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Fluctuations in potable water quality in Cyprus during the past two decades – the role of seawater desalination

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ABSTRACT

The scarcity of drinking water resources in Cyprus has started becoming a major issue during the past decades, as a result of prolonged draughts and failure to implement a sustainable water conservation and management policy. Cyprus, a semi-arid classified area in the Eastern Mediterranean, has traditionally been relying on water reservoirs for the collection and treatment of rainwater destined for human consumption. Seawater desalination has been introduced during the past 15 years as a means of alleviating the drinking water shortage problem and complementing the dam reserves; however, the usage of desalinated water has not yet been optimized. As a result, desalination plants have been constructed and shut down after only short operation times, some have been built and commissioned only to be put on standby mode soon after, while construction of others was postponed until it was too late to cope with water shortage problems etc. This situation has been creating a series of problems associated with potable water quality in general and other numerous anomalies being observed in the distribution network, the most important of which are the following:

(1) Water shortage during peak periods (e.g. summer months when demand rises sharply due to tourism and irrigation needs).
(2) Blockage at terminal points of the distribution network.
(3) Bad odour and unpleasant smells observed at consumption points.
(4) Elevated heavy metal concentrations in potable water supplies.
(5) Elevated THM's concentrations in potable water supplies.
(6) Corrosion of metal piping in the distribution network.

This study shall examine these problems in depth and provide suggestions that will help in establishing a truly sustainable drinking water policy on the island.

Keywords: Prolonged draughts; Water conservation; Seawater desalination; Potable water quality; Biofilm formation; Distribution network

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1. Introduction

Aristos Loucaides Chemical Laboratory Ltd. is an analytical laboratory in Cyprus. Its presence in the local market is imposing, and it is considered to be one of the major players in the private sector.

Since its establishment in 1989, the company has been extensively involved, among others, in the provision of analytical services in the drinking water sector in the island.

Its long-standing experience has been closely linked to the evolvement of the potable water quality in Cyprus during the past 24 years. The lab has invested a lot in maintaining the quality of its analytical results. As a result, it has become ISO 17025 accredited by the United Kingdom accreditation service (UKAS) since 2005 (and since September 2014 accredited with the Cyprus accreditation body) and has also recently (2013) been awarded UKAS accreditation on the expression of opinions and interpretations on its test certificates. This last achievement, again a unique accomplishment on the island, has been the result of the multidisciplinary and long experience of the laboratory's director in the analytical sector.

The laboratory's technical competence has been recognized by international customers as well as the local market; service contracts are in operation with different governmental and private organizations, offshore companies based in Cyprus and also overseas customers seeking analytical services support.

The laboratory has been collecting analytical data on potable water quality since 1990 and has been actively involved in many projects relating to potable water production, treatment and distribution, including water refineries, seawater and brackish water desalination plants, transportation of potable water to the island by sea, monitoring of nitrate pollution of aquifers and coastal waters.

Dr Erineos Koutsakos, after 20 years in the water treatment industry, has been the Plant Manager of Larnaca desalination plant for eight years and currently the General Manager of both Larnaca and Limassol desalination plants.

In this paper, an attempt shall be made to describe the fluctuations in potable water quality on the basis of specific key parameters and to assess the effect that was introduced with the advent of seawater desalination in the late nineties.

2. Historical data

Cyprus, a semi-arid classified area in the Eastern Mediterranean, has traditionally been relying on water reservoirs for the collection and treatment of rainwater destined for human consumption. Cyprus summer is prolonged, starting from early May–June and persisting with as high temperatures as 35–40+ °C till end of October. Consequently, the need not only for a sustainable source of potable water emerges but also the need for uninterrupted water supply to agriculture and other vital sectors of the economy, like tourism.

However, prolonged drought periods that have been observed on a seven year repeated cycle, have shown that an additional and sustainable source of potable water would have to be exploited in order for the island to survive these long periods where water virtually becomes a scarce resource. During these periods, several measures are taken by the local water boards, aiming to promote water conservation. These measures often include cuts in the potable water supply. This policy, however, has historically shown that water demand rises instead of being reduced, as a consequent result of households installing additional storage tanks. In addition, the Water Development Department (WDD) of the Ministry of Agriculture, Natural Resources and the Environment, the government body that is responsible for the availability and management of potable water resources throughout the island, is organizing events and campaigns to raise consumer awareness on the value of water and to stress the importance of saving every single drop of water. Moreover, the WDD is striving to control the numerous boreholes that exist all over the island in an effort to preserve our underground water resources and prevent unauthorized drilling that causes severe pollution problems; also, it exercises strict control on private desalination plants, both inland for the desalination of brackish water and at coastal areas. We are citing, at this point, the booming that was observed in private desalinations during the early nineties, when prolonged drought periods dictated the need for many nurseries and garden centres to commission their own reverse osmosis (RO) plants. This gave a first "bitter taste" of how serious are the problems that can arise when RO plants are commissioned and operated without basic provisions for brine disposal and pretreatment for boron removal that is severely toxic to many plantations.

