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Spanish experience in desalination for agriculture

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ABSTRACT

Desalination in Spain has a long story. From the early 60s many installations for drinking water supply were built, mainly in the Canary Islands. Soon it was assumed that other users would need water supply at competitive prices. Agriculture was one of them. The leap from the islands to mainland was in the 90s, when there was a substantial water shortage. In this decade, more than 200 installations were built for this application, mainly treating brackish water. More recently, the installation of large capacity plants from Spanish government programme "AGUA" would mean the end of small plants for agriculture although a discussion about the price for desalinated water arose between the government and the agricultural users. In this paper, we will describe the Spanish experience in desalination for agriculture from an historic point of view. We will also discuss the economic aspects such as the price of water obtained from desalination plants compared with other sources such as superficial or reused water as well as the percentage of water costs in agriculture production and other beneficial aspects such as increased production. With the experience gained for more than 17 years and 60 different size installations built, this paper will be illustrated with some examples where farmers have built their own desalination plants. Another interesting aspect will be to show how to do the planning for an irrigation system for agriculture based on desalination.

Keywords: Agriculture; Desalination; Irrigation

1. Introduction

Desalination for agriculture is reported all over the world and mainly in Mediterranean countries. The necessity for a safe, reliable and local food supply is becoming lately a strategic necessity and priority, and the use of a safe source of water with quality and a competitive price, makes desalination an increasingly frequent option.

The use of water for agriculture represents 70% of the global use of water and in developing countries the consumption of water in the agricultural sector exceeds 80% [1]. This gives us an idea about the magnitude of the problem of water supply for this application.

Many people think that this application is not feasible due to the high water costs, but the reality is that it has been used in many countries with success for years. If we analyze the data provided by the International Desalination Association [2], currently there are around 66.4 million m^3/day installed in desalination

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plants all over the world and only 1.9% is used in agriculture (although other sources [3] supplied a value around 3%). However, this data cannot be analyzed so easily because evaporation technologies account for 35% of the total installed capacity (and obviously it is difficult if not impossible to use this water for irrigation because of its high cost), and there are countries where this percentage is much higher. For example in Spain, more than 22% of the desalination capacity is used for agricultural irrigation [4] and in some regions is even more.

Within this framework, it must be emphasized that it is necessary to carry out feasibility studies of the technology in different countries and its potential for expansion, promoting safe and local food production, and considering factors such as weather or drought periods.

Seventy-five percent of Spain's water demands comes from agriculture and irrigation (in areas such as Almeria it can be more then 90%), which explains the search of alternative water sources. We must take into account that the high added-value agriculture takes place in the Mediterranean area, being precisely the region with water scarcity problems. Reuse is another important non-conventional water source, representing around 13% of total treated wastewater (at national level), although in the Mediterranean region this value is increased to 75–90%, depending on the area.

Spanish agriculture has to deal with a limited availability of water with an irregular regime of precipitation (drought, decoupling of the annual regime with schedules of irrigation, torrential phenomena, etc.) and recurrent droughts. Recent data (February 2012) from the Spanish Drought Observatory confirm the beginning of a drought period in Spain; the last quarter has been the most dry period in the last 50 years with a reduction of around 40% of the national average rainfall for the season.

In such conditions, to have a sufficient quantity of water becomes a strategic element to ensure the viability of many farms. However, it is reported [5] that water consumption in agriculture grew up twice more rapidly than total consumption of water in the economy as a whole in Spain from 1990–1992 to 2001–2003. Much of this increase is due to the 8% increase of irrigated land in that period, representing more than a quarter of the total area irrigated in the EU15 in 2001–2003.

The main problem arises from the fact that in our country in general, the most fertile and productive areas for agriculture are in the regions with less availability of water resources. This situation is more serious in the Spanish Southeast, in provinces such as Almeria and Murcia where the agricultural industry is one of the main economic pillars. In Almeria, for example, agriculture represents nearly 20% of the economy, whereas in Spain the overall contribution is around 5%.

Regarding the origin of water for agriculture application in Spain, a reference from 2009 [6] points out that 78.6% is from superficial water, 20.4% from groundwater and only 1% is from non-conventional resources (desalination and reuse). Once more we have to point out that data are at national level and in certain regions the percentage of desalinated water is significantly higher.

2. Peculiarities of desalination for agriculture: differences with other applications

2.1. Differential aspects

Desalination plants for agriculture in general have some differential aspects to consider in comparison with other desalination plants (drinking water and industrial). Some of them are:

- Limited requirements of personnel, chemicals and membrane replacement (due to the lower water quality required) which means reduced costs.
- Ability to regulate water production according to electrical tariffs in order to produce water at lower energy cost (in general this is particularly true for brackish water plants with big storage ponds).
- Lower requirements with respect to product water salinity and post-treatment, leaving out specific problems with boron or other crop toxics.
- Simplicity; reduced requirements for civil works, automation and safety measures to guarantee production.

2.2. Water quality

There are numerous standards for the qualification of water depending on its possible use for irrigation. Among them are standards Riverside, H. Greene, L.V. Wilcox, etc. which qualify the water according to several parameters, being basically relationships between conductivity and concentration of sodium and other ions. These standards are related with the effects of water over the soils and modification of soil structure.

Depending on the type of crops and the characteristics of the soil (permeability, drainage, etc.) it could be necessary for different quantity and quality of water for the irrigation, which will have an important role in designing the desalination plant.

2.2.1. Remineralization

Permeate from reverse osmosis (RO) plants has a reduced level of calcium and magnesium as well as a slightly acid pH. This could cause damages in the soil structure for which it is recommendable to remineralize in order to adjust the relationship between sodium, calcium and magnesium.

There are desalination plants for agriculture with conventional remineralization systems (lime dosing or calcite/dolomite filters), but the most common remineralization system for agriculture water is the blending with water from other origins (superficial or ground water), reducing in this way the overall cost of product water. In any case the cost of post-treatment is virtually negligible vs. desalination cost itself.

