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A ONE DIMENSIONAL MODEL AS A TOOL TO PREDICT THE HYDROLOGICAL REGIME OF TWO COASTAL LAGOONS IN LA PLETERA SALT MARSHES

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Abstract

Coastal wetlands are among the most productive and fluctuating ecosystems of the world. These ecosystems, however, are affected by human activities that may change their nutrient dynamics and water regime, thus causing water quality degradation, lagoons and wetlands disappearance or the establishment of invasive species. In this context, La Pletera salt marshes are composed of several coastal lagoons and wetlands that were affected by the incomplete construction of an urban development in 1987. This area has been the focus of two Life+ restoration projects (http://lifepletera.com/en/life-pletera/) aimed to recover its ecological functionality. A first creation of new lagoons was undertaken in 2002 simply based on the excavation of a hole below sea level, which ensured water permanency all year round. In 2016, during the second Life+ project, some new lagoons were excavated. Between 2014 and 2017, regular sampling campaigns have been carried out to measure temperature, salinity, water levels and other physicochemical parameters, including main ions, environmental isotopes and nutrients in La Pletera salt marshes lagoons. In this study the hydrological regime of two old lagoons (named Life A and Life B), and a new one created in 2002 (Life C), is studied by means of the dimensional model GLM (General Lake Model) in La Pletera salt marshes. The main objective of this research is to assess their main hydrochemical and hydrological characteristics and dynamics. This model computes vertical profiles of temperature, salinity and density. In the lagoons, GLM has been used to evaluate the water inflows and outflows, by adjusting them to the daily known water volumes, and also the evaporation fluxes. The study is mainly focused in dry periods, when the inflows of the lagoons decrease and evaporation increases. Results show that the old lagoons are more affected by evaporation and in the new lagoon water circulation is higher.

Keywords: Groundwater-surface water interactions, hydrological regime, coastal lagoons, General Lake Model

1. INTRODUCTION

Coastal wetlands have been usually described as the confluence of inland and marine water. These ecosystems are considered among the most fluctuating and productive ecosystems of the world, performing a wide range of ecosystem services, such as shoreline stabilization, sediment and nutrient retention, coastal water quality buffering, among others (Mitsch and Gosselink, 2000; Costanza et al., 1997; Gedant et al., 2011; Beer and Joyce, 2013).

Depending on their connection to the sea, coastal lagoons have been categorized in open and closed lagoons, being classified, in this second group, those lagoons which have no connection or a short period of connection to the sea (Félix et al., 2015). The settlement and structure of biological communities in coastal enclosed lagoons are driven by the morphological characteristics of each lagoon and by freshwater inputs, which may vary naturally or due to human pressures on their flow rates and biogeochemical characteristics. Moreover, changes in water regimes cause water quality degradation, lagoons and wetlands disappearance or the establishment and expansion of invasive species (Crivelli, 1995; Pérez-Ruzafa et al., 2002; O'Connell, 2003; La Jeunesse and Elliott, 2004; Badosa et al., 2007).

La Pletera salt marshes are composed of wetlands and some coastal lagoons that were affected by the incomplete construction of an urban development in 1987. This protected area is located in the north of the mouth of the Ter River (NE Spain; Figure 1), in a region dominated by agricultural and tourism activities. This zone presents a subhumid Mediterranean climate with a mean annual temperature of 16°C, and an average rainfall of 590 mm/year (Estartit meteorological station, 1966-2016 period; Pascual, 2017; www.meteolesrtartit.cat and Montaner et al., 2010). The Ter River is the main watercourse (Figure 1) and presents a mean discharge of 8.74±0.29 m^3/s in Torroella de Montgrí (2006-2016 period; ACA, 2016, www.gencat.net/aca). The flooding events caused by the Ter River in the studied area have been reduced due to the construction of several dams upstream during the 1960s, and the river channeling in the 1970s.

