Desalination 136 (2001) 115–124

Maltese experience in the application of desalination technology

A. Riolo
Water Services Corporation, Qarmi Road, Luga LQA 05, Malta
Tel. +356 234130; Fax +356 223016; email: ariolo@maltanet.net

Received 11 September 2000; accepted 25 September 2000

Abstract

This paper is intended to describe some of the experiences in Malta in the application of desalination technology. This is put in the context of its relevance to national development and the economy, to the technology environment where it fitted and to its contribution to and impact on integrated water management.

Keywords: Reverse osmosis; Performance; Energy; IRM

1. Introduction

At least three distinct phases in the history of Maltese involvement with desalination can be distinguished.

1. The first phase, around 1885, is mentioned for historical interest and completeness, and also to show that some considerations that arise now when desalination is discussed were also valid then.
2. The second phase, between 1965 and 1980. Thermal desalination using the multi-stage flash process was used in conjunction with the power station then being built.
3. The third, most recent phase, from around 1982 to the present, when reverse osmosis technology was applied on a relatively large scale.

In all these phases, the various technologies applied were in their infancy when introduced in Malta. This is a reflection on the importance of water to national development, on the scarcity of natural resources (the availability of which was further limited by the technology available to harvest it), and on the pressure that these circumstances put on the authorities to go to extraordinary length to augment supplies at minimum cost. Sometimes decisions entailing calculated risks had to be taken.

2. The first phase — distillation plant, located at Tigne, 1886

This small plant was installed by the Government to provide water to a small local

Presented at the conference on Desalination Strategies in South Mediterranean Countries, Cooperation between Mediterranean Countries of Europe and the Southern Rim of the Mediterranean, sponsored by the European Desalination Society and Ecole Nationale d'Ingenieurs de Tunis, September 11–13, 2000, Jerba, Tunisia.

community and to the British Army barracks in the area. It consisted of a simple boiler with a condenser, employing naval technology of the time. At that time, the exploitation of natural resources was limited to harvesting of springs at the surface of the ground. There were no galleries or boreholes to extract water from the mean sea level aquifer, which were to come later when appropriate civil engineering technology was available. These springs were far from the point where the water supply was required and the infrastructure to deliver it was not yet available.

An alternative to the desalination plant involving the construction of a pipeline was in fact debated. This pipeline was constructed a few years later, and the operation of the distiller was discontinued. This is an indication of the poor reliability of the desalination system and probably of its cost, as reports in local newspaper of the time showed.

Another matter of debate was the quality of the water out of the plant, with supporters of the system holding it to be of good quality, while opponents holding it to be detrimental to health and the whole exercise a waste of public funds.

Malta was always at the forefront of technology where water management was concerned. This example of the early introduction of desalination technology on a municipal scale was not an isolated case. Other examples are available such as the country being only the second country in the world after Britain to introduce chlori-nation of public water supplies.

3. The second phase — utilization of a thermal flash desalination plant, 1967

A flash thermal distillation plant was constructed in Malta between 1967 and 1973. Four units × 5000 m^3/d were built as part of a dual-purpose water–electricity complex where passout steam was used to provide the required heat.

These units were of the first generation design, with poor materials of construction, and some design flaws. Acid dosing for scale control was a difficult circumstance to live with at the time, but all in all they served the country well by providing water at a crucial point in the country's history — just after political independence, when the development of tourism and industry was taking off.

Construction, operation and maintenance of a flash plant demand the standard steam and other engineering capabilities normally required for power station operation, with differences such as in the chemistry of the processes. It therefore integrated very easily into the engineering infrastructure of the country where there were and are skilled workers in power engineering and in steel working in shipyards. Appropriate training programmes helped specialization in technology. One could, in fact, observe that in all cases, the Maltese engineering community adopted well to desalination technology in its various forms.

Our engineering experience with flash plants is now outdated, and it would not be useful to relay it. Some general observations and comments remain valid.

An important advantage of the technology is the excellent quality of the product (at less than 5 ppm), which makes it invaluable to use for blending with groundwater. This procedure helps to reduce concentrations of nitrates, sodium, chlorides and other ions, which may be present in ground water, especially in coastal zones where seawater desalination plants are, almost by definition, located.

