

Water supply management in Cyprus under climate uncertainty

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Abstract

Climate change and improved life quality have increased water demand, while water supplies are shrinking. The increasing water demand in combination with extensive dry periods due to climate change has decreased water resources. Due to the above, measures had to be taken to resolve the water supply insufficiency. Those measures should be as friendly as possible to the environment, so no further vulnerabilities are caused to the environment by treating the current ones.

Numerous measures have been taken to resolve the insufficiency of water resources. Originally, dams were constructed to store water. From the late 80's, the entire island was supplied mainly with water from the dams, as the construction of the "Southern Conveyor Pipeline" was in progress. After the operation of the "Southern Conveyor Pipeline", water demand was initially satisfied, but few years later Cyprus suffered from extensive dry periods, which resulted to water shortage due to the decreased inflows to dams. The favored solution for the coverage of water insufficiency was desalination.

Desalination facilities provided sufficiency of water but at the same time introduced further impacts on the environment, such as increase of greenhouse gas emissions, because of their power demand, and saline density increase, due to the rejection of residual salt back to the sea. Conclusively, the pursuit of new more advanced technologies on renewable energy sources and environmentally friendly methods should always be a priority.

1. Impacts of climate change on water resources

The impacts of climate change are being noticed primarily and more intensively on water resources. Water resources are important to both society and ecosystems. We depend on a reliable, clean supply of drinking water to sustain our health and we also need water for agriculture, recreation and manufacturing.

The increasing need of water due to the above uses is exacerbating the impacts of climate change on water resources. Climate change and improved life quality have increased water demand, while water supplies are shrinking. This shifting balance should challenge water managers to meet the needs of growing communities, sensitive ecosystems, agriculture and manufacturing at the same time.

1.1 Impacts on Water Cycle and Water Demand

The water cycle is a very delicate balance of precipitation, evaporation, and all the steps in between. Higher temperatures increase the rate of evaporation of water into the atmosphere, leading to increase of atmosphere's capacity to withhold water. Increased evaporation may dry out some areas and at the same time increase precipitation on other areas, as depicted in the figure below.

