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Mitigation cost of desalination intake impact on coastal wetlands

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ABSTRACT

In this study, the cost of environmental protection practices established by environmental licenses to protect the Agua Amarga saltmarsh were quantified. The goal of the protection practices was to prevent the lowering of the ground water level due to the intake systems of the Alicante desalination plants. To this end, a seawater irrigation program was established. The volumes oscillated between 216,000 m^3 during the 2013–2014 campaign and 1,171,200 m^3 in the 2017–2018 campaign. The irrigation program had an average cost of €7,342/y, with a maximum of €14,004 for the 2017–2018 campaign and a minimum of €2,329 for the 2013–2014 campaign. The irrigation program maintained the groundwater level in the saltmarsh and compensated for the effect of the intake system on the saltmarsh.

Keywords: Saltmarsh; Irrigation; Desalination; Environmental impact; Cost

1. Introduction

Seawater desalination is an expanding industry that not only can supply coastal regions with freshwater [1] but also generates environmental impacts that should be managed [2]. Although a significant number of papers have studied the impact of brine discharge on the marine environment [3–6], and have discussed how brine discharge can be managed and minimized [2,7–10], other aspects have received less attention, including the impact of seawater intakes. Open intakes impact the environment by impinging and entraining marine organisms, which results in destroyed organisms [11,12]. Subsurface intake systems avoid impingement and entrainment impacts [10,13] but may cause other impacts on surrounding wetlands if they affect groundwater levels [14].

Wetlands are ecosystems that provide valuable services [15] and are reported to be among Europe's most threatened ecosystems. Verhoeven [16] indicated that 80% of the original wetland areas across Europe have disappeared in the last millennium. In the context of global change, wetland degradation can be exacerbated by its impact on groundwater [17]. Groundwater withdrawal by desalination plants may lead to a drop in piezometric levels, which causes negative impacts in water-dependent ecosystems, such as wetlands [14].

Both Alicante I and II desalination plants use subsurface intake systems. Alicante I, which began operations in 2003, has 33 vertical wells located close and parallel to the coastline. Alicante II, which began operations in October 2008, takes water in through 118 inclined drains that are located inside a 1 km long tunnel and also has 11 horizontal directional drillings [13]. The Alicante desalination plants are located on the edge of a saltmarsh known as the "Saladar de Agua Amarga." The environmental licenses of both desalination plants indicate that mitigation measures need to be adopted to prevent the lowering of the groundwater table. To this end, a controlled seawater irrigation

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program was established to maintain piezometric levels [18]. Some previous studies analyze the effect of the irrigation program on the saltmarsh vegetation [14,18–20] but, up to the moment, the cost of this program has not been quantified. The objective of this study was to quantify the energetic cost of the irrigation system used to maintain the piezometric levels and protect the saltmarsh in relation with desalination plants production.

2. Material and methods

The Agua Amarga saltmarsh originated as an ancient salt-work that was in use until the middle of the XXth century [18]. Fig. 1 shows the saltmarsh with the position of the piezometric network that is used to estimate the impact of the desalination intakes on the groundwater level and the effectiveness of the irrigation system. Piezometric data used in this paper was facilitated by the Polytechnic University of Cartagena. The Agua Amarga saltmarsh is a Municipal Natural Park of ~180 ha, which is included in the Valencia Community wetlands catalogue that hosts EU protected habitats [14]. The saltmarsh has one central area with salt-work ponds where irrigation occurs and a peripheral area. Fig. 2 shows the details of the irrigation system. Peripheral area vegetation is composed mainly of *Suaeda vera*, *Lygeum spartum*, and *Limonium* spp., whereas vegetation in the central area is composed mainly of *Sarcocornia fruticosa*, *Arthrocnemum macrostachyum*, *Salicornia patula*, and flooded ponds with *Ruppia maritima* [19].

The irrigation system consists of a chamber with a pump that provides seawater to the saltmarsh. It has a network analyzer model PM710 that continuously registers the pump's energy consumption. Monthly energy consumption and desalination production were obtained from the owners of the desalination plants.

The irrigation program was established on a yearly basis by the environmental authorities with the objective of maintaining seasonally flooded ponds and recover the piezometric level of the aquifer to protect the flora and fauna. Each irrigation campaign starts in November and finishes in October of the following year. The period studied began with the 2011–2012 irrigation campaign and continued through the 2018–2019 irrigation campaign.

3. Results

Alicante desalination plant production varied depending on water supply needs. The maximum production level occurred in the 2017–2018 campaign, whereas the minimum production level occurred in the 2012–2013 and 2013–2014 campaigns (Fig. 3).

