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# Agricultural drainage water characterization to determine the desalination possibilities for irrigation in a semi-arid environment

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**ABSTRACT**

Agriculture drainage water (ADW) can be desalinized and could provide water resources for irrigation. The major concern is the excess of soluble salts in ADW. In this sense, it is possible to use reverse osmosis (RO) system plants to reduce salinity and provide irrigation water of high quality. Several parameters such as pH, electrical conductivity (EC), total suspended solids, etc., should be taken into consideration before planning the installation of a reverse osmosis system. In this study, the water quality of an ancient drainage system of the SE of Spain was evaluated. The final results are directly applicable to help decision-makers and engineers to take an adequate decision, in order to select which of the drainage canals is the best option to produce desalinized water at low cost.

*Keywords:* Agriculture; Climate change; Electrical conductivity; Water flow; Water reuse

## 1. Introduction

Water scarcity is considered as one of the most vital and significant environmental issues globally with climate change impacts to follow in the framework of agricultural sector demand [1,2]. In response to the growing world population and economic growth, water withdrawals for human consumption will be intensified, increasing the competition for freshwater between urban, industrial, agricultural, environmental, and recreational desires [3]. The highest water demand activity in the agri-sector [4], will lead to a rise in evapotranspiration rates, thereby increasing crop water demand across Europe [5] and globally [6]. Under this background, the reuse of water as well as wastewater [7–10] for agricultural purposes is a necessary target for land sustainability and food supply [11].

Traditional irrigation systems of the South of the Alicante province (Spain), which have more than a thousand kilometers of drainage canals, can offer water for desalination in better conditions, than that coming from the Mediterranean Sea, because of the lower salinity comparing with seawater. However, it must be considered that feed water quality is influenced by seasonal variation (i.e., irrigation necessities, floods, drought, and climatic impact) [12]. For these reasons, it is important to study the water quality and the available flow to maintain a desalination plant active. In the South of Alicante, drainage water is commonly reused for irrigation

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several times (two or three times) along a complex agricultural system developed three centuries ago. This system, based on an ancient water network, reveals a real example of water resources optimization looking for maximum use of the resource in a low and irregular rainfall area of the Spanish peninsular Southeast [13]. As a result of the water reutilization, water is becoming more and more saline after each use, so it is highly common in these areas the cultivation of salt-tolerant crops such as pomegranates or palm trees. However, drainage water reuse on increasingly salt-tolerant crops concentrates dissolved solutes and reduces its volume [14], mainly due to evapotranspiration.

Among the options for enhancing freshwater resources is the desalination of salty groundwater, brackish drainage water, and seawater [15]. Zarzo et al. [16] provide a novel and additional water resource for agriculture and irrigation. Moreover, treatment and utilization of agriculture drainage water (ADW) is mandatory for development needs in arid and semi-arid zones [17] where the scarcity of this resource is critical to keep agricultural productivity. Drainage canals, which recover excess water from agricultural irrigation and subsurface waters, can be a good alternative and a possible source for irrigation water after adequate treatment and management. ADW is a complex mixture of dissolved and suspended chemical species and may contain a wide variety of microorganisms [18]. Opportunities for recovering significant amounts of water depending on the availability of large quantities of ADW [19].

ADW frequently has a great amount of soluble salts that makes it difficult for direct use for irrigation, especially considering non-tolerant crops to salinity. The salt content of the collected subsurface drainage water mainly reflects the salinity characteristics of soil solution, which in turn is influenced by soil parent material, the salinity of the shallow groundwater, and salts brought into the soil with irrigation water [3]. The direct reuse of this ADW for irrigation may result in salinization and reduces agricultural yield [20]. Moreover, saline water application not only reduces agricultural production but also causes soil destruction [21–23] and greater salt damage caused by long-term irrigation [24].

