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Start-up of brackish water desalination for agricultural irrigation in the Canary Islands (Spain)

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ABSTRACT

The Canary Islands are an arid region. Therefore, water resources are scarce and several islands depend strongly on the sea and brackish water desalination. Water desalination, in the water policy of the Canary Islands, has been deeply rooted in the last 40 years, allowing solving and overcoming the shortage. This article concerns the beginning of the brackish water desalination for agricultural purposes in the Canary Islands (Spain). It provides the data and experience acquired during the early years in the region; one of the authors of this paper was working in the department of desalination of the first companies in the Canary Islands like Riegocan, AM García Glez. and Temkon. These companies worked with membrane manufacturers like Fluid System, Filmtec and Desalination Systems and pressure pipe manufacturer—Advanced Structures. Fifteen brackish water reverse osmosis desalination plants were built in the Canary Islands to provide water for agricultural irrigation between 1979 and 1983. These plants had a significant impact on agriculture.

Keywords: Brackish water; Reverse osmosis; Desalination plants; Operating data; Irrigation

1. Introduction

The Canary Islands have taken the lead on desalination in Europe since the 1960s [1] and have continued to use intensively the technologies as a means of providing water resources for urban supply and agriculture. Despite the efforts to increase water reuse rates [2–14], the desalted water is considered a source of water for agriculture [15] as freshwater resources may soon be insufficient to reach the growing demand for food. A report of the Food and Agriculture Organization [16] concluded that despite the costs of desalted water remained relatively high to be used in agricultural irrigation, for high-value cash crops (greenhouse

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vegetables, etc.) are economically feasible. In Spain the ~22% of desalinated water goes to agricultural irrigation, and it began in the Canary Islands. The "Centro Experimental de Los Moriscos" of the Caja Insular de Ahorros in Las Palmas was part of the pioneering work, applying new technologies in the Canaries [17].

The beginning of the RO in the Canary Islands (no pilot-scale) was in 1979. The first plants were to desalinate brackish water which did not have a good enough quality to be used in agricultural irrigation. It was decided to use the desalination technology to reduce the salinity and exploit the groundwater wells available. Most of them were located in Gran Canaria and Fuerteventura. These plants had production capacities between 20 and 500 m^3/d and a wide range of feedwater salinity (TDS between 4,000 and 15,000 mg/L). In general, desalination plants for agriculture have some different aspects to consider in comparison with other desalination plants (drinking water and industrial), for example, lower requirements with respect to product water salinity and post-treatments.

During this period, 219 plants were budgeted by the department of desalination in Riegocan (Aguas y Riegos de Canarias, SA) company of the Canary Islands, with a total budget of five million €. Fifty plants corresponded to brackish water desalination for agricultural applications. Finally 15 plants were built, 3 in Gran Canaria, and 12 in Fuerteventura Figs. 1 and 2 (scaled maps). Some characteristics of these plants are shown in Table 1.

