European Water 7/8: 39-45, 2004.

Desalination: The Cyprus Experience

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Abstract: Cyprus, an island with a semi-arid climate and with its water resources already intensely utilized, is suffering from structural and temporary water shortages. With a high level of utilization of its natural water resources, water demand increasing rapidly and water availability decreasing due to repeated droughts, the Government of Cyprus has decided to construct a number of desalination plants. The target capacity of these plants is 120.000 m^3/day or 40.0 million m^3 per year thus increasing water availability and the level of reliability for domestic and irrigation users. During the last ten years the availability of water from the Government projects and from other sources was very limited which led to cuts up to 30% of the normal for the supply to the domestic sector and up to 70% of the normal demand to the agricultural sector. These cuts had serious adverse effects on the social and economic activities and a negative impact on the environment. At the moment there are two plants in operation supplying water to the Nicosia-Larnaca-Famagusta water supply system with a nominal daily supply of 92.000 m^3, representing 90% of the annual demand, the first since April 1997, with a nominal daily output of 40.000 m^3, and the second since May 2001, with a nominal daily output of 52.000 m^3. The third plant, which will supply water to the Limassol, town at a rate of 20.000 m^3 per day, is planned for operation by the year 2004, where the last plant, for completing the original plan, will be constructed in Paphos by the year 2006, with an original daily capacity of 10.000 m^3. The first and second plants use the reverse osmosis process with a recovery of 50% and electric energy from the electric power grid. They both use an open sea intake and the water is undergoing a pre-treatment for reducing the Silt Density Index and the pH for the protection of the membranes. The desalinated water is post-treated for achieving an acceptable quality complying with the Cyprus and European drinking water quality standards. Brine is discharged to the sea at a depth of at least 15 meters and at a distance of at least one-kilometer from the shore. The sea environment around the brine disposal point is monitored, on a continuous basis and the results so far are at acceptable levels. In all cases Environmental Impact Assessment Studies were carried out before construction and mitigation measures were imposed on the Contractors for minimizing adverse environmental effects. The Build, Own, Operate and Transfer principle (BOOT) was chosen as the method of project financing on a ten-year basis. This paper will outline the approach, the Tender document contents, the tender evaluation procedure, the project construction, the project operation and contract management, the environmental effects and the costs of water. It will also outline the benefits and adverse effects of the desalination plant in operation.

Key words: Water shortage, seawater desalination, BOOT (Build, Own, Operate, Transfer), Environmental Impact Assessment Study, Water supply reliability, water cost.

1. WATER DEVELOPMENT AND AVAILABILITY AND DEMAND GROWTH

Cyprus, the third largest island of the Mediterranean Sea, with an area 9250 square kilometers and inhabited with approximately by 1.0 million people, has a typical Mediterranean climate with hot dry summers and mild wet winter. The average precipitation is 500mm per year mostly occurring in winter with no perennial rivers. River flows in winter are stored either in riverbed or coastal gravel aquifers, or in surface reservoirs created behind dams built in the last forty year. Cyprus is the first country in Europe with the largest number of dams per square kilometers and the largest storage volume per capita, with over 100 dams and total capacity 304 million cubic meters. Cyprus is also one of the few countries, which have developed and implemented during the period 1970-2000, a Master Water Plant based on the principles of Integrated Water Resources Management. While water demand continued to increase due to population growth, betterment of the standard of living, tourism growth and the imposed demographic change brought by the occupying forces of Turkey (movement by force of the population and the import of colonizes from

Turkey and the occupying army amounting to 35.000 troops), the available water resources are decreasing due to climate changes (repeated droughts in the years 1991 and 1996-2001), the human intervention and pollution of water resources, and the misuse (depletion of aquifers), which created a deficit in the fragile water supply and water demand balance. From the records of the last eleven years only two years had a rainfall above average, two years had rainfall around average and the remaining seven years had a precipitation much below the average by as mush as 25 percent. In the years 1996-2000, the average inflow to the dams was only 25 percent of the estimated average annual inflow, creating great water shortage both for domestic and irrigation.

