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ORIGINAL ARTICLE

Interaction of aquifer–wetland in a zone of intensive agriculture: the case of Campo de Dalías (Almería, SE Spain)

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Abstract The Campo de Dalías (Almería, south-eastern Spain) was the backdrop for the development of intensive agricultural activity during the 1970s. Due to the poor natural soil development, the agriculturalists opted for a system that involved quarrying silt and clay deposits that could be used as soil in the greenhouses. In parallel, poor water quality in the upper aquifer caused the gradual abandonment of boreholes and a generalised rise in piezometric levels. These factors have favoured the formation of a series of artificial wetlands in the abandoned clay pits (Onayar, Cabriles and Balsa del Sapo ("Toad Pond") being the most significant). In Balsa del Sapo, the water column rose 3.5 m between October 2007 and February 2011. There has been a continuous fall in the electrical conductivity of the surface water, which has gone from 14,500 μS cm^{-1} in 2004 to 4,100 μS cm^{-1} in 2013. The most recent concentrations are close to those found in the groundwater. The same situation is detected for Cl, SO_4 and Na ion concentrations in the surface and groundwater. These data show the groundwater–surface water interaction in the Balsa del Sapo. Nevertheless, the sharp rise in surface water level has created a flood hazard (due to the shallow topography of the area), both for people living in the vicinity and their property. This is an endorheic zone where a number of ramblas (gullies) draining the southern face of the Sierra de Gádor mountains converge. The Campo de Dalías is a spectacular example of the changes that can occur in a semiarid agricultural area as a result of intensive groundwater abstraction. These changes are directly related to the management of water resources, the most recent consequence of which is the increased risk of flooding. Hence, there is a need to consider the management of these water resources to achieve a more sustainable use, which is compatible with the environmental protection of the wetland and which will give some guarantee of flood protection for people and property.

Keywords Clay pits · Artificial wetlands · Piezometers · Groundwater–surface water

Introduction

Inland wetlands exhibit a notable morphological diversity, as well as high biodiversity and frequent changes in the conductivity/salinity of the water. In semiarid regions, they tend to be particularly valuable because of their contribution to diversifying the landscape (González Bermúdez 1989). Numerous schemes have been described for eliminating nutrients and buffering pollution of artificial wetlands (Moreno et al. 2007) and such schemes are an efficient and economical tool for controlling non-point/disperse pollution in large agricultural areas (Kovacic et al. 2006), in different climates (Moreno et al. 2010), and related to drainage networks (Jia et al. 2011).

Since 1990, the Campo de Dalías has witnessed the formation of a series of wetlands, consequence of the abandonment of a number of clay pits. Their origin means

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they are considered as artificial wetlands. Their origin is related to the intensive agricultural activity that occurred on the Campo de Dalías in the 1970s. The high profitability of greenhouse agriculture, linked to the availability of suitable technology, meant that it became viable to plant crops in areas that were previously the least favourable, by depositing a layer of artificial soil over the poor and saline natural soils. Specifically, it involved placing a 30- to 50-cm layer of silt (which equates to some 4,000 m^3 ha^{-1}), in which the crops could be cultivated (Castilla 1986). The poor natural soil in this area encouraged the excavation of clay pits for extracting silts and clay for use as substrate in the greenhouses. Silty clays were extracted from pits in Onáyar, Cabriles and Balsa del Sapo, amounting to an 8 million m^3 (Castro et al. 1999). The most extensive clay pits were in the vicinity of Balsa del Sapo, an area that, until the end of the nineteenth century, was used mainly for grazing goats or growing limited cereal crops (Fig. 1). The endorheic character of the area means that is it the receptor for surface runoff from storm events. The low-lying topography, relative to the rest of the landscape, means that the water table of the underlying aquifer lies close to the ground surface, which means that well construction is a viable option (La Calle and Martínez 2013).

The wetland known as Balsa del Sapo comprises two former clay pits, divided by a narrow strip of land. Water has been accumulating in these pits over recent years, increasing the estimated area of open water from between 55.8 and 59.6 ha in 2007 (Daniele 2008) to between 60.8 and 60.4 ha in 2013. The other recognised wetlands (Cañada de Cabriles and Cañada de Onáyar) are smaller. From an environmental point of view, Balsa del Sapo is of sufficient interest to be listed on the Andalusia Wetlands Inventory (since 2007) and on the National Inventory of Wetlands (since 2009). These figures of environmental protection are justified by the unique habitat for microorganisms, flora and fauna that is represented in Balsa de Sapo (Casas et al. 2003).

Fig. 1 Balsa del Sapo at the beginning of the silt and clay extraction

The coastal part of Campo de Dalías also accommodates a series of diverse wetlands that are either influenced by the sea, groundwater discharges or by the effects of a high evaporation rate (Sánchez-Martos et al. 2013). To the east, the vulnerability of deltaic environments has been described and also how lagoons can reflect anthropogenic changes over the whole river basin (Rodríguez-Rodríguez et al. 2011). Nevertheless, Balsa del Sapo lies away from the coast and its origin, evolution and history are closely associated with the development, growth and spread of agricultural activity in the Campo de Dalías. For all these reasons, a sustainable water resources plan is needed for this wetland, which also addresses the lack of water resources, both in terms of quality and quantity, for agricultural irrigation. Various authors have confirmed the importance of groundwater management and its relationship with wetlands (Sophocleous 2002; Hayashi and Rosenberry 2002; Jolly et al. 2008; Bertrand et al. 2013). The groundwater–surface water interaction can be a important determinant of the quantitative hydrology that underpins the wetland ecosystems (Schot and Winter 2006) to appropriately manage and conserve the associated wetland (van der Kamp and Hayashi 2009; Rodríguez-Rodríguez et al. 2007) and the environmental requirements of the groundwater-dependent ecosystems must be considered (Tomlinson and Boulton 2010). The connection between surface quaternary units and deep hydrogeological units has been shown to be responsible for the existence of wetlands (Carol et al. 2010), where geological factors influence the flow of groundwater towards wetlands (Stei et al. 2004). Therefore, there is a need for precise knowledge about wetland hydrogeology dependent upon groundwater (Hancock et al. 2009) for environmental management of these ecosystems.

