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Garillis aquifer brackish water desalination—a case study

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ABSTRACT

The severe drought during 2007, which came after a long period of below the average rainfall, had drastically reduced the water reserves of the surface and underground reservoirs. Therefore, in order to eliminate the dependency of the towns and tourist centers on annual rainfall and in view of the increasing water demand, the Government turned the attention to non-conventional water resources such as desalination. The city of Limassol, especially came across a huge potable water scarcity because of the aridity of Kouris Dam, and the growing population and expanding tourist industry that were placing extra pressure on the existing water supply. A significant water recourse for the city of Limassol was Garillis aquifer, which is located at the center of the residential area of the town, but at that time was not suitable for human consumption due to high levels of nitrates (NO_3). The Cyprus water development department (WDD) awarded Nirosoft Ltd, in July 2008 the implementation of a cost-effective solution, which would relieve the water shortage without disturbing the local population. The scope of the built-own-operate-transfer (BOOT) contract was the supply of Desalinated Water using Mobile Brackish Water Desalination Plant, capable of treating 13,000 m^3 of raw water per day. The water produced by the Plant complied with the Law 87(I)/2001 (EEC Directive No. 98/83), with exceptions in some of the parameters that were differently specified in the contract. The water quality of the raw and product water, and the problems/experiences of WDD during the three years of operation will be discussed in detail in this paper.

Keywords: Limassol; Garillis aquifer; Brackish water; Desalination

1. Introduction

Water scarcity has always been a serious problem for Cyprus, which together with Malta have the lowest water availability per capita in Europe. Like other Mediterranean countries, Cyprus has a semi-arid climate and limited water resources which depend mainly on rainfall. However, rainfall in Cyprus is unequally distributed with considerable regional variations; water resources are scarce and droughts occur frequently [1]. During the hydrological year 2007–2008, Cyprus was faced one of the most acute and prolonged droughts (only 272 mm of rainfall) since the beginning of the twentieth century, with very

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severe water shortages and environmental impacts. The 2008 winter was extremely dry, the second driest since 1901 and the inflows to the reservoirs was only 18.7 million m^3 of water, the lowest in the last seventeen years. The aridity of Kouris Dam, which provides Limassol Water Treatment Plant with raw water, caused a huge potable water scarcity to the city of Limassol. By the end of 2008, the water storage of Kouris reached dangerously low levels. The lowest level was recorded on the 15th of October 2008, with only 0.513 million m^3 of water.