Similar processes with seawater desalination is been applied to the drainage water. From the economic point of view, an appropriate selection of the desalting scheme as well as on the operational features are needed [25]. For instance, in the case of low flows from agricultural drainage systems, although several technical options can be considered, small to medium volume reverse osmosis (RO) system plants could be used [26]. In addition, nowadays these plants can be supplied by solar energy to treat saline water [27] and provide water for irrigation as a sustainable alternative with a low carbon footprint [28]. The structure of these RO systems would be similar to that presented in Fig. 1. First, it is necessary to pre-treat the drainage water, so it reaches adequate physical and chemical conditions, to avoid membrane saturation. The pre-treatment process may include sand, carbon, and nanofiltration [17], but these technologies should focus on relatively low-cost systems [19] making them affordable by farmers and should be joined to irrigation efficient systems. After the extraction of the water from the RO system, water flow is split into two streams: one has no (or limited) salinity and the other has high salinity (Fig. 1). The low salinity stream is known as "permeate or product water" while the high salinity stream is known as "concentrate, brine, or reject" [29]. The management of the brine is one of the major concerns.

There are many factors that affect a desalination plant, including the substantial operation costs, recovery efficiency, membrane fouling level, energy consumption as well as the production, and the disposal of the end product (i.e., brine) [30]. Among several parameters (i.e., total suspended solids, pH, etc.), the relevant desalination costs may be related to also to electrical conductivity and total dissolved solids (TDS) [31]. Desalting subsurface drainage water is costly due to the increasing salinity and the potential for scaling and fouling of RO membranes [32]. As consequence, the service life of the membranes becomes shorter and the cost increases accordingly [33], a low saline ADW is preferable to reduce cost. Energy will be increased when ADW salinity is high. In the case of ADW, the feasibility of effective desalination with high-performance low-pressure RO membranes has been demonstrated [17]. Even more, less cost per cubic meter of product water and the excellent tolerance to salinity changes of RO has been proven [26].

In water consumption sectors, that is, agriculture, low-cost desalination methods are vital [34,35] and several small plants feeding with solar energy have been developed for commercial use. Furthermore, it is part of the 4th strategies from the European Green Deal, Circular Economy Strategy, and UNSDG [36–38] aimed at reducing greenhouse gas emissions to mitigate climate change. A good example of low-cost treatment for a brackish aquifer (with electrical conductivity values above 6,000 μS/cm) is given by Aparicio et al. [39] for the small desalination plant situated at the University of Alicante in San Vicente del Raspeig (Alicante, Spain). Due to the continual increase of the drainage water suitability for reuse in irrigation purposes, must be intensively assessed [40]. One of the most important KPI to assess the desalination units is the EC [41]. However, it is important to determine the availability of a permanent flow of water supply to maintain the system working [18] and provide enough water for irrigation.

Regarding this, the main objective of this paper was to study the water quality of the drainage system in the counties of La Vega Baja and the Baix Vinalopó (Alicante, Spain), in order to determine which of the canals has adequate characteristics, enough flow, and water quality (salinity) that can favor the desalination by using a RO system.

## 2. Materials and methods

The study was conducted in the Elche Depression and lower Segura river basin, located in the Eastern sector of the Betic Ranges in the South of the Alicante province (Spain). The selected area is mainly agricultural, with flat topography, situated at the end of the rivers Segura and Vinalopó. It is developed on three main types of soils: Fluvisols, Solonchacks, and Gleysols [42], transformed along the last century by agriculture.

The origin of this area is an ancient coastal lagoon and marshes, transformed from centuries by farmers. The drainage system, formed by numerous canals, was the main conductor of this transformation, created to reduce the shallow groundwater level and drain the area. Since the 18th century, the establishment of agriculture and the foundation of new rural settlements were favored [43]. The old Elche lagoon (Albufera de Elche) was formed by a coastal sand barrier during the late Holocene [44,45] at which time marine conditions would have extended 19 km inland from the present coast and persisted until at least the bronze age [46], was dried.

Drainage canals were analyzed to recover the water from a dense network of minor agriculture canals and were divided into two groups, depending on the mouth of the two main rivers where the canals finally flow and discharge their waters to the sea: Vinalopó River and Segura River (Fig. 2). A total amount of 13 drainage canals (Table 1) were analyzed between 2016 and 2018 (12 sampling periods from September-16 to July-18, taking four subsamples per canal), and monitored for a sufficient length of time due to possible seasonal changes [14]. Samples were taken at the end of the drainage canal but far enough from the coast to avoid influences from seawater (sample points presented in Fig. 2). Most of these canals are open-air canals, ground edges along their path, and cemented in some sections to maintain the shores. Because the subsurface passage of water through the bed and aquifer material provides several natural treatment processes [47], it is important to keep the ground banks, such a natural riverside, improving the quality of the agricultural drainage waters.