In terms of quality, the importance of groundwater flow and its relationship with the salinity of wetlands is well known (Petrides et al. 2006; Kohfahl et al. 2008); this is a highly relevant aspect in semiarid regions (Jolly et al. 2008; Djabri et al. 2008; Crosbie et al. 2009) where evaporation processes favour a progressive concentration of salts (Miralles et al. 2006). Moreover, it should be considered that wetland ecosystems are particularly vulnerable due to flow of nutrients from the surrounding watershed (Nouri et al. 2010). As a result of the problems associated with the rise in water level of the Balsa del Sapo, a series of papers have been published, which analyse the origin of the clay pits and their possible relationship with the aquifer, and propose alternative solutions (Dominguez et al. 2006). In addition, the groundwater inflow has been calculated based on the volume of water that has accumulated in the wetland (Daniele et al. 2007), and the problems associated with pumping and drainage of its waters have also been discussed (Ortega and Rivas

2012). More recently, the historical evolution of the areas was considered, evaluating the actions that have been undertaken by the Public Administration to try and resolve the problems associated with the rise in water level in this wetland (La Calle and Martínez 2013).

The case study presented is a prime example of the changes that have occurred, in recent years, in semiarid agricultural area that are used for intensive agriculture: the development of greenhouses, intensive groundwater abstractions, impact on water quality, quarrying for the extraction of silt, wetland formation, risk of flooding of land and property close to the wetlands and, lastly, effects related to the management of water resources. This paper focuses on the origin and evolution of Balsa del Sapo, based on a study of the quality and quantity of its surface water. Different alternatives are presented and discussed for the sustainable management of this wetland.

Hydrogeological setting

The Campo de Dalías is a coastal plain some 330 km^2 in extent, in the shape of a semi-ellipse. To the north, it is bounded by the Sierra de Gádor, while its other edges are littoral and touch the Mediterranean Sea (Fig. 2a). Its relief is a little rugged, sloping gently towards the sea but broken by scarps and a series of tectonic, endorheic basins between Las Norias and El Ejido. The area receives most of its surface water drainage from short, steep ramblas, which flow from the southern face of the Sierra de Gádor and have no outflow to the sea. Three hydrogeological units are identified within the Campo de Dalías (Pulido-Bosch et al. 1992; Molina 1998): Balerma-Las Marinas, Balanegra and Aguadulce (Fig. 2a).

The Balanegra unit lies at the western end of the Campo de Dalías. It comprises Miocene carbonates and calcarenites. Towards the centre of the Campo, it dips progressively and is confined beneath the Pliocene marls. The Aguadulce unit lies at the eastern end and has a more complex geometry. It is made of Miocene dolomitic limestone, calcarenite and volcanic rocks; Pliocene calcarenite with sandy episodes and Quaternary fill (Sola et al. 2013).

Due to its situation, the Balsa del Sapo wetland seems to be linked to the Balerma-Las Marinas Unit. This unit is the most extensive of the three (225 km^2) and occupies the central portion of the Campo de Dalías. This aquifer basically comprises Pliocene calcarenites; towards the wall are sands and marly sands, which appear in the transition into the impermeable base of this aquifer (a marl layer more than 700 m thick). The calcarenites are partially covered by continental and marine Quaternary deposits. They are some 100-m thick in the north, decreasing to the south as the proportion of terrigenous elements increases. The Pleistocene deposits are formed by a marine conglomerate, sands or marly sands, and fine sands. A continental Quaternary formation of red silts with rounded quartz softens the scarps and fills the tectonic, topographical depressions. There are other Quaternary outcrops as well, including the alluvial fans spreading out from the foot of the Sierra Gádor, and sediments of salt flats, lagoons and marshlands. The marls overlie limestones and dolomites from the Balanegra Unit. Transmissivity values are highly variable (200–800 m^2 day^{-1}) and this reflects the heterogeneity of the lithology: the lowest transmissivity is in the sandy marly facies, while the highest are in the calcarenites with their greater saturated thickness.

Recent neotectonic activity has played an important role in the present-day disposition of the area, which has had considerable influence on the hydrogeology (Pulido-Bosch et al. 1989). According to Marín-Lechado et al. (2004), the faults oriented NW–SE affect the Pliocene and Quaternary deposits and develop half-grabens in the Quaternary. The E-W faults are a product of reactivation during the terminal Miocene event. Both systems have caused an overall tilting of the abrasion surface towards the NE.

The southern boundary of the aquifer is formed by the Mediterranean Sea. The coastal fringe is occupied by sandy marls and Quaternary deposits but at no point do the calcarenites contact the sea. The eastern boundary coincides with a fracture, along which there are piezometric jumps. Given that the potential of this unit is greater than the Aguadulce Unit it abuts, this implies that we are dealing with a flow boundary. Under a natural regime, it is quite possible that the opposite occurs—i.e. there would be a north-to-south inflow from the Sierra de Gádor (Pulido-Bosch et al. 2005).

In 2010, groundwater abstractions from the Campo de Dalías were 142 hm^3, 89 % of which came from the carbonate aquifers (IGME 2012). The Balerma-Las Marinas Unit has witnessed a gradual decline in pumped abstractions, from 18 to 9 hm^3 year^{-1} between 1981 and 1993. Since then, abstractions stabilised at below 10 hm^3 year^{-1} until 1998/1999 (González et al. 2003). This reduction is associated with deterioration in water quality, which led to the boreholes being abandoned. Currently, the wetland overlies a hydrogeological unit that has a clear positive water balance.