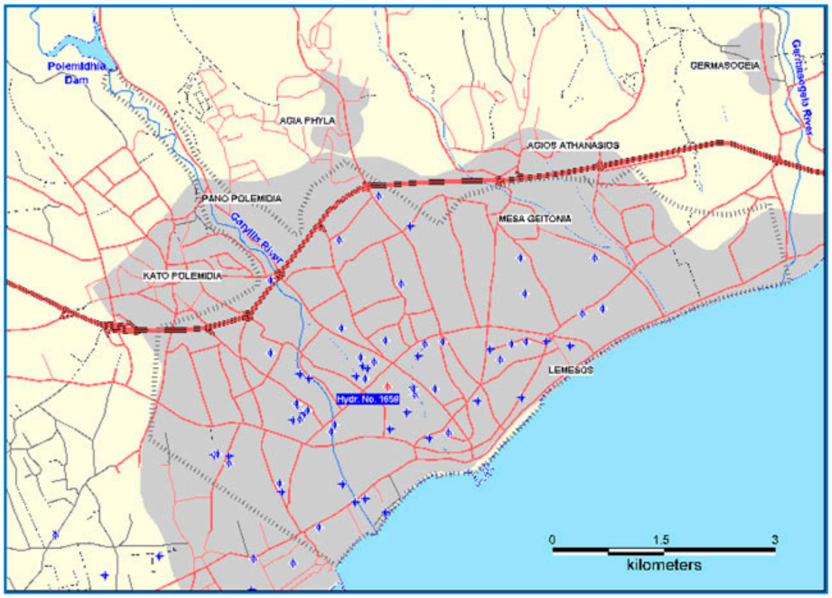
2. Garillis aquifer

In response to the severe water shortage Limassol was facing, a series of emergency measures were applied which included among others the transferring of potable water from Greece using tankers, almost 100% ban on water supply for irrigation, strict restrictions on water supply to households, use of boreholes for domestic supply, and the treatment of the Garillis aquifer's brackish water to potable water. Garillis aquifer is a coastal alluvial aquifer and it used to be one of the most important aquifers in Cyprus. Together with the Akrotiri and Germasogeia aquifers, Garillis aquifer forms the main groundwater resources for the Limassol district. This aquifer is a natural continuation of the Akrotiri aquifer to the east. The entire aquifer is developed in the center of Limassol Town district, which is a crowded residential area (Pic. 1) [2].

Until 1995, sewage effluent absorption wells dug for each house in Limassol Town constituted one of the two major sources of water for recharge of the aquifer. Fast urbanization of the area and direct sewage disposal in the aquifer gradually deteriorated groundwater quality and made water body of the aquifer unfit for human consumption due to high levels of nitrates (NO_3). Chemical analyses that were performed by the State General Laboratory at the beginning of 2009 confirmed that the nitrate ion concentration exceeded 80 mg/L (Table 1).

3. Garillis aquifer desalination plant

The Cyprus water development department (WDD), following a tender procedure No. TAY 37/2008, awarded in July of 2008, Nirosoft Industries Ltd, the Contract for "Treatment of the Garillis aquifer Raw Water to Potable" on a Build-Own-Transfer basis. The scope of the project for WDD was the implementation of a cost-effective solution which would relieve the water shortage without disturbing the local population. The project was completed in record time—five months from order to completion and consisted of a containerized brackish water RO-desalination plant with all required pre- and post-treatment, with a feed capacity of 13,000 m^3/d assuming continuous operation of the units 24 h/d. The treatment process of the desalination plant comprised of:



Pic. 1. Garillis aquifer (Limassol)—location map [2].

Table 1
Indicative parameter values given in the contract

Element	Value	Element	Value
Electr. cond.	1,580 μS/cm	TDS	1,154 ppm
Total hardness ($CaCO_3$)	633 ppm	pH	7.6
Chlorides	204 ppm	Sodium	94 ppm
Sulfates	89 ppm	Potassium	4.8 ppm
Carbonates	0 ppm	Calcium	109 ppm
Bicarbonates	476 ppm	Magnesium	88 ppm
Nitrates	90 ppm	Boron	0.17 ppm

- Pre-treatment by multimedia and cartridge filters.
- Brackish water reverse osmosis(RO).
- Remineralization and post chlorination.

Eight boreholes were exploited (G3 (BH1959/129), G4 (BH1960/024), G5 (1961/020), G6 (BH1951/210), G8 (H5022-1382), G9 (H5022-1383), G11 (BH1983/048), and G12 (BH1983/035)), which are located in Garillis aquifer and distributed in the residential area of Limassol. The raw water was pumped from the eight boreholes to the inlet of the raw water reservoir. A raw water analysis of a sample of water taken from Garillis aquifer area was given as indicative in the tender documents. The table below shows the data provided.

The water produced by the plant complied with the Law 87(I)/2001 (EEC Council Directive No. 98/83), with the exception of some parameters that were differently specified as follows:

- Turbidity less than 4 NTU.
- Color less than 5 Hazen (Pt/Co).
- Odor and taste NIL.
- Langelier index positive.
- Alkalinity not less than 30 ppm HCO_3.
- Total dissolved solids less than 600 ppm.
- Dissolved oxygen not less than 60% of saturation.
- Nitrates less than 15 ppm.
- Ammonia less than 0.1 ppm.
- Total organic carbon less than 2 ppm.