Salinity was analyzed by determining the electrical conductivity at 25°C as well as the water pH. TSS was determined by filtration (glass microfiber filters 1.2 μm) and the major anion and cation related to salinity (chloride and sodium), were analyzed following the Standard Methods for Examination of Water and Wastewater [48,49]. Additionally, the flow of the canals was estimated in a rectangular-shaped section, following the methodology based on the float method [50], to know which of them could provide enough water to maintain a stream for a small or medium-size RO system plant.

Statistical descriptive analysis (maximum, minimum, mean, standard deviation (SD)) and the ANOVA *F*-test were used to determine the statistical significance and differences between the means.

## 3. Results and discussion

The main characteristics of the drainage water determined in each of the canals are presented in Tables 2 and 3. The results showed no significant differences, regarding the pH, but differences have been detected in the rest of the parameters. According to the pH, waters can be considered moderately alkaline and the pH range allows the reuse for irrigation purposes [51].

In general, according to the salinity, determined by the electrical conductivity, drainage waters from the canals associated with the Segura river are generally less saline than those associated with the Vinalopó river. Mean EC range between 3.1 and 15.5 mS/cm, indicates a high degree of salinity (for agricultural purposes) and specifies a high amount of dissolved substances in water [52], but in all of the cases under the salinity estimated for the seawater [53]. The feed water, based on its quality can be processed into RO plants similar to those used to brackish water (BWRO) where the salinity ranges from 500 to 10,000 mg/L. In contrast to the seawater RO plants (SWRO) where the salinity is around 30,000 mg/L [54]. Additionally, BWRO is further sub-grouped into low salinity BRWO that process feed water with salinity between 500 and 2,500 mg/L, and high salinity

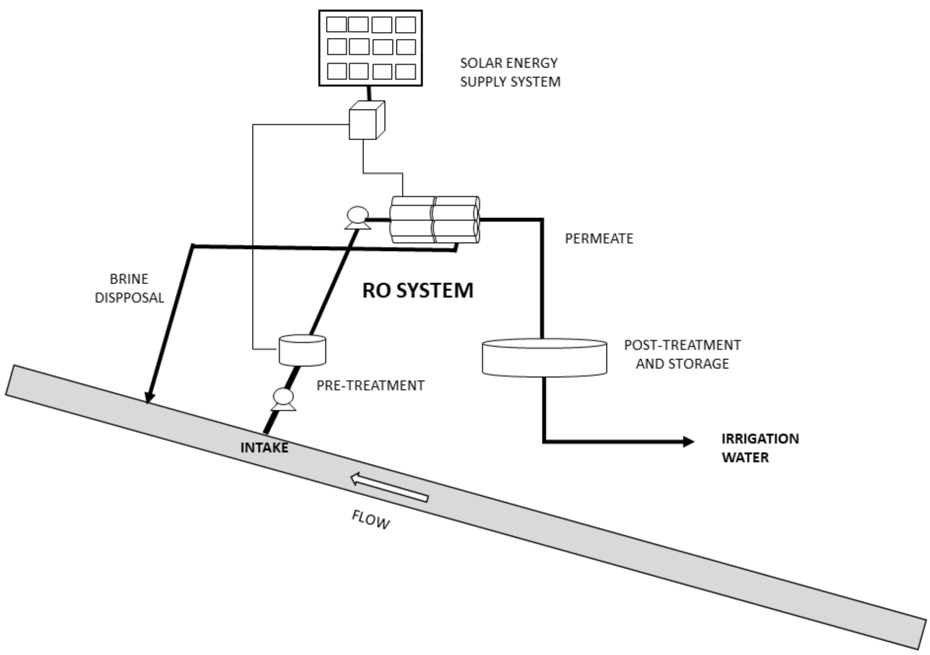


Fig. 1. Basic scheme for desalination of water from drainage canal.