The capital cost of flash plants is very sensitive to the size of the unit. This was one of the characteristics that mitigated against the application of this technology in 1982 when expansion of the desalination facilities was unavoidable. Units that are of "economic" size for the MFS process are too large compared to the daily requirement in Malta. On the other hand, this does not apply to RO plants.

Another more serious factor was fuel consumption and cost of fuel.

Our investigations at the time (1982) showed that while our dual-purpose plant required some 20 tons of fuel per million gallons of production, an RO plant only required about half that amount. The specific fuel consumption for thermal desali-nation could be reduced by higher investment in design of better performing equipment, but by then the cost of fuel had also gone up very significantly. Water cost by this process would have been very high. In general, high costs of fuel favour RO technology. The direction things were taking at the time was already apparent.

Thus, when water demands made the purchase of new desalination plants imperative and heavy investment could no longer be postponed, we were faced with a difficult decision — to balance the cheaper water cost from RO against the risks associated with the innovative nature of the technology at that time (1981).

A RO desalination plant was chosen, backed by an O&M contract with the supplier to guard against the plant not performing to contract specifications.

4. The third phase — RO desalination, 1982

Our experience with RO desalination has generally been very positive and is a good demonstration that RO technology works. Today 50% of our water supplies come from desali-nation, and about 10% of the energy generated by the power stations is devoted to that activity.

4.1. Seawater feed quality

The flowsheets of our plants are the simplest possible, with little or no pretreatment (Fig. 1).

The quality of our feed water is extremely good. We do not have open sea intakes but rely on sea wells — boreholes dug close to the seashore in limestone rock. Their depth is about 60 m, and their diameter 43 cm. They yield between 6000 and 8000 m^3/d of feedwater, and its quality in terms of silt content (SDI of 1–1.5) and biological quality are very good. At those depths the stable low temperature and absence of light ensure there is no proliferation of microbiological

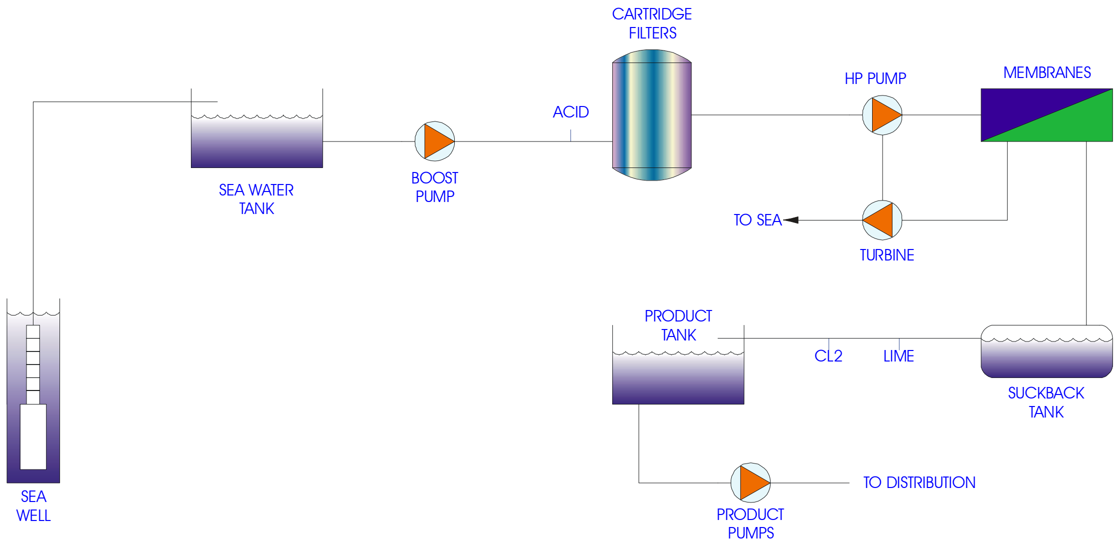

Fig. 1. Flowsheet of simple RO desalination plant.

or bacterial life that effects membrane performance. It is to this excellent quality of the feedwater that we owe a good measure of our success in RO technolog; 30% of our membranes bought in 1982 are still sufficiently effective as to be retained in operation now.