In Spain, there are some interesting studies done by the *Fundacion Centro Canario del Agua* in the Canary Islands about the remineralization of desalinated water (including the research and design of remineralization systems and even a good practices manual) and specifically for agriculture described in many papers and works from this organization (www.fcca.es).

2.2.2. Boron

One of the main current problems when we speak about desalination for agriculture is the toxicity of boron for different crops and the high boron membrane passage. This is especially problematic for seawater and the reason why in many plants a second pass RO is required.

There are some classifications regarding tolerance of boron by crops depending on the concentration of boron in water, such as the following [7]:

(a) *Sensitive crops* (0.30–1.0 mg/l): Apple, cherry, lemon, oranges, peach, grapefruit, avocado, elm tree, apricot tree, fig, grapes, plum and beans.
(b) *Semi-tolerant crops* (1.0–2.05 mg/l): barley, cabbage, carrot, lettuce, onion, potato, pumpkin, spinach, tobacco, olive, roses, tomato and wheat.
(c) *Tolerant crops* (2.05–4.0 mg/l): asparagus, cranberry, cotton, cucumber, gladiolus, Sesame, tulip, beet, bean, grass, peppermint and rye.It also seems that this toxicity is more related to the rate or velocity of accumulation of boron in the plant than in its toxicity itself.

In our experience dealing with the agricultural sector, we have seen the effects of boron mainly on oranges and lemons, with a reduction of production, leaves whitening, etc. This happened when crops were irrigated with brackish water with poor quality and levels of 2–3 mg/l of boron or even more. When crops began to be irrigated with desalinated water (mainly from brackish water from wells), the effects disappeared.

The concentration of boron in groundwater varies significantly depending on the area. In general, in South Europe (Italy, Spain) the concentration is usually between 0.5 and 1.5 mg/l, being lower in the North of the continent. It is interesting to note that most of the concentration of boron in the planet is in the oceans, with a range in seawater which normally fluctuates between 4 and 6 mg/l.

The situation varies in different countries. In Spain, for example, the requirement from the new desalination plants from the AGUA programme was 0.5 mg/l of boron in product water, which was clearly a requirement from the agriculture sector because the drinking water standard in Spain and in European Union (EU) countries is 1 mg/l. Another different example could be the requirement of 0.3 mg/l of boron in many plants in Israel.

Currently the technologies used for boron reduction are a partial second RO pass or an ion exchange resin, combined with pH increase, which increases the capital expenditure and operational expense of the desalination plants.

3. Advantages and disadvantages of the desalination for agriculture

The main benefits of the use of desalinated water for agriculture are:

- Non-conventional and additional water resource;
- in the case of seawater, inexhaustible resource not depending on the weather;
- increase in productivity and quality of agriculture products;
- less water consumption and
- recovery of salty soils.

In an unpublished study done by the authors some years ago, it was observed that later to the irrigation of a field of citric fruits with desalinated water (previously the water supply was from wells with 5–7 mS/cm or superficial water with 1.2–2.2 mS/cm or blending of both), when desalinated water was used the production increased around 10% from the superficial water and more than 50% from the brackish well water, with reduced water needs by 20%. Although this is an old study, the current situation could be similar.

If we consider the economic benefits, the results are quite a bit better (although the supplied data are from some years ago, the comparison continues being good):

The study was done in a 40 hectare farm, with 417 trees per hectare and drip irrigation, with a crop variety Navel Late (oranges) (Table 1).

In similar experiences carried out in Canary Islands with banana in greenhouses irrigated with desalinated wastewater, the necessary quantity of fertilizers was reduced by half, the water needs were reduced by 30% and the production also increased, and the maturation was earlier [8].

There are some published studies about the impact of water quality in productivity. For example is reported [9] that for a selection of products (including almond, orange, pepper, lettuce, cucumber, tomato, broccoli and celery), the optimum salinity in water for irrigation was below 2 mS/cm. From this point any increase in salinity produced a reduction in productivity, being remarkable that almond (the most sensitive) followed by orange, pepper and lettuce, got a production close to zero with salinities between 4.5 and 6 mS/cm. In this case celery was the least sensitive crop with a reduction close to 50% at around 6.5 mS/cm and close to zero at 12 mS/cm.

The production of crops is also dependent on the volume of water used for irrigation, and this has two different and conflicting effects; higher volume of desalinated water implies more cost, but if there is not enough quantity of water, the use of desalinated water will increase the productivity.

Another interesting positive finding is that the large number of plants installed for agriculture in Spain in the last decades have enabled the water companies to acquire a great experience in the sector dealing with very different types of water. These plants have incorporated new technological advances even before the public utilities e.g. energy recovery devices both for brackish and seawater, testing of new membranes, etc. always with the aim of reducing costs with an innovative spirit.

On the other hand, desalination for this application has other disadvantages:

- Higher water costs (depending on the source) not economically sustainable by some products or in certain areas (inland).
- Water has to be ionically balanced (SAR (sodium adsorption rate) and other indexes).
- High quality requirements from the point of view of some toxics (such as boron).
- Possible exhaustion of aquifers in the case of ground water desalination.
- In the case of brackish water, the additional problem of brine management and discharge without an economically feasible solution inland.

Regarding the groundwater, a report from the OCDE [5] indicates that a generalized overexploitation of aquifers take place in the Mediterranean coast of Spain. Around a 13% of the irrigated land in this area is supplied from exhausted aquifers or with salinization risk.

