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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. The primary goal of this study was to suggest measures that can be taken to resolve the water supply insufficiency in Cyprus. 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. Reviewing the measures that have been taken to resolve the insufficiency of water resources in Cyprus, numerous dams were originally constructed to store water, followed by the construction of the "Southern Conveyor Pipeline" and finally desalination plants. Desalination facilities provided sufficiency of water but at the same time introduced further impacts on the environment, such as increase in greenhouse gas emissions, because of their power demand, and saline density increase, due to the rejection of residual salt back to the sea. The economic effect in conjunction with the environmental impact of desalination units on various sections is presented, taking into account greenhouse gas emissions and the Kyoto protocol. The study concludes with the pursuit of new more advanced technologies on renewable energy sources and environmentally friendly methods from around the world that could be applied in Cyprus for its economic benefit and satisfaction of public water supply.

Keywords: Water supply; Water deficit climate change

1. Impacts of climate change on water resources

The impacts of climate change are being noticed primarily and more intensively on water resources due to the importance of water resources for both society and ecosystems. We depend on a reliable, clean supply of drinking water in order to sustain our health; furthermore, water is essential for agriculture, recreation, and manufacturing [1].

The increasing demand 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.

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1.1. Impacts on water cycle and water demand

Water cycle is a very delicate balance between precipitation and evaporation, among other processes. Greenhouse gas emissions created by human activities, increase temperature which in turn change this balance. Higher temperatures increase the rate of evaporation of water into the atmosphere, leading to increase in atmosphere's capacity to withhold water as vapor. Increased evaporation may dry out some areas and at the same time increase precipitation on other areas, as depicted in Fig. 1 [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 [2].

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. Cyprus experienced extensive dry periods, over the recent years, due to reduced precipitation and high temperature [3].

The quality of water supply in coastal regions is at risk due to global rising sea level and fluctuations in precipitation (information about the coastal areas' groundwater level is given by the Water Development Department [4]). Rising sea level increases the salinity of groundwater due to brackish water intrusion into groundwater reserves [1], as illustrated in Fig. 2. In addition to that, over-pumping in combination with the occurrence of drought, where the renewal of water resources is limited, is making things worse.

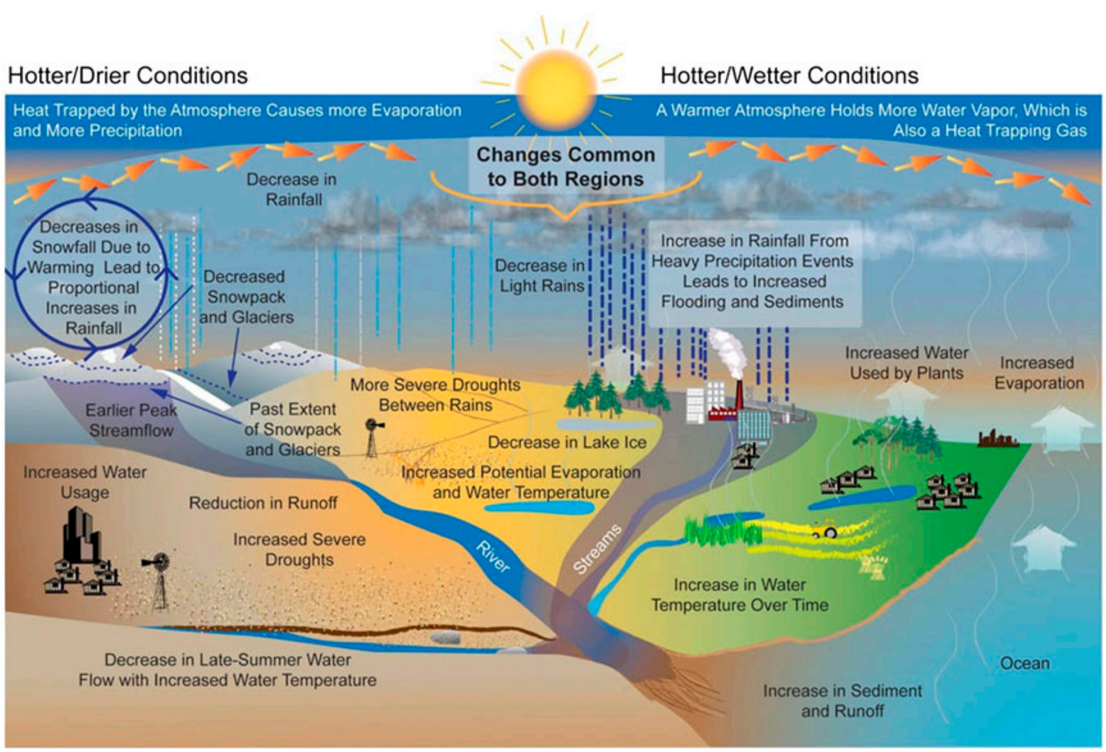

Fig. 1. Climate change effects on water cycle [1].