We considered from time to time the economics of more complex pretreatment but found that when we had quantitative indications of annual membrane deterioration — 3% per annum over the manufacturer's projection — that this pretreatment was not justified. Any pollutants were transient in character, changing from season to season and circumstances. We could not guarantee the production of a specification that could cover all eventualities, let alone guarantee the performance of the pretreatment installation.

One of our major worries is the possibility of an oil spill of significant size that would knock a plant out of action through polluting the seawater intake area and the wells from where feed seawater is harvested. This is a real risk, considering that some of the major oil transport sea lanes pass close to Malta. We mitigated this risk by distributing the location of the plants along the coastline such that it is unlikely that an oil spill would influence more than one plant at a time. We are now building a measure of flexibility in the distribution system to be able to take advantage of redundancies in the various plants to produce and transfer water to the area usually served by the stricken site, and to use the stock to the best advantage of water held in man-made storage and service reservoirs.

Another potential problem, but one which is more or less within our control, is land-based pollution. Land-use in the area which may affect the plant is monitored. This was not only done at the time of site-selection but also when new projects in the area are in the planning permit stages.

4.2. Energy consumption

Energy consumption per unit of water produced is a preoccupation at the design stage and throughout the life of the plant. The parameters to comment on are:

- initial design
- membrane deterioration
- cost of energy as charged to the plant
- net technologies for energy recovery

5. Initial design

The first Maltese plants were built around the then state-of-the-art integrated turbo pumps, specifically designed for RO desalination. These were found to be extremely reliable machines and have been in uninterrupted service since 1983.

The last phase of RO plant construction in 1994 was based on a different design concept — energy recovery from separate reverse-running pumps. This was done for environmental reasons. One was to eliminate noise pollution in inhabited and prime tourist areas generated by the high-speed turbo pump and gearbox, and the other was for small gains in efficiency. This different design concept was to have a determining effect on the choice of the new energy recovery devices being retrofitted today.

Whatever the pumping set-up adopted, we always chose high-quality equipment, and this did not let us down throughout the plant's life.

6. Membrane deterioration

Membrane deterioration, through compaction and use, also has a significant bearing on specific energy consumption. Replacement and addition of membranes to obtain the cheapest water costs, balancing investment against cost of energy consumed, is therefore an issue that must be tackled intelligently backed by accurate information through the plan life. One must consider

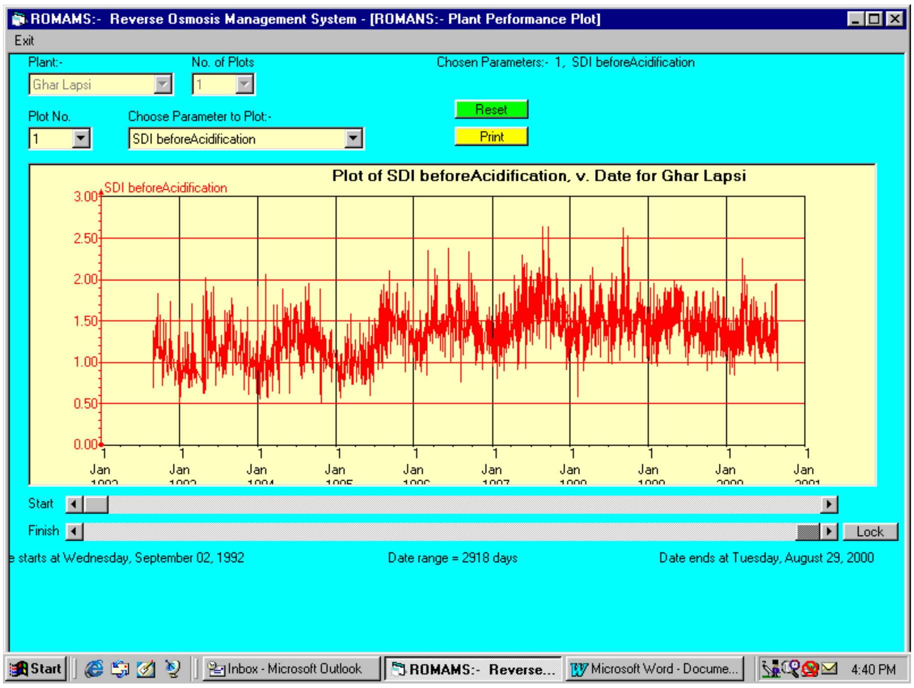

Fig. 2. Output of ROMAMS software.

technological constraints and optimized investment. The technological constraints include a limit on the number of membranes that can be added to avoid too low a flow per membrane and deterioration in water quality, as well as the difficulty of managing membranes of various ages operating together. Membranes were therefore changed in banks, one train at a time, when it became cost-effective to do so.