Additionally, the water should have been disinfected, chemically balanced, and microbiologically safe.

4. Desalination process

The treatment steps comprised of:

- Multimedia sand filters in pressure vessels (for removal of fine particles up to 20 μm and colloids) with automatic backwash by air and water.
- Acid (HCl@37%) dosing system (for pH adjustment of the feed to the RO unit) to minimize membrane scaling.
- Anti-scalant dosing system (for prevention of scaling on the RO membranes).
- Five-micron cartridges in stainless steel housings, for removal of residual solids.
- High pressure feed pumps, to provide the high pressure needed for desalination by RO.
- Desalination by complete brackish water reverse osmosis membrane separation system (spirally wound membranes).
- Cleaning in place unit to clean and sanitize the RO membranes in place without removing them from the unit.
- Adjustment of RO permeate hardness, alkalinity, and pH by calcite remineralization.
- pH adjustment of the final treated water, if required.
- Post-chlorination dosing system, to maintain a residual disinfection in the final treated water.

4.1. RO stage

Design of the RO stage was supported by the reverse osmosis system analysis software (ROSA), by Filmtec, with the following assumptions:

- Low permeate flux <25 L/m/h.
- Fouling factor 0.85.
- The ROSA evaluation was performed at the temperature of 20°C.

The main components of the RO unit were:

- Special 8″ spiral-wound separation membranes (manufactured in thin film polyamide), model: BW30-400 by DOW Filmtec.
- High pressure membrane vessels (for seven elements each) in composite material with a pressure rating of 300 psi.

63 pressure vessels in a two-array configuration.

4.2. Post-treatment

Post-treatment of the RO permeate was required to achieve the following:

- pH adjustment.
- Remineralization: addition to the RO permeate of alkalinity and hardness at levels that stabilize the water to make the water suitable for human consumption.

4.3. pH Adjustment/NaOH Dosage

Automatic and controlled dosage of caustic soda (NaOH 45%) to enable pH adjustment of the final treated water stream prior to delivery to WDD. The dosing and mixing with the treated water was optimized by the installation of a static mixer.

4.4. Post-chlorination

Automatic dosing of sodium hypochlorite liquid solution (12%) to maintain residual disinfection in the treated water in the range 0.2–0.5 mg/L of free chlorine.

4.5. Membranes

The membranes had large surface area (400 ft^2) and compact design, so the efficiency of the system was increased and the fouling rate remained low.

5. Plant operation problems and quality of feed water

In September of 2009, WDD noticed some unusual sedimentation in the brine pumps, which was not present during the first half year of operation. The fouling was affecting the whole plant and WDD's brine equipment and piping. The first problems were observed after the first six months of operation and this was because the fouling was progressive and depended on a number of factors such as the quality of the feed water and the system recovery rate. According to the plant operating parameters and the ROSA software calcium sulfate, barium sulfate precipitation and silica formed (Pic. 2).

Pic. 2. Membranes extracted from the plant (Nirosoft).

Nirosoft Industries Ltd requested an analysis (ICP Scan) of the scale which indicated that the main metal which was precipitated was calcium which, along with magnesium, is a major component of hardness in brackish water. Sulfur was also in high concentration in the fouling due to the presence of sulfate (SO_4) ions in the raw water. Barium and Strontium were also present in the sample of the fouling, along with calcium form barium, strontium, and calcium sulfates, respectively, in the presence of sulfates. The solubility of calcium, barium, and strontium sulfate is low and can cause scaling problem in the back-end of a RO [3]. The solubility of these salts is lower with decreasing temperature. Silicon (Si) was also in a high concentration in the scale, according to the ICP Metal Scan. The total concentration of silicon does not specify what the silicon compounds are. The "Total Silica" content of is composed of "Reactive Silica" and "Unreactive Silica." Reactive silica (e.g. silicates SiO4) is dissolved silica that is slightly ionized and has not been polymerized into a long chain. Reactive silica is the form that RO and ion exchange chemists hope for. Reactive silica is the form of silica to be used in RO projection programs. Unreactive silica is polymerized or colloidal silica, acting more like a solid than a dissolved ion. Silica, in the colloidal form, can be removed by a RO but it can cause colloidal fouling of the front-end of a RO [4].