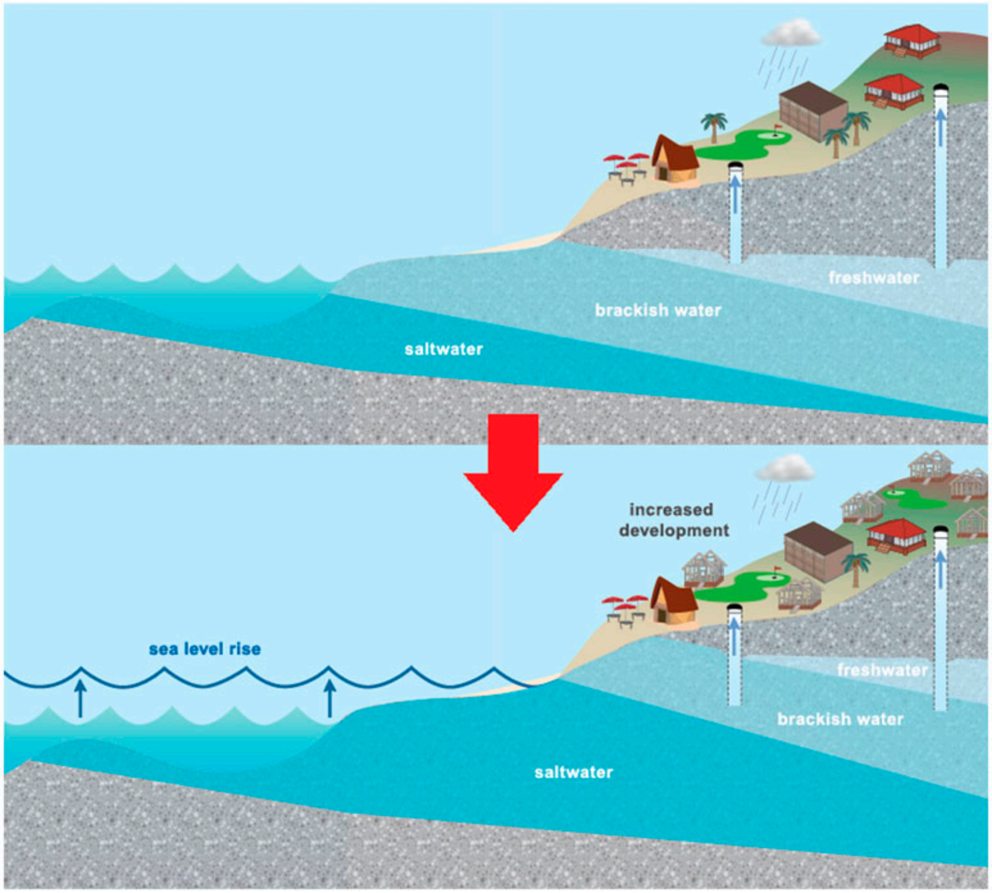

Fig. 2. Rising sea level increases groundwater's salinity [5].

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 1,951 m above sea level. *Pentadaktylos* mountain range lies along the northern coastline with peaks below 1,000 m. *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 1,100 mm at the top of the central massif. As we go down toward northern and eastern island, the values decrease. At the central valley and southeastern areas along the shores, the value is lower than 300–350 mm [6]. According to the data provided by the Meteorological Service of Cyprus [7,8] and depicted in the following graphs (Figs. 3 and 4), the

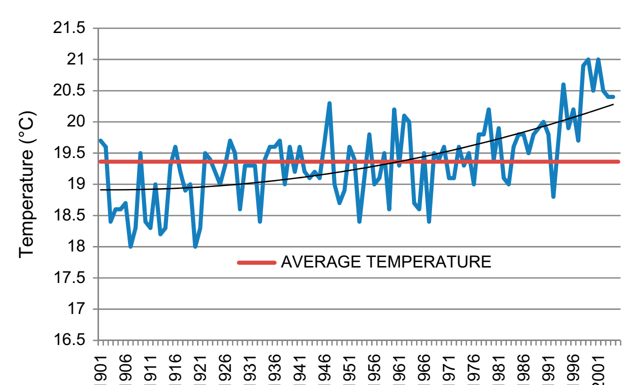

Fig. 3. Annual temperature fluctuations in Cyprus (Nicosia) (1901–2001) [7].

