Scientific Annals, School of Geology, Aristotle University of Thessaloniki Proceedings of the XIX CBGA Congress, Thessaloniki, Greece	Special volume 99	173-181	Thessaloniki 2010

PILOT STUDY FOR ARTIFICIAL RECHARGE OF THE SOUTH-EASTERN MESAORIA AQUIFER (CYPRUS), USING TERTIARY TREATED WASTEWATER

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Abstract: In many arid or semi-arid countries, like Cyprus, groundwater is the main source for domestic and irrigation use. The degradation of groundwater resource can be quantitative and qualitative, if the abstraction exceeds the natural recharge rate. For this reason treated water at these areas is a valuable water resource and should be taken into account in designing a rational water policy. Furthermore, the interest in artificial recharge of groundwater using pretreated waste water continues to increase, especially in the semi-arid countries. In this paper, the possibility of artificial recharge in the South-Eastern Mesaoria (Kokkinochoria) aquifer, close to Liopetri village, is examined. This study area is characterised by low precipitation (330 mm) and it is covered by deposits of Nicosia formation, Pliocene aged, which consists of marls and fined to coarse grained calcitic sandstone. The aquifer is developed between the sandstones horizons and sands. The average thickness of the aquifer is up to 80 m and the maximum 120 m. Overpumping during the last decades, through a large number of boreholes, has caused a decline of groundwater level and the occurrence of negative piezometry up to 30 m below mean sea level. As a result, sea intrusion phenomena are recorded for distance up to 1-2 km inland. Therefore, the use of tertiary treated wastewater, which is produced at Agia Nappa-Paralimni treatment plant, is proposed for the application of artificial recharge through boreholes. Adequate pretreatment of the reclaimed water is also considered prior to the recharge, taking into account the final use of the aquifer's water.

Key words: Artificial recharge**,** Aquifer, Treatment, Waste water, Cyprus

1. Introduction

In Cyprus, groundwater is the main source for drinking and irrigation use. It is estimated that water consumption increases during the last decades in Cyprus; the major water use category is irrigation (Republic of Cyprus, 2004; UNESCO, 2005). The degradation of groundwater resource can be quantitative and qualitative, if the abstraction exceeds the natural recharge rate. For this reason treated water at these areas is a valuable water resource and must be taken into account in designing a rational water policy (Angelakis et al. 2006). Artificial groundwater recharge with reclaimed waste water effluents has been successfully used worldwide to control water depletion in overexploited aquifers (Peters et al., 1998; Constantinou & Georgiou, 1999; Rinck-Pfeiffer, 2000; Tsagarakis et al., 2004).

This study deals with the possibility of application of artificial recharge in the South-Eastern Mesaoria aquifer, close to Liopetri village (study area), using the reclaimed wastewater, which is produced at Agia Nappa-Paralimni treatment plant. This scientific work was carried out by the Aristotle University of Thessaloniki (Laboratory of Engineering Geology and Hydrogeology) in cooperation with LDK ECO Environmental consultants S.A. and Atlantis consultants, in the framework of a research program, funded by the Republic of Cyprus (Ministry of Agriculture and Natural Resources, Department of Water Development).

2. Study area

The study area is located south of Liopetri village, part of the South-Eastern Mesaoria basin. It covers an area about of 6 Km^2; 3 Km^2 out of them is public land. The elevation of the area is less than 50 m above sea level (Fig. 1). The distance of the study area from the nearest southern cost is 5 Km. The area is characterized by semi-arid climatic conditions. The mean annual rainfall is 330 mm and the mean annual temperature 19.6 ^{o}C. About 90% of annual rainfall occurs in wet period (November-April), while summers are usually dry. The driest months are July and August. A decreasing linear trend in annual rainfall is recorded (Larnaca station). Based on Thornthwaite method, the estimated mean actual evapotranspiration represents percentage of 80% of the annual rainfalls (Constantinou, 2004).

From a geological point of view, the study area is covered by deposits of Nicosia formation, Pliocene aged (thickness >800 m), which consists of marls and fined to coarse grained calcitic sandstone. The upper part consists of secondary limestone compact crust (kafkala) and soft secondary limestone (chavara). The average thickness of the aforementioned limestones is 6 m. The presence of kafkala constricts the infiltration of water to the deeper aquifers. Sandstones and sandy facies are observed at depth 30-45 m below ground surface (Constantinou & Irakleous, 2006).