2. WATER SHORTAGES

Cyprus faced serious water shortages due to the climate change and the repeated droughts. In the average there was a decrease of water availability, around 40 percent, from the dams and to a smaller extent from the groundwater. In the 1990/91 hydrological year, the deficit was so acute so restrictions were imposed on the water supply by 20 percent on the domestic supply and between 30-70 percent in irrigation. Water to irrigation was rationed with priority to permanent crops then to green houses and a very small amount of water was supplied for seasonal crops. The same picture was repeated in the tears 1996/2000. Figure 1 shows the average water demand, the actual water supply and the water deficit in all the major dam projects in Cyprus for the years 1987-1999. The year 1990/91 shows a deficit around 75 millions out of 114 millions of normal demand, the year 1996/97 shows a deficit of 68 millions out of 114 millions of normal demand, where the years 1997/98 and 1998/99 show a deficits of 102 and 114 millions out of average demand 136 millions per year. The water crisis was faced effectively by introducing desalination in 1997, by imposing restrictions to the supply of water, by intensifying the implementation of water demand measures and water saving methods and by mobilizing lower quality water, accelerating the use of treated domestic effluents and the development of non developed natural resources.

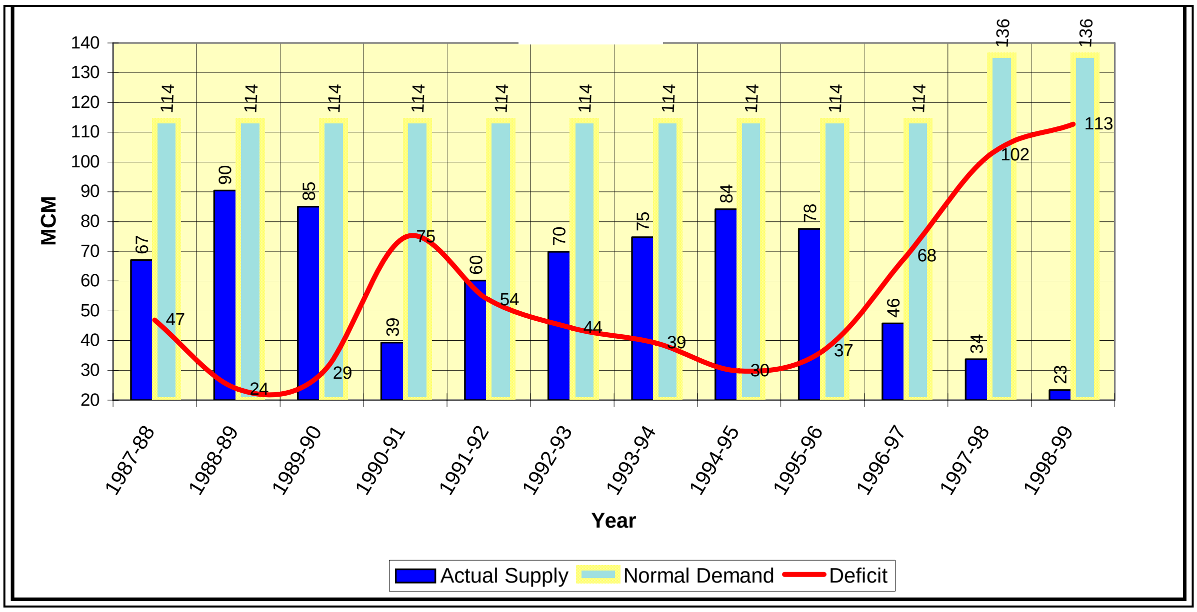

Figure 1. Governmental water supply projects (dams only).