It is remarkable that in Campo de Cartagena in Murcia (the main point of concentration of desalination plants for agriculture in Spain), the Spanish Environment Ministry built in 1997 a pipe network for collecting the brines from desalination plants (many of them illegal at this time) in order to avoid discharges to a protected area (Mar Menor, a small lagoon with seawater connected to the Mediterranean Sea). Brines together with water from agricultural drainages were sent to a new desalination plant capable of treating that water to bring it back, once desalted, to the irrigation distribution channels. Some data about this plant are shown in Table 8, column 3 (Drenajes). A similar experience was tried in the South of Alicante but with less success and even a plant with deep-well injection of brine installed (Jacarilla brackish water reverse osmosis [BWRO]) with this discharge was cancelled further.

About the costs, it is necessary to point out also that many problems of agriculture production arise from the reduction of product margins or benefits (even some products are being sold below the production costs, because there are products imported from other countries with lower costs). In this case, water cost is a problem but not the key or main problem.

Another point is that water can be expensive depending on what we are comparing it with. For example, we think that the common discussion about desalination vs. reused water for agriculture is pointless because each of these technologies has its optimum application in function of production costs, distance to the point of application, required quality, etc., and of course if another water source is not available, any price will be acceptable.

Regarding the water price, another important factor to consider is the utilization rate, because when the plant is not operating the price per m^3 is increased to increase the relative contribution of the fixed costs.

Many of the users in the area between Alicante and Almeria, are using water from the Tajo-Segura transfer and in the last years this superficial water has been the main supply for agriculture. Recently (18 February 2012) the Spanish Council of Ministers approved new tariffs for the utilization of the Tajo-Segura aqueduct for the current year, with a significant price decrease based on the reduction of the cost of electric energy of the last period, below their esti-

Table 1
Comparison of economic benefits in a farm using water from different sources

Water origin	Superficial (Tajo-Segura Rivers transfer)	Brackish water from wells	Permeate from BWRO plant
Water price (€/m^3)	0.1322	0.054[a]	0.2284 (including payback)
Incomes (fruit sales) (€/year)	15,037	7,519[b]	16,539[c]
Expenses (€/year)	3,885	3,885	4,273
Benefit (€/year)	11,152	3,634	12,268

Note: economic data were supplied by the farmer, participant in the study.
[a]With well in property.
[b]In this case the fruit production is below 50% compared to irrigation with superficial water.
[c]Increased incomes due to the higher production.

mations. According to the Ministry of Agriculture, Food and Environment these rates are intended to recover the annual costs of operation, operation and maintenance of the aqueduct, as well as to amortize the investments made by the Government. The tariffs have been reduced more than 30% this year from 0.174 to 0.124 €/m^3. On the other hand, some environmental organizations, such as world wide fund for nature in Spain, have complained that the calculation of the new rates for the use of the Tajo-Segura aqueduct seems to have not included the environmental costs. Really these prices are fixed by the government and we do not know the real cost. We must bear in mind also that according with the EU Water Framework Directive is mandatory the full-price water recovery by 2010.

Anyway, water transfer between different regions is sometimes conflictive by political and economical reasons and it is deeply affected by the weather conditions.

It is generally admitted that water costs are a reduced percentage of the overall cost of crop production, around 5%, although some authors reported that this could range between 5 and 25%, depending on water price and even more than 45% for crops with a high water requirement (as oranges or lemons) [10]. Other interesting data could be the differences for the same product (e.g. tomatoes) when we compare production in greenhouses or in an open field, as shown in Table 2 [9].

Table 2
Effect of water price over the overall production cost of tomatoes (expressed as increase in % of total cost)

Water price (€/m^3)	Greenhouses (%)	Open field (%)
0.12	2.2	5
0.54	9.3	19.3

Source: Ref. [9].

In an interesting report from the Spanish Ministry of Environment [11], the economic recovery of water for agricultural products was calculated. The results showed that greenhouse products (horticultural, flowers and ornamental plants) provide greater added value per unit of irrigated water with 5.79 €/m^3 on average in Spain. Far from these values, with intermediate productivity are vineyards and fruit trees (1.08 and 0.68 €/m^3, respectively). On the other hand, the cereal grain reach an average productivity of around 0.06 €/m^3, which being the main crop in Spain, produces an average of 0.41 €/m^3 for all the products.

In a study made in 2008 [12] by the community of users of water in the area of Nijar, Almeria, some interesting data here supplied about the productivity of water in agriculture (Table 3):

In this case, water consumption per hectare was 5,600 m^3, with a total consumption of 150 hm^3 and water productivity of 11.41 €/m^3. The water costs supplied [12] were 0.22 €/m^3 for brackish water, 0.44 €/m^3 for desalinated water and 0.33 €/m^3 for resulting blended water.

Another problem to evaluate the cost of water, mainly from desalination, is the energy price. In recent years, it has been increasing very fast, and due to this, the main cost in a desalination production, the water costs are continuously increasing (although this

Table 3
Almeria and its production under plastic. Relationship water-harvest

Crop Type	Hectares	Production value (in thousands of Euros)
Greenhouses	26,833	1,714,969
Lettuces	4,260	90,248
Extensive (not lettuces)	3,277	97,852
Total	34,370	1,903,069

Source: Ref. [12].

occurs also with water from other sources when pumping or other energy consumers are implied). However, there are public and private initiatives using desalination for agriculture and it is predictable that this will continue to happen in the future.

4. History of desalination for agriculture in spain

As it is well known, Spain has historically suffered important lack of water resources that has worsened over time, including cyclic drought periods, like the current situation. These problems are more important in the most drought prone areas in Spain, such as the South Mediterranean coastal areas or in the islands (Balearic and Canary Islands).

The history of desalination in Spain starts in the 60s, and we could summarize it as follows;

1964: 1st desalination plant in Lanzarote (Canary Islands).
70s: construction of further desalination plants in Canary Islands.
80s: installation of desalination plants for irrigation in Canary Islands as well as on the mainland.
90s: installation of desalination plants for irrigation on the mainland, due to the severe drought.
1995–2000: significant growth in installed capacity.
2000–2005: execution of large desalination projects.
Installation of desalination plants treating wastewater.
2005–2011: AGUA Programme.
2012: Current situation.