Materials and methods

Piezometric levels in the Balerma-Las Marinas unit have been monitored over recent decades, with the latest survey in 2010. Piezometric data correspond to November 1986, January 1991, June 2007 and June 2010. The number of control points was 30 and 41 in 1986 and 1991,

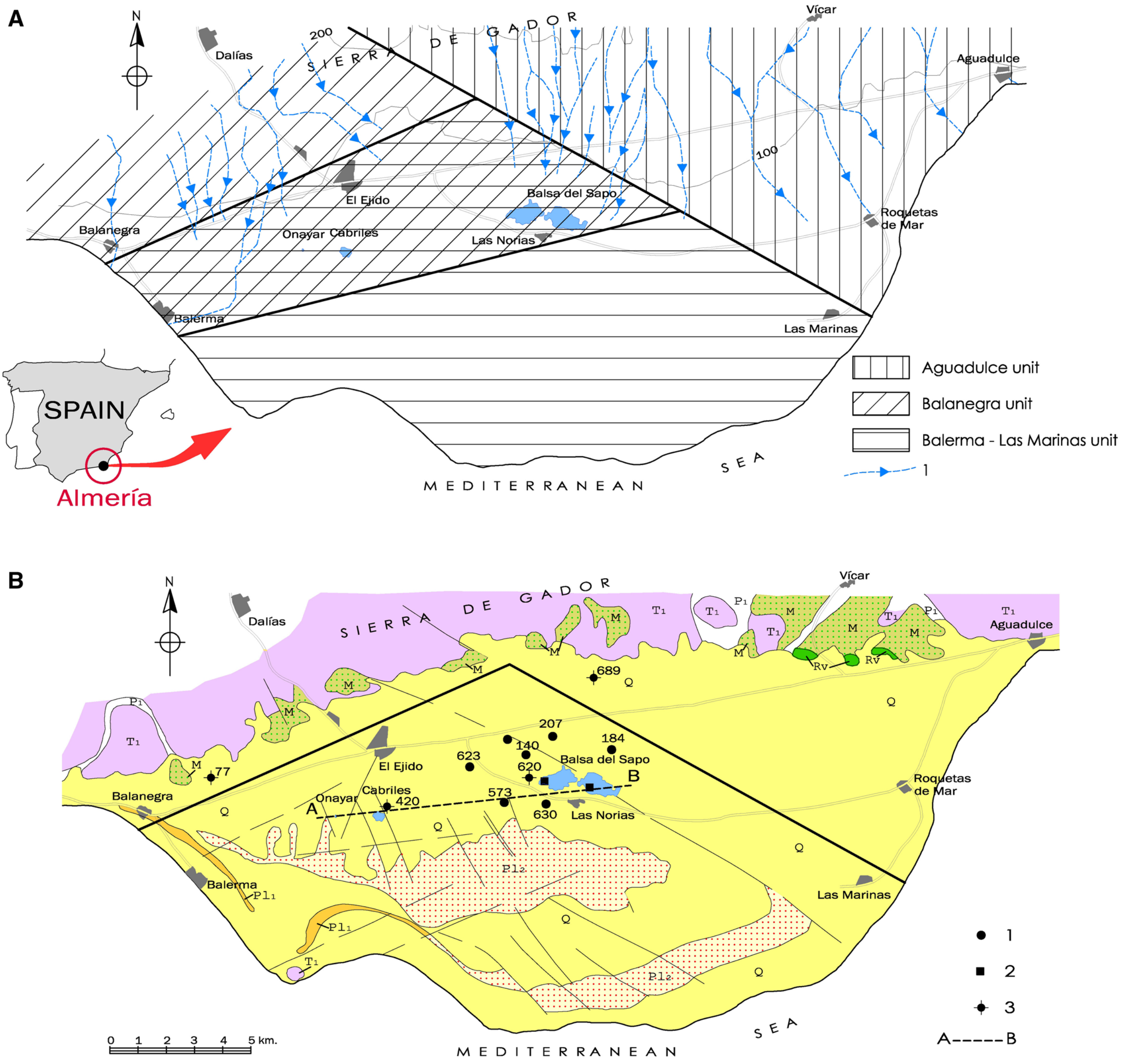

Fig. 2 **a** Location of the study area and of the hydrogeological units. The principal ramblas are shown (*1*). **b** Hydrogeological scheme of the Campo de Dalías. *Q* Quaternary deposits; *Pl*$_2$ Pliocene calcarenites; *PL*$_1$ Pliocene marls; *M* Miocene calcarenites; *Rv* volcanic rocks; *T*$_1$ limestones and dolomites; *P*$_1$ Metapellites. *1* Groundwater sampling point. *2* Surface water sampling point. *3* Piezometers. *4* **a**, **b** Hydrogeological section given in Fig. 4)

respectively. In recent years, the number of points is decreased because of the abandonment of wells in the aquifer, being buried (Fig. 3). The groundwater contour maps were prepared as part of this study. Drawing isolines involves interpolation. The height of the water level in the wetland has been monitored by the El Ejido municipal council. Hydrogeochemical data correspond to two surveys in 2001 and 2007. The number of samples taken was six in both occasions. In addition, samples of surface water were taken from the twin pits that accommodate the wetland, on different dates (Table 1). Temperature, electrical conductivity (EC), pH and bicarbonate titration were determined in situ. Samples were taken in duplicate, filtered using a 0.45 µm Millipore filter and stored in polyethylene bottles at 4 °C. For cation analysis, to prevent absorption or precipitation, samples were acidified to pH <2 with environmental grade (ultra pure) nitric acid. Sample composition (Ca^{2+}, Na^+, Mg^{2+}, K^+, Cl^- and SO_4^{2-}) was determined by means of ICP-Mass Spectrometer at Acme Labs (Vancouver, Canada). Microbial parameters were not determined.