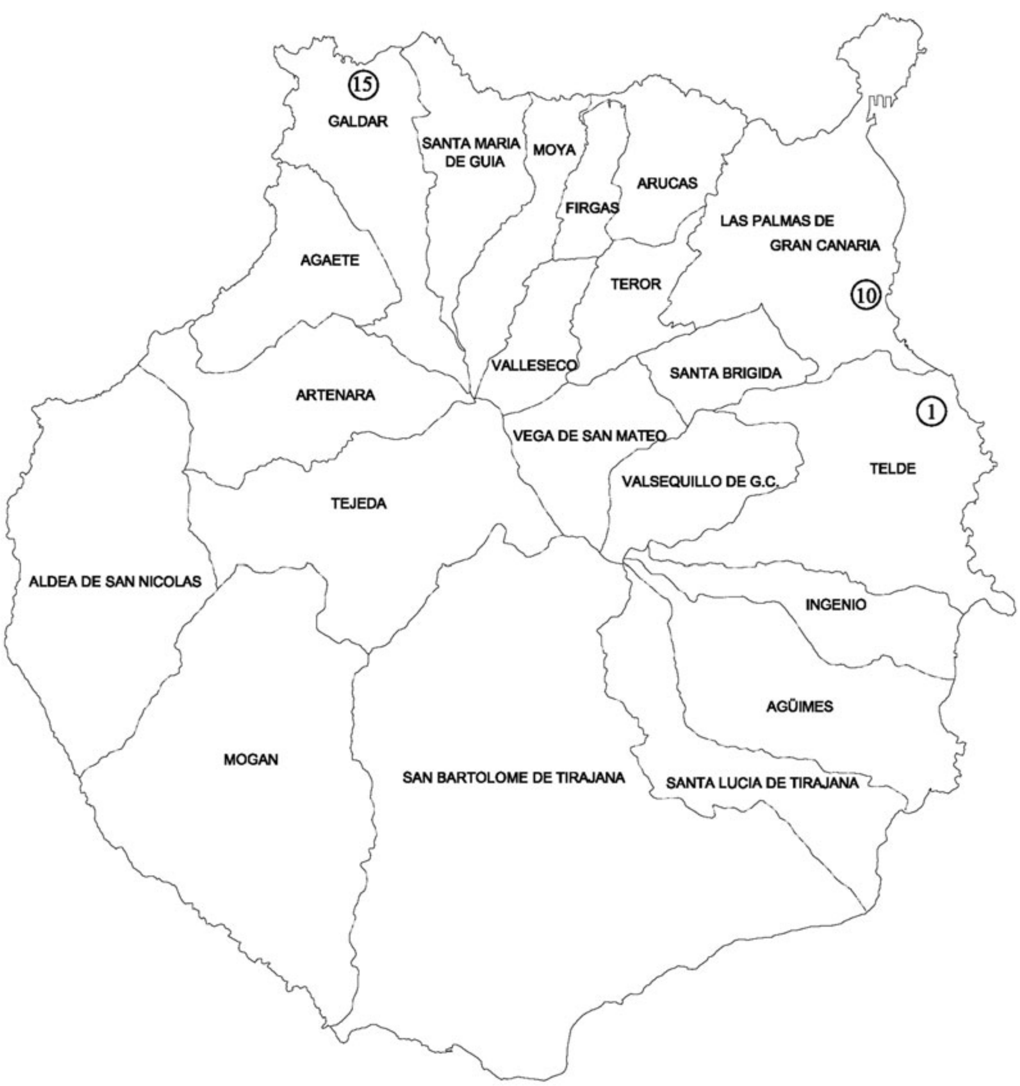

Fig. 1. Plants location in Gran Canaria Island.

Fig. 2. Plants location in Fuerteventura Island.

2. Plants description

2.1. Feedwater intake

Most of brackish water sources in the Canary Islands are exploited by groundwater wells. The well must be characterized in terms of depth, water quality, capacity and potential interconnection with other wells in the area that could be impacted by the operation of desalination plant's intake or could have a negative impact on plant's source water quality. The quality of feedwater to the RO systems is known to be of utmost relevance in the subsequent operation of the plant. A desalination unit is designed to remove salt, and all other undesirable components should be removed prior to desalination itself. The diagram of these plants is shown in Fig. 3. The water intake in all cases was by wells. The range of well depth was 20–60 m. Table 2 shows the chemical analysis of the feedwater in mg/L. Some inorganic compounds (sparingly soluble in water) force pre-treatment process to be used in brackish water reverse osmosis (BWRO) desalination plants due to scaling issues, and so on. The concentration of silica in the feedwaters was one of the main limiting factors in maximizing water recovery on RO systems.