4.1. The beginning: Canary Islands

The Canary Islands were the place for the beginning of desalination in Spain and Europe. The first plant was installed in Lanzarote Island in 1964 for drinking water supply. The plant had 2,300 m^3/day capacity and the technology was MSF. This plant was followed in 1969 by Las Palmas I, in Gran Canaria, with 20,000 m^3/day capacity by MSF.

In the mid-seventies, the first plant installed for agriculture was a small plant (80 m^3/day) in Fuerteventura using brackish water. The first seawater reverse osmosis (SWRO) plant for irrigation was built in 1987 for the company Bonny in a plant called Las Salinas, with 6,900 m^3/day capacity expanded to 500 m^3/day further. In 1988 in los Llanos de Juan Grande (Gran Canaria) another 6,000 m^3/day capacity plant was built for agriculture with membranes (RO). This was followed in 1989 by another plant from a cooperative society called Agragua, located in Galdar, Gran Canaria, with 15,000 m^3/day using hollow fibre membranes.

The first large desalination plant by membranes (RO) was built in 1990 in Las Palmas de Gran Canaria, with a capacity of 36,000 m^3/day which has been expanded successively to the current capacity of 80,000 m^3/day.

There are many examples in the Canary Islands using Electrodialysis Reversal (EDR) as desalination technology in 90s. Some examples are between 1,000 and 2,000 m^3/day including plants with partial use for agriculture, such as ICOD 2 (2,100 m^3/day, 2003) or Tamalmo (2,100 m^3/day, 2003) [3]. The great expansion of the use of EDR in Canary Island is due to two main factors: the presence of silica in underground water due to the volcanic origin of the islands and a good commercial work from the EDR suppliers.

Forecasts of the Canarian Government set a production of desalinated water of 188.0 hm^3 for 2012 [13]. The most relevant current data on desalination are in Table 4.

It is remarkable that the high number of private initiatives (vs. the public ones) shows the relevant use of desalination for agriculture and tourism in the region. It is interesting to note that in Lanzarote and Fuerteventura 100% of the drinking water supply is from desalination plants and for Gran Canaria is around 80%.

According to the same report, the current cost of water production from seawater is 0.5–0.6 €/m^3, whereas if the origin is brackish water, the price is 0.2–0.3 €/m^3. These values are consistent with those found in the rest of Spain and in our own experiences.

Balearic Islands also have an important desalination capacity, around 30 hm^3/year, but in this case, the desalination plants are mainly public ones for drinking water supply being the origin of water used for agriculture mainly from groundwater extraction or reused water. The authors have no information about any important plant in Balearic Islands for agriculture, although there are some plants for irrigation of golf courses.

The irrigation of golf courses, although it is not exactly an agriculture application, shares many char-

Table 4
Relevant data on desalination in Canary Islands

Island	Desalination plants	Public	Production (m^3/day)
Tenerife	44	5	118,143
Gran Canaria	137	11	336,195
Fuerteventura	64	4	65,049
Lanzarote	80	0	62,570
La Gomera	1	0	4,100
El Hierro	4	4	2,000

Source: Ref. [11].

acteristics with this application, using reused water or desalinated water, and with similar requirements (irrigation of the *green* in golf courses requires, in general, water with conductivity below 500–600 μS/cm).

4.2. The boom of small desalination plants in the mainland

From the scarcity period around mid-90s, many farmers and agriculture businessmen decided to install desalination plants in the Southeast of Spain (mainly Mediterranean coastal areas) to solve the problem of available resources. There are estimations indicating that between 1995 and 2000 more than 200 desalination plants were installed for this application in these areas (mainly in Alicante, Murcia and Almeria provinces), with typical sizes rated between 100 and 5,000 m^3/day, with some larger plants.

At that time, agriculture was highly dependent on water transfers from other regions but problems began with cyclic droughts causing the agriculture industry to look for alternative solutions, such as desalination and water reuse.

Most of these desalination plants were RO type although in the Canary Islands some EDR facilities (around 20) were also constructed, as it was mentioned, ranging from 1,000 to 5,000 m^3/day.

Some examples of plants from this period could be:

Mazarron (Murcia): 13,500 m^3/day (BWRO) + 30,000 m^3/day (SWRO).
Cuevas de Almanzora (Almeria): 30,000 m^3/day BWRO.
Aguilas (Murcia): 20,000 m^3/day.
Rambla Morales (Almeria): 60,000 m^3/day SWRO.
Pulpi (Almeria): 12,000 m^3/day BWRO.
La Marina (Murcia): 16,000 m^3/day SWRO.
Aguilas (Murcia): 22,000 m^3/day SWRO.

These plants were built with government approval and in many cases subsidies, but coming from private initiatives (agricultural user associations). Some of them incorporated innovations such as power auto-generation or energy recovery devices for brackish water or seawater.

Some problems with the extension of the small desalination plants were the exhaustion of groundwater from aquifers, uncontrolled brine discharges and even the proliferation of illegal or unregistered plants. Anyway most of these plants are currently closed down because end-users are buying or are going to buy water from the large public desalination plants.

The Spanish government built in 2001 the Carboneras SWRO plant, the biggest plant at that time in Spain, with 120,000 m^3/day capacity and partially used for agricultural supply. At the beginning, the problem was the construction of the distribution pipes which caused delays to the completion of the works in the plant, although currently there are large pumping stations and pipe networks operating. In 2004 the works for the construction of the Valdelentisco SWRO plant began. It is currently in operation (officially opened in 2008), with 136,000 m^3/day and also a partial supply for agriculture.

