Consequently, in deep aquifers of low hydraulic conductivity, groundwater exhibits increased salinity. The same occurs in cases where aquifer recharge is limited and therefore salt flashing cannot be achieved.

Cyprus' **groundwater quality** is generally of good status. However, in specific aquifers serious quality issues are observed that are either naturally occurring or related to human activity. Such issues are the high salt content and elevated concentrations of a number of ions such as chlorites, sulfates, nitrates, sodium, fluorite and boron.

The most serious quality problem is the **increased water salinity** which is mainly observed in coastal and in deep sedimentary aquifers. In the first case, the problem is caused by seawater intrusion induced by groundwater overpumping. Such cases are observed mainly in the aquifers of Southeastern Mesaoria (Kokkinochoria), Northwestern Mesaoria, Akrotiri and Kiti - Pervolia. In the second case, salinity is due to limited aquifer recharge and to prolonged groundwater-rock contact time. A typical example of this case is a big part of the Central Mesaoria aquifer. Furthermore, in some cases salinity is due to the presence of trapped (connate) sea water which is mostly seen in pillow lavas.

Another serious problem is the increased nitrate concentration in groundwater. The primary sources of groundwater nitropollution, in decreasing order of contribution, are agriculture, husbandry and the disposal of urban wastewater. The most vulnerable aquifers to nitropollution are those of Southeastern Mesaoria, Akrotiri, Kiti-Pervolia, Pegeia, Polis Chrysochous and a part of the Central and Western Mesaoria Aquifer in the the Orounta area. These areas have been declared as Nitrate Vulnerable Zones (NVZ) according to the European Directive 1991/676/EEC.

Less serious quality issues occur in smaller aquifers due to the **presence of naturally occurring sulfates, boron and fluorite**. High concentrations of sulfates occur in gypsum and lavas, with the latter exhibiting high boron concentrations as well. Elevated fluorite concentrations are predominantly seen in chalks.



The best quality groundwater is found in gabbro as well as in diabase rocks of the Troodos ophiolites. This is due to the dynamic character of this aquifer and to the consequent fast replenishment of groundwater. In addition, human activity that can jeopardize groundwater quality is relatively limited in the Troodos area.

Sulfates (mg/l)
•0-100 •100-200 •200-250 •250-1000 •>1000

Boron (mg/l)
•>0.5 •0.5-1 •1-5 •6-10 •>10

Electrical Conduct (μS/cm)
•>1,000 •1,000-2,000 •2,000-2,500 •2,500-10,000 •>10,000

Chlorites (mg/l)
•0-100 •100-200 •200-250 •250-500 •>500

Monitoring

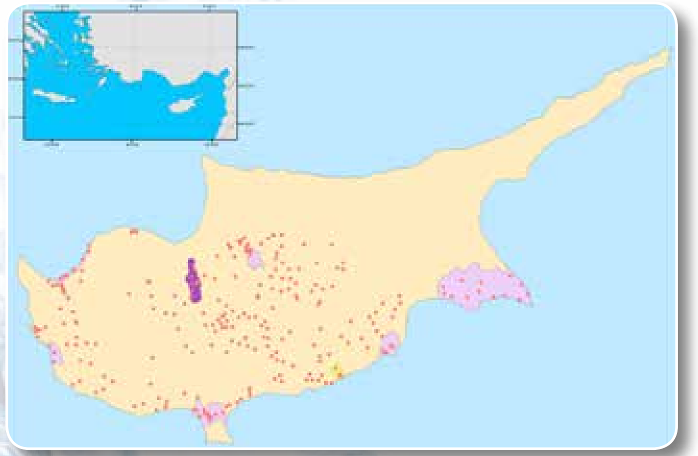
In order to facilitate groundwater protection and management, proper monitoring networks need to be operated aiming towards early detection of qualitative and quantitative variations in time and space. The Cyprus Geological Survey Department carries out timely, continued and focused monitoring by operating the following monitoring networks:

(a) Monitoring network for the protection of waters from nitrates of agricultural origin: This network comprises 252[1] nitrate concentration monitoring stations, according to the provisions of the European Directive 1991/676/EEC.

(b) Monitoring network for the protection of groundwater against pollution and deterioration: This network comprises 92[1] monitoring stations aiming at monitoring the concentration of various pollutants, according to the provisions of the European Directives 2000/60/EU and 2006/118/EU.

(c) Groundwater level automated monitoring network: This network comprises 80[1] automated dataloggers, which store hourly groundwater level and, in selected stations, temperature and conductivity fluctuations.

[1] The number of stations is amended according to needs and available resources.



• Monitoring station • Vulnerable to nitropollution zone (NVZ) • Abolished vulnerable to nitropollution zone • Under investigation vulnerable to nitropollution zone

• Monitoring station • Town