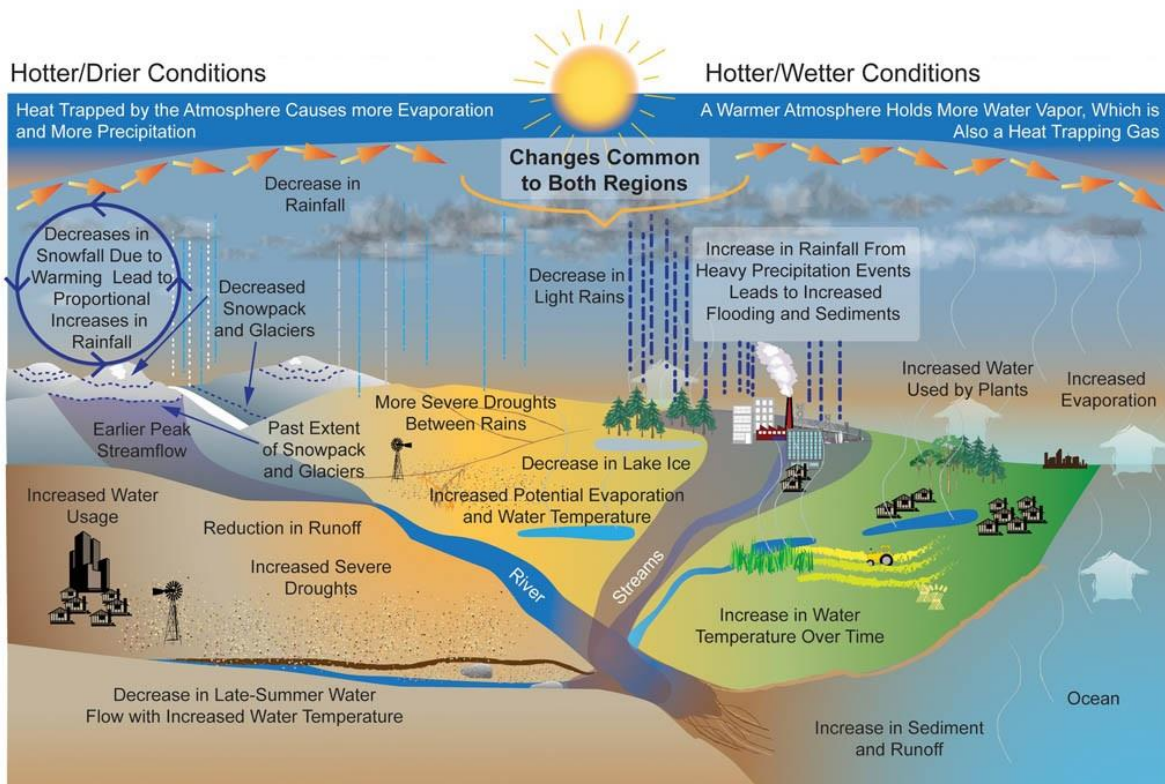


Figure 1. Climate change effects on water cycle. [1]

This figure clearly depicts the changes in the water cycle for both hot/dry and hot/wet conditions. Heat trapped by the atmosphere causes more evaporation and more precipitation. A warmer atmosphere holds more water vapor, which is also a heat trapping gas. The figure highlights several conditions, such as decrease in rainfall, extent decrease of snowfall and glaciers, earlier peak streamflow and a reduction of runoff. It also shows that decreases in snowfall due to warming, lead to proportional increases in rainfall. The combination of decreased late-summer water flow with increased water temperature and increased water usage leads to increased severe droughts [1]. These changing climatic conditions are clearly visible in Cyprus, where extended periods of drought occurred over the last decade leading to reduced inflow to dams.

1.2 Impacts on Water Supply in Cyprus

Cyprus has been facing water supply issues over the last decades. During the recent years, water insufficiency issue increased due to climate change in combination with water demand increase. During those years, Cyprus experienced extensive dry periods due to reduced precipitation and high temperature.

The quality of water supply in coastal regions is at risk from globalising sea level and fluctuations in precipitation. Rising sea level and the occurrence of drought in combination with drawdown of groundwater level due to over-pumping, increased the salinity of groundwater due to salt water intrusion.

2. Topographic and hydrologic data

Cyprus is located at the southeast of the Mediterranean Sea and is divided in four natural areas, *Troodos* mountain range, *Pentadaktylos* mountain range, *Mesaoria* valley and coastal plains and valleys along the shores. The *Troodos* mountain range lies at the central-west part and its highest point is 1951m above sea level. *Pentadaktylos* mountain range lies along the northern coastline with peaks below 1000m. *Mesaoria* valley lies between the two mountain

ranges. Mediterranean climate is characterized by warm and dry summers (May – September), mild and rainy winters (November – March) and two intermediate transitional seasons (autumn and spring) which, each one, last for one month. The winter months, December to February, cover 60% of the total annual precipitation.

Depending on the topography, the level of precipitation varies. Specifically, the average annual precipitation increases in the southwestern windward slopes, from 450 mm to nearly 1100 mm at the top of the central massif. As we go down towards northern and eastern island the values decrease. At the central valley and southeastern areas along the shores, the value is lower than 300-350mm [3].According to the data provided by the Meteorological Service of Cyprus and depicted in the following graphs (Figures 2 and 3), the annual temperature is constantly increasing, while the annual precipitation is constantly decreasing. This combination constitutes the negative effect of the climate uncertainty on the water resources.