Based on the above, the scale on the membranes was most probably sulfate scales, including calcium sulfate, strontium sulfate, and barium sulfate. Also, the fouling of the membranes was caused by silica and colloids. Based on that, it was recommended the use of a scale inhibitor for carbonate and sulfate scales and also a dispersant for silica, organics, and colloids. In addition the proper chemicals should have been used for the cleaning of the membranes, taking into advice the specificity of the plant. The successful operation of RO systems at higher recoveries would require chemicals designed to inhibit various types of scaling and fouling. With proper dosing, a well-engineered scale inhibitor can successfully control scaling and fouling. Normal cleaning of the membranes with Hydrochloric acid was not effective, which indicated that the scale was not calcium carbonate. The only agent that actually removed the scale was HF (hydrofluoric acid), which indicated that the scale was characterized by calcium sulfate (Gypsum) [5].

Furthermore, WDD performed a series of chemical analysis on samples of the feed (raw) water from

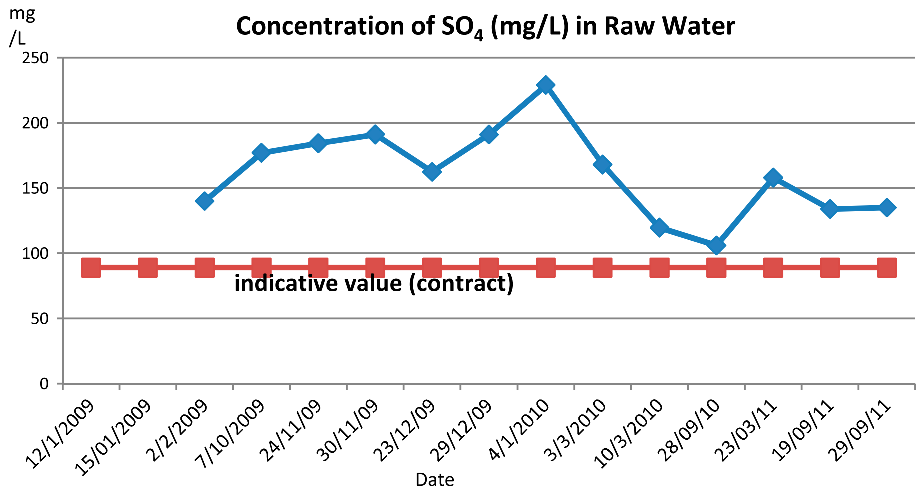


Fig. 1. Sulfate concentration in raw water.

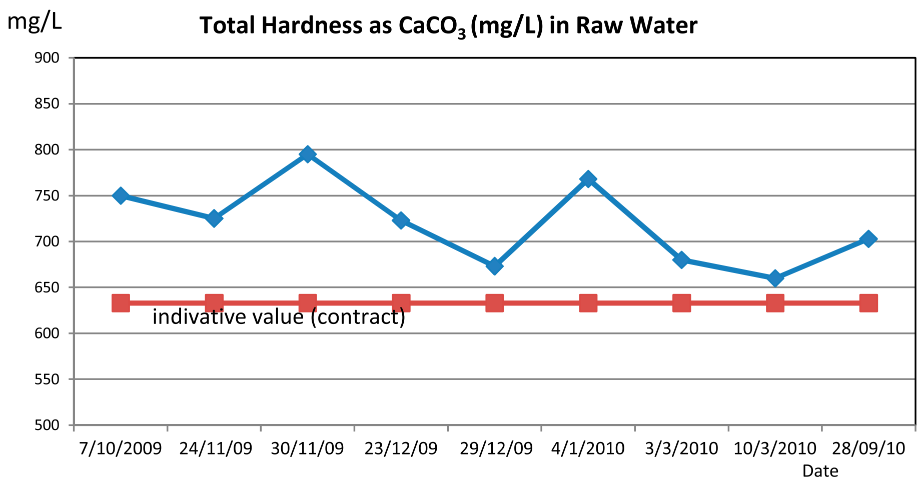


Fig. 2. Total hardness in raw water.