Table 1
Characteristics of the BWRO desalination plants

Plant	Company	Capacity (m^3/d)	Contract (date)	Start (date)	Location	Investment (€)	Crop
1	Fluid System	200	8/1978	1/1979	Los Moriscos, Gran Canaria	40,000	Ornamentals
2	Riegocan	60	7/1979	12/1979	Tarajalejo, Fuerteventura	7,400	Tomatoes
3	Riegocan	250	7/1979	1/1980	Tarajalejo, Fuerteventura	30,000	Tomatoes
4	Riegocan	100	8/1979	1/1980	Tarajalejo, Fuerteventura	12,000	Tomatoes
5	Riegocan	20	8/1979	12/1979	La Lajita, Fuerteventura	3,500	Tomatoes
6	Riegocan	100	3/1980	8/1980	Pájara, Fuerteventura	19,300	Vegetables
7	Riegocan	100	3/1980	9/1980	Ajui, Fuerteventura	19,300	Vegetables
8	Riegocan	150	4/1981	10/1981	Pájara, Fuerteventura	29,000	Ornamentals
9	Riegocan	100	6/1981	12/1981	Tarajalejo, Fuerteventura	24,700	Tomatoes
10	Riegocan	20	7/1981	11/1981	Las Palmas, Gran Canaria	12,000	Ornamentals
11	Riegocan	100	4/1982	9/1982	Gran Tarajal, Fuerteventura	25,200	Tomatoes
12	AM. García	100	12/1982	6/1983	Gran Tarajal, Fuerteventura	25,200	Tomatoes
13	AM. García	150	1/1983	6/1983	El Matorral, Fuerteventura	31,300	Vegetables
14	AM. García	500	2/1983	8/1983	El Matorral, Fuerteventura	75,800	Vegetables
15	Temkon	250	4/1983	10/1983	El Agujero, Gran Canaria	90,000	Bananas

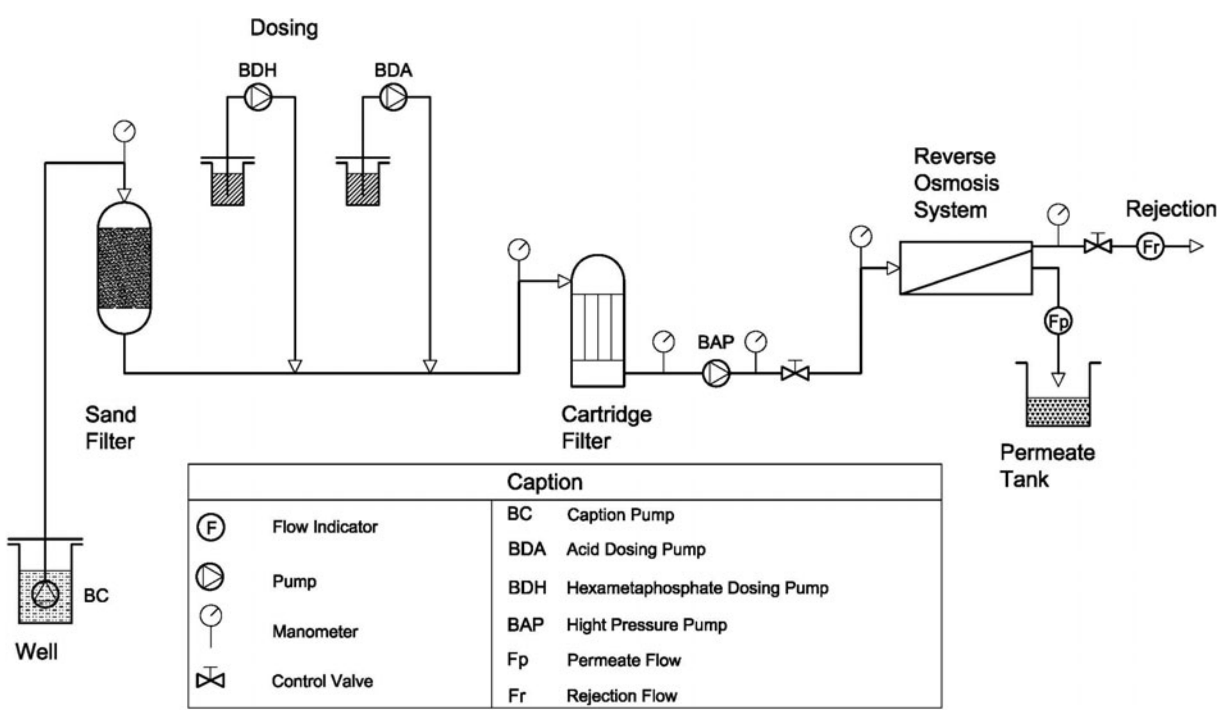

Fig. 3. Desalination plants diagram.