3. MEASURES TO INCREASE WATER AVAILABILITY

In facing the water shortage, which did not seem to be parodic but it was here to stay, the Government decided to promote the desalination of seawater for the following three reasons. a) To increase the availability of water in the supply side, b) to increase the reliability of supply by the water supply systems and c) to safeguard the supply of domestic water and make it independent from the precipitation behaviour. Parallel to the above the water policy was adjusted accordingly by deciding to accelerate the reuse of domestic effluents, intensifying the application of water demand measures, apply water reallocation, use lower quality water, promote public awareness for water shortage and educate users how to use water wisely, effectively and efficiently.

4. DESALINATION PLANS TO INCREASE WATER AVAILABILITY

From the above the most effective and quick measure to augment water supply is seawater desalination, because of the short time required to construct and put in operation desalination plants and the raw water is abundant. Other measures, such as the treated domestic effluents reuse schemes, and water saving plans, are not immediately effective since their implementation requires long term planning and execution (Buros, 1990). The desalination programme includes the construction of four desalination plants of total daily nominal capacity around 120.000 m^3. The four plans are to deliver water exclusively for domestic consumption to the towns and villages now supplied with water from the Government water supply systems. Already two plants of total daily nominal capacity 92.000 m^3 are in operation. The Dhekelia Desalination Plant, put in operation in April 1997, with a nominal daily capacity of 40.000 m^3, was the first plant where the second plant the Larnaca Desalination Plant (Figure 2) was put in operation in May 2001, with a nominal daily capacity of 51.700 cubic meters. Both plants supply water to the Central Water Supply System, which delivers water to the Nicosia town and villages, to the Larnaca town and the villages, to the occupied town of Famagusta, the tourist area of Famagusta district and to all villages in the free area of Famagusta. The third desalination plant will be constructed in Limassol, with a nominal daily capacity of 20.000 m^3, to be put in operation in 2004 and the fourth in the Paphos area with a nominal daily capacity of 10.000 m^3, to be put in operation after 2006 (Zodiatis and Ladner, 1999).

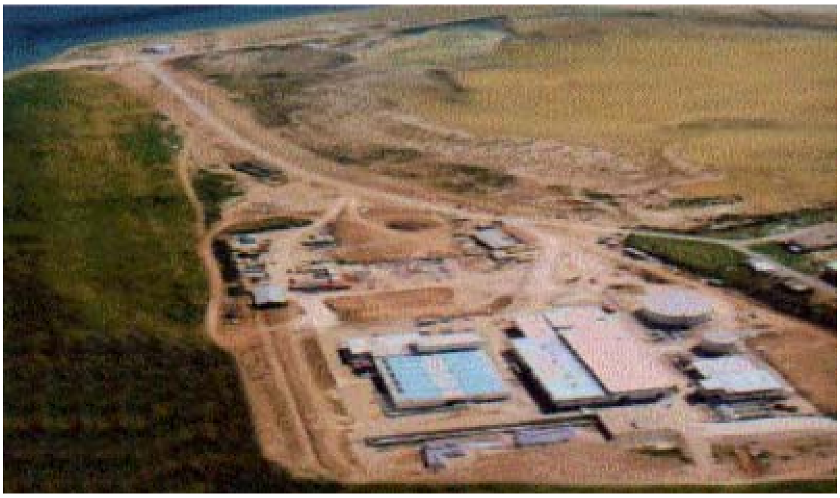

Figure 2. Larnaca desalination plant plan view (Courtesy of IDE-OCEANA)

5. DESALINATION TYPES AND FINANCE

Before taking a final decision concerning the implementation of a seawater desalination plant the following considerations were made.

a) Is there a real need for desalinating seawater? To decide on this question studies must be carried out on water demand and water demand projection, water availability evaluation and water availability projection and costs, water supply reliability, drought frequency and severity and water management methods and their effectiveness. If water demand cannot be satisfied with adverse effects on the economy, the social life and the environment, considerations for desalination may be made.

b) Social acceptance of seawater desalination. This includes studies on the selection of the site of the desalination plant, its environmental, economic and social effects in the vicinity and in general. Criteria were set for site location study and for the Environmental Impact Assessment Study that were carried out. The studies were carried out by consultants using the Terms of Reference prepared by the Environment Service of the Government, with the participation of the affected local communities and other environmental organizations. The criteria for selection of suitable site were set as follows.