3. Hydrogeology - Characteristics of the aquifer

The main aquifer system is developed at sandstones horizons and sands. The base of the aquifer mainly consists of marls and has a rugged topography with alternations of ridges and troughs. Due to the presence of impermeable strata in the ground surface, the phreatic aquifer locally absents and the aquifer system is of confined conditions. The average thickness of the aquifer is up to 80 m and the maximum 120 m. Based on the lithological profiles (Fig. 2) of the drilled boreholes, it is concluded that the thickness of the aquifer in the eastern part of the study area is less than in the western part. In the study area close to Liopetri village, the depth of the marly base of the aquifer ranges between -25 and -40 m below mean sea level (m.s.l.).

The average thickness of the unsaturated zone, below sea level, is 25 m, whereas the average thickness of rocks of the unsaturated zone above sea level is 50 m. The thickness of the saturated zone depends on the local hydrogeological conditions and the pumping regime ranging between 1-5 m. In general, the direction of groundwater flow is from the North to the South and is controlled by the

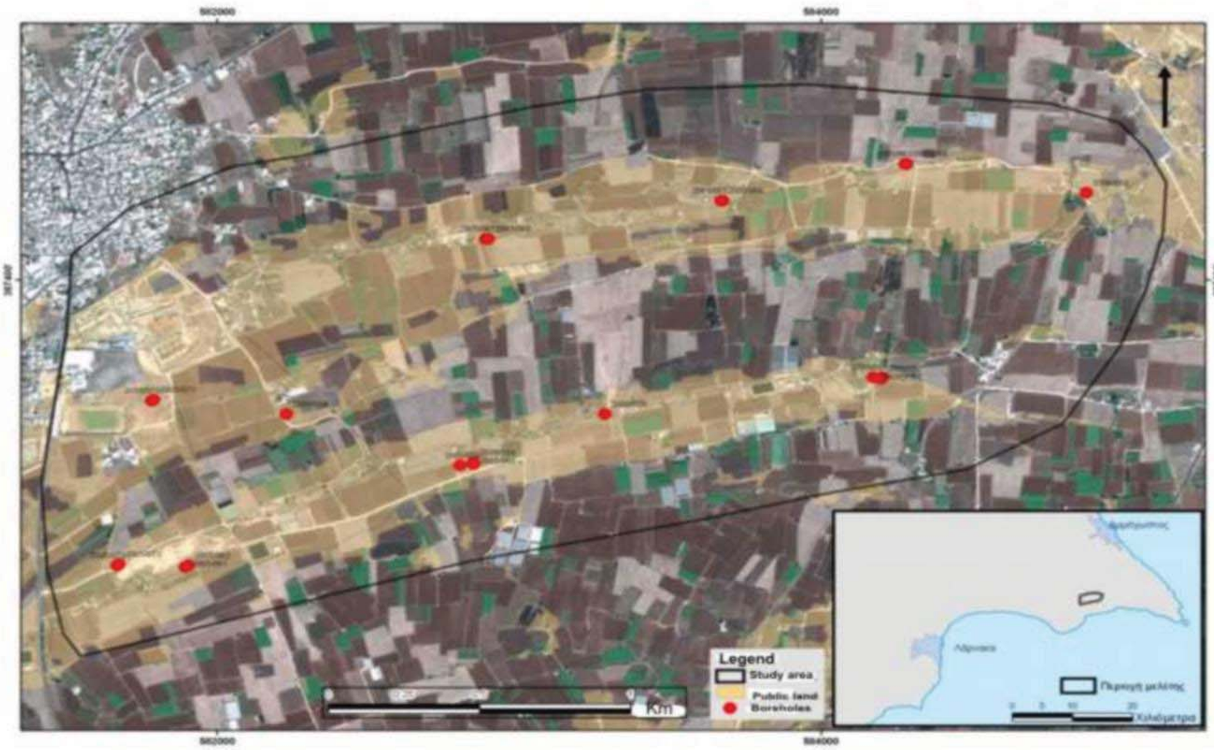

Fig. 1. Location of the study area (Constantinou and Irakleous, 2006).

creation of depression cone in the areas where overpumping takes place.

Groundwater recharge in the aquifer occurs via the following mechanisms: direct infiltration of rainfall and return flow of water applied for irrigation. The problem of the South-Eastern Mesaoria aquifer is that the irrigation abstraction exceeds the rate of natural replenishment. In most parts of the aquifer the yield of boreholes has been reduced (<3 m^3/h), because of the reduction of the saturated thickness of the aquifer and a lot of boreholes or wells are useless (Theodosiou, 1994).