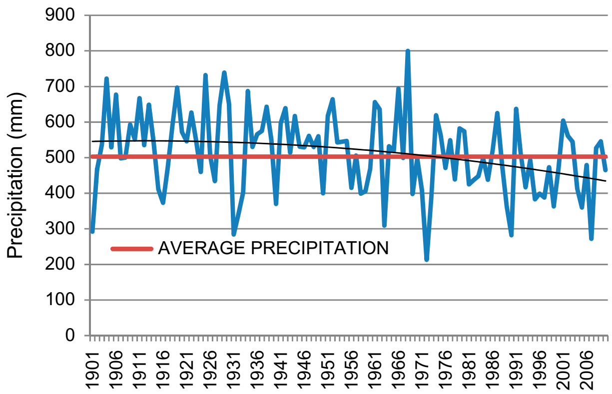

Fig. 4. Annual precipitation fluctuations in Cyprus (1901–2006) [8].

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.

3. Measures to conquer the 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 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 twentieth 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 [9]. Nevertheless, the problem was not 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" [10]. 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 [9]. The most remarkable dam project was the construction of Kouris dam at the late 1980s, as a part of the "Southern Conveyor Project" which through the conveyor pipeline was serving the districts of Limassol, Lefkosia, Larnaca, and nonoccupied Ammochostos. This radical increase of dam construction can be seen in Fig. 5.

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 1980s. 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, nonoccupied Ammochostos districts) [12]. The "Southern Conveyor Project" is the most significant water supplying construction in Cyprus [13] and can be seen in Fig. 6, along with other major water works in the island. Since then, the above four districts have been supplied by water mostly from Kourris dam through the "Southern Conveyor Pipeline" and Paphos district is provided with water from Asprokremos dam and Kannaviou dam [14].

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

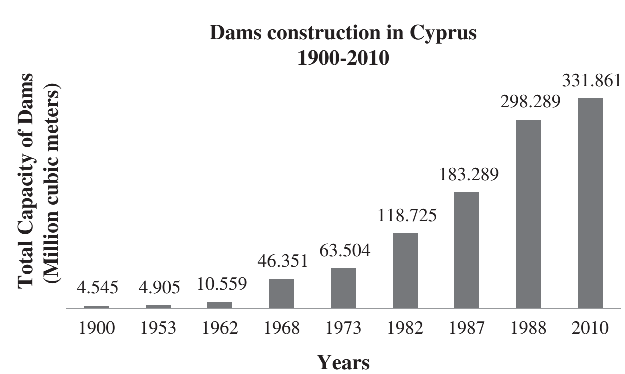

Fig. 5. Total annual capacity of Cyprus dams [11].

Fig. 6. Major water works in Cyprus, including the Southern Conveyor Project [14].

dams were below the average of the 26 years period (1987–2013), as it can be seen in Fig. 7.

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 could not 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 [15].

The desalination project began immediately, with the first two plants starting operating in 1997 and 2001 [15] at Dhekelia with capacity of 40,000 m^3/d (extended to 60,000 m^3/d by 2009) and Larnaca with capacity of 52,000 m^3/d (extended to 62,000 m^3/d by 2009) [16]. These first two plants covered adequately Larnaca, Lefkosia, and nonoccupied Ammochostos districts demand. However, due to the raise of drought and demand, more measures had to been taken. At 2008, although the two plants were operating, and the only district that 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€/m^3) [17], 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 (desalination of brackish water from the basin of the river) in 2008 and 2009 for the coverage of Limassol district, and at Paphos in 2010. In addition to these, 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 delivery of the project was delayed due to damage of the construction in July 2011 [18] (where the construction works stopped, the damage was estimated and