As a more serious answer to the above problems, the first seawater desalination plant was commissioned in the late nineties (1997), at Dhekelia, near the Electricity Authority of Cyprus (EAC) power station. The Larnaca desalination plant, next to Larnaca International Airport followed in year 2000, the mobile seawater desalination unit at Moni during year 2008, the Garyllis brackish water plant in Limassol and the mobile seawater desalination unit at Kouklia, Paphos

Table 1
Reservoir water—typical composition in Paphos area—before and after refining

Parameter	Unit	Value (reservoir outlet)	Value (refinery outlet)
pH	–	8.05	8.04
Electrical conductivity	μS/cm at 20°C	435	447
Total hardness	mg/L as $CaCO_3$	179	173
Turbidity	NTU	2.49–3.12	0.69
True colour	Pt–Co	7–19	3
TOC	mg/L	2.5	2.4
Total suspended solids (TSS)	mg/L	<2	<2

in the year 2011, that only operated for a few months before being eventually removed last year. The latest and most contemporary seawater desalination plants were commissioned in 2013; one within the Vasilikos EAC's power station and the other at Episkopi, Limassol. The latter has utilized the Amberlite™ ion exchange resin for boron removal.

As a result of the variable water supplies and origin, potable water quality in Cyprus has been showing substantial variations. These variations, in turn, affect the condition of the potable water supply network, in household and industrial applications alike. The effects are alternating between heavy scale with subsequent biofilm formation, and scale dissolution followed by debris deposition and release of bad odours into the distribution network.

A more detailed examination of these variations and the relevant effects on consumers can be carried out by looking at specific water quality parameters and how these vary depending on the water source. In general, potable water quality is governed by local legislations that are mainly based on the 98/83/EU directive. Parameters that are of prime importance are pH, electrical conductivity, total hardness, chlorides, alkalinity, total dissolved solids and boron. Derived parameters, like the Langelier saturation index (LSI) are also important, as this greatly affects the pipes themselves of the distribution network. Total organic carbon (TOC) has also been introduced as an additional monitoring parameter. It is particularly useful when assessing the effectiveness of the refining process for reservoir water.

When rainfall is satisfactory and the water reservoirs overflow, as it has happened in 2012, the desalination plants are put on stand-by. Water collected in reservoirs passes through water refineries that basically remove suspended matter by flocculation and filtration, followed by disinfection, before pumping into the mains network. Reservoir water is occasionally blended with borehole water before being refined for human consumption.

Typical values for reservoir and borehole water are given in Tables 1 and 2 below.

On the other hand, during periods of drought with dry winters (like last year), desalination plants come into operation and the distribution network is exposed to a different situation. Potable water produced by seawater desalination plants is very strictly monitored by the WDD. Typical values for the main parameters in desalinated water are given in Table 3 below.

Above tabulated results show clearly the main differences between desalinated and dam water.

More specifically, Desalinated waters exhibit much lower hardness than dam waters (see Section 3.1 below). As dams are predominantly collecting rain water, their electrical conductivity and boron values are in general lower than those of desalinated water. The boron concentration limit in desalinated waters has recently been reduced to 500 μg/L compared to the old upper limit of 1,000 μg/L (as imposed by the European drinking water directive—see also discussion in Section 3.4 below). However, as dams are also receiving lots of debris and organic residues, their TOC values are always higher than those of desalinated water. A more detailed discussion on TOC is made in Section 3.5 below.

3. Discussion

3.1. Effects of changes in water hardness

The advent of desalinated water in the late nineties has caused many changes in the distribution network. Areas that were traditionally supplied with very high total hardness mains water (350–400 mg/L as $CaCO_3$) had to adapt virtually overnight to the "less scale depositing" tendency of desalinated water. The result was that the long-formed calcium carbonate deposits and biofilm on the inner surface of the distribution network, that in many cases reached a few centimetres in thickness, started to gradually "dissolve", thus releasing debris and bad odour through consumers' taps.