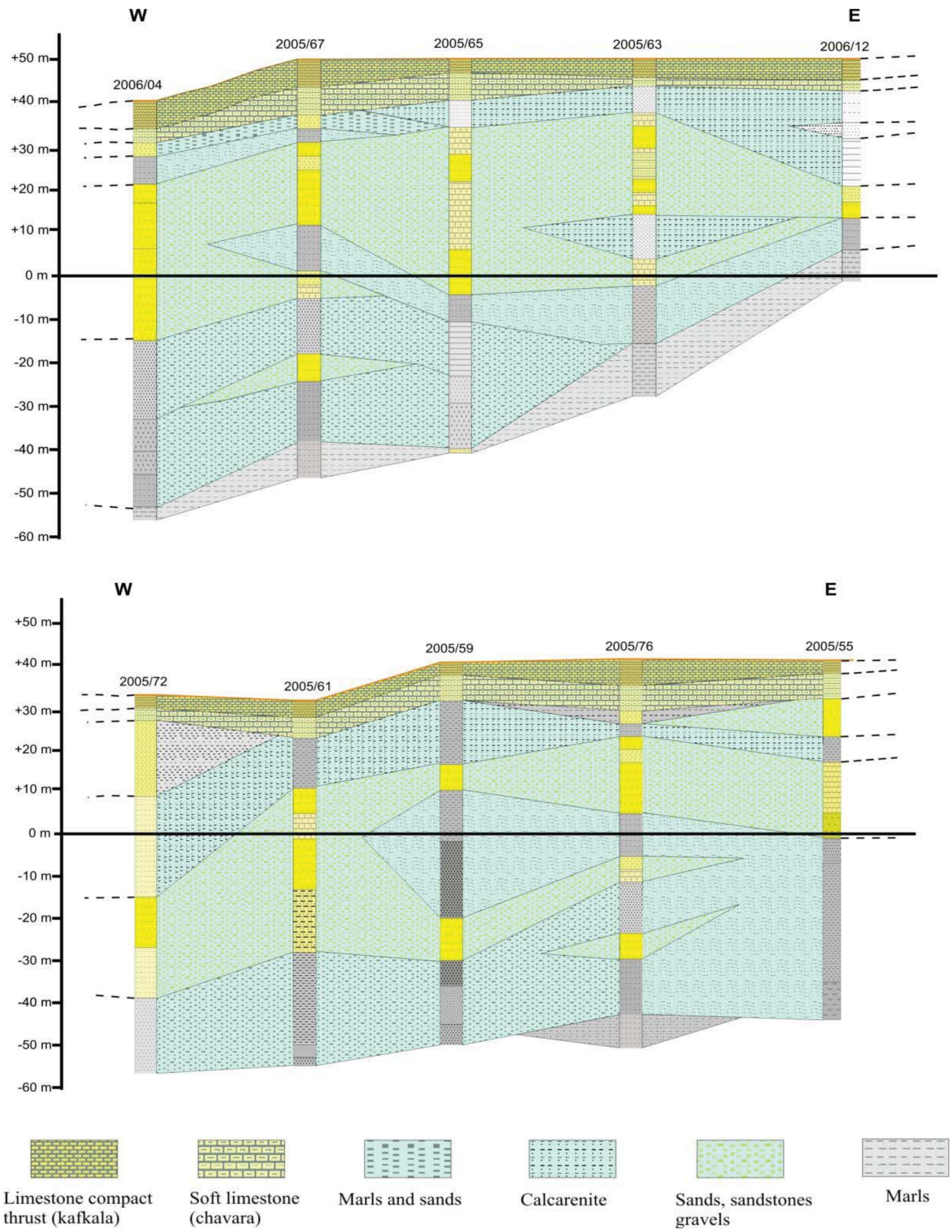

Fig. 2. Characteristic geological profiles in the study area in the North and South part.

The groundwater table is 34 m (January 2009) below mean sea level (negative piezometry) except of in the northeastern part, close to Sotira village. The water table is highest in April or May and lowest in November (Fig. 3). Overpumping during the last decades through a large number of boreholes has caused a decline of groundwater level and the occurrence of negative piezometry up to 30 m below mean sea level (Fig. 4). As a result, sea intrusion phenomena are recorded for distance up to 1-2 Km inland in the northern part (Republic of Cyprus, 1982).