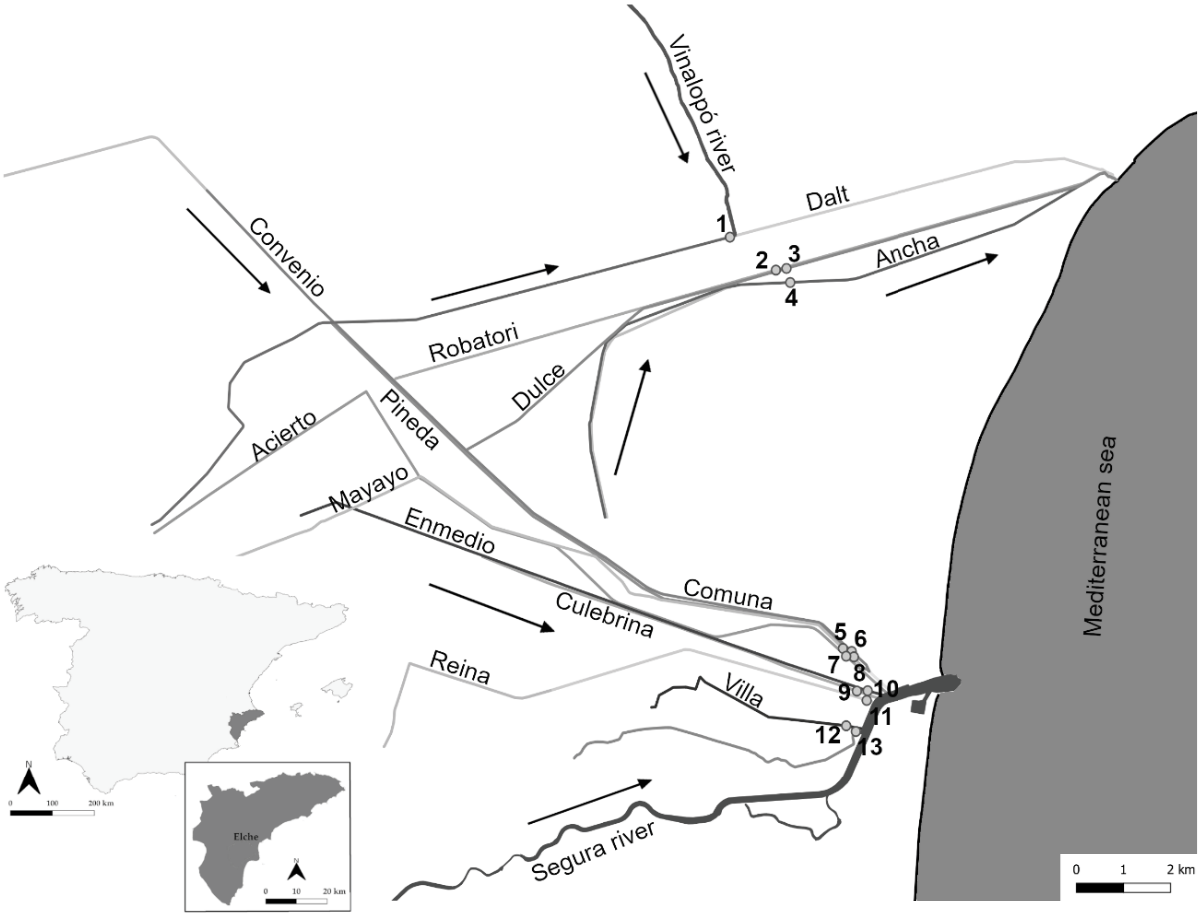


Fig. 2. Drainage canals and sampling points (location numbered from 1 to 13). Arrows indicate the direction of the water flow.

Table 1
Drainage canals studied in the South of Alicante (Spain) and number assigned to the sampling point to extract ADW for analysis

| Area of discharge | Drainage canal | Sample point |
|---|---|---|
| Mouth of Vinalopó river | Azarbe de Dalt | 1 |
| | Azarbe del Robatori | 2 |
| | Azarbe Dulce | 3 |
| | Azarbe Ancha | 4 |
| Mouth of Segura River | Azarbe del Convenio | 5 |
| | Azarbe de Pineda | 6 |
| | Azarbe Mayayo | 7 |
| | Azarbe del Acierto | 8 |
| | Azarbe de Enmedio | 9 |
| | Azarbe Culebrina | 10 |
| | Azarbe de la Reina | 11 |
| | Azarbe de la Villa | 12 |
| | Azarbe de la Comuna | 13 |

BRWO plants that process water with salinity between 2,500 and 10,000 mg/L [54]. This difference is critical for the energy cost. The mean EC value of most of the canals indicates that ADW belongs to the second subgroup, and ADW should be treated by high salinity BRWO plants.