Some plants have been built with nanofiltration (NF) technology for brackish water, even without high pressure pumps (using the driving force from the well pumps, for example). In general, for agriculture application NF is economically less interesting than RO due to further blending with water from other sources. In these cases it is possible to build a smaller plant with RO + blending than the equivalent NF plant, because the NF permeate admits less blending due to the lower water quality.

It is also remarkable that in some coastal areas where high salinity in wastewater was detected (in some cases, >3,000 μS/cm), desalination plants treating secondary wastewater were installed. Some examples are Alicante and Benidorm plants with ultrafiltration (UF) + RO between 30 and 50,000 m^3/day, Mar Menor Sur (7,000 m^3/day UF + RO) and many plants in Canary Islands with RO or EDR (for example, Valle de San Lorenzo, with 8,000 m^3/day EDR; Barranco Seco, 28,800 m^3/day with UF + EDR; Maspalomas, 6,800 m^3/day EDR and some others with smaller size).

Sometimes even the installation of membrane bioreactors has been planned for wastewater treatment previous to the desalination technology (RO or EDR), avoiding in this way an intensive pre-treatment.

Related with this fact, the authors have been doing different studies for the last 12 years in a 100 m^3/day transportable pilot plant including different technologies (physical–chemical treatment, filtration, UF, microfiltration, RO and NF) and installed in different wastewater treatment plants. The results showed that it is possible to produce water for irrigation from wastewater with salinities around 3,000 μS/cm using RO at a cost below 0.2 €/m^3 [14]. In this study it was concluded that RO was the best economical option instead of NF, as it was mentioned previously.

In another installation built by Valoriza (Xeresa Golf, Alicante, Spain, 5,000 m^3/day), wastewater from a wastewater treatment plant with 2,000–3,000 μS/cm conductivity was desalinated by RO obtaining product water with a cost of 0.289 €/m^3 [15], although in this case product water was used for a golf course irrigation and the wastewater had a very high level of suspended solids and organic matter.

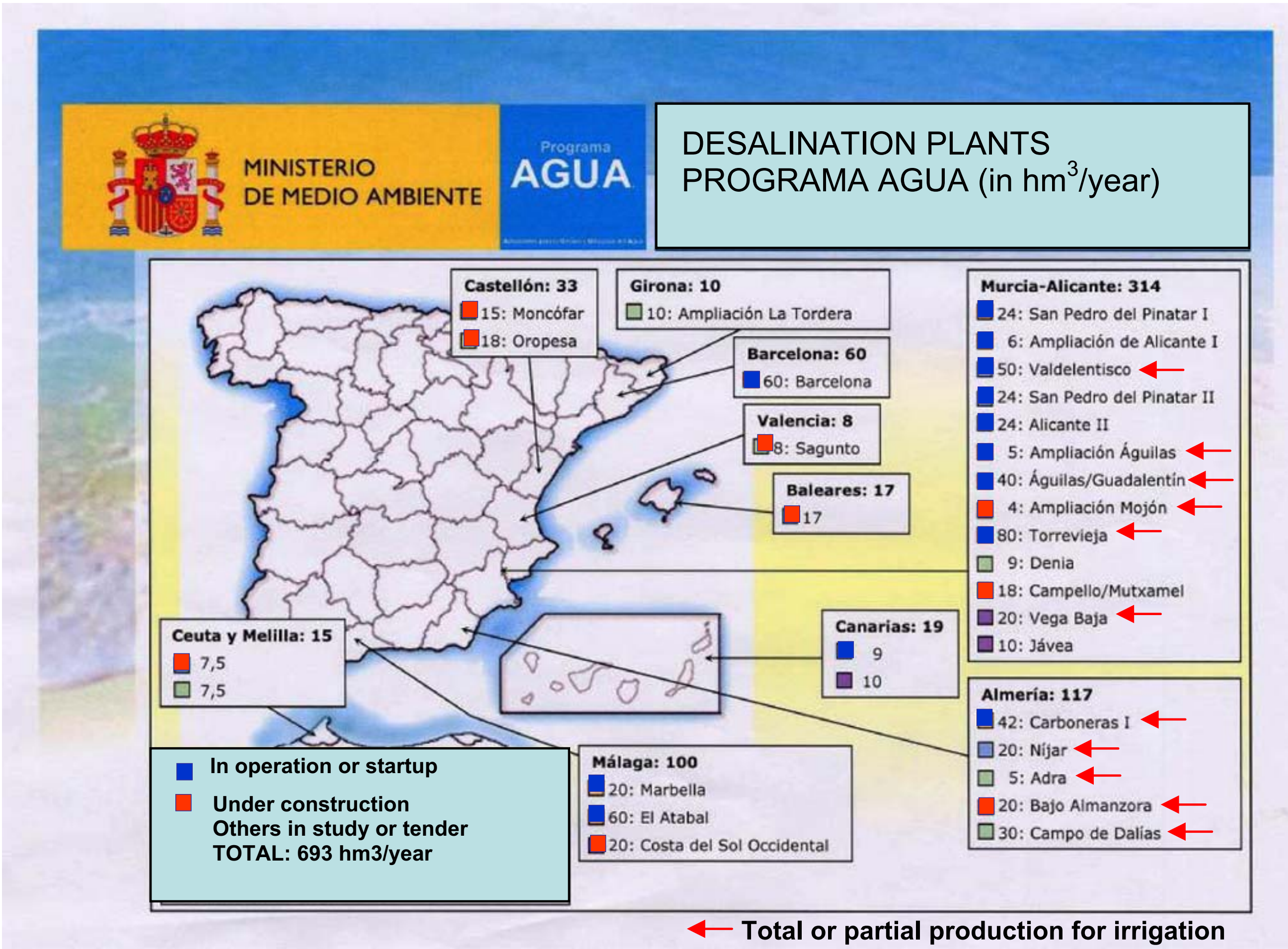

Fig. 1. AGUA programme.