The average hydraulic conductivity value is $k=2.6x10^{-6}$ m/s, as deduced from the conducted pumping long test analyses, and is greater than the value deduced from the tests of short duration ($3.7x10^{-7}$ m/s). The mean specific yield is assumed to be 8.5%. Based on the values of hydraulic conductivity and the depth of the aquifer layers, the mean transmissivity was estimated to be T=18 m^2/day. The stabilization discharge of groundwater level during the constant head tests varies between 6 m^3/h and 20 m^3/h (Fig. 5) (Constantinou & Irakleous, 2006).

Seawater intrusion due to overexploitation and the nitrate pollution because of the intensive use of fertilizers are the main causes of groundwater quality deterioration in the study area (Republic of Cyprus, 2003). Based on results of chemical analyses

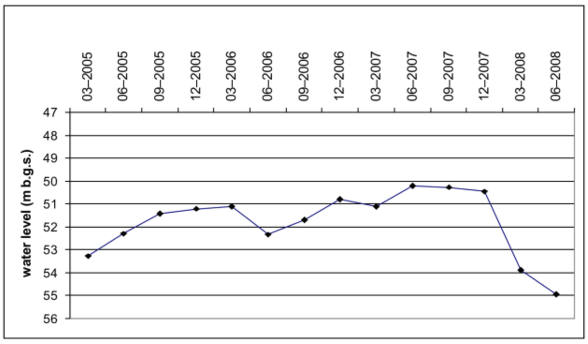

Fig. 3. Fluctuation of groundwater level.

from 5 samples (January 2009) it is concluded that: Electrical conductivity at 25 °C ranges from 700 μS/cm to 3150 μS/cm (Fig. 6). Chloride concentration ranges from 82 mg/l to 278 mg/l. High values of electrical conductivity and chloride concentration can be associated with the seawater intrusion in the southern part of the study area. Very high concentrations of iron (Fe) and manganese (Mn) are recorded at one sample; 193 μg/l and 10.4 μg/l, respectively. The predominant water type is: Na (Mg) - HCO_3 (SO_4). The concentrations of heavy metals (Pb, Cd, Cr, Ni, As) are low.

4. Possibility of application of artificial recharge

Artificial recharge using treated wastewater in the South-Eastern Mesaoria aquifer, via deep bore-

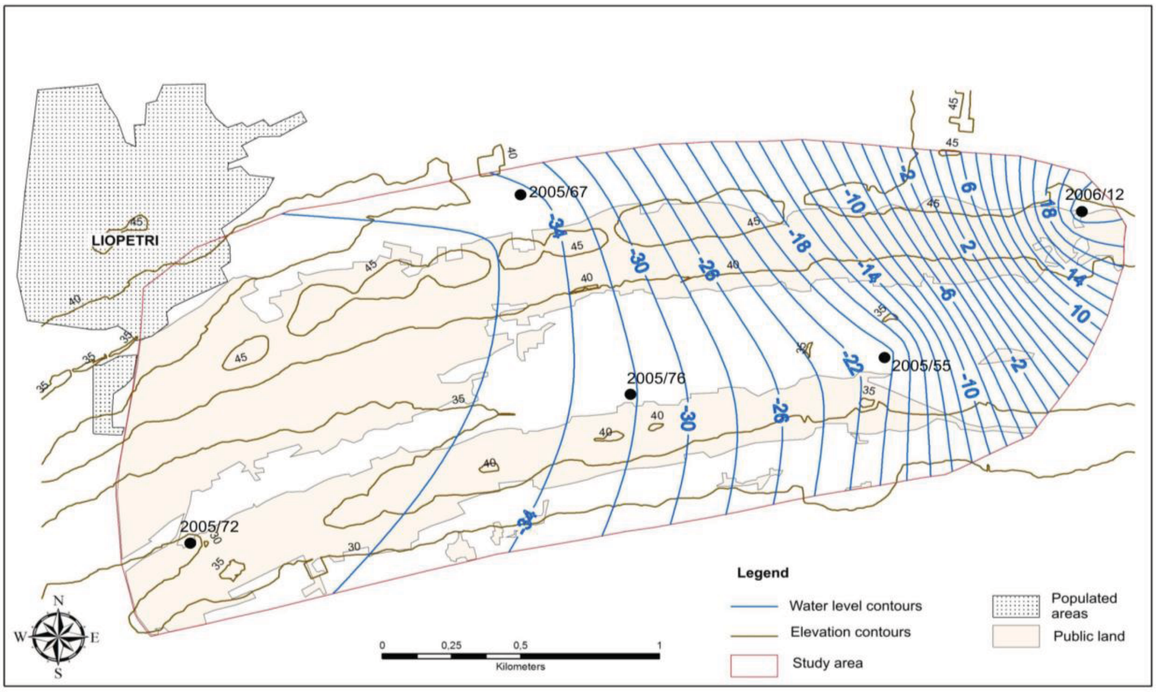

Fig. 4. Groundwater level contours map (m a.s.l.) in the study area.