The amount of water provided monthly to the saltmarsh is given in Table 1. Quantities provided varied from 216,000 m^3 during the 2013–2014 campaign to 1,171,200 m^3 in the 2017–2018 campaign.

In general, the higher the production of the desalination plants, the higher the volume of water provided to the saltmarsh by the irrigation system (Fig. 4), although this relationship was not observed when using monthly data (Fig. 5). This low relationship between monthly data is due to a different annual pattern of production and irrigation (Fig. 6). Maximum production was observed during the summer months, whereas maximum irrigation was observed in the spring to favor vegetation growth and bird nesting.

Figs. 7–9 indicate the piezometric level at three different points, the irrigation volume, and the rainfall amounts during the study period. It is possible to observe that, at all points, the rainfall increased the piezometric level. The irrigation increased the piezometric level mainly at

Fig. 1. Agua Amarga saltmarsh. Piezometers position is indicated.

Fig. 2. Water distribution system in the salt marsh.

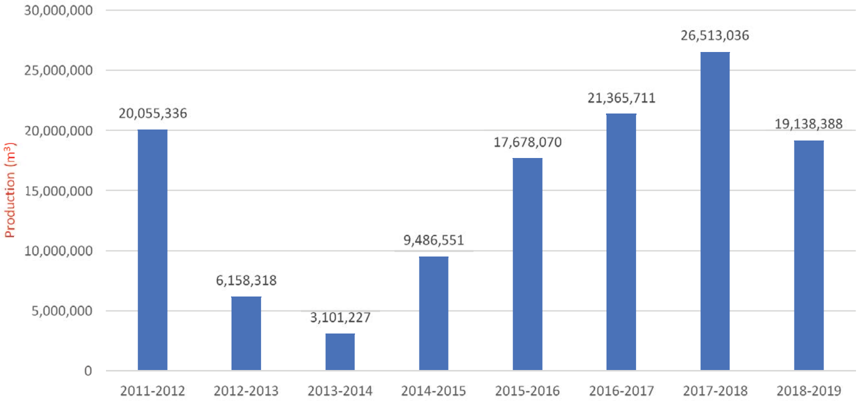

Fig. 3. Production of both desalination plants (m^3).

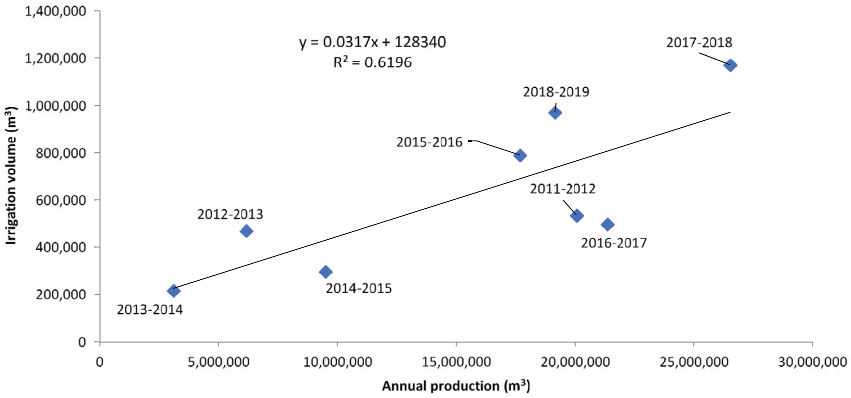

Fig. 4. Relationship between annual production of desalination plants and irrigation volume to the saltmarsh.

Table 1
The amount of water (m^3) provided by the irrigation program to the saltmarsh

	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019	Average
November	86,400	0	0	0	0	0	91,200	33,600	17,829
December	62,400	0	0	0	81,600	2400	81,600	148,800	44,914
January	38,400	0	0	0	70,400	0	96,000	96,000	37,486
February	79,200	52,800	0	0	57,600	28,800	120,000	120,000	54,171
March	72,000	81,600	0	67,200	72,000	38,400	129,600	144,000	76,114
April	57,000	96,000	72,000	72,000	105,600	55,200	96,000	67,520	80,617
May	90,772	134,400	100,800	110,400	72,000	86,400	115,200	57,600	96,686
June	48,000	61,145	43,200	48,000	91,200	72,000	144,000	67,200	75,249
July	0	28,800	0	0	62,400	76,800	144,000	124,800	62,400
August	0	14,400	0	0	72,000	57,600	76,800	86,400	43,886
September	0	0	0	0	57,600	48,000	48,000	24,000	25,371
October	0	0	0	0	48,000	33,600	28,800	0	15,771
Total	534,172	469,145	216,000	297,600	790,400	499,200	1,171,200	969,920	630,495