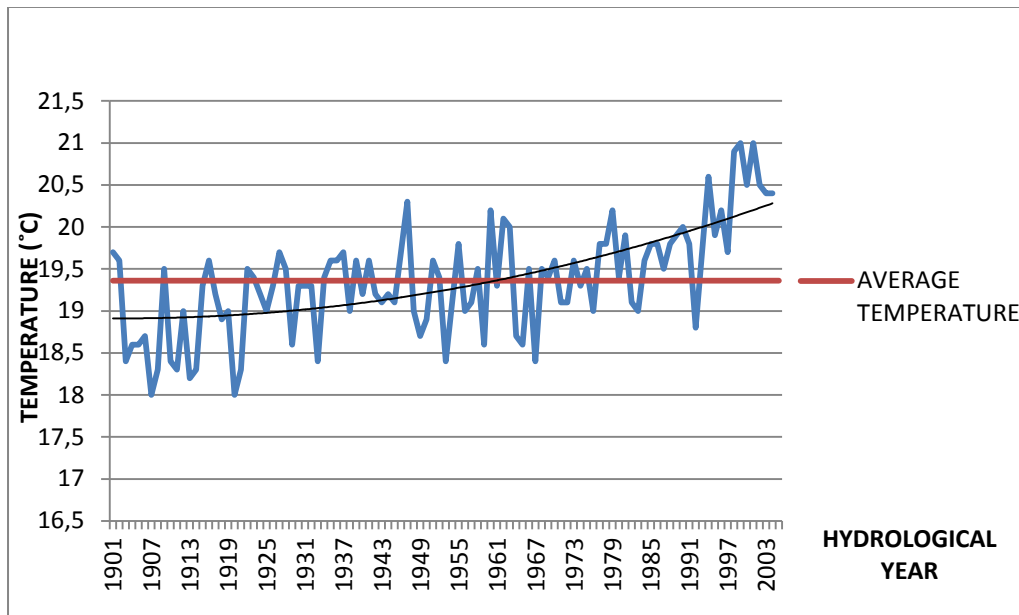


Figure 2. Annual temperature fluctuations in Cyprus (1901 – 2001). [Meteorological Services]

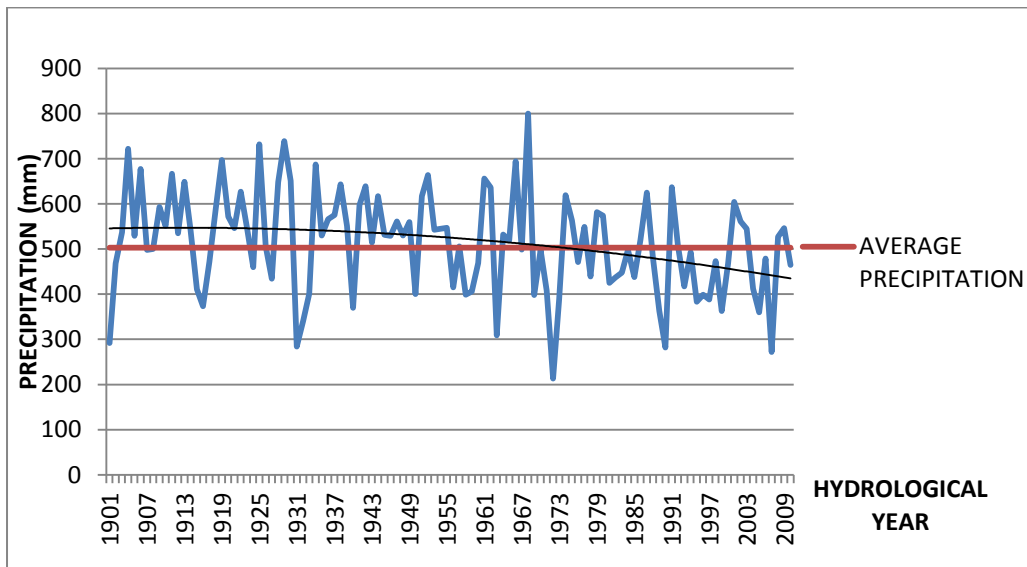


Figure 3. Annual precipitation fluctuations in Cyprus (1901 – 2006). [Meteorological Services]

3. Dealing with insufficiency of water resources

3.1 Construction of dams

Droughts and water shortage was always a problem that Cyprus faced. The main reason has been the climatic