Table 5
Distribution of water uses in some important plants

Plant	Water for Agriculture (hm^3/year)	Drinking water Supply (hm^3/year)
Aguilas–Guadalentin	55	13
Valdelentisco	37	20
Torrevieja	40	40
El Mojon (Drenajes)	6	-
Bajo Almanzora	15	5

The experience in Canary Islands shows values from 0.2 to 0.4 €/m^3 for wastewater desalination with some failed experiences (plant out of operation) with prices around 0.7 €/m^3.

4.3. AGUA programme

The government elected in 2004 decided to develop desalination intensely as the best solution for solving scarcity problems in coastal areas, instead of the transfer from the Ebro River from the north to the south of Mediterranean coast planned by the previous government. This programme was so-called AGUA programme and included about 20 seawater desalination plants around the coast, reuse projects and an improvement of irrigation infrastructures. The planned desalination programme was designed to produce 693 hm^3/year, including partial production for agriculture. This programme was partially funded by the EU.

Production costs for these plants were calculated in the range between 0.5 and 0.6 €/m^3, with the idea that each end-user would receive desalinated water at different costs:

Drinking water: about 0.5–0.6 €/m^3.
Agriculture irrigation: 0.3 €/m^3.
Services, industry and recreational uses: >1 €/m^3.

The reality is that currently there are plants in start-up period or with some impediments for their operation (lack of definitive electric connection, completion of the brine emissaries, etc.) and the water purchase agreements from irrigators are still not fully in effect (see Fig. 1).

In Table 5 water production for agriculture of some the most important plants is shown.

4.4. Current situation

The change of governments in past elections in Spain completely changed the situation making it even more complicated. On the one hand, the new government declared in the past more support to the transfers between basins instead of the desalination, and who should be responsible for the operation of the desalination plants built. On the other hand, the farmers and other sectors claiming that the price of desalinated water is very expensive. All this occured in a deep economical and financial crisis and at the time of new agricultural agreements between the EU and Morocco in which Spanish farmers feel injured.

What will the future bring? who knows …

The reality is that the situation is more normal than it appears, with farmers operating their own desalination plants and some of them willing to buy desalinated water. In fact some farmers are proposing to switch off their old desalination plants and negotiate the purchase of water from the large public desalination plants. If the current situation of drought continues, it is probable that the users will be more favourable for the purchase of desalinated water.

One must not neglect that when we are talking about agriculture that uses desalinated water in the Spanish Southeast, in general we are referring to a type of farmer associated with large communities of irrigators or big companies which are producing crops with a very high added value (tomatoes, lettuces, melon, citric) which are generally exported to other European countries at very high prices. Logically, in inland areas and with low added value crops, all the expressed conclusions have no value.

Of course, we are speaking too of highly efficient irrigation systems including drip irrigation and the maximum use of each drop of water, and even in some cases hydroponic crops. A report [5] indicates that the land irrigated in Spain by drip irrigation and other efficient systems was 9% in 1989 and it was increased to 31% in 2003.

The description of desalination plants made in the present article should not be considered exhaustive, although the most important plants used for this application in Spain have been mentioned.

5. Examples of desalination for agriculture in spain: costs and experience

5.1. Cuevas de Almanzora BWRO plant

The "Comunidad de Regantes" (irrigation community) of Cuevas de Almanzora is an association of agricultural producers which supplies water for different clients and end-users in the area of Cuevas de Almanzora, Palomares, Villaricos and Vera, in the Almeria province, Spain.

In 2002 a new desalination plant (Fig. 2) began to solve water problems of this community. A BWRO plant was designed for a total flow of 30,000 m^3/day, with the building, intake and other installations ready for future expansions up to 60,000 m^3/day. Given the increasing salinity forecasts and even the possibility of exclusive future use of seawater, the plant was built with components prepared to treat seawater including 1,200 psi pressure vessels, high pressure piping 904L SS and high pressure pumps ready for a Pelton turbine coupling, etc. This would make it possible to convert current facilities to treat seawater at a reduced cost. The installation of RO trains was train by train, recording an increase in salinity in the raw water.

Fig. 2. Cuevas de Almanzora BWRO plant.

Construction stopped with four trains which it was enough for community water needs and to maintain a stable aquifer. In recent years 5,000 m^3/day were added with the incorporation of another small disused plant from an associated farm.

The installation was partially subsidized by local government (Junta de Andalucia), and including European Community funds. The total investment cost was around 12 million €.

The plant has been treating well water with salinities ranging from 9,000 to 20,000 μS/cm (increasing salinity with time). Quality of product water is different depending on the requirements of each end-user. Water quality is also different depending on the irrigated crops e.g. tomatoes, lettuce, potatoes, melon, or the type of user e.g. agriculture irrigation, golf course or sometimes even drinking water for surrounding districts. In fact we could say that the plant produces "a la carte water".

Supplied quality is controlled by means of an automatic blending of permeate and raw water with the conductivity control of each flow. The price is also different and calculated for the different qualities or demands. In Table 6 the typical cost distribution is shown, being the sale prices usually below 0.3 €/m^3 [16].

Personnel costs are very reduced in this case (as usual in desalination plants for agriculture irrigation) because the plant is managed by only four people who control the plant at nights or weekends by means of alarms sent from the SCADA system to their mobile phones. The reduced energy consumption (below 1.2 Kw h/m^3 including pumping stations) is due to the use of variable frequency drive in all the main pumps and the installation of energy recovery devices (turbocharger) between stages.

Another very important issue in this plant is the use of special energy tariffs also with a discontinuous operation. The plant stops automatically in peak and high-peak hours reducing the energy costs. Unfortunately, sometimes the peak water demand occurs in months with more energy peak hours, making more difficult to manage this situation.