Following Scherer and Meehan [55], EC is a proxy measurement to determine the TDS in water. Using the conversion factor given by these authors, the TDS varied approximately between 2,300 and 12,700 mg/L, while most of the canals have from 3,000 to 6,000 mg/L approximately. The acceptable TDS concentration for irrigation purposes is about 750 mg/L [15], so it is important to consider that reducing EC, makes it easy to achieve the desired value for TDS in the treated water due to the direct relation between EC and TDS.

EC (salinity) follows the same pattern that those found for chloride and sodium (Table 3), as it was expected. Most of the soils are formed on an ancient saltmarsh area, they have been irrigated for centuries with medium or low-quality water and soil salinity may be determined by the presence of dissolved salts. Considering the chloride concentration, the degree of restriction for reuse directly the drainage waters is severe because it is over 355 mg/L [51].

The flow rate was very different for each canal and should be considered to determine which can supply

Table 2
Characteristics of the drainage water

| Drainage canal | pH | | | | EC (mS/cm) | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Max. | Min. | Mean | SD | Max. | Min. |
| Dalt | 7.8 | 0.2 | 8.2 | 7.6 | 12.8 | 3.4 | 16.2 | 9.3 |
| Robatori | 7.8 | 0.2 | 8.2 | 7.5 | 9.1 | 3.2 | 12.3 | 5.9 |
| Dulce | 8.0 | 0.2 | 8.2 | 7.7 | 3.1 | 0.5 | 3.6 | 2.6 |
| Ancha | 7.8 | 0.2 | 8.0 | 7.6 | 11.0 | 2.0 | 13.0 | 9.0 |
| Convenio | 7.8 | 0.2 | 8.0 | 7.7 | 10.8 | 1.1 | 12.0 | 9.7 |
| Pineda | 7.9 | 0.2 | 8.1 | 7.8 | 7.1 | 2.2 | 9.3 | 4.9 |
| Mayayo | 8.0 | 0.2 | 8.2 | 7.7 | 6.2 | 2.8 | 9.0 | 3.4 |
| Acierto | 7.8 | 0.2 | 8.3 | 7.7 | 5.7 | 1.6 | 7.3 | 4.1 |
| Enmedio | 8.0 | 0.2 | 8.3 | 7.8 | 4.8 | 1.1 | 5.8 | 3.7 |
| Culebrina | 7.9 | 0.2 | 8.2 | 7.7 | 4.7 | 1.0 | 5.6 | 3.7 |
| Reina | 8.1 | 0.2 | 8.4 | 7.8 | 3.7 | 0.8 | 4.5 | 3.0 |
| Villa | 7.9 | 0.2 | 8.3 | 7.8 | 4.0 | 0.9 | 4.9 | 3.0 |
| Comuna | 7.9 | 0.2 | 8.3 | 7.7 | 3.8 | 0.9 | 4.7 | 2.9 |
| ANOVA *F*-test | ns | | | | *** | | | |
| Drainage canal | Flow ($m^3/s$) | | | | TSS (mg/L) | | | |
| | Mean | SD | Max. | Min. | Mean | SD | Max. | Min. |
| Dalt | 0.303 | 0.171 | 0.686 | 0.178 | 35 | 19 | 68 | 13 |
| Robatori | 0.311 | 0.182 | 0.483 | 0.000 | 48 | 33 | 75 | 9 |
| Dulce | 0.003 | 0.004 | 0.003 | 0.000 | 35 | 42 | 137 | 7 |
| Ancha | 0.193 | 0.102 | 0.253 | 0.000 | 34 | 14 | 57 | 12 |
| Convenio | 1.468 | 1.219 | 4.180 | 0.564 | 46 | 28 | 120 | 15 |
| Pineda | 0.523 | 0.409 | 0.690 | 0.000 | 104 | 57 | 198 | 42 |
| Mayayo | 0.164 | 0.117 | 0.378 | 0.000 | 62 | 107 | 399 | 4 |
| Acierto | 0.810 | 0.715 | 0.945 | 0.152 | 39 | 14 | 57 | 19 |
| Enmedio | 0.137 | 0.121 | 0.270 | 0.000 | 46 | 18 | 85 | 21 |
| Culebrina | 0.182 | 0.109 | 0.270 | 0.000 | 37 | 19 | 60 | 16 |
| Reina | 0.967 | 0.796 | 2.179 | 0.100 | 32 | 25 | 103 | 8 |
| Villa | 0.050 | 0.092 | 0.200 | 0.000 | 29 | 15 | 66 | 12 |
| Comuna | 0.050 | 0.092 | 0.200 | 0.000 | 24 | 18 | 78 | 9 |
| ANOVA *F*-test | *** | | | | *** | | | |