It has been a disappointment for us to have built a valuable and extensive database of the Dupont membrane performance and now have the manufacturer retire from the market. Our experience is, however, valuable to help us manage other types of membranes effectively.

To ensure optimum membrane management we developed, in conjunction with consultants, a database to record membrane identity and characteristics and performance, and the relative software to aid decision making. This software — in effect a simulation model — is available for customizing to different users and for different membrane makes.

To summarize, some charts from the WSC's RO membrane management database and model (ROMANS) showing plant performance are given (see Figs. 2–4).

6.1. Cost of energy charged to the plant

In this paper the main point to emphasize is not the commercial cost, which may depend on arbitrary non-technical decisions, but rather the benefits of integrated management of water and electricity. One could take advantage of the fact that water is storable and if circumstances exist where the cost of electricity or the load on the generator varies throughout the day operate water

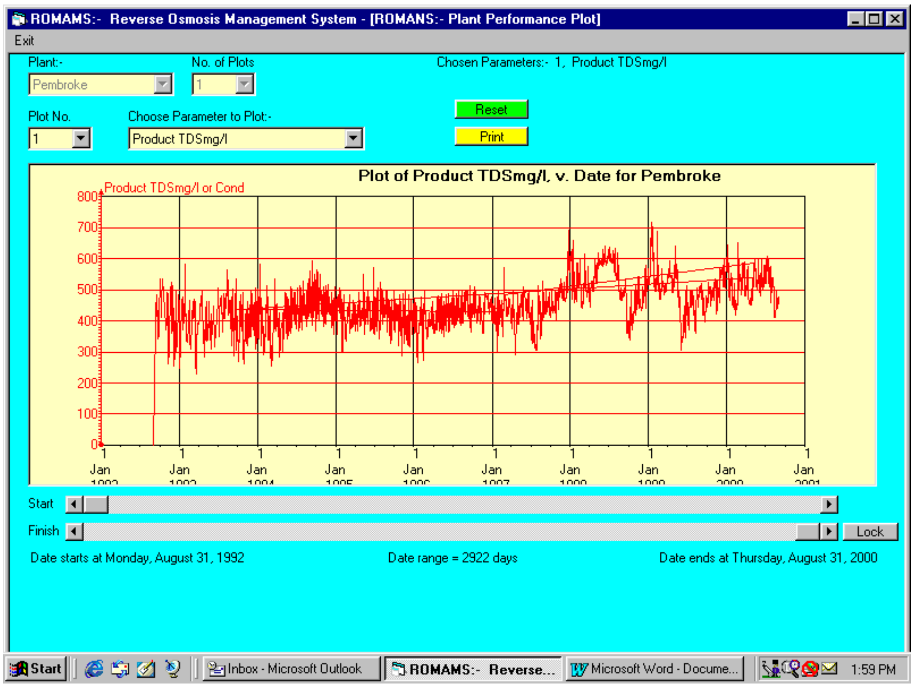

Fig. 3. Output of ROMAMS software.

