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Options for water scarcity and drought management—the role of desalination

R. Hochstrat[a,b,*], T. Wintgens[a], C. Kazner[b], T. Melin[b], J. Gebel[c]

[a]*Institute for Ecopreneurship, University of Applied Sciences Northwestern Switzerland, Gründenstrasse 40, 4132 Muttenz, Switzerland*
Tel.: +41-61-467-4794; email: rita.hochstrat@fhnw.ch, thomas.wintgens@fhnw.ch
[b]*Department of Chemical Engineering, RWTH Aachen University, Turmstrasse 46, 52056 Aachen, Germany*
email: christian.kazner@avt.rwth-aachen.de, thomas.melin@avt.rwth-aachen.de
[c]*S.T.E.P. Consulting GmbH, Eupener Strasse 30, 52066 Aachen*
email: gebel@stepconsulting.de

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ABSTRACT

Recurring droughts across Europe have increased the awareness for the vulnerability of current water management systems at both national and EU level. While the European Commission contemplates concepts, member states are taking actions to cope with restricted availability of water resources. The paper presents a summary of drought planning activities of some water scarce regions. It can be shown, that all concepts include seawater desalination as key component of drinking water supply. Additionally, wastewater reuse plays another important role in mitigating water shortage. A more detailed analysis is given for Cyprus which shows that there is remarkable potential and the intention to combine the various elements of water savings, water reuse and exploring new water resources.

Keywords: Adaptive strategies; Desalination; Drought management; Cyprus, Water reuse; Water scarcity

1. Background

More frequent drought periods especially in southern European countries during the 1990s have repeatedly revealed the limitation of available water resources. The vulnerability of even temperate climate regions has become obvious in summer 2003 when a heat wave struck large parts of Europe. Portugal, Spain and France suffered another drought in 2005 with high losses in agricultural production and forest due to wildfires. A recent survey revealed that 33 river basins in Europe are affected by water scarcity, representing 11% of the EU territory and 17% of the EU population [1] (EC, 2007). It is evident that water supply in such regions faces particular challenges.

Drawing up effective adaptive strategies will have to take into account that challenges occur at different levels of the water (supply) sector and therefore have to be equally diverse in their responses. We distinguish the following levels of investigation

1. Technology and operation.
2. Organization, management and finance.
3. Policy, economic measures and legislation.

Diversification of water resources utilisation has been confirmed as a major element in adaptive strategies. In combination with water demand management measures, increased flexibility with respect to exploitable resources can make a contribution to overcome water shortages. The utilization of alternative water sources such as seawater and brackish water through desalination as well as water reclamation and reuse are adaptation measures applied or considered. The paper summarises the status of implementation or contemplation of those measures in water stressed European

*Corresponding author.

regions. In particular, it discusses the variable role of desalination and membrane processes in assuring water supply by exploiting resources of impaired quality, be it salt content or other undesired constituents (e.g. organic contaminants and micropollutants).

2. Desalination as water scarcity and drought mitigation measure—the position of the European Commission

The Commissions Communication on Water Scarcity and Drought [2] identifies the need to move towards a water efficient and water saving economy by full implementation of the Water Framework Directive (WFD). This objective shall be achieved through a combination of complementary measures making particular use of economic instruments to price water right and allocate water and water related funding more efficiently. This also applies to the community strategic guidelines with regard to funding additional water supply infrastructure, which needs to be re-defined. In their position, they favour a clear hierarchy of water management measures and water uses, which puts water saving as the first and utmost important step of all possible and necessary activities. The development of additional water supply infrastructure (including desalination and water reuse) is regarded critically. Nevertheless this option should be assessed taking into account the specific bio-geographical circumstances of Member States and regions.

Figure 1 illustrates the hierarchy of various options ranking water demand management and savings over water reuse and production of water from alternative sources by desalination. It also points out some of the major issues to be considered when selecting the option.

In Europe, desalination technology is currently reviewed by the European Commission in terms of some key sustainability issues such as energy consumption, carbon foot-print and cost [3]. The study indicates that the accomplishment of further energy savings in RO desalination is of key importance for the minimisation of additional CO_2 emissions.

3. Desalination as water scarcity and drought mitigation measure—its role on member state level

Though placed in the corner of a last resort option by the European Commission in the relevant documents on Water Scarcity and Drought [1,4] desalination has grown to be one of the most important water scarcity adaptation and mitigation options all over the world, predominantly in the Middle East, North Africa, North and Central America, South East Asia and Australia [5].

Due to its high investment cost and its rigid and rather inflexible supply regime desalination is best suited to supply a fixed amount of water [6]. It is an essential cornerstone of drinking water supply particularly in water scarce regions, such as Malta, the Balearic Islands, regions of Spain, Greek Islands and Cyprus.