2.2. Pre-treatment

The groundwater in the Canaries usually carries silica [18] and bicarbonate [19], which is an important factor to take into account in the pre-treatment design and operation. As a pre-treatment system there was a sand filter, sodium hexametaphosphate (5 mg/L) and sulphuric acid dosage for pH adjustment of about 5.5–6, and 25 μm polypropylene cartridge filter. There were cartridge filters between the sand filters and the RO system. Cartridge filters were RO membrane

Table 2
Feedwater average composition

Plant	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	SO_4^{2-}	NO_3^-	Cl^-	SiO_2	Fe	TDS	pH	T_{min}	T_{max}
1	326.70	352.40	1,371.90	27.40	307.40	537.50	55.20	3,145.05	51.00	0.1	6,174.7	8.05	22	23
2	263.52	364.23	4,427.00	62.00	307.68	2,311.25	192.50	6,409.40	30.00	0.3	14,367.9	7.45	24	25
3	58.56	88.98	2,810.00	45.20	475.33	1,063.44	61.50	3,632.00	25.00	0.2	8,260.2	8.10	24	26
4	186.40	169.57	968.00	32.30	362.44	471.76	0.00	1,786.56	30.00	0.1	4,007.1	7.40	24	26
5	470.94	485.63	930.63	27.30	260.37	1,254.43	340.00	2,430.33	39.00	0.1	6,238.7	7.06	23	25
6	163.70	220.70	1,060.10	31.20	910.10	1,159.00	124.00	1,140.50	32.00	0.2	4,841.5	6.98	23	24
7	248.30	354.50	1,832.00	52.00	769.30	1,057.40	164.70	3,025.00	35.00	0.1	7,538.3	7.47	23	24
8	148.49	167.02	1,098.71	29.68	519.40	1,317.93	123.53	1,127.17	31.00	0.1	4,563.0	7.09	23	24
9	122.00	192.79	2,276.00	19.00	402.36	1,042.04	87.50	3,261.97	28.00	0.1	7,431.8	7.85	24	26
10	16.19	29.48	431.50	25.00	198.62	85.00	10.85	622.62	29.00	0.1	1,448.4	7.87	22	23
11	74.18	85.42	2,310.00	50.00	301.77	769.59	21.00	3,247.43	23.00	0.2	6,882.6	7.98	24	26
12	136.50	304.40	1,775.00	38.30	542.70	935.40	82.20	2,842.40	28.00	0.1	6,685.0	7.30	23	24
13	42.94	64.07	1,980.00	31.20	473.36	724.32	36.50	2,533.03	27.00	0.1	5,912.5	7.56	23	24
14	23.42	35.59	1,687.00	29.00	661.79	809.10	10.50	1,794.63	27.00	0.1	5,078.1	7.83	23	24
15	95.99	139.74	973.30	32.30	668.86	694.92	352.50	1,002.55	35.00	0.10	3,995.3	7.9	22	23

protection facilities for suspension solids and colloids; the main purpose they served was to capture particulates in the pre-treated source water to prevent damage or premature fouling of the RO membranes. Those plants did not have post-treatment equipment since in all cases the production was for agricultural irrigation purpose. The permeate was stored into a product tank, which was uncovered. It allowed to have an appropriate pH value for irrigation as pH was increased. The design of these plants was carried out by following technical information in those years [20–22].

2.3. *Reverse osmosis racks and operation*

The capacities did not have a wide range, from small settings designed to provide 20 m^3/d to the largest plant with a production capacity of 500 m^3/d. The use of reinforced plastic or fibreglass in the low-pressure zones of the facilities had become a standard. However, the high pressure is more subject to corrosion, and it is on this side where high-quality materials were installed. These materials include different stainless steels like 304, 316 and 316 L.

The types of membrane, arrangement and the main technical characteristics of the RO system of each plant are shown in Table 3.

Chemical cleanings frequency varied from plant to plant. It generally took place each 2–4 months of operation. The temperature range was about 22 and 26°C. To carry out the chemical cleanings the following chemicals were used in the solution:

(1) 2% citric acid, pH about 2.5.
(2) 1% sodium carbonate, pH about 10.5.