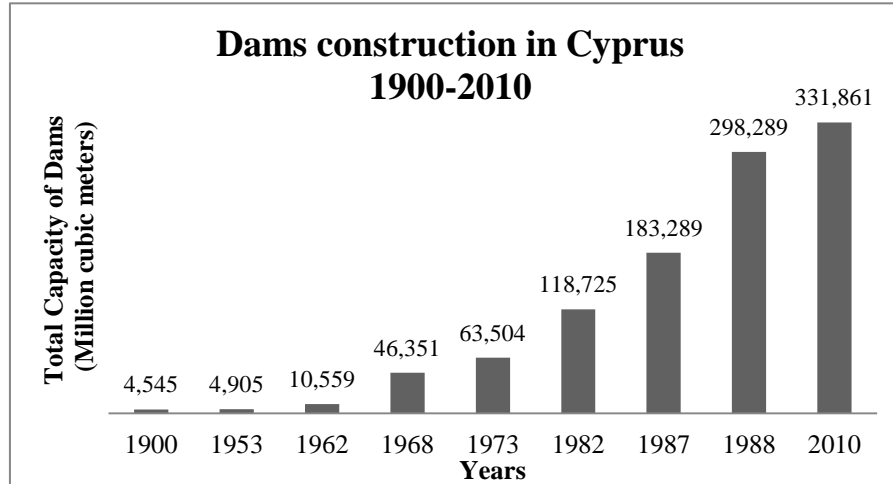


Figure 4. Total annual capacity of Cyprus dams.

conditions due to its location. Consequently, water managers were obliged to promptly handle the problem of water shortage. In the meantime they had to find ways to collect, store, and transfer water in order to satisfy the water supply and irrigation needs. At the beginning of the 20th century it was clear that the solution to the water shortage issue was the construction of dams. The first dam was built at *Kouklia* in 1900 to cover the demands of the region.

However the period between 1945 and 1958 was the most productive with respect to the construction of dams. Nevertheless the problem wasn't being treated as a general problem that concerned all residents, but as a local problem of each region individually. For the first time, since the establishment of the Republic of Cyprus in 1960, water shortage was treated as a common problem that was affecting the residents of the entire island. Water managers immediately started the construction of large dams to store water, and at the same time they developed a campaign to prevent consumers from wasting water. The slogan was "not a drop of water to the sea" [5]. According to the campaign they immediately started designing and constructing dams. Dams were constructed at almost every large river. Currently, due to this policy, there are over 100 dams, 58 of which are registered at the International Commission on Large Dams (ICOLD) [3]. The most remarkable dam project was the construction of *Kouris* dam at the late 80's, as a part of the "Southern Conveyor Project" which through the conveyor pipeline was serving the districts of *Limassol*, *Lefkosia*, *Larnaca*, and *non-occupied Ammochostos*. This radical increase of dam construction can be seen in Fig. 4.

3.2 Southern Conveyor Pipeline

The eastern part of the island has a low altitude and, as a result, the construction of dams is impossible. Furthermore it is far from the mountainous area, where the dams are located. Because of this, the eastern areas were supplied with water only by pumping wells until late 80s. That changed when the "Southern Conveyor Pipeline" started operating, transferring water from *Kouris* dam (North *Limassol*, *Troodos* mountain foothills) and has been supplying the Northern, Northeastern and Central areas (*Limassol*, *Larnaca*, *Lefkosia*, *non-occupied Ammochostos* districts). The "Southern Conveyor Project" is the most significant water supplying construction in Cyprus [5] and can be seen in Fig. 5, along with other major water works. Since then, the above four districts have been supplied by water mostly from *Kouris* dam through 'Southern Conveyor Pipeline' and *Paphos* district is provided by water from *Asprokremos* dam and *Kannaviou* dam.



Figure 5. Major water works in Cyprus, including the Southern Conveyor Project. [Water Development Department, <http://www.moa.gov.cy/moa/WDD/WDD.nsf/0/bed8f791f8232344c22570ec0029db96>]

3.3 Desalination

Due to climate change, Cyprus suffers from extensive dry periods. During the recent years, Cyprus experienced two extensive dry periods (1995-2001, 2004-2008). During these periods the inflows to the dams were below the average of the 26 years period (1987-2013), as it can be seen in the following chart.