In Europe, Spain is leading in terms of installed desalination capacity, with some schemes providing even water to agriculture [7]. In a concerted effort to combat recurring water shortages and to achieve the goals of the Water Framework Directive, the A.G.U.A. program had been launched in 2004 to supply additional 1100 Mm³ of water to the Mediterranean river basins in a four year period. Desalination was planned to deliver more

Priority of action	1	2	3	4
Type of action				Water transfer
			water production seawater desalination	
		Water reuse		
	Water demand management, water saving	Supply infrastructure measures		
Instruments to be applied	Economic instruments, fostering water efficient technologies and practi ces			
Issues to be considered		Public and environmental health issues	Brine treatment energy demand	Environmental impact, cost

Fig. 1. Hierarchy of measures to address water scarcity issues and the role of desalination.

Table 1
Overview on quantitative contributions of different planned water management options in a few selected water scarce regions in Europe.

	Aim	Saving, Increase of efficiency	Reuse	Desalination	Rainwater harvesting	Increase secure yield of existing water infrastructure	Total
		Mm³/yr					
Spain - A.G.U.A. 2004–2008	WFD implementation drought mitigation	231 (21%)	137 (13%)	641 (59%)	–	74 (7%)	1083
Catalonia till 2025 [8]	WFD implementation increase of ecological flow	75 (25%)		200 (67%)	–	25 (8%)	300
Malta [9]	WFD implementation achieving good status of GW; abstraction (-20%)	0.75 domestic	6-7	–	0.25	–	8
Cyprus by 2012 [10,11]	WFD implementation drought management	not quantified	52 (58%)	appr. 37 (42%)	–	not quantified	89

than half of this amount (58%), while water saving measures contributed one fifth. Water reuse was to deliver 137 Mm³/yr (13%) as summarized in Table 1.

The Catalonia Water Management Plan exhibits a major commitment to water saving, reuse and production with an overall increase in resources by 300 Mm³/yr. The measures also pursue the restoration of impaired resources. The main contribution will come from desalination (67%) with reuse and water efficiency measures saving 25% of the total amount.

In Malta the emphasis is on substituting irrigation water, to date those abstracted from aquifers, by reclaimed effluents in order to achieve the good status of groundwater resources by 2015.

Domestic savings will not greatly contribute to a relief of pressure on groundwater, as drinking water is already being primarily supplied from desalination plants. Nonetheless, water tariffs and water saving appliances are supposed to save 0.25 Mm³/yr.

Only in Cyprus water reuse seems to contribute more than desalination to future water resources augmentation. But as the data situation is very scant and no official numbers could be obtained this is a very vague conclusion.

4. Desalination and reuse

In most applications desalination provides water for potable uses or water for first uses in other sectors. Nevertheless reverse osmosis technology itself is increasingly applied to close water cycles and features a crucial step in many water recycling schemes. It has become the key water desalination technology not only for seawater applications, where thermal desalination processes still play an important role, but also in brackish water desalination and in the reclamation of effluents from wastewater treatment plants for high quality purposes [12,13].

In water reclamation, effluent desalination is applied mostly in the context of industrialised countries with high quality requirements, sufficient financial resources and a "no-risk" perception related to potential health burdens arising from water recycling. In this respect, double membrane processes featuring mostly ultrafiltration as a pretreatment stage and reverse osmosis, generally equipped with "low-fouling" brackish water desalination membranes, are utilised e.g. when it comes to indirect potable reuse (e.g. in cases such as Groundwater Replenishment Scheme in California, Torreele/Belgium, Western Corridor Project in Brisbane and NeWater in Singapore), often in connection with managed groundwater recharge, high quality industrial purposes (e.g. West Basin/California, Wollongong/Australia, NeWater and several schemes in China) or domestic dual reticulation systems with a potential risk of misconnection (e.g. Sydney Olympic Park/Sydney). In some conditions salts are also critical components in unrestricted irrigation applications, particularly due to salt-intolerant plant and as the groundwater can get affected, desalination is applied (e.g. Sulaibiya scheme in Kuwait, Rincon de Leon, Spain).

An alternative technology for treating brackish groundwater or effluents is electrodialysis reversal

(EDR), which can be competitive also due to lower pretreatment requirements. Installations in Europe include brackish water desalination in Valencia and effluent desalination in Gran Canaria and Tenerife [14].The largest EDR plant in Europe has been implemented recently by Aigües Ter Llobregat (ATLL) close to Barcelona with a capacity of 200,000 m^3/d.