The cleaning time was between 45 and 60 min, in both cases. It should be noted that it was necessary to change the high pressure equipment, and sometimes even replace the membranes after one year of operation. However in some of these plants it was because of the inadequate materials, or cause of the feed water conditions (increased salinity, etc.). All plants were designed for daily operation with shut-downs kept to a minimum due to the need for water, as the islands are usually subject to drought. (The average rainfall is 300 mm). Actually high-capacity factors are achieved in the desalination plants, most of them operating over 90% of the time at nominal capacity, and even over 95% in some cases where maintenance is strictly scheduled.

The plant number 15 is the only one still in operation. It was renewed in 1986 using Filmtec BW30-8040 RO elements without using acid in the pre-treatment with just antiscalant products (first experience in the Canary Islands) [23,24].

3. Impacts of desalinated water on crops

The use of desalinated seawater can have the disadvantage of inadequate concentrations of some ions like Na^+, Cl^-, B and nutrients [25–28], which can cause soil damage, stunt plant growth, toxicity, etc. In this case the 15 plants were designed to desalinate brackish water. The plants 4 (Fig. 4), 8 and 10 (Fig. 5) were built to irrigate ornamentals because the brackish

Table 3
Technical characteristics of the RO systems

Plant	Passes	Stages	High-pressure pump type	Membrane		Pressure vessel			Elements	Recovery (%)	RO system arrangement		Initial feed pressure (kg/cm^2)
				Manufacturer	Model	Type	Manufacturer	Model			Pressure vessels	Arrangement	
1	1	1	Centrifugal	Fluid Systems	TFC 4600 PA	FRP	Fluid Systems	4´´X600 psi	6	50	10	1	28.0
2	1	1	Piston	Fluid Systems	TFC 4600 PA	FRP	Fluid Systems	4´´X600 psi	6	40	4	1	35.0
3	1	1	Piston	Fluid Systems	TFC 8600 PA	FRP	Fluid Systems	8´´X600 psi	6	48	3	1	32.0
4	1	2	Piston	Fluid Systems	TFC 4600 PA	FRP	Fluid Systems	4´´X600 psi	6	70	6	4:2	25.0
5	1	1	Piston	Fluid Systems	TFC 4600 PA	FRP	Fluid Systems	4´´X600 psi	6	50	1	1	28.0
6	1	1	Piston	Fluid Systems	TFC 8600 PA	FRP	Fluid Systems	8´´X600 psi	6	55	1	1	26.0
7	1	1	Piston	Fluid Systems	TFC 8600 PA	FRP	Fluid Systems	8´´X600 psi	6	50	1	1	28.5
8	1	2	Piston	Fluid Systems	TFC 8600 PA/TFC 4600 PA	FRP	Fluid Systems	8´´X600 psi/4´´ X600 psi	6	70	3	1(8´´):2(4´´)	27.5
9	1	1	Piston	Fluid Systems	TFC 8600 PA	FRP	Fluid Systems	8´´X600 psi	6	50	1	1	28.0
10	1	1	Centrifugal	Fluid Systems	TFC 4600 PA	FRP	Fluid Systems	4´´X600 psi	3	55	2	1	23.5
11	1	1	Piston	Fluid Systems	TFC 8600 PA	FRP	Fluid Systems	8´´X600 psi	6	55	1	1	28.0
12	1	1	Piston	Fluid Systems	TFC 8600 PA	FRP	Fluid Systems	8´´X600 psi	6	55	1	1	28.0
13	1	2	Piston	Fluid Systems	TFC 8600 PA/TFC 4600 PA	FRP	Fluid Systems	8´´X600 psi/4´´ X600 psi	6	70	3	1(8´´):2(4´´)	29.0
14	1	2	Centrifugal	Fluid Systems/ Filmtec	TFC 8600 PA/ BW30 8040	FRP	Advanced Structures	8´´X600 psi	6	72	6	4(TFC):2 (BW30)	27.0
15	1	1	Centrifugal	Desalination Systems	B 851	FRP	Advanced Structures	8´´X600 psi	4	55	4	2:2	25.5

water sources did not meet the water quality requirements of these kind of crops. Before construction of these plants, the farmers could not grow ornamentals. The same situation was with the plants 6, 7, 13 and 14 dealing with peppers, eggplants, cucumbers and beans. The plant 15 was built to increase the production of bananas, the farmers had an unused due with high salinity, so the desalination plant allowed the farmers to increase the crop area in 110,000 m^2.