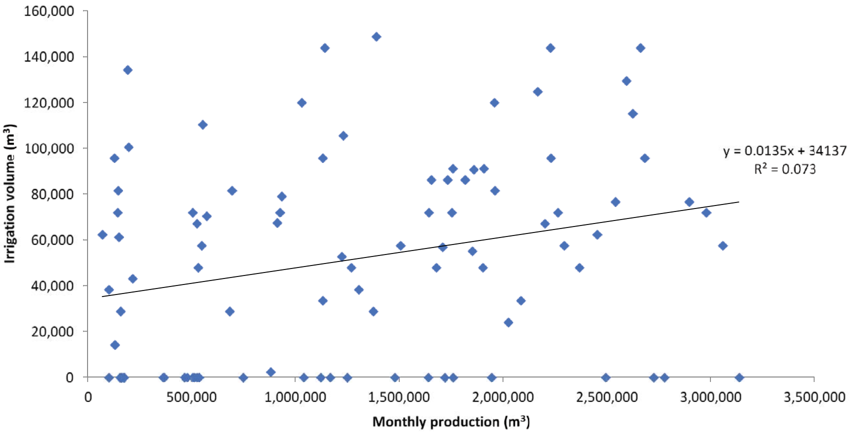

Fig. 5. Relationship between monthly production and monthly irrigation volume to the saltmarsh.

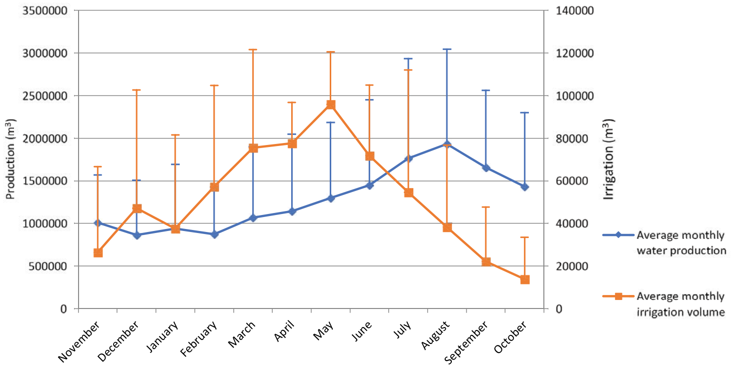

Fig. 6. Evolution of the monthly averages of irrigation volume to the saltmarsh and production of desalination plants with standard deviation error bars.

points 1 and 8; meanwhile, no relation was observed at point 2, which is further from the irrigation area (Fig. 1). This may be observed by the increase of the piezometric level in April–May 2015 that it is produced in points 1 (Fig. 7) and 8 (Fig. 9) while it is not observed in point 2 (Fig. 8).

The monthly energy consumption of the irrigation pump between November 2011 and October 2019 is shown in Table 2. The energy price is given in Table 3. The energy price varied between years and months. On average, the price was highest in July and lowest in August.

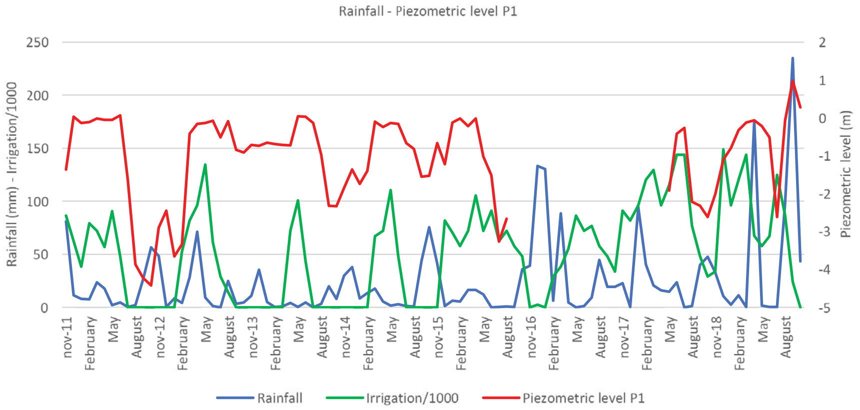

Fig. 7. Evolution of piezometric level, rainfall, and irrigation volume (in thousand m^3) at piezometer 1.