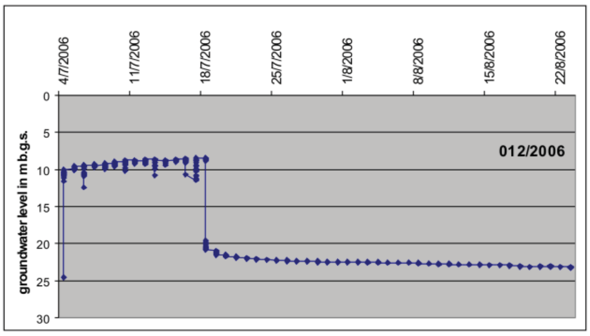

Fig. 5. Fluctuation of groundwater table during the pilot test (Constantinou & Irakleous 2006, Geological Survey Department).

holes, is an internationally acceptable practice, which is compatible with the 2000/60/EC directive and may be contributed to cover a part of irrigation needs, as well to the sustainable water resources management in this region (Voudouris et al., 2006; Soulios et al., 2007).

Due to the presence of limestone crust (kafkala) at the surface, the application of artificial recharge through boreholes (maximum depth 90 m) is proposed using the reclaimed wastewater, which is produced at Agia Nappa-Paralimni treatment plant. The maximum annual recharge volume of the aquifer system through 90 recharge boreholes is estimated to be $3.24x10^6$ m^3 water. The mean recharge rate of each borehole is 120 m^3/day. The proposed duration of recharge is 10 months (300 days). Adequate pre-treatment of the reclaimed water is also considered prior to the recharge, taking into account the final use of the aquifer's water.

Clogging of boreholes that are used for artificial recharge, caused by gas bubbles, bacteria, chemical reactions and suspended matter, is a well-known phenomenon (Olsthoorn, 1982; Martin et al., 2002; Rinck-Pfeiffer, 2006). Clogging during artificial recharge increase the water table in the borehole and reduces the recharge rate. Based on geological conditions of the study area, a schematic installation is shown in Figure 7, in order to minimize the clogging effect.

The recycled water will infiltrate through gravel pack, providing favorable conditions for ventilation and laminar flow due to small water flow velocity. Clogging of the boreholes by suspended solids (SS) is not expected to affect the viability of the proposed project as long as the recycled water contains SS levels ≤3-4 mg/l (Rinck-Pfeiffer et al., 2002).

5. Quantity and quality of recycled water

The data from the operation of the Ag. Napa Wastewater Treatment Plant (WWTP) shows that there is, in general, surplus of recycled water in regard to the irrigation and/or other needs of the two communities (Ag. Napa and Paralimni) served by the plant (Fig. 8).