The crops of tomatoes in Fuerteventura Island (desalination plants 2, 3 (Fig. 6), 4, 5, 9, 11 and 12) were a particular case. The farmers had to irrigate

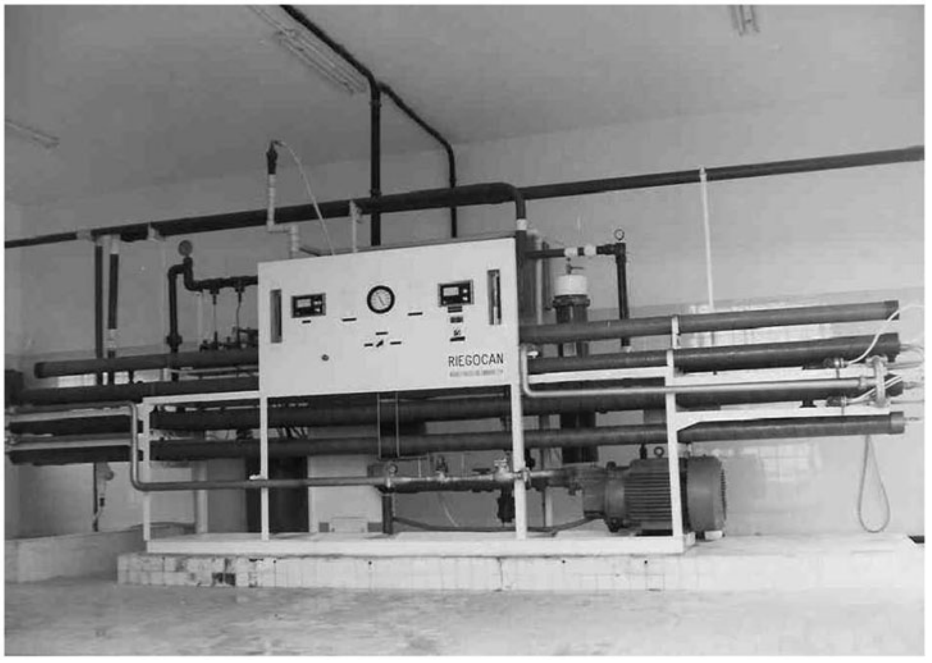

Fig. 4. Desalination Plant 4.

Fig. 5. Desalination Plant 10.

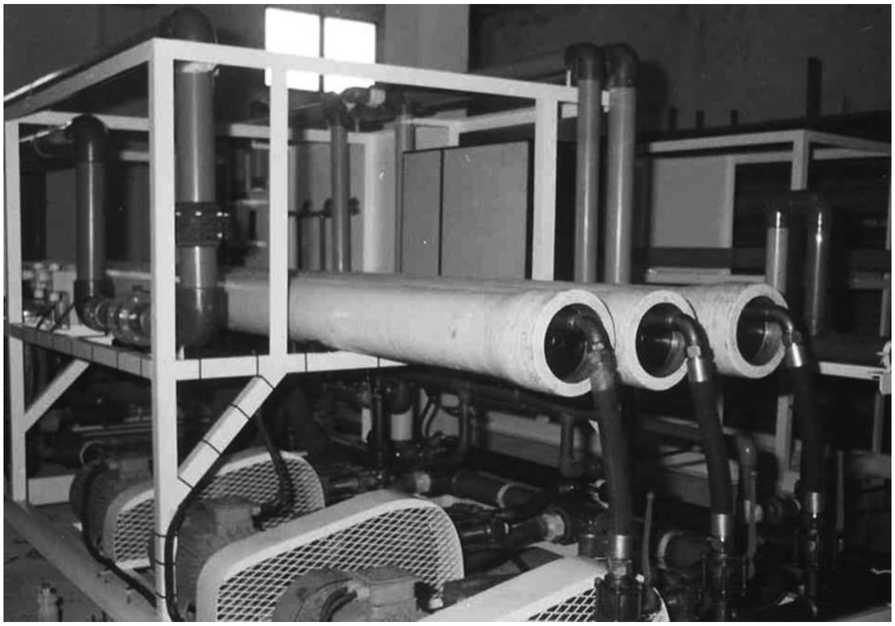

Fig. 6. Desalination Plant 3.