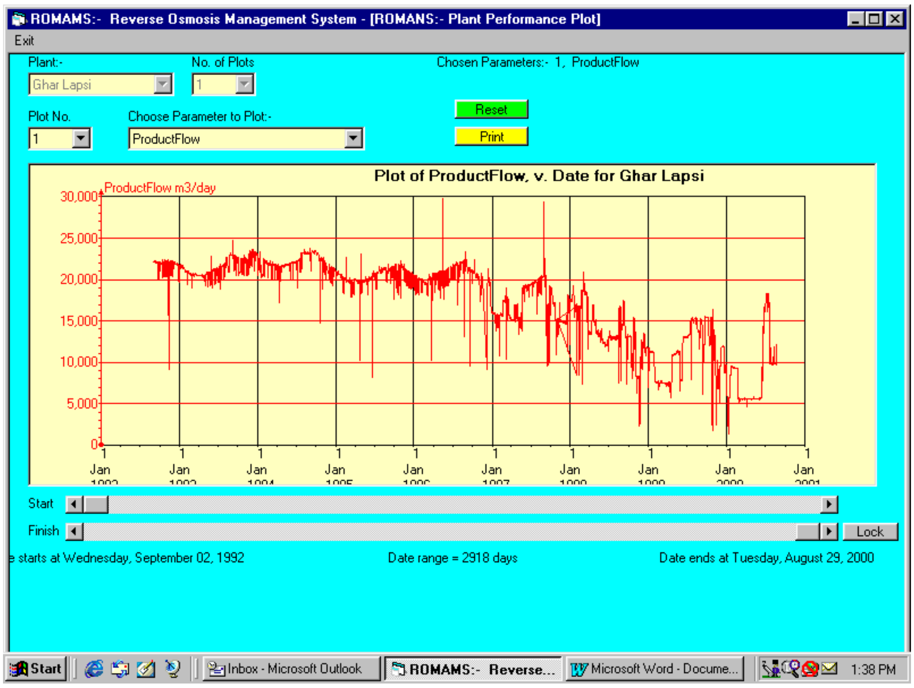

Fig. 4. Output of ROMAMS software.

plants when power is inexpensive. This would require a knowledge of the variation of the cost of energy throughout the day, which could be obtained by mathematical models of the generation plant unless dual tariffs fixed for the desalination plant exist.

At the WSC, we ran tests using the older commercial equipment, and we had the plant shut down and restarted on a cyclic basis. We observed no significant ill-effects to the membranes and could quantify the exact cost of the operation including incidental costs such as for flushback and membrane washing. We have not adopted this mode of operation for commercial reasons (insufficient reduction in energy cost by the energy supplier).

6.2. New technologies for energy recovery

The advent and commercial exploitation of new energy recovery technologies presented us with a good opportunity to review the plant flowsheet and incorporate energy savings. We issued a Request for Information in the international press, asking for information on new energy recovery devices and what could be done to retrofit them in an existing plant. The resulting proposals were carefully analyzed. This retrofitting could be combined with an exercise aimed to convert our plant to operate at 1000 psi with spiral-wound membranes since the Dupont membranes (at 1200 psi) are no longer available.

In some cases we found that the most appropriate solutions were replacement of reverse running pumps by Pelton wheels. We moved from 81% to 86% efficiency in energy recovery, which translates to an improvement of 0.41 kWh/m^3 (4.08–3.67 kWh/m^3), assuming new membranes are installed on the RO trains at their present 1200 psi operating regime. Change to 1000 psi pressure levels would be more rewarding with the improvement being 0.88 kWh/m^3. This exercise was done at minimum cost since, apart from the purchase of the Pelton wheel, all other hardware was retained. The engineering work associated with the installation was all done in-house at little cost.

Different considerations applied to the plant based on the integrated turbo pump. This device would need to be discarded in this case, and both the pump and ER device would need to be bought new. A different flowsheet was, therefore, possible. We are now, in fact, considering basing these refurbished trains on new pressure exchangers. These devices operate at 95% efficiency, significantly better than the 74% of the turbine used in the other cases. With pressure exchangers, specific energy consumption goes down from 4.28 kWh/m^3 to 2.8 kWh/m^3 if new membranes are fitted — all this being operated at 1000 psi.

Also, in this latter case the same motor rating and the electricity infrastructure which we retained enabled us to rebuild the new trains of practically double the previous output since specific energy consumption was so much less. This increase in capacity was acceptable because the older trains initially had much lower output, and as a result we did not finish with RO train sizes that were too large for our needs.

We have found the installation of all forms of new energy recovery devices to be extremely rewarding, and expect recovery of our expenditure in 1 or 2 years through reduced running costs.