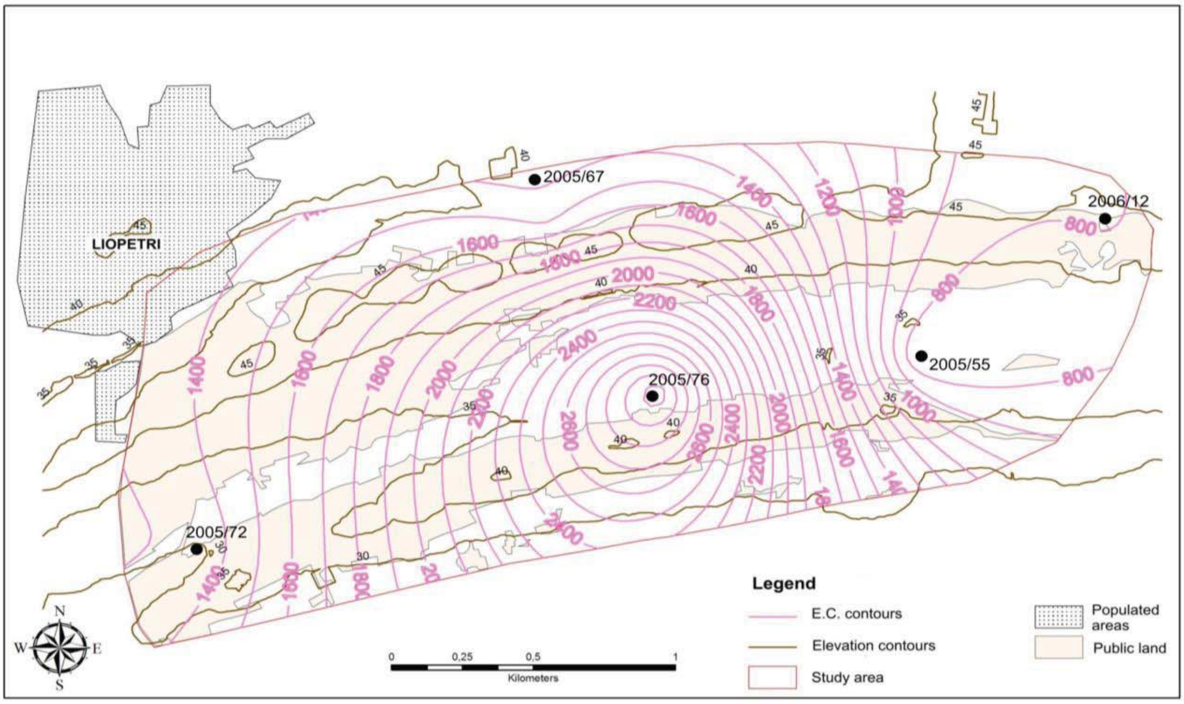

Fig. 6. Distribution of the groundwater electric conductivity (μS/cm).

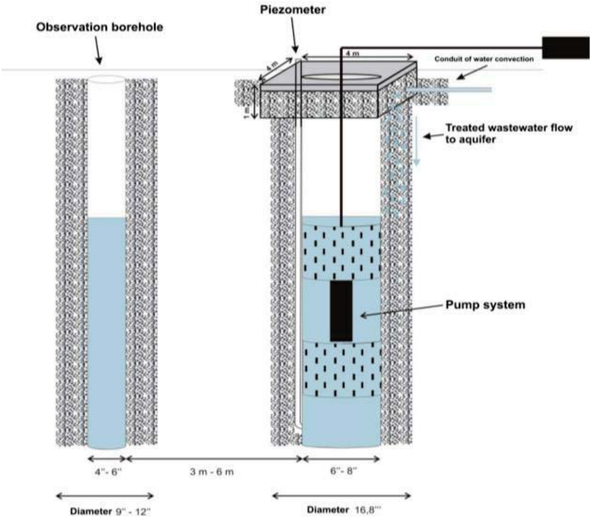

Fig. 7. Proposed installation of the recycled water recharge system via deep boreholes.

Within the framework of the project two basic scenarios were studied. The first one (BS1) considers that 5 more towns/villages (Deryneia, Sotira, Frenaros, Acheritou and Liopetri) are going to be connected with the WWTP in Ag. Napa and so the recycled water will be produced from all 7 towns/villages. The second scenario (BS2) considers that no other town/village is going to be connected to the WWTP and the recycled water will only come from the two towns of Ag. Napa and of Paralimni.

In order to estimate the future amount of surplus recycled water (2040), the present water demand (at Ag. Napa and Paralimni) was determined, which was considered to increase by an annual ratio of 0.5% for the next 10 years. In regard to the scenario BS1, it was considered that the 5 towns/villages will be connected to the Ag. Napa-Paralimni WWTP in 2012 and that all of their production of recycled water will be used for the artificial recharging of the aquifer.

The necessary works for the transfer of the recycled water to the area of recharging will be constructed in three phases, in accordance with the drilling of wells. The maximum design capacity at each phase is:

- Phase A΄: 41.67 l/s or 150 m^3/h
- Phase B΄: 83.33 l/s or 300 m^3/h
- Phase C΄: 125 l/s or 450 m^3/h

Regarding the quality of the recycled water, it appears to be overall adequate for its designated uses.