with the untreated brackish water, as a consequence of this, the production was between 8,000 and 10,000 kg per 5,500 m^2. Salinity also had a negative impact to the soil forcing the farmers to change the growing areas every two years approximately. The tomatoes were small, usually having problems of nutrient abortion due to water quality. The farmers neither could use some irrigation techniques like hydroponics in order to reduce labour nor increase the production; this was also due to water quality. Desalted water brought a production increment of about 100% per unit area, reducing the use of fungicides. In some cases (desalination plants 11 and 12), hydroponic crops increased the production up to 100,000 kg per 5,500 m^2.

4. Conclusions

An overview of desalination activities in the early years in the Canary Islands has been presented. BWRO desalination technology greatly contributed to the development of agriculture in the Canary Islands since the permeate water improvement was carried out as a consequence of:

(1) Increased production and quality of existing crops.
(2) Crop diversification, turning agriculture into those of higher demand.
(3) Use of other irrigation techniques and higher-yielding crops, hydroponics, etc.
(4) Desert areas decrement.
(5) Improving the quality of groundwater, as being of higher quality irrigation water, percolation contribution to improved soil structure.
(6) Environmental improvement due with soil salinity.

All the experiences gathered during these early years served as a support for the future design of BWRO desalination plants for agricultural purposes. From that time until now, it has had a very fast expansion of the RO technology in the Canary Islands [29]. It includes a large number of BWRO desalination plants for agricultural purposes in Gran Canaria, Fuerteventura and Tenerife. Nowadays ~10% (~7.3 hm^3/year) of desalinated water goes to agricultural irrigation [30].

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References

[1] F.O. Oltra, F.T. Lobatón, La desalación y su situación en España (Desalination and its situation in Spain), Sección de Publicaciones de la J.E.N, Madrid, 1972 (in Spanish).