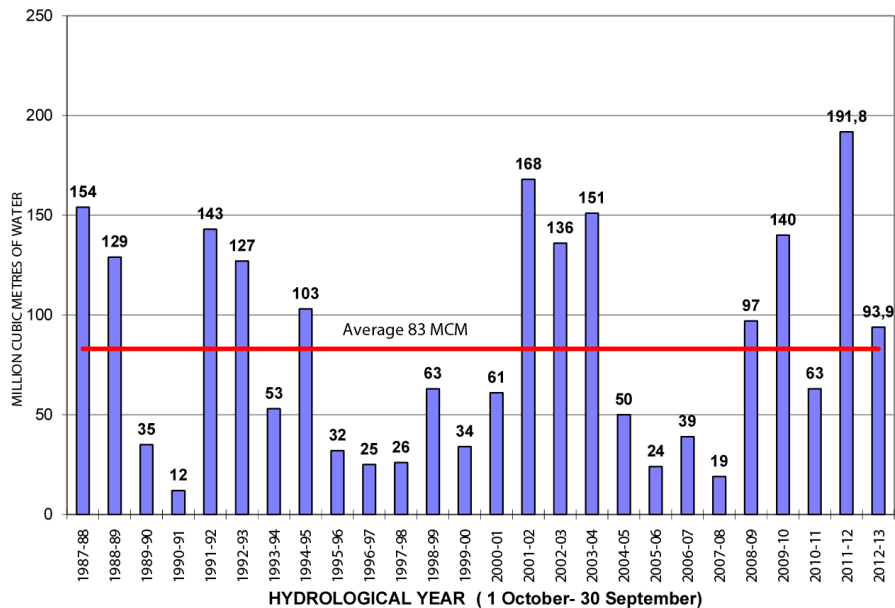


Figure 6. Water accumulation in the dams (1987 – 2013). [Statistical Information, WDD, http://www.moa.gov.cy/moa/wdd/wdd.nsf/statistics_en/statistics_en?OpenDocument]

During those periods inflows to the dams were decreased, due to reduced rainfall combined with high temperatures (evaporation of surface water). Consequently, water supply demand couldn't be ensured only by surface water. An alternative solution had to be found, in order to stop depending only on rainfall to cover the water demand. The favored solution was desalination.

The desalination project began immediately, with the first two plants starting operating in 1997 and 2001 at *Dhekelia* with capacity of 60000 m³/day and *Larnaca* with capacity of 62000 m³/day. These first two plants covered adequately *Larnaca*, *Lefkosia*, and *non-occupied Ammochostos* districts demand. However, due to the raise of drought and demand, more measures had to be taken. At 2008, although the two plants were operating, and the only district which was providing water exclusively from *Kourris* dam was *Limassol*, the dam almost dried out. Due to the urgency of the circumstances, radical measures had to be taken. This initially led to water cuts, water import from Greece at a high price (4€/ m³), and the instant construction of four mobile desalination plants of high cost, which eventually were going to be replaced by new permanent desalination plants.

Specifically, those mobile plants were constructed at *Moni* and *Garyllis* river in 2008 and 2009 for the coverage of *Limassol* district, and at *Paphos* in 2010. In addition to this, the officials also planned the construction of two permanent desalination units at *Episkopi* in 2012 and *Paphos* in 2013 and at the same time the closure of the mobile plant of *Paphos*. Furthermore a mobile plant was constructed by the Electricity Authority of Cyprus (EAC), next to *Vasilikos* power station which was going to be replaced by a permanent plant in 2012. However the plant was ready in 2013 because of an explosion at a nearby naval base in 2011 that damaged the construction. The original plan was that five permanent desalination plants were going to be operating in 2013 with total capacity of 260 m³/day, creating water plenitude for the whole island. Nevertheless, the operation of *Paphos*, *Episkopi* and *Vasilikos* permanent plants weren't needed due to precipitation increase, leading to water inflow increase to dams creating plenitude in dams [7]. The radical precipitation increase can be seen at Fig. 6 above. Those three plants are standby and can start operating whenever further need is created.