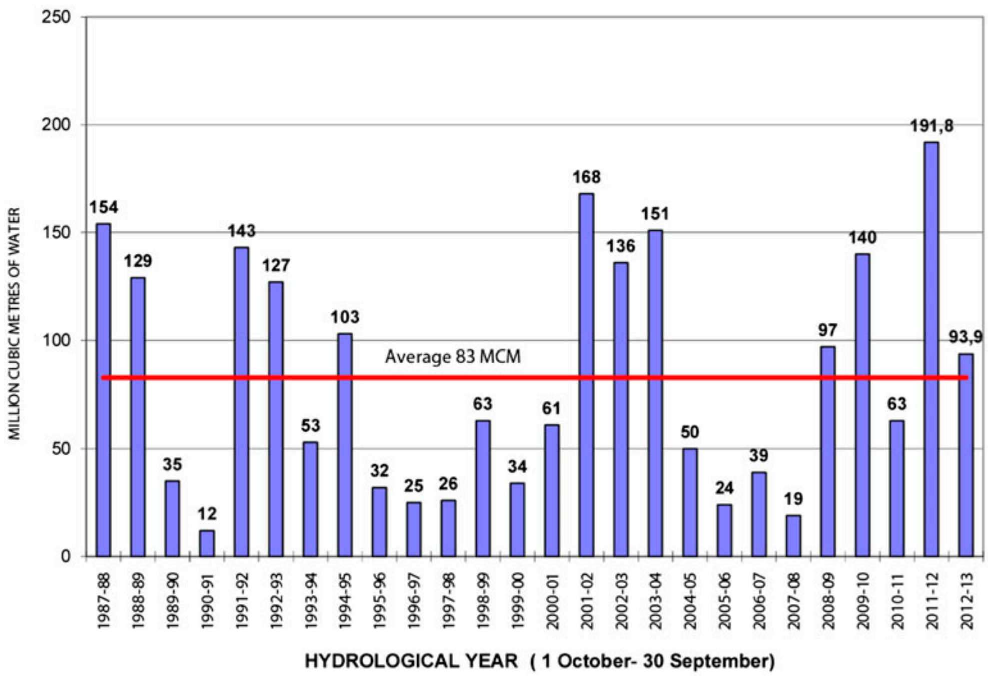

Fig. 7. Water accumulation in the dams (1987–2013) [2].

after a month the repairing started along with further construction works), caused by an explosion at the nearby naval base, and it is expected to be delivered during 2014 according to EAC [19]. The original plan was that five permanent desalination plants were going to be operating in 2013 with a total capacity of 260 m^3/d, creating water adequacy for the whole island. Nevertheless, the operation of Paphos, Episkopi, and Vasilikos permanent plants were not needed due to precipitation increase, leading to water inflow increase to dams [15]. The radical precipitation increase can be seen in Fig. 7. Those three plants are on reserve and can start operating whenever further need is met.

Over the last two years, precipitation increase created sufficiency of water by increased dam inflow. Water sufficiency 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.

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 m^3 (from October) until now, which is only 6.61% of last year's same period (77,321 million m^3). This sharp precipitation decrease is clearly illustrated in Fig. 8, with inflow to dams for December and January (which are considered the most productive months with respect to precipitation) for the last four years [20].

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 satisfactory water amount to the whole island. Although at this time, everything seems to be in order, we are facing a new different kind of problem. Due to economic reasons, the full operation

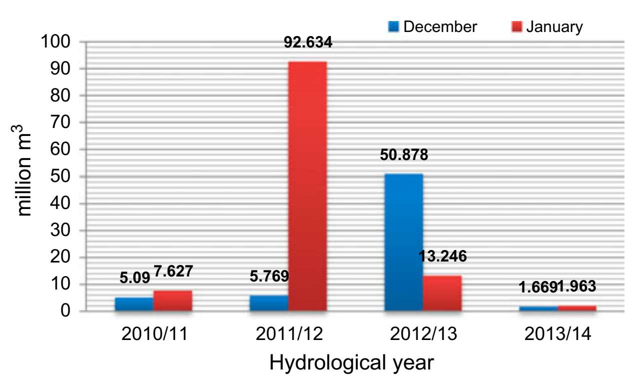

Fig. 8. Water accumulation in the dams, during December and January 2010–2014.

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 prospective 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 (reverse osmosis is higher energy consumer) [21].