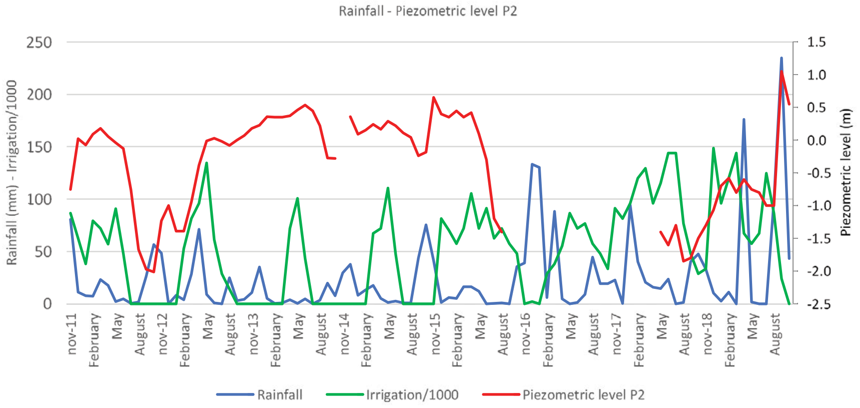

Fig. 8. Evolution of piezometric level, rainfall, and irrigation volume (in thousand m^3) at piezometer 2.

Table 2
Energy consumption (kW/h)

	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019
November	13,824	0	0	0	0	0	14,592	5,376
December	9,984	0	0	0	13,056	384	13,056	23,808
January	6,144	0	0	0	11,264	0[1]	15,360	15,360
February	12,672	8,448	0	0	9,216	4,608	19,200	19,200
March	11,520	13,056	0	10,752	11,520	6,144	20,736	23,040
April	9,120	15,360	11,520	11,520	16,896	8,832	15,360	10,803
May	14,523	21,504	16,128	17,664	11,520	13,824	18,432	9,216
June	7,680	9,783	6,912	7,680	14,592	11,520	23,040	10,752
July	0	4,608	0	0	9,984	12,288	23,040	19,968
August	0	2,304	0	0	11,520	9,216	12,288	13,824
September	0	0	0	0	9,216	7,680	7,680	3,840
October	0	0	0	0	7,680	5,376	4,608	0
Total	85,467	75,063	34,560	47,616	126,464	79,872	187,392	155,187

The irrigation program had an average cost of €7,342 per campaign, with a maximum of €14,004 for the 2017–2018 campaign, and a minimum of €2,329 for the 2013–2014 campaign (Table 4). This cost considers only the energy costs but not any equipment maintenance or labor costs.

4. Discussion

The water withdrawal from the Alicante desalination plants caused a progressive lowering of the aquifer piezometric levels before 2009 (the year the irrigation program

Table 3
Energy cost (€/kWh) per month

	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019	Average
November	0.0744	0.0831	0.0746	0.0652	0.0790	0.0761	0.0788	0.0707	0.0752
December	0.0808	0.1043	0.0739	0.0692	0.0872	0.0872	0.0859	0.0804	0.0836
January	0.0827	0.1081	0.0760	0.0717	0.0732	0.0926	0.0786	0.0814	0.0831
February	0.0947	0.1075	0.0739	0.0720	0.0587	0.1083	0.0850	0.0819	0.0852
March	0.0742	0.0741	0.0680	0.0682	0.0485	0.0907	0.0601	0.0704	0.0693
April	0.0691	0.0726	0.0667	0.0682	0.0414	0.0882	0.0607	0.0659	0.0666
May	0.0711	0.0731	0.0664	0.0678	0.0433	0.0899	0.0744	0.0659	0.0690
June	0.1007	0.0812	0.0708	0.0718	0.0623	0.1001	0.0773	0.0761	0.0800
July	0.1121	0.0887	0.0867	0.0731	0.0677	0.1016	0.0835	0.0827	0.0870
August	0.0686	0.0645	0.0642	0.0640	0.0564	0.0628	0.0647	0.0642	0.0637
September	0.0839	0.0701	0.0712	0.0784	0.0626	0.0679	0.0706	0.0815	0.0733
October	0.0778	0.0671	0.0674	0.0752	0.0743	0.0754	0.0661	0.0795	0.0728
Average	0.0825	0.0829	0.0717	0.0704	0.0629	0.0867	0.0738	0.0751	0.0757

started). The levels fell from between approximately −2.5 and −5 m to between approximately −4 and −7 m [20], which contributed to the salinization and degradation of the marsh habitats due to increased desiccation. The seawater recharge program carried out over the saltmarsh induced changes in groundwater quality and piezometry. As a result, piezometric levels increased by about 2 and 3 m below the saltmarsh, and a general decrease in groundwater salinity was measured between 15 and 100 g/L [18].