Table 6
O&M costs for 17,000 μS/cm conductivity in raw water

Concept	€/year	€/m^3
Variable costs		
Chemicals		0.048
Membrane replacement		0.020
Cartridge filters and others		0.004
Energy		0.127
Maintenance		0.01
Total variable cost		0.211
Fixed costs		
Personnel	148,750	0.030
Fixed maintenance	16,227	0.003
Other fixed costs	19,833	0.004
Total fixed costs	184,811	0.048
Total Cost		0.248

5.2. Aguilas–Guadalentin SWRO Plant

Aguilas–Guadalentin SWRO (Fig. 3) is one of the largest plants from the AGUA programme with 210,000 m^3/day capacity. At this moment (February 2012) is in start-up stage.

The plant has been designed for supplying water for different users as is shown in Table 7.

Users of the desalination plant will be communities of farmers from the municipalities of Aguilas, Pulpi, Puerto Lumbreras and Lorca which added a total of 48 hm^3/year intended for irrigation, ensuring the irrigation of 9,600 ha of extraordinarily productive agriculture. The plant includes also the pre-treatment of 17.8 hm^3/year of seawater for the current desalination installations of the community of agricultural users of Aguilas, in order to produce additionally 8.6 hm^3/year of desalinated water.

The investment in the plant was around 239 million € including plant and distribution pipes (with around 48 Million € from EU funds) and as it has been shown the production will be 81% for agriculture. Prices will be fixed by the public company Acuamed in the rates fixed by the Agua programme. In all these plants the price of energy is directly negotiated by Acuamed as a whole, not by each operator.

Fig. 3. Aguilas–Guadalentin SWRO plant.

Table 7
Distribution of water uses in Aguilas SWRO plant

	Supply (hm^3/year)
Mancomunidad de los Canales del Tabilla (Public Drinking Water management company)	10
C.RR. Pulpi (agriculture irrigation end-users community)	8
C.RR. Puerto Lumbreras (agriculture irrigation end-users community)	7
C.RR. Lorca (agriculture irrigation end-users community)	25
C.RR. Aguilas (agriculture irrigation end-users community)	15
Pulpi Municipality and Galasa (drinking water management company)	3
Total	68

5.3. Other experiences

In Table 8 the data of some interesting installations built by Valoriza Agua for this application are shown [17].

6. How to confront the development of an agriculture production based on desalination

Food supply is an area of strategic value to any country and an agriculture production based on desalination can guarantee self-sufficiency. The authors have carried out some projects of this type in different countries and it will be summarized how it was proceeded.

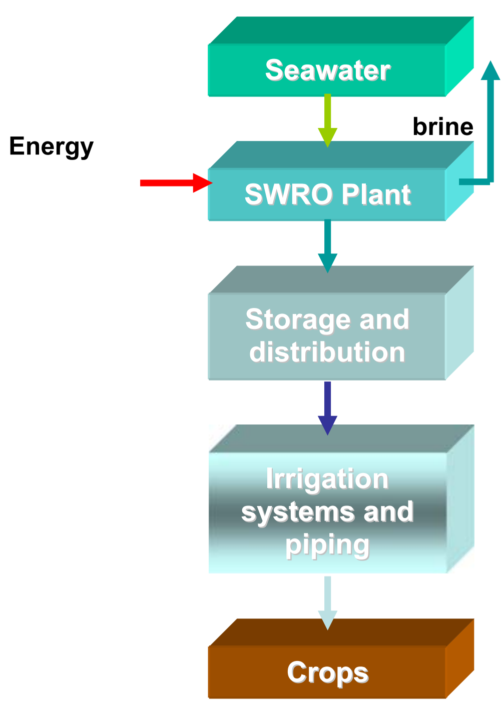

Fig. 4. Scheme of agricultural production with desalination.

The basic idea for any development of this kind implies the intake of seawater and its subsequent desalination, irrigation of a large area of land with the design of an agriculture production system, water distribution and storage and ancillary services and installations (Fig. 4).

Logically, these projects have a number of issues which have to be covered and studied and among others; climate and possible arid conditions, availability and quality of the land, feasibility of different crops in the region, land/greenhouse production requirements, as well as the economical aspects (prices of products, water availability and price, distribution, etc.).

For the development of these projects many aspects have to be analyzed, as the following:

- territorial scope;
- human geography;
- topography and soil geomorphology;
- environment;
- climate and
- state of agricultural markets (production, consumption and needs).

And related with agricultural production many data have to be compiled and studied:

- agricultural suitability of land;
- crop choices for the area;
- agronomic decision models;
- water balance;
- needs, inputs and infrastructures and
- R&D associated with agricultural development.

With all this information compiled, the next stage is to determine the size of the project which could be

Table 8
Some examples of desalination plants for agriculture irrigation

	1	2	3	4
Plant	Cuevas de Almanzora, Almeria, Spain	Mazarron, Murcia, Spain	Drenajes, Murcia, Spain	Pulpi. Almeria, Spain
				
Owner	C.R. Cuevas de Almanzora	C.R. Mazarrón	Environment Ministry	C.R. Pulpi
Erection (year)	2003	1995	1997	1997
Capacity (m^3/day)	30,000	13,500	6,000	10,000
Technology	RO	RO	RO	RO
Raw water	From wells with increasing salinity	From wells with increasing salinity	Superficial water from agric. drainages	Superficial water + water from wells
Salinity	9,000–18,000 µS/cm	9,000–20,000 mg/l TDS	12,500 µS/cm (average)	6,200 µS/cm (average)
Product water requirements	<500 µS/cm	<300 mg/l TDS	<250 mg/l TDS	<500 µS/cm
Physical Pre-treatment	Sand filtration + cartridge MF	Physical–chemical treatment with clarifier + double stage filtration (sand + sand/anthracite) + cartridge filters	Physical-chemical treatment with clarifier + double stage filtration (sand + sand/anthracite) + cartridge filters	Physical–chemical treatment with clarifier + double stage filtration (sand + sand/anthracite) + cartridge filters
Chemical pre-treatment	Antiscalant	NaClO, $NaHSO_3$, HCl and antiscalant	NaClO, $NaHSO_3$, coagulant, floculant and antiscalant	NaClO, $NaHSO_3$, coagulant, floculant (when it is necessary) and antiscalant
Post-treatment	Blending with raw water	Blending with raw water	Blending with raw water	Blending with raw water
Technical innovations	Energy recovery (turbocharger)	Energy recovery (turbocharger)	Energy recovery (turbocharger), different membranes (antifouling) and spacers on each train	
Difficulties	Increasing salinity, increasing sulphates	Increasing salinity	Variable water quality with high organic matter loads	Variable water quality with high organic matter loads
Electrical consumption (Kw h/m^3)	1.2	Old plant which has been reformed; we have no current data	1.2	1.2
Operational costs (€/m^3)	0.248	No current data	0.3	0.203 €/m^3 (0.25 €/m^3 including payback)