(mean value, standard deviation SD, maximum value Max, minimum value Min, and ANOVA *F*-test ***$p \leq 0.001$; **$p \leq 0.01$; *$p \leq 0.05$; ns = not significant)

enough water for a small or medium RO system. The mean water flow results in a wider range, between 0.001 and 4.18 $m/^3s$, from extremely low flow to an important mean value over 4 $m^3/s$. In this sense, a constant flow of about 0.5–1 $m^3/s$ could provide enough water for a small or medium RO plant. Considering a high-efficiency RO plant and low energy consumption, the selection, in this case, maybe determined by the percentage of desired desalinized water/brine ratio. Low saline waters may facilitate selecting a high water/brine ratio.

TSS was also determined because the pre-treatments should reduce the TSS to avoid problems in the membranes, reducing these associated with suspended particulates, which could serve as seeds for promoting surface crystal nucleation [56]. It is important to consider the presence of suspended solids but also other floating objects that can be presented in the drainage canals due to mismanagement of people and, in such case, the pre-treatment should include screening systems to remove these elements prior to desalination treatment. As it might seem from Table 2, great variability of TSS was determined. However, most of the mean values are under 70 mg/L of TSS, reducing the risk in the ADW treatment, excepting the Pineda drainage canal which can be discarded for a lower cost RO system.

To implement a desalination treatment, EC and flow should be determined and help for the process optimization (low salinity and availability of enough feed water). It is necessary to maintain the flow [14] to optimize the performance of the water treatment plant. Analyzing the water quality of all the canals, El Convenio and La Reina, have a higher mean flow close or over 1 $m^3/s$, which can be enough to supply a small RO plant. When feed water supply is guaranteed, electrical conductivity is the main parameter to be considered.

Table 3
Chloride and sodium measure in drainage canal

| Drainage canal | Cl (mg/L) | | | | Na (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Max. | Min. | Mean | SD | Max. | Min. |
| Dalt | 2,996 | 966 | 3,962 | 2,030 | 1,858 | 579 | 2,437 | 1,279 |
| Robatori | 1,952 | 815 | 2,767 | 1,137 | 1,261 | 533 | 1,794 | 728 |
| Dulce | 647 | 173 | 820 | 473 | 394 | 104 | 498 | 290 |
| Ancha | 2,520 | 559 | 3,079 | 1,960 | 1,552 | 342 | 1,894 | 1,209 |
| Convenio | 2,484 | 315 | 2,799 | 2,169 | 1,539 | 180 | 1,718 | 1,359 |
| Pineda | 1,485 | 595 | 2,080 | 890 | 913 | 325 | 1,238 | 588 |
| Mayayo | 1,276 | 757 | 2,033 | 519 | 785 | 436 | 1,221 | 349 |
| Acierto | 1,059 | 336 | 1,395 | 723 | 688 | 258 | 946 | 430 |
| Enmedio | 874 | 277 | 1,151 | 597 | 551 | 165 | 716 | 385 |
| Culebrina | 831 | 239 | 1,070 | 592 | 524 | 144 | 668 | 381 |
| Reina | 633 | 160 | 793 | 472 | 396 | 93 | 489 | 303 |
| Villa | 669 | 185 | 855 | 484 | 424 | 114 | 538 | 310 |
| Comuna | 648 | 200 | 848 | 447 | 410 | 124 | 534 | 286 |
| ANOVA *F*-test | *** | | | | *** | | | |

(mean value, standard deviation SD, maximum value Max, minimum value Min, and ANOVA *F*-test ***$p \leq 0.001$; **$p \leq 0.01$; *$p \leq 0.05$; ns = not significant)

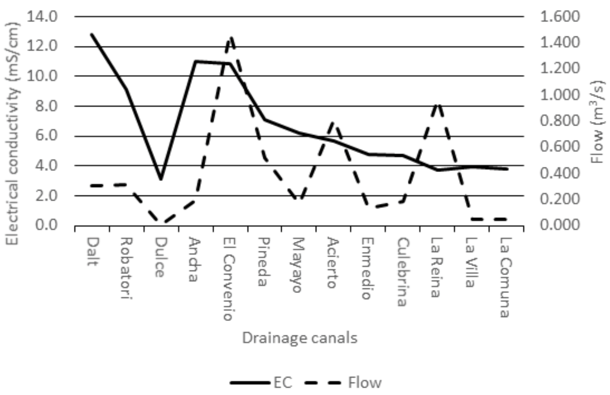


Fig. 3. Electrical conductivity and flow of each drainage canal.