[2] A. Allam, A. Tawfik, A. El-Saadi, A. Negm, Potentials of using duckweed (Lemna gibba) for treatment of drainage water for reuse in irrigation purposes, Desalin. Water Treat. 57(1) (2016) 459–467.
[3] S. Malamis, A. Andreadakis, D. Mamais, C. Noutsopoulos, Can strict water reuse standards be the drive for the wider implementation of MBR technology? Desalin. Water Treat. 53(12) (2015) 3303–3308.
[4] B.K. Pramanik, F.A. Roddick, L. Fan, S. Jeong, S. Vigneswaran, Assessment of biological activated carbon treatment to control membrane fouling in reverse osmosis of secondary effluent for reuse in irrigation, Desalination 364 (2015) 90–95.
[5] M.J.M. Rusan, S. Hinnawi, L. Rousan, Long term effect of wastewater irrigation of forage crops on soil and plant quality parameters, Desalination 215 (2007) 143–152.
[6] M. Al-Shammiri, A. Al-Saffar, S. Bohamad, M. Ahmed, Waste water quality and reuse in irrigation in Kuwait using microfiltration technology in treatment, Desalination 185 (2005) 213–225.
[7] F. Pedrero, J. Alarcón, M. Abellán, P. Perez-Cutillas, Optimization of the use of reclaimed water through groundwater recharge, using a geographic information system, Desalin. Water Treat., in press, doi: 10.1080/19443994.2014.1003979.
[8] J.P. Kushwaha, A review on sugar industry wastewater: Sources, treatment technologies, and reuse, Desalin. Water Treat. 53 (2015) 309–318.
[9] T. Melin, B. Jefferson, D. Bixio, C. Thoeye, W. De Wilde, J. De Koning, J. van der Graaf, T. Wintgens, Membrane bioreactor technology for wastewater treatment and reuse, Desalination 187 (2006) 271–282.
[10] D. Bixio, C. Thoeye, J. De Koning, D. Joksimovic, D. Savic, T. Wintgens, T. Melin, Wastewater reuse in Europe, Desalination 187 (2006) 89–101.
[11] A.I. Silverman, M.O. Akrong, P. Drechsel, K.L. Nelson, On-farm treatment of wastewater used for vegetable irrigation: Bacteria and virus removal in small ponds in Accra, Ghana, J. Water Reuse Desalin. 4 (2014) 276–286.
[12] S. Bunani, E. Yörükoğlu, Ü. Yüksel, N. Kabay, M. Yüksel, G. Sert, Application of reverse osmosis for reuse of secondary treated urban wastewater in agricultural irrigation, Desalination 364 (2015) 68–74.
[13] Y. Fan, W. Chen, W. Jiao, A.C. Chang, Cost-benefit analysis of reclaimed wastewater reuses in Beijing, Desalin. Water Treat. 53 (2015) 1224–1233.
[14] I.K. Kalavrouziotis, P. Kokkinos, G. Oron, F. Fatone, D. Bolzonella, M. Vatyliotou, D. Fatta-Kassinos, P.H. Koukoulakis, S.P. Varnavashet, Current status in wastewater treatment, reuse and research in some mediterranean countries, Desalin. Water Treat. 53(8) (2015) 2015–2030.
[15] G. Meerganz von Medeazza, Water desalination as a long-term sustainable solution to alleviate global freshwater scarcity? A North–South approach, Desalination 169 (2004) 287–301.
[16] J.M. Beltrán, S. Koo-Oshima, Water desalination for agricultural applications, FAO Land and water discussion paper. 5 (2006) 48.
[17] P. Moss, J.M. de Lara y Gil, Twenty-five years of desalination in the Canary Islands: An historical review of the application of reverse osmosis using case studies and operational experience, Desalination 125 (1999) 17–23.
[18] E. Darton, RO plant experiences with high silica waters in the Canary Islands, Desalination 124 (1999) 33–41.
[19] A. Ruiz-García, E. Ruiz-Saavedra, S.O. Pérez-Báez, J.E. González-González, Evaluation of the first nine years operating data of a RO brackish water desalination plant in Las Palmas, Canary Islands, Spain, Desalin. Water Treat. 55 (2015) 2555–2561.
[20] S. Sourirajan, Reverse Osmosis and Synthetic Membranes, John Wiley & Sons, Inc, Ottawa, 1977.
[21] Burns, R.I.S. Corp., Reverse Osmosis Technical Manual, Office of Water Research and Technology, Washington, 1979.
[22] K.S. Spiegler, A.D.K. Laird, Principles of Desalination, Academic Press, New York, NY, 1980.
[23] E. Ruiz, Saavedra, Graphic evolution of the 24.000 hours (3 years) operating data of a RO brackish water desalination plant, in Las Palmas, Canary Islands, Spain, Desalination 76 (1989) 15–26.
[24] E.R. Saavedra, A.G. Gotor, S.O. Pérez Báez, A.R. Martín, A. Ruiz-García, A.C. González, Evaluation of the five years operating data of a RO brackish water desalination plant in Las Palmas, Canary Islands, Spain: A historic case, Desalin. Water Treat. 51 (2013) 4785–4789.
[25] A. Ben-Gal, U. Shani, Yield, transpiration and growth of tomatoes under combined excess boron and salinity stress, Plant Soil. 247 (2002) 211–221.
[26] R.O. Nable, G.S. Bañuelos, J.G. Paull, Boron toxicity, Plant Soil 193 (1997) 181–198.
[27] U. Yermiyahu, A. Tal, A. Ben-Gal, A. Bar-Tal, J. Tarchitzky, O. Lahav, Environmental science: Rethinking desalinated water quality and agriculture, Science 318 (2007) 920–921.
[28] R. Valladares Linares, Z. Li, S. Sarp, Y. Park, G. Amy, J. Vrouwenvelder, Higher boron rejection with a new TFC forward osmosis membrane, Desalin. Water Treat. 55(10) (2015) 2734–2740.
[29] J.J.S. Alonso, L.Á. Álvarez, N. Melián-Martel, J.S. Díaz, The Canary Islands and its passion for water desalination, Desalin. Water Treat. 55 (2015) 2340–2350.
[30] Consejo Insular de Aguas de Gran Canaria, Plan Territorial Especial Hidrológico de Gran Canaria (Special Hydrological Plan of Gran Canaria) (PTE-04), Gran Canaria (Spain), 2010.