Table 2
Borehole water—typical composition in Limassol area—major ions

Parameter	Unit	Value Borehole #1	Value Borehole #2	Value Borehole #3
pH	–	7.60	7.75	8.14
Electrical conductivity	μS/cm at 20˚C	1.098	1.008	0.812
Total hardness	mg/L as $CaCO_3$	448	418	206
TOC	mg/L	4.6	13.8	0.7
Chlorides	mg/L	101	115	69
Sulphates	mg/L	230	200	115
Carbonates	mg/L	<6	<6	<6
Bicarbonates	mg/L	321	345	347
Nitrates	mg/L	1.0	<1	<1
Nitrites	mg/L	<0.007	<0.007	<0.007
Fluorides	mg/L	0.296	0.246	0.154
Sodium	mg/L	109	88	163
Potassium	mg/L	<3.2	<3.2	<3.2
Calcium	mg/L	102	57	35
Magnesium	mg/L	47	67	29
Ammonium	mg/L	<0.12	<0.12	<0.12
Boron	μg/L	172	<65	102

Table 3
Desalinated water

Parameter	Unit	Desalination plant #1	Desalination plant #2	Desalination plant #3
pH	–	8.09	9.01	8.93
Electrical conductivity	μS/cm at 20˚C	473	799	599
Total hardness	mg/L as $CaCO_3$	127	74	43
LSI	at 22˚C	+0.25	+0.52	+0.22
TOC	mg/L	<0.5	<0.5	<0.5
Total dissolved solids (TDS)	mg/L	294	418	330
Chlorides	mg/L	67	204	165
Nitrates	mg/L	<1	<1	<1
Nitrites	mg/L	<0.007	<0.007	<0.007
Calcium	mg/L	37	20	12
Ammonium	mg/L	<0.12	<0.12	<0.12
Free residual chlorine	mg/L	0.34	0.37	0.26
Boron	μg/L	415	419	937

A typical example of the heavy scale depositing effect of potable water is shown in the pictures below, where a water distribution pipe has virtually been totally blocked by calcium carbonate deposits (Fig. 1).

3.2. Biofilm formation and organoleptic issues

As many water scientists would argue, rainwater collected in reservoirs is better than desalinated water in many respects; it is natural, with lower overall salinity, lower sodium chloride and boron concentration, etc.

In practice, however, water drawn from reservoirs is blended with borehole water, and it contains whatever organic residues and calcium minerals leached by rainwater along its way to the reservoirs, not to mention the high organic matter that has been accumulating in the reservoirs during prolonged draught periods and which is being diluted and not effectively removed by the refining process (see TOC values in Table 1 above). Therefore, reservoir water creates more problems relating to biofilm and scale formation in the distribution network. The importance of controlling biofilm formation has been stressed in numerous articles and different techniques have been adopted over the years [1,2]. Biofilm causes an array of detrimental effects on the final consumers' side; households and industries alike. Increased scale deposition on hot water applications results in higher cost and waste of energy in heat exchange applications,