Desalination high power demand generates economic and environmental effects. For example, an average capacity unit (40,000 m^3/d) requires 7,500–9,000 kW to operate. When all units in Cyprus (nine in total) operate, 12% of the total power produced by the 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 CO_2/y. Nevertheless, all the countries that signed the Kyoto Protocol, agreed to a limitation of GHG emissions [22]. 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 limit 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 emissions, 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 [21].

The following Table 1 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

Table 1
Effect analysis of the desalination units' operation [21]

Desalination unit	Production unit (m^3/d)	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 Moni	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

Notes: Very Important = 5, significant = 4, moderate = 3, relatively significant = 2, insignificant = 1.

consumption, the CO_2 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 10,000 m^3/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 CO_2 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).

5. Renewable energy sources and other environmentally friendly technologies

As it has been mentioned above, desalination units require high amount of energy,and 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 [21]. 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 that 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 thought heat source (sun) 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 [23]. Fig. 9 shows the process of desalination using this method.

A plausible solution to the saline rejection is examined by the Chemical Engineering department of the National Technical University of Athens, at an experimental facility placed in Tinos Island, in S. Greece. This particular plant reprocesses the saline that is being produced by the desalination process (the method used is reverse osmosis), instead of rejecting it to the sea. The process comprises the following procedure: vaporization, crystallization, and drying results to an average percentage of 65% pure water and 35% pure salt [25]. This may be a high-energy-consuming process; however, it could be used for low water production 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 to Cyprus. 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. Moreover, it only requires a container of no more than 12 m in length/long. This solution could also be considered for low water production units, as its daily production is 500–10,000 m^3/d, whereas Garyllis desalination unit's production is at the upper limit of 10,000 m^3/d [26].

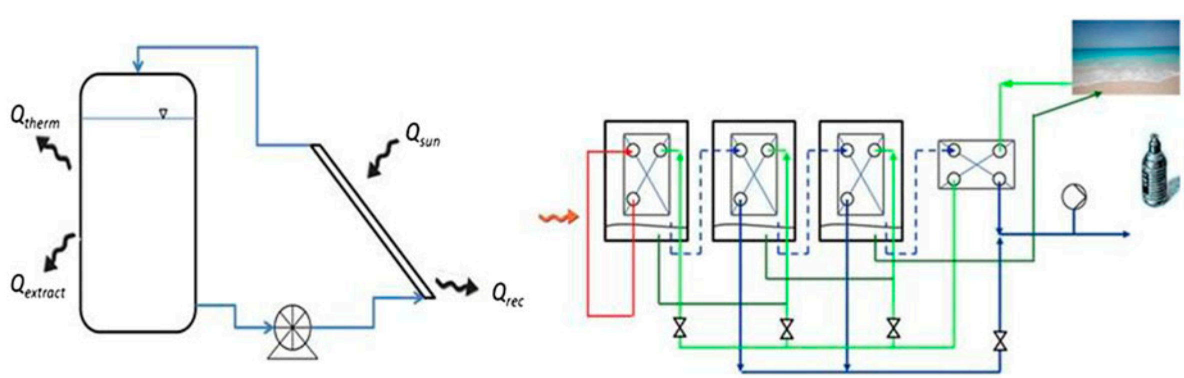

Fig. 9. Process of electric energy production and thermal desalination of STEP-EW [24].

Another interesting method is under investigation by researchers at the West of England University of Bristol, the 2015 European Green Capital. They 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 that 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 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 [27]. This technology may be at an early stage, with the experimental facilities producing only 2 m^3 of drinking water in a 12 d period, but it is estimated that in the near future the production of an actual size facility could reach 2 m^3/d. 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 microfiltration, reverse osmosis, and ultraviolet disinfection. After this procedure, water reaches high drinking standards. A country such as Singapore, of only 700 m^2 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 50% of future water demand of the island by 2060. Moreover, Singapore produces 10% of its water demand by desalination and also has plans to increase the desalination proportion to 30% by 2060 [28]. Singapore is a country with similar characteristics with Cyprus that face similar drinking water issues, so Singapore's example of wastewater treatment should be examined as an economic and environmentally friendly solution that can co-exist with desalination. In addition, Singapore's future plan for the coverage of 80% of its water demand by sustainable solutions is impressive and should set an example to all other countries that all is possible when taking action in the right direction and planning ahead.

Fig. 10. Optimized water cycle management [29].

The following Fig. 10 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 watertreatment 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.

6. 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 facilities. 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 or 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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