However, changes in flow rate due to seasonality can affect the desalination treatment and vary the amount of salts. If the concentration of the inlet to the desalination unit is low, the final volume of the permeate could be maximized by blending the permeate with the inlet water, thereby decreasing the unit cost of irrigation water [57]. Nevertheless, low salinity feedwater types require less applied pressure than high salinity feedwater types for desalination [58], reducing the energy cost. For both canals, El Convenio and La Reina, a great difference in mean values of EC were obtained, favoring the selection of the La Reina canal. Representing both parameters, mean electrical conductivity expressed in mS/cm and average flow expressed in $m^3/s$, a previous approach to understand which is the preferable ADW and as a consequence, the drainage canal, to install a desalination plant. As a result of representing both parameters (Fig. 3), the La Reina canal could be used for desalination purposes.

The effectiveness of a desalination plant would be associated with a compromise between salinity (EC, TDS) and availability of water (flow). For instance, the Dulce drainage canal gave the minimum value for salinity (3.1 mS/cm); however, the mean water flow was 0.003 $m^3/s$. On the other side, El Convenio has the highest mean water flow of 1.468 $m^3/s$, but salinity was almost three times the salinity of La Reina.

After these considerations, RO is proposed because of its reliability and comparatively low energy consumption in which leads to a significant reduction of energy cost [59]. The unit product cost was the lowest RO ($0.3–0.7/$m^3$) comparing with other treatments [60].

The management of brine disposal is a fundamental issue [61] that should be considered in the early planning stage [19]. The brine has two options if a plant is installed: (i) gone with the drainage water to the sea following the flow direction after the catchment of feed water to the RO system from the canal (Fig. 1), or (ii) construct a parallel canal or pipe for the brine to discharge this into the sea (open sea waters). The volume of brine produced is determined at each individual (operational) desalination plant [58] and, low salinity feedwater favors the reduction of brine volume. Therefore, the situation of the treatment plant, close to the end of the drainage system (La Reina, sampling point 11), facilitates the brine disposal to the sea and can be discharged by using the same drainage canal because water is not going to be re-used for irrigation after that point. Nevertheless, brine can lead to the pollution of coastal waters, damage to sensitive marine life that will ultimately threaten the food chain [62,63] and this should be considered for a future and sustainable design. For instance, nitrates must be considered to avoid coastal eutrophication and several solutions can be applied as those given by Álvarez-Rogel et al. [64], by using woodchips bioreactors or constructed wetlands.

## 4. Conclusions

Water physicochemical characterization is considered vital for the selection of the operational factors of a desalination treatment plant. In our case, and considering a RO scheme, an approach based on easy measurable parameters, EC, estimation of the flow, TSS, could give us, a quick method to understand which is the best option (canal), to install a desalination treatment plant. These parameters can be considered for the optimization of the process and the design of the plant as well. The targets, are to determine salinity and availability of enough water flow, in order to choose the better RO system and reduce the relevant cost, minimize the consumption of energy during operation and extend the membrane life. In this study, La Reina canal the EC is 3.7 mS/cm and the flow rate is 0.967 $m^3/s$, which indicates that a small unit must be applied. In fact, the project will be centered in a solar desalination plant, that could be extended to other canals of the ancient drainage system in order to get new resources of water, with high quality, that can be used for high-value crops (non-tolerant to salinity) and be a support of farmers income and diversification of agricultural production under water scarcity scenery. Furthermore, future water scarcity may reduce the possibilities for sustainable development, as well as, to retain or create new adequate jobs [65], ensuring at the same time water quality according to the Water Framework Directive. In this line, several projects like DESEACROP LIFE 16 ENV/ES/000341 try to give solutions, increasing the possible sources for irrigated agriculture by using salty waters, which is in the line of this article.


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