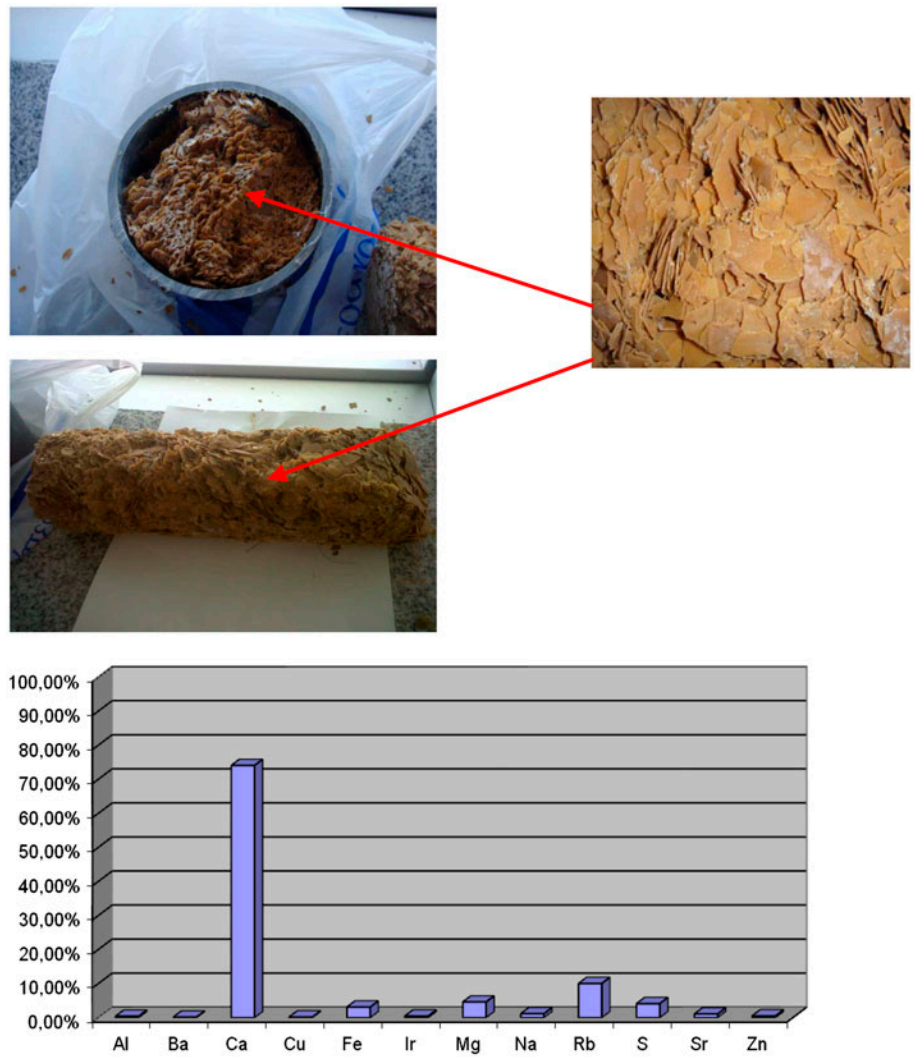

Fig. 1. Scale deposits in potable water distribution network and ICP scan showing predominant ions in these deposits.

unnecessary downtimes, increased risk of system colonization with bacteria, etc. Moreover, an additional risk of possible release of elevated aluminium concentrations in the mains supply always exists (aluminium sulphate is the main flocculent used in water refineries). Also, though not harmful, the earthy and/or musty taste imparted to water (by MIB and Geosmin) is another organoleptic issue facing communities supplied with reservoir water, usually during late summer months. These substances cannot be removed with conventional water treatment and their removal calls upon the use of higher-cost techniques (powdered activated carbon).

More specifically, looking at the scale deposition tendency of potable water, this has been showing tremendous variations during the past two decades. Ranging from around 400 mg/L and above as $CaCO_3$ (during the late 1980s) to less that 200 mg/L with the advent of desalination plants. These variations have been upsetting the distribution network, causing rise in the maintenance costs and affecting the organoleptic attributes of the water resulting in consumer complaints, as stated above.

Typical mains water composition, reflecting above problems, is shown in Table 4 below. Also, Fig. 2 below shows clearly the biofilm formation potential in a used polypropylene household filter. As already mentioned above, aluminium, calcium and silica are the predominant ions in the biofilm formation.

3.3. LSI variations

In addition, the “corrosion” tendency of water should also be examined in conjunction with the

Table 4
Mains potable water, urban and suburban Nicosia (2013)

Parameter	Unit	Residence #1	Residence #2	Residence #3	Residence #4	Residence #5
pH	–	7.87	8.11	7.97	7.98	7.81
Electrical conductivity	μS/cm at 20˚C	679	682	681	719	687
Total hardness	mg/L as $CaCO_3$	265	258	271	285	263
Chlorides	mg/L	71	70	70	77	73
Boron	μg/L	102	117	102	120	116
Aluminium	μg/L	115	164	124	126	160

"scale depositing" tendency. The LSI has been adopted as a yardstick against which the scale-dissolution tendency of water is assessed. As noted above, this parameter is strictly monitored for desalinated waters, as severe corrosion of the distribution network and end users equipment may occur, if this is not adjusted properly. The WDD has adopted the value of +0.2 as a minimum for the product water leaving desalination plants.