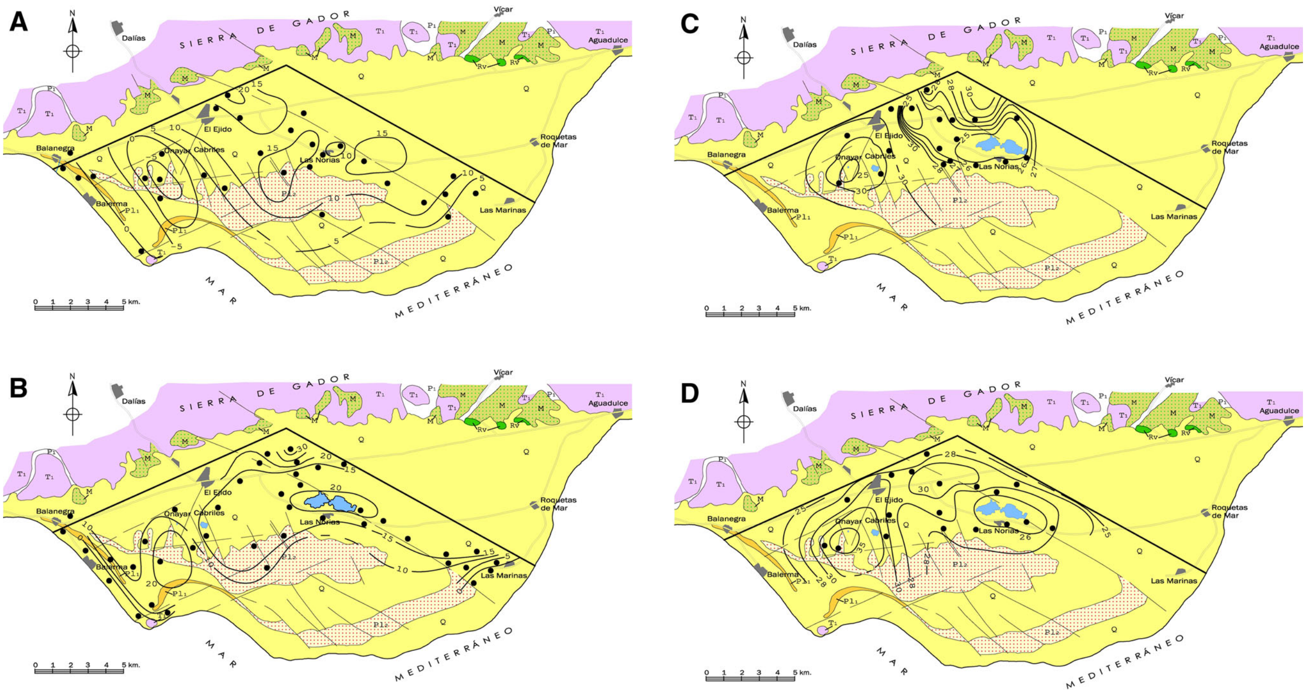

Fig. 3 Piezometric surface in the Balerma-Las Marinas Unit **a** November 1986. **b** January 1991. **c** June 2007. **d** June 2010)

Results and discussion

Trends in piezometric level

The earliest piezometric data available for the Balerma-Las Marinas unit are from the 1970s and 1980s. In 1982, the water table lay as high as 5 m a.s.l. Water level was highest in the north and west of the unit, while around Onayar there was a large, steep drawdown cone, with the lowest water level recorded at −20 m a.s.l. (Molina 1998). In 1986, the highest water level was still in the northern sector, while in the Onayar drawdown cone, it had risen to a −5 m a.s.l., and in the area around Las Norias (where the wetland later formed) the piezometric surface was between 10 and 15 m a.s.l. (Fig. 3a).

In January 1991 (Fig. 3b), the piezometry showed some small variations; the highest water level (20–30 m a.s.l.) was still in the north, the drawdown cone around Onayar went from −5 to 5 m a.s.l. These two areas registered continuous rises in water level, which were due to the abandonment of boreholes and infiltration of irrigation return water, favoured by the sand content of soils. It is worth noting that a large part of the surface area corresponding to this hydrogeological unit is occupied by greenhouses dedicated to market–garden crops.

In October 2001, there was a marked rise in water level; around the wetland, groundwater levels exceeded 24 m a.s.l., while in Onayar and Cabriles, it was between 15 and 20 m a.s.l. Figure 3c, corresponding to June 2007, shows that the piezometric contours were aligned NW–SE in the vicinity of the Balsa del Sapo wetland, where they exceeded 25 m a.s.l. Meanwhile, to the west, they exceeded 30 m a.s.l. (Daniele 2008). The most recent map of piezometric surface, corresponding to June 2010, shows a continuing rise in water levels, with 26 m a.s.l. near the wetland and slightly more than 35 m a.s.l. to the west (Fig. 3d).

Figure 4 shows piezometric evolution over the past 30 years for two monitoring points in the Balerma-Las Marinas Unit, located to the east of Balsa del Sapo (no 610) and close to Cabriles (no 420). Both show a rising trend of water level of between 12 and 17 m a.s.l. However, in no 77 (Balanegra unit) and no 689 (Aguadulce unit) the trend is in the opposite direction, with drops in water level of 35 and 15 m, respectively. The most recent values at these two points were −34 and −10 m a.s.l., respectively.

Figure 5 is a scheme of groundwater flow in the Balerma-Las Marinas unit, showing how flow towards the depressed area leads to accumulation of water in the wetlands.

Evolution of water level in the Balsa de Sapo wetland

Continuous monitoring of water level at Balsa del Sapo began in October 2003. It was measured weekly from 2003 to 2006 and daily so far today. As commented above, the wetland comprises two flooded pits, separated by a narrow strip of land. Water level in the two depressions is similar, with a rising trend recorded between 2004 and 2006 (Fig. 6). This has led to occasional flooding of several

Table 1 Chemical data for surface waters and groundwaters

Sample		Date	EC	Cl	SO_4	HCO_3	Na	Mg	Ca	K
Groundwater	140	May-01	3,100	750	420	305	366	144	129	6
	184		3,070	745	272	269	261	124	117	11
	207		2,490	745	113	266	340	109	98	14
	573		3,290	762	193	328	390	115	126	20
	630		4,540	1,205	526	322	664	149	206	19
	623		2,690	691	143	353	330	113	85	11
Groundwater	140	Jun-07	3,150	703	297	305	402	113	105	18
	184		3,080	280	135	311	148	51	20	55
	207		2,180	620	224	246	308	108	104	16
	573		3,890	865	363	329	448	132	136	6
	623		3,530	405	123	384	219	60	15	52
	630		4,440	974	606	360	611	173	188	8
Surface water	a	Jun-01	22,000	6,031	2,644	305	3,591	715	102	143
		Jun-03	14,500	2,919	547	756	1,284	428	234	65
		Jun-04	15,100	2,786	989	763	1,594	314	250	85
		Jun-07	11,000	3,255	1,515	580	1,981	338	22	12
		Jul-09	7,610	1,775	880	549	1,467	51	51	41
		Jun-13	4,200	1,320	947	439	729	177	115	47
	b	Jun-03	15,730	3,153	561	714	1,284	441	238	65
		Jun-04	15,150	2,990	944	665	1,621	260	339	91
		Jun-07	11,590	3,388	1,566	561	2,182	325	27	83
		Jul-09	7,950	1,962	740	567	1,495	47	61	61
		Jun-13	3,980	1,156	859	439	676	166	87	30