However, some parameters seem to exceed the desired limits:

- Conductivity and chlorides (Cl^-): The values for these two parameters are higher (average of 1700 μS/cm and of 460 mg/l, respectively) than the desired values as determined in the Directive 75/440/EEC (limit values for surface water to be used for drinking purposes). Nevertheless, since the recycled water is eventually used for irrigation purposes the average values were considered acceptable.
- Cyanides (CN^-): Very high concentrations of cyanides were measured in the recycled water. The high values of cyanides in combination with the increased level of COD and the high values of FOG in the recycled water, indicate that industrial type of wastewater is illegally discharged in the sewer system of Ag. Napa and Paralimni, which could originate from various type of industrial activities (metals processing, photographic and printing activities, production of synthetic rubber, production of adhesives, production of paints, pharmaceutical activities, leather treatment, production of animal food and agricultural pesticides/biocides, production of detergents, mining activities and from wineries).
- Fat, Oil and Grease (FOG): The constant exceedances of the WWTP's specification limit value, regarding the FOG content in the recycled water, was due to the absence of an oil separator in the treatment process.

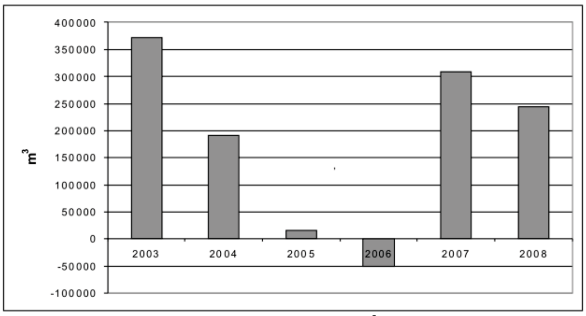

Fig. 8. Surplus recycled water (m^3) from Agia Napa-Paralimni treatment plant.

6. Recycled water treatment works

The treatment works include the following:

6.1. Removal of the FOG and the cyanides (CN^-) content.

These treatment options are designed to treat the entire recycled water produced from the WWTP. Two separate lines are designed for the treatment of recycled water produced by Ag. Napa and by Paralimni, respectively.

Each unit consists of a Dissolved Air Flotation (DAF) unit (for the removal of FOG) and of an Alkaline Oxidation unit for the removal of cyanides. The overall design capacities of both lines are 36600 m^3/day for scenario BS1 and 27100 m^3/day for BS2.

6.2. Ultrafiltration of surplus of recycled water

This treatment option refers to all scenarios under consideration and is designed to treat the surplus of recycled water that is used for the recharging of the aquifer. It is designed to be constructed in 3 phases in accordance with the drilling of the recharging wells. The capacity of each phase is 150 m^3/h. The ultrafiltration treatment is followed by disinfection with NaOCl solution.

7. Proposed construction works for the artificial recharge and hydraulic works

The proposed construction project for the artificial recharge of the aquifer includes the construction of 90 injection boreholes in the public land, South of Liopetri village, covering an area of 3 Km^2. The injection boreholes are proposed to be constructed in 3 stages of 30 boreholes each, due to the production of recycled water will gradually increase until the year 2040. The proposed depth of boreholes is 90 m in the western part of the study area and less than 50 m in the eastern part. After drilling, the borehole will be complete (casing and gravel pack) and development (cleaning and surface protection).

At a distance of about 3-6 m from selected injection boreholes a limited number (5-6) of observation boreholes (piezometers), covering the total study area, is proposed to drill. Inside these piezometers, instruments can be installed for water level measurements, as well as for the determination of groundwater quality parameters.

The proposed recharge method includes the injection of recycled waste water through one borehole for storage and pumping from other boreholes. It is recommended the installation pumps in injection boreholes, in order to clean periodically the boreholes in the case of clogging after long time recharge. In order to transfer the recycled water from Ag. Napa WWTP to the recharge area (aquifer) the following hydraulic works were studied, depending in the selected scenario:

1. Recycled water transfer project from Paralimni daily balancing reservoir (6000 m^3) to Agia Napa daily balancing reservoir (5000 m^3).

This project was carried out focusing on two alternative scenarios due to physical elevation differences between the two reservoirs. The first scenario examines the development of a pumping station (total dynamic head of 22 m) and a pressure pipeline (1200 m, HDPE pipe, DN355mm, 6 atm) and the second scenario examines only a gravity pipeline (2900 m, HDPE pipe, DN400mm, 6 atm).

2. Main conveyor pipeline for recycled water transfer, by gravity, from Paralimni-Agia Napa sewage treatment plant to South-Eastern Mesaoria aquifer area (total length: 11330 m)

This project was carried out focusing on two main alternatives and nine scenarios. The first alternative deals with the development of the pipeline in one phase with maximum caring capacity (125 l/s) and examines three different pipe materials (HDPE, steel and ductile cast iron). The second alternative deals with the development of the pipeline in two phases (double pipeline); an immediate construction of the first pipeline (first phase) with caring capacity of 83.34 l/s and after 16 years the construction of the second pipeline (second phase) with caring capacity of 47.67 l/s or more, depending on the number of injection wells at that time. The second alternative examines again three different pipe materials for each phase. In order to select the best solution, sizing and cost estimation was conducted for all scenarios. The outcome resulting from the comparison of all scenarios was to choose the first alternative with a ductile cast iron pipe, DN400.