Over the last two years, precipitation increase had created sufficiency of water by increased dam inflow. Water plenitude had made the operation of desalination plants unnecessary. Therefore it was decided that desalination units except *Dekelhia* plant, would stay on standby until they would be needed. Moreover the shutdown of the expensive, energy intensive desalination plants was considered an opportunity to reduce the overall water supply budget during economic crisis.

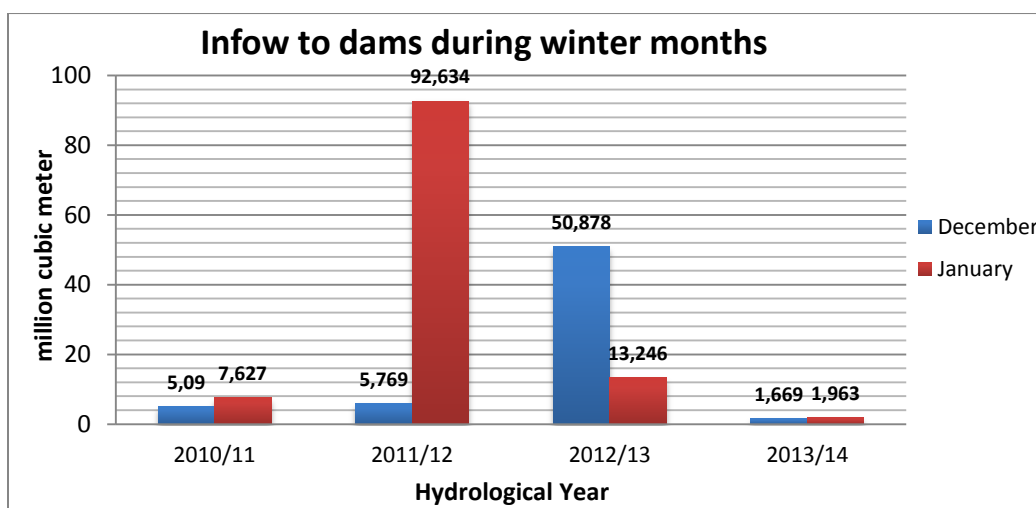


Figure 7. Water accumulation in the dams, during December and January 2010 – 2014.

Unfortunately, things turned out differently than expected, with current year's precipitation being the lowest in the last decade. Current year's inflow to dams reached only 5,107 million m³ (from October) until now, which is only

6,61% of last year's same period (77,321 million m³). This sharp precipitation decrease is clearly illustrated in Fig.7, with inflow to dams for December and January (which are considered the most productive months with respect to precipitation) for the last four years [8].

This new dry period that seems to be starting, meets Cyprus under new circumstances, more prepared than ever. Desalination facilities are ready to operate and give plenitude of water to the whole island. Although this time, everything seems to be in order, we are facing a new different kind of problem. Due to economic reasons, the full operation of the desalination plant appears to be too hard to be handled because of desalination's high energy consumption and cost. Nevertheless this might be an indication that we need to see the problem from another perspective and as an opportunity for new, modern ways for water supply that cost less and harm the environment less at the same time.

4. Further vulnerabilities on the environment: Desalination units' negative effect

Taking into account that desalination is an energy intensive process, reverse osmosis was chosen due to its low energy requirements. This method was considered the best solution (of its time). Moreover, the plants' locations were chosen such as to have the least impact on the environment, as can be seen in Table 1.

Desalination units are usually placed at coasts, which are selected for water pumping rather than leisure and tourism. In addition to that, when the units are operating, the pumps generate high level noise pollution. Consequently, the surrounding land is devalued. Therefore desalination plants should be equipped with the appropriate technology in order to reduce the noise volume, and also placed at a location where the surrounding environment impact is as less as possible. A good example is *Larnaca's* Desalination Unit, which was placed near *Larnaca's* Airport; thereby the noise generated by the pumps is covered by the airport's higher noise pollution.