Ion concentrations in mg L^{-1} (*EC* electrical conductivity in $\mu S\ cm^{-1}$)

[a] Western pond

[b] Eastern pond

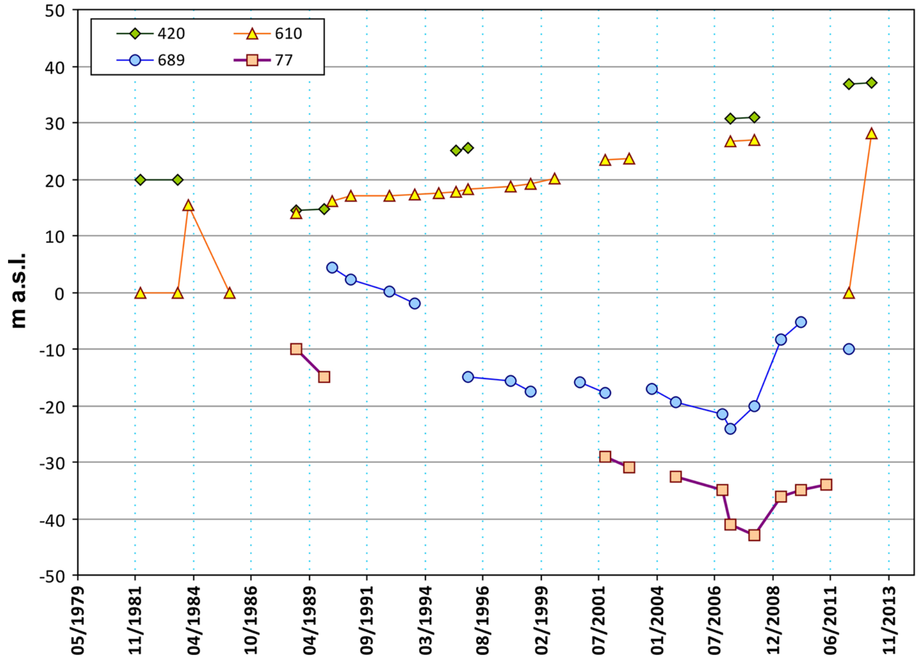

Fig. 4 Piezometric trends at groundwater monitoring points, nos 610, 420, 77 and 689 (Location of these points can be seen in Fig. 2b)

hectares of greenhouses and a number of dwellings (Fig. 7). Given this flood risk, in 2006, the Administration began pumping up to 180 L s^{-1} from a pumping station installed in the western clay pit. The pumped water was discharged into the Mediterranean Sea. This pumping corrected the situation and, in 2007, levels had descended by almost 2 m. The pumping also put a stop to the progressive flooding of the greenhouses and reduced the flood

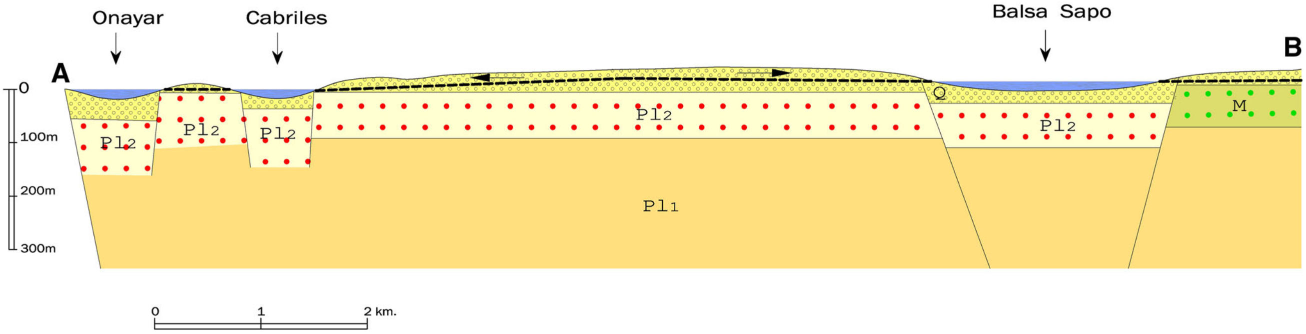

Fig. 5 Hydrogeological scheme of the wetlands in the study area (*Q* Quaternary deposits; *Pl_2* Pliocene calcarenites; *PL_1* Pliocene marls; *M* Miocene calcarenites). Location of the cross section is shown in Fig 2b