7. Water quality issues associated with RO product

We have met several water quality issues associated with RO product. The negotiations for accession to the European Union presently being conducted with Malta provided us with an opportunity to look at them again, with EU standards as a background. Our experience is, of course, based on the Dupont membrane, which lately is being withdrawn from the market.

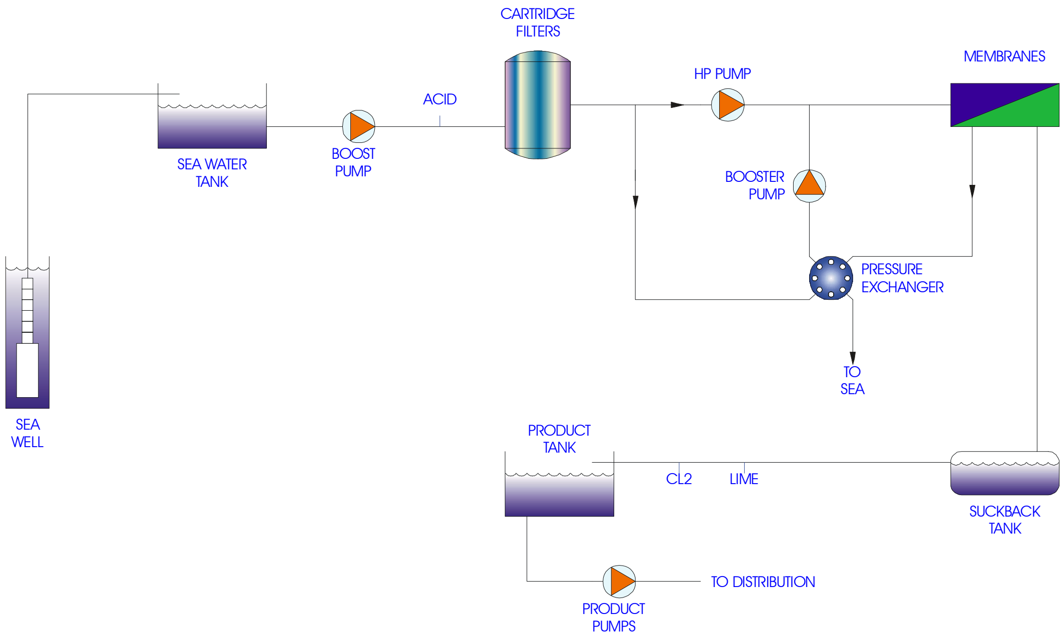

Fig. 5. Flowsheet of a simple RO desalination plant incorporating a pressure exchanger.

Our plants are all designed on a single pass flowsheet (Fig. 5).

The recommended levels of sodium and chloride in EU Directive 98/83/EC are 250 mg/L and 200 mg/L, respectively. Both are classified as indicator parameter. Due to the very high concentrations of these parameters in seawater, it is difficult to obtain the recommended concentrations after a number of years. The most important relevant parameter is the age of the membrane and proper operational procedures and practices.

RO membranes have a low rejection of boron ions. The membrane manufacturers claim that, during tests carried out under conditions similar to real plant operation, the rejection of boron at a standard solution of 4000 ug/l was approximately 91% at a pH of 6.9. This implies that starting with a boron concentration level in feed water varying between 4500 ug/l to 6500 ug/l, the product water should have a theoretical boron concentration of 410–590 ug/l when the membrane is new. No data have as yet been provided for older membranes.

The corporation carried out investigations to determine boron levels in RO feed water (seawater sample) and the product water from various RO plants and individual trains. The RO product water ranged between 730–890 ug/l. with one train having a maximum value of 990 ug/l. (The recommended level for boron in EU directive 98/83/EC is 1 mg/l. The WHO level is 0.5 mg/l.)

The chemical nature of the product water renders it aggressive. Untreated RO product is acidic: typical pH 5.5–6.9, has a low alkalinity and a high content of dissolved carbon dioxide. These three parameters are interrelated, and a change in the level of one of them would alter the levels of the other two.

These parameters are used to calculate the Langelier Saturation Index (LSI), which is an indicator of the corrosiveness of the water. A positive LSI is aimed for so that the water has a tendency to precipitate calcium carbonate and thus some protection against corrosion is achieved.