Apart from the energy, cost and CO_2 emission issues linked to the actual desalination are sustainability concerns related to the transportation and brine disposal infrastructure if users should be supplied, if not placed in vicinity of the sea. Brine disposal is a major point of concern mostly addressed by appropriate placement of diffusers and monitoring of the environmental impact [15]. Process combinations for treatment of process-derived waste brines in water reclamation have been investigated in the European RECLAIM WATER project, e.g. utilizing activated carbon adsorption plus membrane filtration as well as electro-deionisation [16].

5. Implementation and contemplation—the case of Cyprus

Cyprus is the most water-stressed member state of the European Union with a water exploitation index exceeding 45% [7,17]. In 2008, after a series of dry years the reservoirs dropped to unprecedented low levels and necessitated to cut water supply and to import tankered water from Greece. Obviously, there is need to improve the adaptation to increasing water scarcity and drought.

5.1. Water saving

Water demand management measures have been implemented in both the agricultural and the domestic sector. The economic instruments applied are charges to promote the water efficiency (e.g. rising block tariffs in domestic water supply and over consumption rates for quantities exceeding the maximum allowable in agriculture) [10]. Yet with a selling price of 0.19 EUR/ m^3, irrigation water is still in high demand.

Irrigation efficiency in the government irrigation schemes is high. The use of drippers, mini sprinklers and low capacity sprinklers is applied to greenhouse cultures, citrus and other trees as well as field vegetables. Subsidies on the installation costs, resulted in a rapid expansion of the new irrigation systems [18]. It is estimated that currently over 95% of the total irrigated land of the country is being served by modern irrigation methods The on-farm irrigation systems comprise 90% micro-irrigation, 5% sprinkler irrigation and 5% surface irrigation [19].

While the irrigation technology is reasonably advanced, the irrigation schedule leaves room for optimising the water application (depending on soil moisture etc.). Further, changes in cropping pattern may offer a potential for water saving in the agricultural sector.

Further improvement of water efficiency can be realised in the distribution networks. Loss of water varies greatly between drinking water suppliers. Water Boards manage to keep them in the range of 17–28% equalling a total of 7.6 Mm^3. Leaky pipes and theft in the municipalities and community networks however generate losses between 35–40% [20].

5.2. Water reuse

Water reuse provides additional drought-proof water supply, favours a more local sourcing of water and avoids the use of drinking water quality sources where such high quality is not needed. The potential for water reuse depends on the availability and accessibility of wastewater, hence the wastewater infrastructure, and the acceptability by potential end-users and consumers.

5.2.1. Reuse applications

In general, all treated wastewater is reused, primarily for irrigation of agricultural land, parks, gardens and public greens (Fig. 2). Most crops irrigated are trees such as citrus and olive or fodder crops and cow grass.

A small proportion is used for groundwater recharge. At Paphos the Ezousa aquifer is recharged artificially with 2–3 Mm^3 reclaimed effluent per year, which is reabstracted for irrigation. Investigations by Christodoulou et al. (2007) showed that the aquifer would be able to store more water, once available [21].

The contribution of recycled water to all irrigation water supplied by the Government Water Works makes up about 7–10% which equals 3–5 Mm^3.

Only in exceptional cases, mostly during winter, when there is no irrigation water demand, treated effluent is discharged to the sea. This amount can be as high as 3–4 Mm^3 but recently only made up 1 Mm^3 as irrigation of crops had to start earlier in the year.

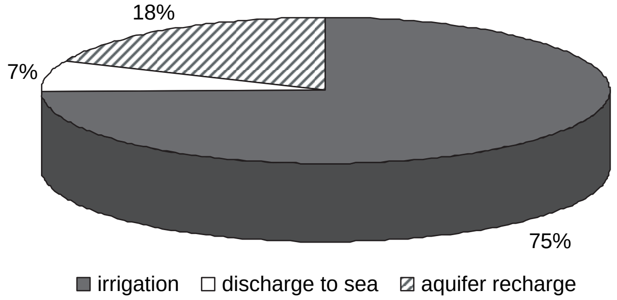

Fig. 2. Re-use of treated effluent in 2007 [10].

5.2.2. Future perspectives

There is an immense potential for growth of water reuse practices driven by both the demand for water and the increasing volumes of treated effluent. Aiming for compliance with the Urban Wastewater Treatment Directive (91/271/EEC) requirements, the wastewater collection and treatment infrastructure is being significantly expanded and upgraded.

The pollution load to be treated is set to 675,000 population equivalent (p.e.) of which 80% are generated in urban agglomerations, which are the greater areas of Nicosia, Larnaca, Limassol and Paphos, and the municipalities of Ayia Napa and Paralimini [22].

Existing sewage treatment plants have been extended recently. The Limassol-Amathus sewage treatment work has been enlarged from a treatment capacity of 70,000 p.e. to 272,000 p.e. and is now able to handle 40,000 m^3 per day. Such upgrades correct the overload under which some plants have been working for years and eventually improve the effluent quality.