The more "corrosive" or "less scale depositing" desalinated water has been closely related to the bad odour that was noticed by end users in the Paphos area back in 2010–2011, when the Paphos desalination plant was commissioned in 2010. This area had traditionally been supplied with very high total hardness water (>400 mg/L as $CaCO_3$). During the first months of the plant's operation, there were many complaints from consumers relating to bad odour through their taps. The explanation for this was the gradual "dissolution" of the heavy biofilm on the inside of the distribution network. The thickness of the biofilm usually allows for the development of anoxic conditions that favour the multiplication of a plethora of bacteria that are associated with bad odours.

The above effects on biofilm stability as a result of the introduction of desalinated water into distribution networks, mixed at various proportions with natural waters, have been extensively investigated in various articles; it has actually been experimentally demonstrated that use of an increasing proportion of desalinated water results in less biodiversity [3].

3.4. Boron concentration changes

The boron concentration in potable water supplies is another critical issue that has received a lot of attention since the advent of seawater desalinations. Boron concentration in seawater in our area normally ranges between 5,000 and 6,000 μg/L. The first plants were operated with the 1,000 μg/L boron as the maximum permissible concentration in the product water, which is in line with 98/86/EU requirements. This has however been reduced to 500 μg/L in the latest plants, e.g. the Limassol desalination plant, at Episkopi. This measure was taken by the WDD as an additional contribution towards safeguarding the quality of the water resources on the island. Cyprus, as Malta, depends on limited water resources and have traditionally been exercising stringent monitoring on boron runoff. All liquid detergents contain stabilizers of the enzyme (that are normally boric compounds/derivatives, e.g. boric acid). In addition, granular detergents contain boron-rich bleaching agents (sodium perborate that is gradually being phased out and replaced by sodium percarbonate). An upper boron concentration of 30 ppm has been imposed on all granular detergents. It is noted that boron concentrations in excess of this were found in several granular detergents between 2004 and 2005 (up to 30,000 ppm). Seawater desalinations are now producing water with higher boron concentrations than reservoir water (450–500 vs. 40–200 μg/L). However, desalinated water is undergoing stringent quality control checks on a daily basis and its quality has traditionally been considered to be much more stable over steady state operating conditions. Reservoir water, on the other hand, is impossible to be controlled to the same level and its homogeneity suffers, depending on blending requirements and rainfall.

3.5. TOC variations

The TOC that accumulates in water reservoirs during period of prolonged drought comes as an additional parameter that needs to be monitored, as it provides a very useful and sensitive indicator of organic pollution. Debris, disintegrating organic matter and leaching of a variety of organic contaminants that end up in water reservoirs, make the TOC monitoring even more imperative. Closely linked to this is the formation of the carcinogenic disinfection by-products. Recent incidents of suburban areas where drinking water supplies originate from