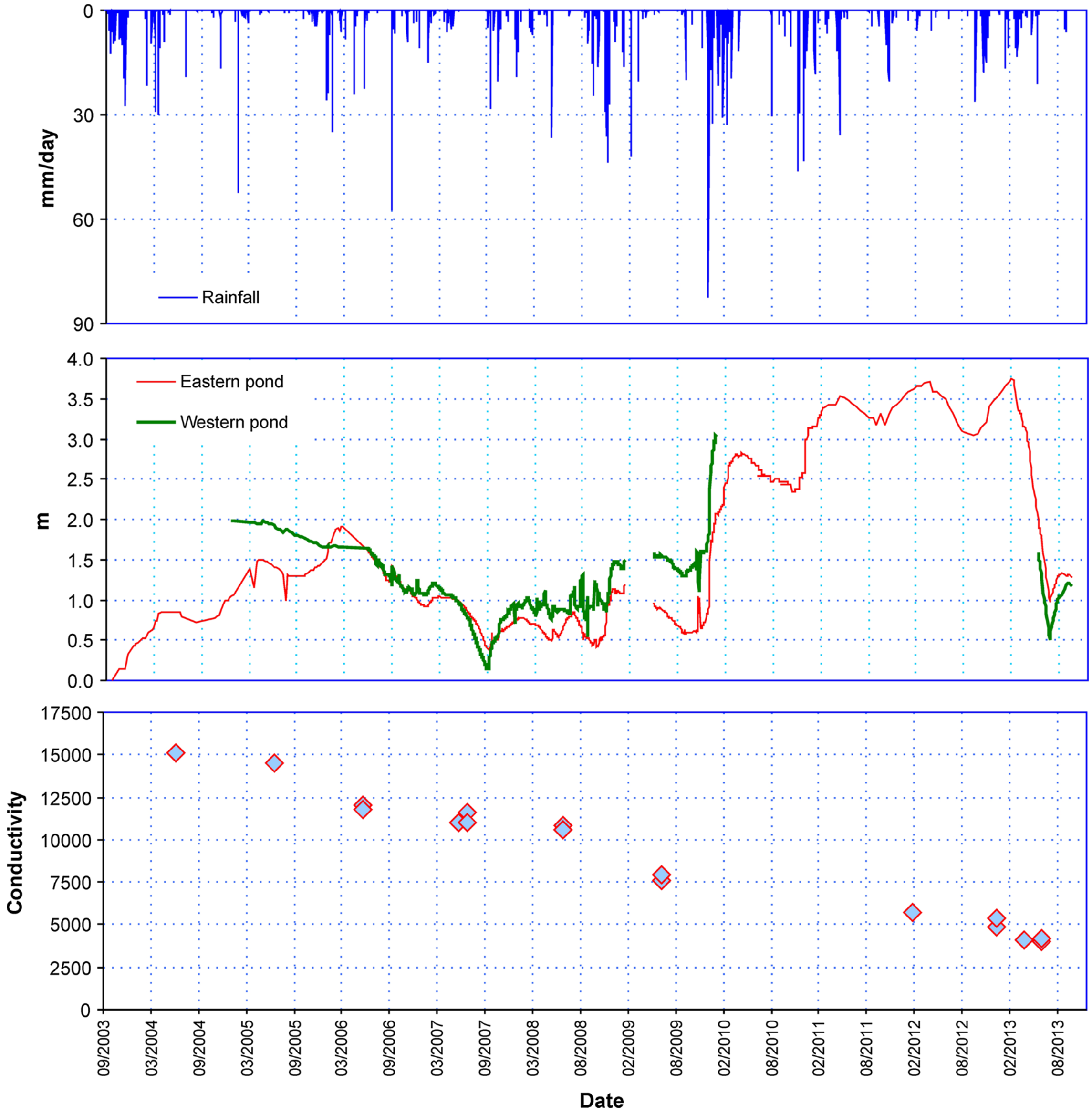

Fig. 6 Evolution in water level in the wetland, rainfall (La Mojonera station) and electrical conductivity (μS cm^{-1}) of the water in Balsa de Sapo for the period 2003–2013

Fig. 7 Flooded greenhouse next to Balsa del Sapo

risk associated with heavy rainstorms in the endorheic area (Fig. 2a).

Between 2009 and 2010, there was a renewed rise in water level (3 m), as a consequence of the heavy rainfall over the hydrological year 2009/2010 (675 mm, approximately twice the average annual rainfall). A total of 780 mm fell—about three times the amount recorded in previous years. The irregular operation of the pumping station would also have had an impact. Over the hydrological year 2010/2011, the water level of Balsa del Sapo continued to rise, peaking in February. From this point, the rise was more gradual and less regular, with some years registering a fall of 0.5 m year^{-1} (Fig. 6). The peak level was recorded at the beginning of 2013 (3.61 m), and this was followed by a rapid fall as a result of pumping at a rate of 688 L s^{-1}. Pumping continued over 4 months, from February to June 2013, removing a total of 6.43 hm^3. This had the effect of reducing water level by 2.66 m in the western pond and 2.80 m in the eastern one. Once pumping stopped, hidden lateral inflows from the surrounding Pliocene calcarenites produced a renewed rise in water level, as depicted at the end of the graph in Fig. 6.

These rises in piezometric level have resulted in the formation of new wetlands—La Cañada de Cabriles and Onáyar, both former silt and clay pits. La Cañada de Cabriles also consist of two pits, which have surface areas of 14.1 and 1.8 ha, respectively. The depth of water oscillates between 7 and 10 m. At Onáyar, three pits have been flooded; these are 21, 0.63 and 0.2 ha in extent, with water columns of between 20 cm and 1 m.

Surface waters and groundwater

As previously commented, the volume of accumulated water in the Balsa del Sapo has varied substantially over the last 10 years. Moreover, the salinity of the water has been decreasing—from 14,500 µS cm^{-1} (June 2004) down to 4,100 µS cm^{-1} (July 2013; Fig. 6). To interpret this trend correctly requires a study of the water chemistry—an analysis that is also required to determine the potential use of this “surplus” water. The surface water composition was considered on the basis of samples taken on seven occasions in both ponds of the wetland, between 2001 and 2013 (Table 1). For the groundwater, the data used were from the aquifer sampling points in the Balerma-Las Marinas unit, which lies <2 km from the ponds. These yielded data for May 2001 and June 2007. Locations are shown in Fig. 2. The Schöeller-Berkaloff diagram (Fig. 8) shows that the surface water contained higher ion concentrations and a greater variability than the groundwater. Electrical conductivity varies from 2,180 to 4,450 µS cm^{-1}. In both cases, the ions present in highest concentrations were Na and Cl. Concentrations of Ca, Na, Mg, Cl and SO_4 in the surface water samples fell over time. By June 2013, some ion concentrations were almost as low as those in the groundwater (Table 1). This gradual decrease over time is consistent with the fall recorded in electrical conductivity (Fig. 6).

A more detailed analysis of salinity was carried out by considering the Na, Cl, and SO_4 ions in both the surface water and groundwater samples. Groundwater salinity in the Balerma-Las Marinas Unit is affected by dissolution–precipitation processes, by mixing of water from different sources, and by the marked presence of evaporite salts (Molina 1998). The ratios between Cl/SO_4, Cl/Na and Cl/Mg are shown together in Fig. 9, which indicates the very close relationship between the groundwater and surface water ($r^2 = 0.98$, 0.94 and 0.83, respectively). The surface water distribution is more disperse, mainly the relationship between Cl and Ca, since Ca ion can be affected greatly by the dissolution–precipitation processes. Its salinity fell quite considerably over the sampling period, reaching values close to the groundwater samples in June 2013 (Fig. 9).