This study quantified the cost of the environmental protection practices established in environmental licenses for the Alicante desalination plants, which were established to protect the Agua Amarga saltmarsh by preventing the lowering of the groundwater level. The irrigation program changed during the various campaigns studied to fulfill technical criteria to protect the flora and fauna of the saltmarsh. The volumes oscillated between 216,000 m^3 in the 2013–2014 campaign and 1,171,200 m^3 in the 2017–2018 campaign. In general, the irrigation was higher in years with a higher production of desalinated water although there is not a direct relationship between the amount of water produced and the irrigation program.

The irrigation system has allowed to maintain, in the central part of the salt marsh, seasonally flooded ponds necessary for the development of *Rupia maritima* while it has a lower impact on the peripheral area of the salt marsh.

The irrigation program enabled groundwater levels in the saltmarsh to be maintained, and it compensated for the effect of the intake system on the environment [14,18,19]. Seasonality of the irrigation program is related to the natural characteristics of the saltmarsh, with a higher flowering and bird nesting in spring, when maximum irrigation is produced [14].

The environmental impact of desalination plants may be reduced with the application of the Environmental Impact Assessment process [21,22]. The Environmental Impact Assessment of the Alicante desalination plants established an irrigation program to prevent impacts on the saltmarsh;

Table 4
Cost (€) for each of the irrigation program campaigns

	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019
November	1,028.06	0	0	0	0	0	1,149.12	380.15
December	806.89	0	0	0	1,137.87	33.47	1,120.99	1,914.71
January	508.34	0	0	0	824.15	0	1,208.01	1,250.76
February	1,200.63	907.76	0	0	541.05	499.07	1,631.78	1,571.71
March	854.63	968.06	0	733.26	558.18	557.45	1,246.72	1,620.87
April	629.81	1,114.85	768.31	785.51	700.21	779.28	932.03	712.32
May	1,033.12	1,571.48	1,071.12	1,197.10	499.13	1,242.91	1,371.25	606.99
June	773.03	794.89	489.56	551.27	909.46	1,152.79	1,780.03	817.90
July	0	408.72	0	0	676.38	1,249.00	1,923.35	1,651.93
August	0	148.70	0	0	650.02	578.54	794.42	888.03
September	0	0	0	0	576.84	521.62	542.14	313.14
October	0	0	0	0	570.77	405.48	304.48	0
Total	6,834.51	5,914.46	2,329.00	3,267.13	7,644.05	7,019.61	14,004.32	11,728.51

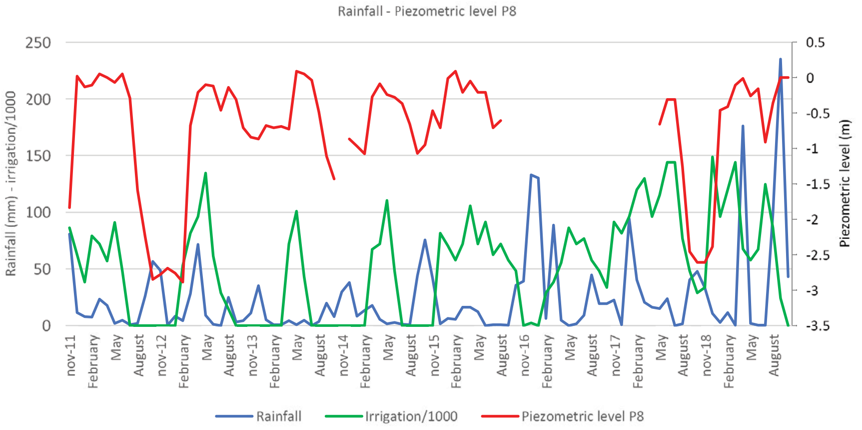

Fig. 9. Evolution of piezometric level, rainfall, and irrigation volume (in thousand m^3) at piezometer 8.

it also established a seawater bypass system to protect the *Posidonia oceanica* meadow and its associated fauna [9].

The energy cost of the irrigation program represents, on average, €0.52 for each 1,000 m^3 of water produced by the desalination plants, although this cost oscillates between €0.32/1,000 m^3 and €0.96/1,000 m^3. This cost is much lower than the cost of the seawater bypass system that protects the *Posidonia oceanica* meadows from the brine discharge, which oscillates between €0.005/m^3 and €0.014/m^3 [23].

In conclusion the irrigation program fulfilled the established Environmental Impact Statement requirements and protected the saltmarsh from the intake systems of the desalination plants with a low energy cost. Similar systems may be applied on other desalination plants that utilize well intake systems that may impact coastal tidal wetlands.

Acknowledgments

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