Garillis aquifer and also of each one of the eight boreholes individually that were in used in order to investigate the variation of the quality of raw water regarding the chemical analysis. The analysis showed that there was an inconsistency of the quality of raw water that fed the reverse osmosis plant regarding the concentrations of some parameters. The parameters were, at times, diverted from the ones that were given in the contract as an indication. A great variation was documented regarding the concentration of sulfates in raw water (Fig. 1). This was also confirmed by the high concentration of sulfur that was found in the fouling matter.

A large deviation was also recorded regarding Total Hardness of feed water (expressed as $CaCO_3$). Sampling and analysis performed by WDD confirmed from the value indicated in the contract (Fig. 2).

Various analyses of feed water that were performed by WDD's laboratory proved that some parameters were unstable and seldom exceeding by far the contractual ones. That was in connection with the quality of the water of some of the boreholes and their contribution to the daily pumping quantity of water into the plant.

6. Environmental aspect

The desalination plant was located in the heart of a residential area and for that reason, it should have been quiet and ecologically friendly, and operated without causing any disturbances to the neighboring population. One of the contractor's obligations, regarding the protection of the environment, was to limit the nuisance to people resulting from noise of the plant's operations. The Contractor was obliged to take all measures so that the sound emitted by any machinery operating in the desalination plant do not cause any disturbance to nearby residential areas. For that reason, Nirosoft Industries (Cyprus) Ltd requested Panacoustics Ltd to carry out an acoustical study in order to investigate whether noise emissions from the high pressure pumps installed at the Garillis aquifer Treatment Plant would affect residences close to the plant. Furthermore, the design of noise control measures to control noise levels at the residences close to the existing background noise levels during early hours in the morning was investigated. Based on the acoustical analysis, acoustic enclosure was constructed around the RO high pressure pumps so that the noise level emissions would meet the noise criteria set for this project.

7. Conclusions

The inevitable choice to build a reverse osmosis desalination plant for the treatment of Garillis aquifer raw water to potable has proven particularly beneficial for the water supply in the urban area in the Town of Limassol. During the years of operation, 7,936,326 m^3 of potable water was produced which was a significant contribution to the water balance of the total demand in drinking water for Limassol's population (average 14% of the total demand). Specifically, in 2009, 2,832,026 m^3 was produced that equaled to the 17.5% of the total demand, in 2010, 2,795,080 m^3 that equaled to 14%, and in 2011, 2,309,220 m^3 that equaled to 11%.

However, like other membrane filtration processes, fouling was a major obstacle in the efficient operation of RO systems. Using reverse osmosis process to treat underground water to potable should not be the answer: desalination is a power hungry process with high energy costs and environmental impact.

The main objective should be the prevention of further deterioration of groundwater and to achieve "good water status." Provided that there are numerous and increasing pressures on water resources, it is vital to have effective establishments and measures to address the problems and to help secure these resources for future generations. The construction of Limassol–Amathountas central sewage system in 1995 and its expansion resulted in a serious reduction in the contribution of sewage to the Garillis aquifer's recharge. Furthermore, the new Water Framework Directive (2000/60/EC) that came into force on 22 December 2000 will facilitate Cyprus with the legal framework for proper management and protection of water resources.

Acknowledgments

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Abbreviations

RO	—	reverse osmosis
WDD	—	water development department

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