3. Distribution system of rechargeable water between injection boreholes

This study focused on the formulation, sizing and cost estimation of the distribution system between 90 injection wells in part of the South-Eastern Mesaoria aquifer area in three phases depending on the number, time and space schedule of the injection well drilling. The total length of the distribution system is approximately 25 Km of HDPE, 6atm pipes with diameters ranging from DN50mm to DN400mm.

4. Construction of pumping wells and transfer pipelines to the Southern Pipeline System

This project involves the construction of pumping wells and transfer pipelines in order to deliver water to Balancing Reservoir No3 of the Southern Pipeline System. The study focused on two alternative pumping scenarios depending on the annual volumes of water pumped out of the aquifer (700,000 m^3/yr or 440,000 m^3/yr). The application of the first scenario (annual pumped water volume of 700,000 m^3) involves the construction of 12 pumping wells and 2656 m of transfer pipelines (HDPE, 6 atm) whereas the application of the second scenario (annual pumped water volume of 440,000 m^3) involves the construction of 8 pumping wells and 1594 m of transfer pipelines (HDPE, 6 atm).

8. Evaluation criteria of the scenarios

The comparison of the various scenarios considered in the project, is based in three basic parameters, as presented below:

1) Financial criteria
    - Internal Return Ratio (IRR)
    - Net Present Value (NPV)
    - Minimum Water Reuse Cost (MWRC)
2) Environmental parameter
    - Recovery rate of the aquifer
3) Conformity with Water Policy in Cyprus
    - Ability to reuse water from the aquifer of South-Eastern Mesaoria at Liopetri.

9. Conclusions-Discussion

The South-Eastern Mesaoria aquifer system is developed at sandstones horizons and sands. The average thickness of the aquifer is up to 80 m and the maximum 120 m and it is characterised by quality degradation and depletion during the last decades. Artificial recharge using tertiary treated waste water via deep boreholes is one of the options available for increasing the groundwater reserves in the South-Eastern Mesaoria aquifer. The maximum annual recharge volume of the aquifer system through 90 recharge boreholes is estimated to be $3.24x10^6$ m^3 water.

In relation to the estimation for the quantitative recovery of the aquifer, it is proposed that the annual volume of water pumped out the aquifer is 700,000 m^3 for the period from 2010 to 2014 (Phase A′) under the BS1 scenario (including the 5 towns/villages) and 440,000 m^3 under the BS2 scenario (without the 5 towns/villages). Gradually the pumped volumes will increase due to the increase of the recycled volume of water injected into the aquifer. The proposed increase in the volume of water pumped out the aquifer is approximately 10% for every 5 years, starting the year 2014. According to the above, at the end of Phase A' the expected rise in water table under BS1 scenario will be 6.4 m and under BS2 scenario 3.8 m, while at the end of Phase B' the expected rise in water table under BS1 scenario will be 17.3 m and under BS2 scenario 10 m. The rise of the water table up to 25 m (aquifers' unsaturated zone thickness under the sea level) under BS1 scenario will occur in 2023, while under BS2 scenario in 2028.

Generally, the comparison of the various scenarios shows that scenario BS1 (including sub-scenarios as stated above) overwhelms scenarios BS2, in terms of all of the considered criteria (financial, environmental and policy making). Also, all the scenarios which involve the removal of FOG and cyanides, present negative NPV and their MWRC is more than twice the price of fresh drinking water in Cyprus (0.77 €/m^3). Therefore, they are not included in any further comparison. This is the most advanced scenario (in terms of financial, environmental and policy making criteria) under which the recycled water is produced by the 7 towns/villages, its surplus is only treated by ultrafiltration and disinfection with NaOCl and the connection between Ag. Napa and Paralimni is via a pumping station (Voudouris et al., 2009).

Finally, artificial recharge using treated wastewater in the South-Eastern Mesaoria aquifer, close to Liopetri village, via deep boreholes, is an internationally acceptable practice, which is compatible with the 2000/60/EC directive and may be contributed to cover a part of irrigation needs, as well to the sustainable water resources management in this region.

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