- Plant to be away from inhabited or tourist areas.
- Plants to be in the coastal areas where good quality seawater can be abstracted (Fig. 3) and the brine can be discharged without environmental adverse impacts.
- Plants to be near the existing water supply networks for minimizing the connection costs to the water supply systems.
- Plants to be near other infrastructures works mainly related with power supply so that reasonable cost for power supply, are safeguarded.
- Plants to be out and in safe distances from special environmental importance areas.

Figure 3. Larnaca desalination plant. Seawater intake structure (Courtesy of IDE-OCEANA).

c) Are environmental effects manageable? A special Environmental Impact Assessment Study (EIAS) is a prerequisite before a decision is taken to proceed with the implementation of seawater Desalination Project. The study is considering a number of sites selected using the above criteria and is carried out by an independent consultant whose terms of reference and specification are set out by the Environment Service of the Ministry of Agriculture, Natural Resources and the Environment. The studies carried out considered all environmental parameters including marine environment, land, air, sound etc., taking into account the process, the chemicals and the byproducts and their effect. The final output was a series of conditions and restrictions on the plant concerning its location, the chemicals to be used, the location of the seawater intake and brine discharge points, the laying and route of the seawater intake and brine disposal pipelines, the allowable noise levels, the architecture of the plant building, the monitoring programmes and checks on the marine environment, the land environment and the air environment etc. Generally the environmental effects are limited to the marine environment in which the brine is discharged, the noise pollution and the atmospheric pollution due to increased gas emissions for the production of the extra energy. The brine contains the seawater salts with concentrations almost double than that of the seawater plus some chemicals used during the pre-treatment process and for the chemical cleaning of the membranes. The marine environment impacts are mitigated by imposing limitations as to the chemicals to be used in the pre-treatment process and the membranes maintenance, the depth of disposal of the brine (10-15 meters) and the number of diffusers necessary to achieve better dispersion of the salts. Monitoring of the marine environment is necessary for recording any changes and for taking remedial measures. The client monitors the changes at the brine discharge area and prepares studies at six month intervals. The results so far obtained, after five years of operation, show that the effects are negligible and they are limited to an area with radius of 200 meters around the point of discharge. Some rearrangements of the benthos life in the vicinity of the brine discharge point was observed right after the plant was put into operation, but no more changes were detected thereafter.

d) Economic dimensions. Desalinated water is usually more expensive than conventional water and due to the fact that it consumes large quantities of energy, which is imported in Cyprus, the impacts on the economy were studied in detail. The findings were that the economy could afford the high cost and that the additional water would have beneficial effects on the economy, on the social life and on the environment. Further it was found out that the consumers could afford the high cost of water. The additional water would increase the reliability of supply both to domestic and irrigation sectors, and increase the availability of water (Zimmerman, 1996; 1999).

e) Financial considerations. Financing of the desalination plants could be made through the Government Budgets or through the Public Private Participation method. After considering both options it was found out that it was more profitable and practical to adopt the Public Private Participation approach which envisaged for private financing and with the Government undertaking the purchase of the desalinated water. International tenders were issued, inviting interested experienced contractors to submit tenders for the design, build, own operate and transfer within a ten years period a desalination plant with a specific nominal capacity. The Government from its side undertook the obligation to buy the specified quantities of good quality water at the tender price. The Government reserves the right to buy the plant ahead of the ten year period is decided so and special clause is included in the Tender Documents.

f) Plant Specification. The specification provided for any known internationally applied, tested and sound method or process for desalination. Membranes or thermal methods were accepted but the Tenderer should have a minimum experience on the design, construction, operation and maintenance of a similar plant proposed. Based on the specifications and conditions to the Tenderers, and taking into considerations the realities of Cyprus the Tenderers submitted proposals for reverse osmosis plants.

g) Water price, cost components. For tender evaluation and comparison purposes the desalinated price was broken down into three components and the Tenderers were asked to submit the water price as follows.