The direct relationship between the hydrochemistry of wetland and aquifer can be attributed to interdependence between the surface water and groundwater. The trends in the salinity and chemistry of the surface water are coherent with the rise in water level recorded in Balsa del Sapo (3.7 m in 8 years). A significant aspect is the marked temporal variability of the wetland hydrochemistry, and the gradual decline in conductivity related to the rise in water level in Balsa del Sapo. The high rainfall over 2009–2010 caused a significant increase in the volume of water in the wetland. Intense rainfall and groundwater discharge are the two of an increase in the size of the water body; in both cases, water with a lower saline content is introduced to the wetland which is subject to marked direct evaporation.

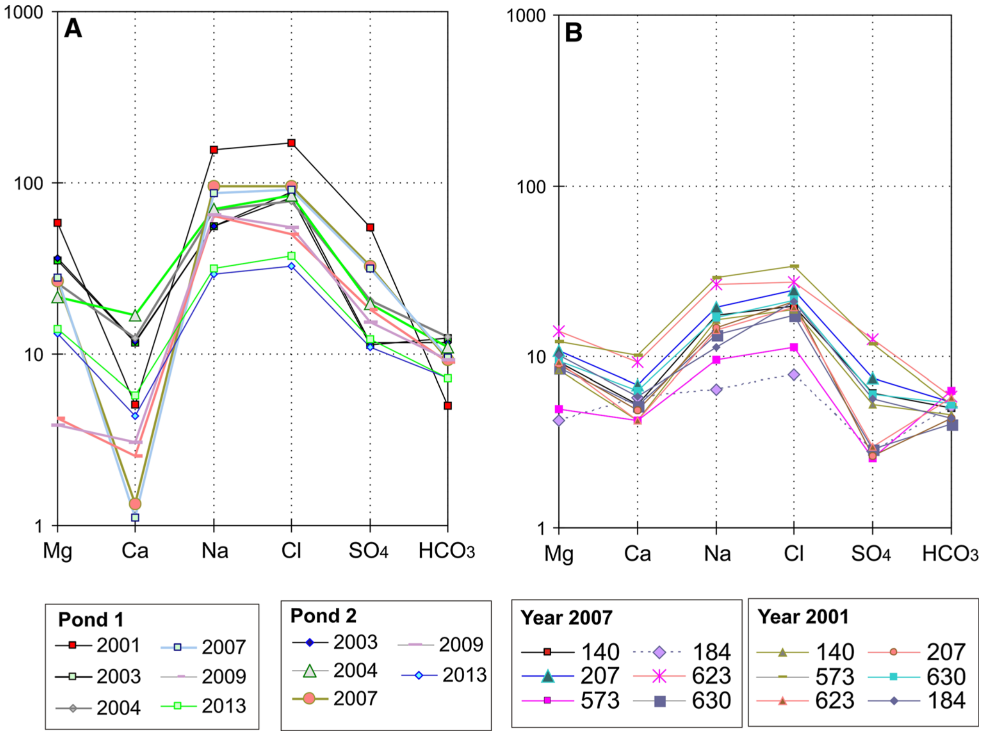

Fig. 8 Schoeller-Berkaloff diagram. **a** surface waters (2001–2013), **b** groundwaters (2001–2007). Data in meq L^{-1}