The operation of a desalination plant has more negative effects on the environment, such as the damage of the marine organisms by the water absorption pipe and the saline discharge to the sea after the desalination process, containing approximately 50% more salt for the same water volume. Also a desalination plant requires high amount of energy to operate (RO is higher energy consumer) [10].

Desalination high power demand generates economic and environmental effects. For example, an average capacity unit (40000 m³/day) requires 7500-9000 kW to operate. When all units in Cyprus (nine in total) operate, 12% of the total power produced by the Electricity Authority of Cyprus (EAC) is used by them. Furthermore electric energy, in Cyprus, is produced by fossil fuel. So when the energy production increases, to meet desalination plants' demand, the emission of greenhouse gases (GHG) increases too. As a result, the power consumed by the desalination plants generates additional 571,72 ton CO₂/year. Nevertheless, all the countries that signed the Kyoto Protocol, agreed to a limitation of GHG emissions [9]. When a country exceeds the limit, it has to pay a penalty fee. An alternative solution that has been given to countries that exceed the limits is to buy emission rights from another country instead of paying the penalty. This alternative is given to governments by Emission Trading System (ETS). As mentioned before, desalination units' operation in Cyprus increases the energy production and as a result the GHG emission, so the danger of exceeding country's emission limits increases with the operation of desalination units. This negative effect has also to be taken into account for the water supply management in Cyprus [10].

The following table shows the effects of the operation of the desalination units on various aspects, such as the land use, the neighboring aquifers, the marine environment, the produced noise, the energy consumption, the CO₂ emission, the water supply, the economy and 'others', with respect to the daily production of water. For instance, the negative effect of the small Brackish *Garylli* unit, which produces only 10000 m³/d, on the land use, the noise, the water supply and the economic impact is very high. On the other hand, the energy consumption, the CO₂ emission and the economic effect of the biggest *Larnaka* and *Dekeleia* units are very significant. Concerning the economic impact, all nine units are rated significant to very important in terms of their operation.

Other (minor) effects are considered those related to the water treatment itself or the operation of the desalination unit, such as fuel storage, material transportation, construction of high voltage pillars, high content of Boron (around 1 ppm) in the treated water, which may cause adverse impact on certain crops (for irrigation use).

Table 1. Effect analysis of the desalination units' operation. [10]

Desalination Unit	Production Unit(m ³ /day)	Land Use	Aquifers	Brine & Marine Environment	Noise	Energy Use	CO ₂ Emission(tons/year)	Water Supply	Other Effects	Economic Impact
Dekelia	60.000	1	1	3	1	5	5	2	3	5
Larnaca	62.000	2	1	2	1	5	5	2	2	5
Paphos	40.000	3	3	2	2	4	4	2	2	4
Episkopi	40.000	1	3	2	1	4	4	2	2	4
Vasilikos	60.000	1	1	2	1	4	4	2	2	5
Brackish Garylli	10.000	4	3	1	4	2	3	4	1	5
Mobile Monis	20.000	2	2	1	1	3	3	1	1	4
Mobile Paphos	20.000	3	3	1	2	3	3	1	1	4
Mobile Vasilikos	20.000	1	1	1	1	3	3	1	1	4

(Very Important=5, Significant=4, Moderate=3, Relatively Significant=2, Insignificant=1)

5. Renewable energy sources and other environmentally friendly technologies

As it has been mentioned above, desalination units require high amount of energy, therefore a solution is needed to reduce their energy consumption. The possibility of using renewable energy sources for the operation of the existing units was examined through the design process of each unit. Every examination resulted that Wind and Solar Energy was impossible to be used, due to the insufficiency of wind dynamic and land space required for the photovoltaic panels installation [10]. Solar Energy, however, could be considered, due to the high solar dynamic of Cyprus even for part of the facilities' energy requirements. Panels could be installed on the rooftop of the structures, which cover a large space.

A promising proposal is the construction of an experimental plant which uses Solar Thermal Energy for the desalination process and at the same time generates electricity (STEP-EW). The unit is located at *Pentakomo*. The technological solution that is proposed is Multiple Effect Distillation Method (MED), which requires low electrical energy self-covered through heat source and operates without any use of chemicals. This particular process of water desalination is environmentally friendly due to its low energy needs; however it does not reduce the saline discharge to the sea [12].