   i. Capital cost component. This cost component is calculated by the use of the capital cost invested for the construction of the plant. The capital cost and desalinated water are converted into equivalent annual figures and by dividing the annual cost by the minimum annual volume of water the capital cost component is calculated. The capital cost component, expressed in Cyprus cents per cubic meter is constant for the ten year period, and is not affected by inflation. The Tenderer is required to state the estimated capital cost and the interest rate at which he requires to be paid in case the Plant is purchased by the State ahead of the ten year period.

ii. Operation and maintenance cost component. This cost is calculated by dividing the annual Operation and Maintenance cost for running the plant by the minimum annual volume of water. The annual cost includes wages, chemicals, membrane and other equipment and machinery replacements, overheads and profits. This component expressed in Cyprus cents per cubic meter is variable since it is adjusted on a quarterly basis by taking into consideration the variation of wages and material costs and indices.

iii. Energy cost component. This cost component is calculated by multiplying the specific energy consumption of the plant (Specific energy is the energy required by the plant to produce one m^3 of desalinated water) by the cost of one KWH and it is expressed in Cyprus cents per m^3. The specific energy is guaranteed for the ten year period and energy cost component varies according to the energy cost, revised on a quarterly basis using the actual energy unit cost.

h) Water quality and water quantities. The water quality specified is for potable water in accordance with the Cyprus and European Specification. The Contractor is required to carry out systematic quality control of the desalinated water and water out of specification is not delivered to the Client. The minimum quantities for which full price shall be paid by the Government are defined in the contracts and additional quantities will be paid with reduced price including only O&M and Energy cost components.

i) Contractual Issues. As a prerequisite to participate to the international tenders the Tenderers should have a relevant experience on similar projects and should have the financial and economic capability to finance such a project. The Tender documents provided for post qualification evaluation of all Tenderers and only tenders submitted by qualified Tenderers were evaluated. A tender guarantee equivalent to 200.000,00 US Dollars was asked for a qualified tender submission. Other contractual issues are the Contractors and Clients obligations during design, construction and operation of the plant, the minimum quantities that must be produced and delivered daily, quarterly and annually as well the penalties the Contractor should pay in case of breach of contract.

6. BENEFITS FROM THE DESALINATION PLANTS

The desalination plants during the last five years have produced more than 75 millions cubic meters, which was supplied for domestic consumption. The present annual capacity is more than 30 millions cubic meters per year, which represents more than twelve percent of the total water consumption in the Government controlled areas and close to 40 percent of the total domestic water consumption. Since the operation of the second desalination all water restrictions on the supply of potable water supply were lifted with positive impacts on the social life and providing security of water supply irrespective of adverse climatic conditions. Desalinated water has increased the availability of water for irrigation water. Concluding it can be said that desalination is an effective alternative water resources development that can augment the available water supply with high reliability of supply.

7. PERFORMANCE OF THE PLANTS, QUANTITIES AND COSTS

The first desalination plant is now operating for five years producing the contractual quantities. The rate of desalinated water production varies according to seawater temperature, which varies from 18^{o}C in winter to 30^{o}C in summer. It has been found out that the maximum output is when the seawater temperature is between 24-27^{o}C. The water temperature affects the water quality, which is always in accordance to the specification. The impacts on the environment have been very small. The marine environment at the vicinity of brine discharge is monitored on a six monthly intervals and from the results it has been found out that the salinity level did not change since the plant was put to operation and not big changes are observed on the benthos population and species. The salinity level varies from 48.000 ppm at the point of discharge to normal seawater salinity at a distance of 200 meters. The water cost level is very sensitive to the energy cost and the exchange rates of the foreign currencies the payments are made. The Contract seems to be balanced and the contentious issues raised by the Client or the Contractor are very few. The reliability of water supply is nearing 100 percent, which shows that desalination is a reliable water resource. The reverse osmosis method has proved under the Cyprus condition to be environmentally friendly and cost effective.

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