developed in larger or smaller size or implemented in different stages.

The chosen technology for desalination will be probably RO because it is the most efficient, with less energy consumption and production costs for seawater.

In a desalination plant for agriculture irrigation some important aspects must be considered such as product water quality (including the level of boron and the equilibrium of salts) and water costs.

In the same way all the equipment for agriculture production has to be designed with the most modern equipment and efficient irrigation technologies taking into account product quality, safety and environmental protection. Pesticide-free agriculture and high efficiency irrigation could be considered, as well as a high level of automation and control.

A crop pattern has to be designed in order to optimize the use of water throughout the year, taking into account the needs of the population. The selection of crops will be done in order to get an estimation of the water demands in order to decide the size of the desalination plant. An estimation of the production (ton/year) for any crop depending on the type of soil, weather in the region, etc. has to be done.

The selection of the crops will depend on the type and consumption in the area, the feasibility of growing in these lands and weather, etc. As an indication, the 10 major vegetal foods consumed around the world according to the FAO [18] are rice, wheat, maize, pulses, sugar, potatoes, cassava, soybean oil, palm oil and rape and mustard oil.

As water production from a SWRO plant is continuous throughout the whole year, the most interesting combination of crops will be which could get similar water requirements along the year, although it is possible to manage water production and use with water reservoirs.

With the crop pattern designed the necessary land area will be obtained, considering the water needs (m^3/year per hectare) for each selected crop.

The irrigation system and network distribution have to be designed, with drip irrigation being recommended. The capacity of storage systems will also be a key factor in improving flexibility in agricultural production. In order to complete the project a drain network to collect and use the excess of water applied has to be considered.

For the operation of any agricultural production development it should not be forgotten all the processes related with pre- and post-production should not be forgotten. These issues are really a complete and complex industry itself that includes several activities.

The post-harvest installations will be very dependent on the crop, and many of them can be done directly in the field, jointly with refrigerated trucks, although in general a complex storage and distribution system is needed.

As an example of the possible post-production activities, the following scheme (Fig. 5) is shown. Regarding the pre-production activities, we can mention the following:

- seed imports;
- plantation (seed growing) and nurseries;
- substrate, compost and
- necessary machinery, etc.

We also have to think about availability, production and distribution of fertilizers, production, distribution and maintenance of equipment and materials (plastics, machinery, valves, pumps, etc.) and pest control by chemical and/or biological treatment.

Another interesting point could be the management of agricultural wastes (fertilizers, plastics, packaging and yard trimmings) and the possible reuse or energy production from it.

It is difficult to design all these activities, but it represents significant investment and development of industrial estates and ancillary industries that will generate wealth. We will have to take into account transport logistics and distribution and it would probably require new accesses and infrastructures (roads, etc.) to absorb the generated truck traffic.

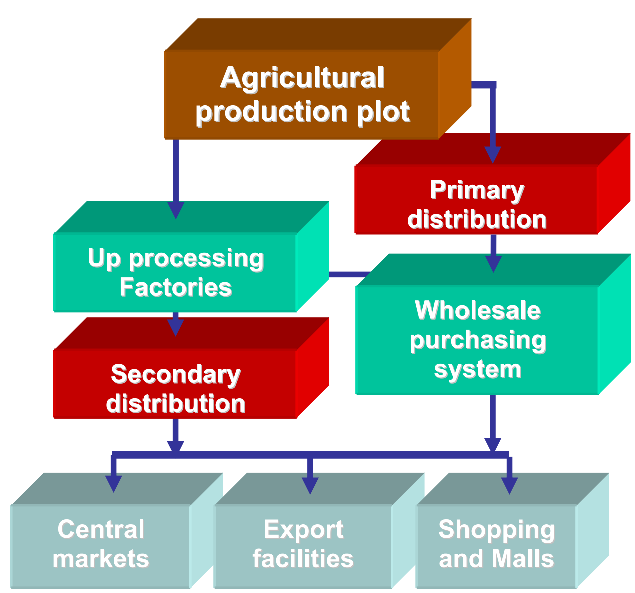

Fig. 5. Agriculture post-production.

As can be seen, a study of this type is quite complex and requires a significant collection of data, but we are confident that in many cases it may be very economically profitable apart from a strategic aspect for many regions.

7. Conclusions

Spain is an example of the use of desalination for agriculture with a long history in this field. Many plants for this application have been installed with different raw water qualities (brackish, seawater and wastewater) and technologies (RO, EDR and NF).

Desalinated water can be more expensive than water from other origins but this depends on many factors such as distance to application, energy prices, availability of other resources, etc.

Many agricultural products can support the price of desalinated water without a great impact in the overall price.

All the possible technical issues (environmental, effects over soils, boron, etc.) for this application can be solved with investments which mean that the key factor for the feasibility will be always water price.

Food supply is a strategic element for any country and a desalination-based agricultural production can ensure it.

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