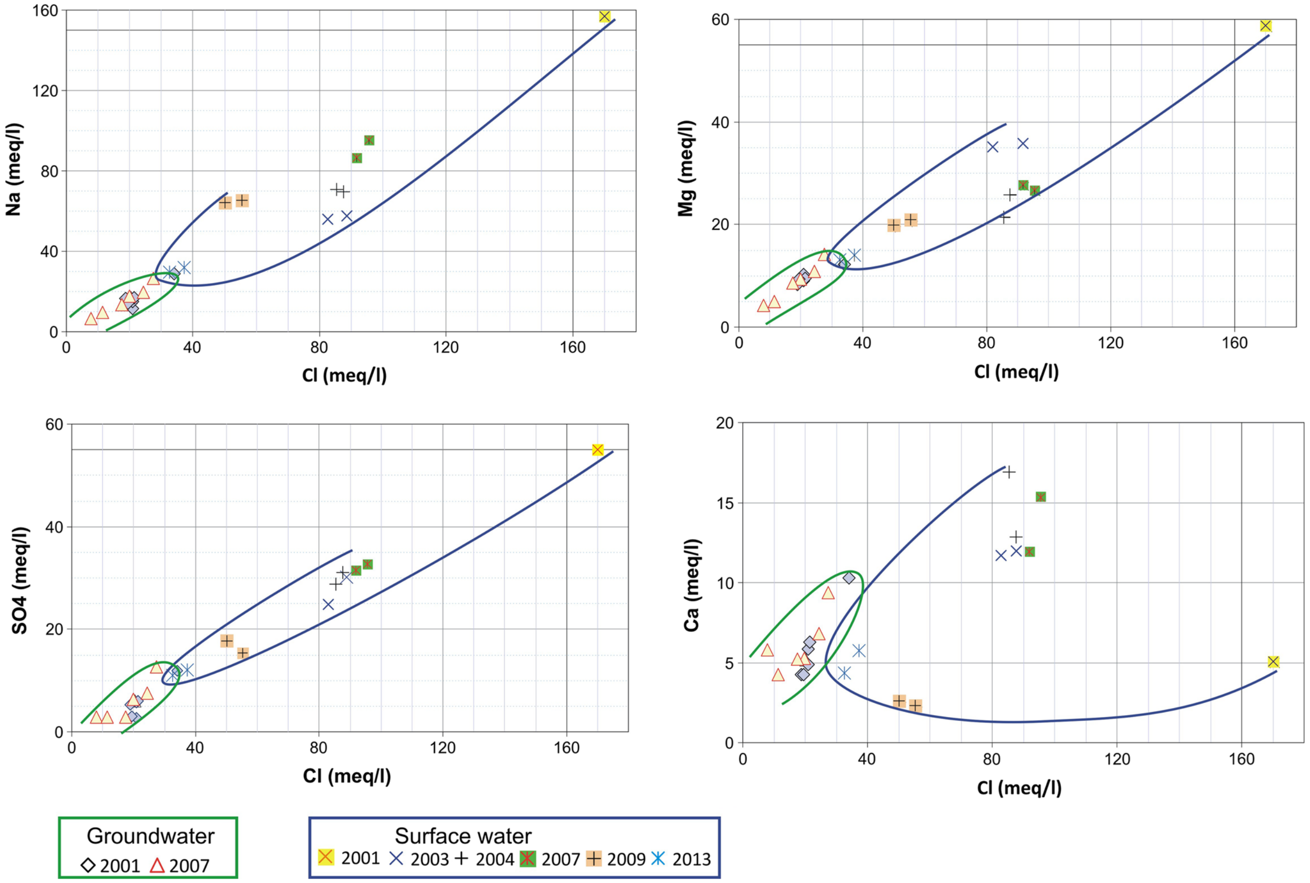

Fig. 9 Ionic ratios for both surface waters and groundwaters, showing the sampling dates

Wetland management

The increasing frequency of flooding of agricultural installations and urban property, due to the continued rise in water level in Balsa del Sapo in 2004, led the Administration to adopt urgent measures of direct pumping ($180\ \mathrm{L\ s^{-1}}$) to partially dewater the wetland. This work involved the installation of two vertical intakes in each of the ponds (Ortega and Rivas 2012). When water levels continued to rise, various public administrations suggested alternatives using different approaches. In 2009, as part of the action called "Desalination and ancillary works for the Campo de Dalías", a project was presented for a debrining plant for Balsa del Sapo. In January 2011, the (national) Ministry for Agriculture and Environment, together with the Andalusian Regional Government (Junta de Andalucía) signed an agreement to draw up a plan for dewatering the wetland. This project aims to avoid flooding in the immediate vicinity by means of a conduit that would take surplus water to the sea during wet spells. After narrowing down various alternatives, the starting solution involves the construction of a 7.5 km tunnel that will run into a canal that flows to the sea. In late 2011, the Governing Council of the Junta de Andalusia gave preliminary approval for the Hydrological Plan for Mediterranean Catchments, containing an annexe that conceives the construction of the Balsa del Sapo Debrining Plant or the modification of the dewatering measures currently in place. In February 2013, faced with the continuing rise in water level, the Andalusian Water and Environment Agency installed additional pumping capacity ($688\ \mathrm{L\ s^{-1}}$) in Balsa del Sapo (Ortega and Rivas 2012). The discharge from this is emptied into the bed of a rambla, from which some of the extracted water infiltrates directly to the aquifer and the rest flows along the rambla to the sea. The two options considered for reducing flooding—the debrining plant or pumped dewatering, have very different characteristics. The pumping option does not propound any rational use for the water—in an area whose agriculture depends directly on efficient water use.

Bearing in mind that the groundwater abstractions from Campo de Dalías probably exceed 80 millions cubic metres per year, it is difficult to believe that there is no solution other than to discharge the "excess" water from the wetland into a rambla bed. The most recent electrical conductivity data for the wetland indicate that the water could be re-used, properly mixed with other water to moderate its salinity (Pulido-Bosch et al. 2013).

The changes to the physical environment of the Campo de Dalías over the last 40 years mean that the conceptual models of water use must be revised. Water resource management needs to be improved in an environment that is extremely vulnerable, and where the sustainability of the pattern of water use was questioned even three decades ago (Ferrando et al. 1975). Given that today's society must inevitably commit to sustainable water use—and all the more so in semiarid areas, appropriate steps must be taken to making better use of this resource, which ensures both the safety of people and property, and of the ecological habitats. This calls for the incorporation of the "surplus" wetland resources back into the hydrological cycle. In turn, this is likely to require recovery of the pumped water back into the aquifer connected to wetlands, and its treatment to make it suitable for crop irrigation. Such action would allow optimal use of water resources of an area whose main aquifers have been provisionally declared as overexploited for several decades.

It is also clear, from a social viewpoint, that disposing of freshwater to the sea through an outfall—in an area where rainfall is scarce—would be viewed with astonishment, when the most intuitive option is to properly recycle it, either by mixing it with better quality water or, more simply, by debrining. It is relevant to point out that the El Ejido municipal council has begun to recognise and exploit the value to this wetland as a tourist and educational resource, through the creation of an ornithological park and visitor centre. The aim would be to convert the Balsa de Sapo wetland into a significant tourist and educational facility, where activities to raise environmental awareness could be developed.

Conclusions

The poor quality of groundwater led to the gradual abandonment of boreholes in this hydrogeological unit, given that there were two other aquifers that could provide water of better water quality. The most direct impact has been a generalised rise in piezometric levels in the upper aquifer, creating a series of artificial wetlands, including Balsa de Sapo, in the former clay pits. The volume of water accumulated has gradually increased. The wetland and the groundwater are interdependent, and the piezometric record in the aquifer confirms this over the last 30 years. The evolution of the hydrochemistry, both of the groundwater and the surface water is coherent with this interpretation. The salinity of the surface waters has reduced to values similar to that of the groundwater. A similar situation has been recorded in the concentration of Cl, SO_4, Na, Ca and Mg ions. Surface runoff is generated only during periods of heavy rainfall. This amount is not significant with respect to the total volume of water accumulated in the wetland and its effect on the salinity should be limited. Therefore, the salinity of surface water must stabilise near groundwater values.

This endorheic area poses a flood risk for people and property in the vicinity, given the low relief. Due to the water deficit in the Campo de Dalías, the most appropriate solution would be the construction of a desalination (debrining) plant to reduce the salinity of the water to use it for crop irrigation. It would also be possible to increase groundwater abstractions and to mix this water with water of better quality. These alternatives would encourage a fall in the water level in the wetlands of Balsa del Sapo, and diminish the flood risk. In addition, this would be an option compatible with the protection of the wetland environment and the development of activities of environmental education—given the high ecological value of this new ecosystem.

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