Untreated RO product has a high negative LSI. In the plants in Malta the addition of lime is used to minimize this problem. One strives to balance this against problems caused by the added lime itself. The rise in pH changes taste, which is perceived by some consumers. Lime leaves some insoluble suspended matter which could cause clogging of small diameter supply mains, if not checked.

8. Non-technical issues

Having summarized some of the technical issues involved, some higher-level observations from our experience in desalination applications may be useful.

Generally speaking, desalination was introduced in Malta when situations of crisis management set in.

Malta is practically an arid country and the situation gets really difficult from May until October when demand for water is high. In the 1980s, tourism was deteriorating and industry was suffering heavy losses as a result of a chronic lack of water. The situation was having a detrimental effect on the economy, on foreign exchange earnings, investment and employment.

Desalination of seawater was seen as an urgent solution to this situation, especially after the successful experience of our first plant. The cost of desalination, although known, was considered a necessary investment in the development of the country, after a lack of investment in water supply in preceding years, both in terms of capital and effort.

A situation of interruption of supply in old mains was having a very detrimental effect on the distribution systems. The very exercise of shutting down sections of the distribution system, designed as a means of water rationing to reduce demand, was having the opposite effect to that intended. It was itself the immediate cause of new leaks springing in the system. We proved and demonstrated this effect later on when our sophisticated programs of leakage control were in full swing.

Actions aimed at ad-hoc rationing of water were by-passed by the population and done wastefully. Water stored for use during cuts was thrown out when supply returned. Refilling of mains and return of supply were generally marked by rust-coloured water as a result of the ingress of air when mains were empty, leading to more dumping and waste by the consumer when rusty water returned to his tap.

This situation of unsteady supply with interruptions programmed to ensure a minimum share to all amidst the scarcity did not permit proper maintenance of the distribution system and adequate leakage control. The situation got from bad to worse. It did not allow the authorities to institute effective demand management practices. Water conservation programmes were not credible in such circumstances and tariff adjustments were not acceptable for the bad service being given. Water became a political issue, which made life even more difficult to the operators.

The lesson from all this is the value of the concept and the implementation of integrated management of the resource, which we are now applying, with constant attention and investment at the right time.

Our large investment programmes in desalination did stabilize the situation. They allowed us to move to proper efficient management of our water resources, which is gradually yielding very satisfactory results. We instituted a highly sophisticated and successful leakage control programme. Tariffs were revised upwards to discourage unwise and avoidable water use. Anything but the highest standards of technical management became unacceptable.

“Water in our taps” and all that is entailed in providing it began to be taken for granted after the crisis was over, and it became unthinkable to get to that situation again.

Indeed, consumer expectations regarding the quality of the water and of the service being provided began to rise, and the corporation's efforts are now concentrated in that direction.

No account on the adoption of desalination would be complete without reference to the environment. The impact of desalination on the environment was studied before the plants were installed, and specific and detailed site-selection exercises were carried out. Impact on the environment was believed to be marginal, especially when balanced against the improvement in the quality of life.

Having had some plants operating since 1982, the immediate aquatic environment around them could be studied in detail to determine accurately the type and extent of the impact of the plant's brine discharge on the marine environment. Plant operating data are available to make the study meaningful. We welcome partners to carry out such studies with us and thus have factual scientific determination of these impacts.

The electricity used in the plant is, of course, accompanied by the normal pollution effects associated with power station operation. This is an unavoidable impact of our desalination activities, but our investment in new energy-reducing devices in water conservation and in water use educational programmes is proof of our commitment to keep this to a minimum. With our new energy devices, consumption levels of 3 kW/h/m^3 are beginning to be realized.

We have also looked at the application of renewable energies to mitigate further this impact. Despite our best intentions, studies have shown that the realities of economic life outweigh the net gains to the environment. We invite manufacturers of the RES-harvesting plant to participate in such studies with us to optimize our relationship with the environment in this respect.

9. Conclusions

Desalination technology has been adopted by this country as an indispensable tool to provide water that is necessary for development. Our studies and experience have given us insights into its technological and engineering aspects and also in its management aspects — its integration with water management techniques, procedures and tools. Indeed, today we are applying and using our experience and knowhow in the manufacture of desalination plants for the private sector.