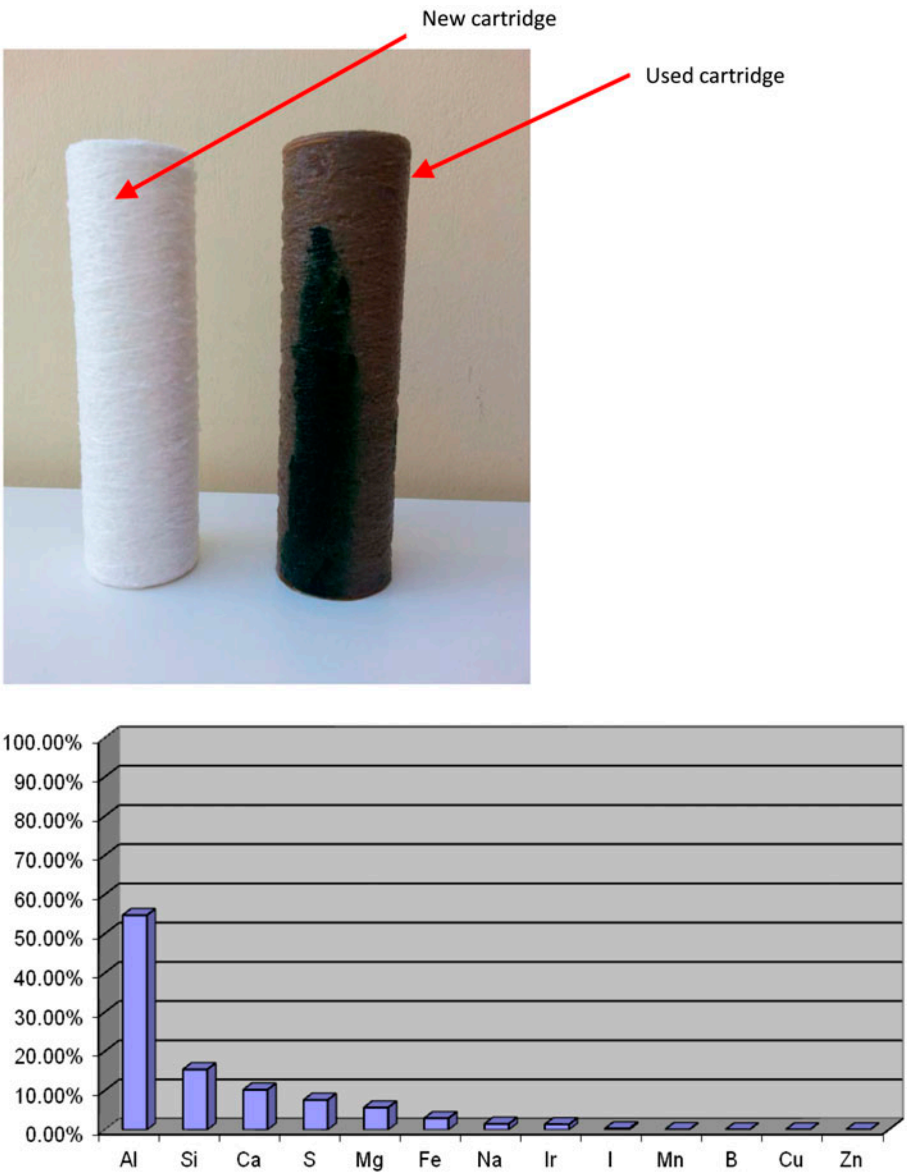

Fig. 2. Biofilm formation and salt deposits on a one year old PP filter cartridge, compared to a new one, and ICP scan showing predominant ions.

boreholes and surface waters only, have raised this issue of disinfection by-products. Waters rich in natural organic matter have been found to contain trihalomethanes (THM's) concentrations exceeding the European directive upper limit of 100 μg/L. THM's formation normally occurs in the main storage tanks that receive surface waters and in which chlorination takes place. These tanks are not subjected to frequent cleaning, and accumulated organic debris forms an ideal environment for the rapid formation of disinfection by-products.

3.6. *Effect of interruptions of water supply (hydrodynamic effects)*

Inevitably, the stopping/starting of water supplies in drought periods causes sudden changes in the hydrodynamic conditions of the distribution network. This Hammer effect disturbs and releases biofilm into the system, causing microbiological and the associated organoleptic problems at consumer taps, as already detailed in Section 3.2 above. It can also cause pipe breakages if the pressure is high enough [4].

In addition, there have been numerous examples of contaminants entering the distribution network as a result of the Siphon effect, in areas that would normally experience water leakages through damaged pipework.

4. Recommendations

Optimization of the water quality provided to consumers shall be the prime objective of a sustainable drinking water policy on the island.

This constitutes a series of measures aiming at improving the quality at the consumers' taps, including, but not being restricted to, the following:

(1) Provide uninterrupted and of constant quality supply of potable water.
(2) Eliminating odours and bad smells (i.e. minimize or avoid variations in the water resource).
(3) Keeping total hardness below 200 mg/L as $CaCO_3$ while at the same time providing a marginally positive saturation index (LSI ≥ +0.2).
(4) Eliminate problems associated with unstable hydrodynamic conditions in the distribution network (e.g. during water cuts), as mentioned in Section 3.6 above.
(5) Keeping salinity below 150 mg/L chlorides.
(6) Providing TOC levels consistent with the directive requirements, i.e. "without noticeable change" which do not support the formation of disinfection by-products.

The above can be accomplished by maintaining desalination plants in continuous operation (avoid stand-by mode), and blending dam water with desalinated water in order to provide steady state water quality supply to the distribution network. The strict monitoring regime of desalination plants coupled to the constant ionic composition of this water, renders it ideal for maintaining stable conditions in the distribution network. Combining this with reservoir water can greatly assist towards reducing the adverse effects of the latter on the distribution network. The lower salinity reservoir water exhibits heterogeneity and unstable composition, which can easily be handled by mixing with desalinated water at the right proportions. Scale deposition will be kept at a minimum, while at the same time greatly reducing the biofilm formation potential and providing a safer water to drink.

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