A projected plant in Nicosia greater area for a population of about 150,000 will use membrane technology to treat part of the 55,000 m^3 effluent per day. The plans foresee to use one third of the water for local irrigation. The remaining 66% will be treated with reverse osmosis and get fed into the irrigation networks of the Southern Conveyor Project [23]. After full implementation of planned schemes the treated wastewater flow will amount to 59 Mm^3/yr in 2012 and increase further till 2025, as summarised in Table 2 [10]. The annual water recycling is expected to use 52 Mm Mm^3 by 2012 which equals 28.5% of today's agricultural water demand [11].

Table 2
Estimated volumes of treated wastewater [10,11].

	2012	2015	2025
	Mm^3/yr		
Municipal wastewater treatment plants	46	51	69
Rural wastewater treatment plants	13	14	16
Total	**59**	**65**	**85**
Annual water recycling	52	–	–

5.3. Desalination

Compared to water capturing in dams, desalination is a highly engineered and energy intensive process. Relying on desalination to produce drinking water shifts concrete infrastructure needs and reliance on rainfall to stainless steel and a dependable energy supply. The associated high cost and environmental impacts cause a considerable reluctance and opposition to implementation. Nevertheless Cyprus has embarked on desalination technology in the late 1990s after a series of drought years.

5.3.1. State of implementation and future prospects

By the end of 2008, Cyprus has an installed desalination capacity of 112,000 m^3/d. The plant in Dhekelia was put into operation in 1997 with a nominal capacity of 40,000 m^3/d. Since 2001 a plant in Larnaca supplies 52,000 m^3/d. In Moni, a mobile unit has been installed and commissioned in December 2008 providing another 20,000 m^3/d. Desalination already makes up for almost 40% of domestic water supply with a clear upward trend (see Table 3).

Future plans encompass the construction of another desalination plant near Limassol (in the Episkopi area, 60,000 m^3/d), and to tender real mobile desalination units that are installed on ships that cruise the Cypriot coastline and supply freshwater to municipalities where needed (WDD tender, Cyprus Mail [23]).

Table 3
Installed and planned desalination capacity in Cyprus [11,24].

Plant Location		Commission date, Year	Nominal capacity	
			m^3/d	Mm^3/yr
Dhekelia	Permanent	1997	40,000	14.60
Larnaca	Permanent	2001	52,000	18.98
Moni	Mobile	December 2008	20,000	7.30
Larnaca		Planned upgrade 2009	10,000	3.65
Paphos (Kouklia)	Mobile	Planned June 2009	30,000	10.95
Limassol	Floating plant	Summer 2009 (for 5 years) to replace imports	20–50,000	18.25
Limassol (Episkopi)	Permanent	Planned for 2013	40–60,000	21.90
Total	–	–	–	**95.63**

Further to the large volume centralised plants, there are also trends for private installations that may directly supply hotels or single users. Further small-scale desalination units (1,500 m^3/d) to serve hotels in the Pegeia district are under discussion[1] and companies are trying to develop this business [25].

Desalination is also an option to satisfy new demand, though highly disputed and controversially discussed in Cyprus. Recently the licences for 14 new golf courses and the accompanying housings (requiring an estimated 30 Mm^3/yr), have been issued under the precondition to have their own desalination unit, which must be powered from renewable energy sources [26]. This is an attempt to reconcile the incompatibility of increasing desalination capacity and reducing greenhouse gas emissions. Research on solar-thermal desalination is underway[2].

5.4. Increasing efficiency and yield of existing infrastructure and resources

The water supply of Cyprus strongly depends on surface reservoirs and rainwater capture. Since the dams already suffer from low inflow, options to improve their efficiency are limited.

On the other hand the development of strategic, protected groundwater reserves would be an essential improvement and provide more drought-proof water supply, as suggested by [27]. Such reserves could be built up with resources from dams becoming available as drinking water is being supplied by desalination. The application of advanced water reclamation technology, such as RO would produce high quality effluents suitable to restore the exploited aquifers.

6. Conclusions

Desalination already plays an essential role in water management. It constitutes a secure source for safe drinking water supply, once demand management measures are fully implemented. In enhancing drinking water supplies through seawater desalination, reverse osmosis competes with thermal desalination processes. The latter can be easily decommissioned, e.g. during winter, and hence are better suited for seasonal operation. They also offer potential to materialise synergies by using waste heat of other processes, such as biogas combustion [28]. Desalination of effluents for water reuse is another relevant and often less costly option, as no seawater intake infrastructure is required to treat even less salty water. To further enhance the acceptance of reclaimed water use, safe barrier against compounds of concern needs to be established and may be provided by reverse osmosis technology.

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