A plausible solution to the saline rejection is examined by the Chemical Engineering department of the National Technical University of Athens (NTUA), at an experimental facility placed in *Tinos* Island, in S. Greece. The method used at this particular desalination plant is also reverse osmosis. However the saline returns back to the membranes and is being reprocessed, instead of rejected to the sea, resulting to an average of 65% of pure water and 35% of pure salt [13]. This might be a high energy consuming process, due to the high pressure pumps that are needed; however it could be used for low production of water units like the desalination facility of brackish water of *Garyllis* River.

A different desalination method is used in Israel, a country with similar hydrogeological and climatic characteristics. Reverse osmosis is applied without the use of chemicals, but rather biofilters that purify the water. It is a viable, economic solution that does not affect the environment with chemical rejection into the sea or the ground [14].

Researchers at the West of England University of Bristol have developed a mobile water treatment system, capable of providing low cost, clean drinking water directly at the source. This technology is suitable for remote inaccessible areas, such as mountain villages not connected to a municipal water supply system, and use untreated water from local drilling. This mobile water treatment system could also be used in small dams that are mainly used for irrigation or a aquifer recharge and cannot afford to operate a refinery in parallel to produce clean drinking water. At the UWE in Bristol, an experimental unit has been established and operates with water that is drawn from a nearby lake. Surface water requires treatment, which is acquired by the use of a disinfectant and a filtration system. Instead of Cl_2 , the most common disinfectant which causes corrosion to the filtration membranes after time, UWE uses another disinfectant that kills the bacteria in the water without causing corrosion to the system [15]. This technology may be at an early stage, with the experimental facilities producing only 2 cubic meters of drinking water in a 12 days period, but it is estimated that in the near future the production of an actual size facility could reach 2 m³/day. In Cyprus, this technology could be applied in old dams that are out of service, such as the dam in *Kouklia*, and provide drinking water to remote villages.

Another interesting technology that has been developed in Singapore is based on recycling water. Used water is purified through micro-filtration, reverse osmosis and disinfection. After this procedure water reaches high drinking standards. A country such as Singapore, of only 700 m² and limited water resources, has to explore other options than depending on neighboring countries on its water supply. Even though the weather is very humid, precipitation covers only 50% of its water demand. The company that introduced and applied this method (Newater) has won prizes on its environmental contribution, and now operates 4 plants that cover 30% of the country's water needs. It is in their plans to cover 55% of future water demand of the island by 2060. [16]

The following figure demonstrates how effective a combination of different water management approaches can be. Water treatment plant and desalination units can provide drinking water for domestic use, whereas waste water treatment plant can satisfy the irrigation needs. Different methods and techniques can coexist and provide the desired solution, in countries like Cyprus or Singapore that are surrounded by water and cannot depend on cross-border water resources.



Figure 8. Optimized water cycle management. [17]

Conclusions

As the past has shown, water resources and water demand are constantly evolving due to climate change. Water cycle is based on a delicate balance of evaporation and precipitation that must be handled properly to avoid worsening current conditions. Water storage and distribution is also part of the water cycle management. Water supply managers should be well aware of the impact of climate change on water resources, when planning for urban water supply systems, or agricultural works. Extreme weather events have shown to impact the provided services. Due to that, the water authority has to take the initiative and make long-term plans, based on the on-going research and the inevitable evidence of water shortage. Moreover, the pursuit for new more advanced technologies on renewable energy sources and environmentally friendly methods should always be a priority to the scientific world. It is essential not to create further vulnerabilities harming the environment in the effort to treat the current ones.

Several solutions have been mentioned in this work that are either tested and applied successfully abroad, or are in the process of research. Some of these solutions could be applied in Cyprus and have a positive impact on today's water supply crisis, creating a network of environmentally friendly and less energy intensive methods. These plans should be flexible and easily adaptable to future conditions, without diversions from the original plan. Rational management of water supply systems can contribute to the community's and the environment's benefit.

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