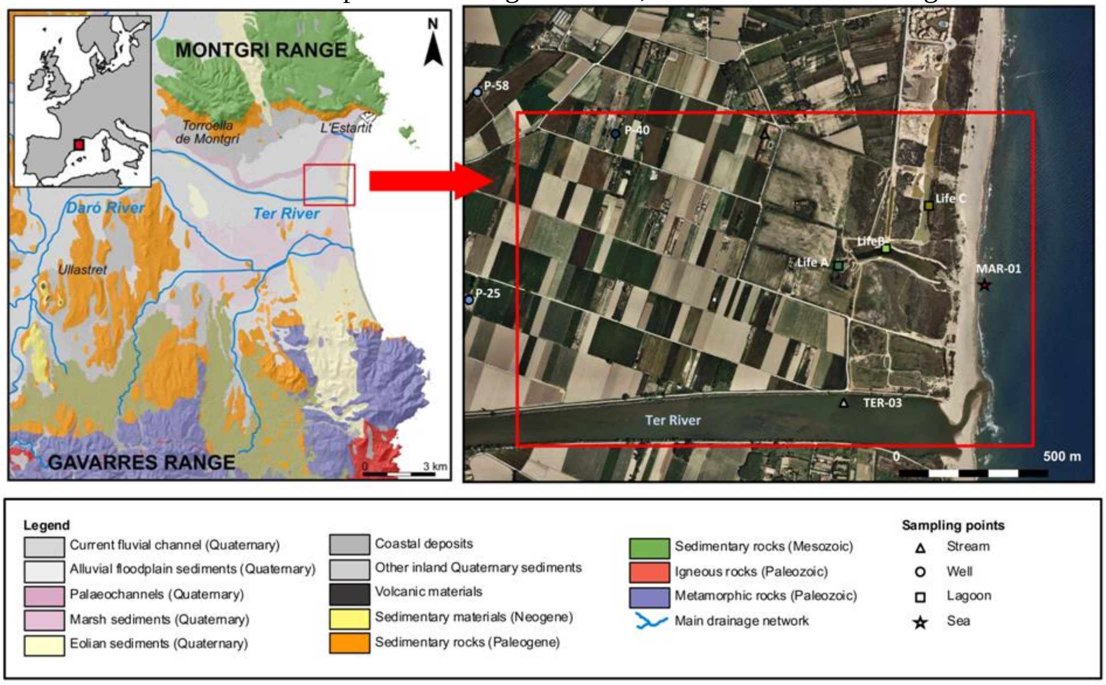

Figure 1. Geographical and geological situation of the study area

This area has been the focus of two Life+ restoration projects (http://lifepletera.com/en/life-pletera/) aimed to recover its ecological functionality. Through these projects, a first creation of new a lagoon was undertaken in 2002 simply based on its excavation below the sea level, which ensured water permanency all year round. During the second Life+ project, in 2016, some new lagoons were excavated with different shapes and depths in order to obtain lagoons with distinct salinity and temporality characteristics. In a previous work, the origin of the lagoons' water was determined, and its dependence on groundwater resources was assessed (Menció et al., 2017). In this paper, we use the one dimension model GLM (General Lake Model) to assess the water balance and salinity dynamics in a 12 years old lagoon (Life C), and in two natural lagoons (Life A and Life B). Therefore, the aim of this study is to determine the main hydrological and hydrochemical characteristics and dynamics of these costal closed lagoons. This model has been developed by Hipsey et al. (2014) and computes vertical profiles of temperature, salinity and density. In the lagoons, GLM has been used to evaluate the water inflows and outflows, by adjusting them to the daily known water volumes. Also, by adjusting the predicted temperature and salinity profiles to the experimental ones, the water circulation in the lagoons can be inferred.

2. METHODS

In order to study the hydrochemical and hydrological dynamics of the Pletera salt marshes lagoons, water levels were determined on a daily basis, using Schlumberger water level data loggers (accuracy ±0.02m) (from November 2014 to September 2017). Electrical conductivity (EC), salinity and temperature were determined *in situ* at a monthly basis in Life A, Life B and Life C lagoons, at different depths (0.1, 0.5 and 1.5m from the surface), using a model multiparametric HACH HQ40d and HQ30d. Additionally, hydrochemical data of groundwater and sweater have been also determined in a monthly basis in sampling points represented in Figure 1 (Menció et al., 2017).

Meteorological data needed to determine the evaporation and precipitation in these lagoons, such as daily maximum and minimum temperature, relative humidity, precipitation, were obtained from the Estartit meteorological station (Pascual, 2017; www.meteoestartit.cat). Data for solar radiation was obtained from the meteorological station of Sant Pere Pescador (Xarxa d'Estacions Meteorològiques Automàtiques de la Generalitat de Catalunya) situated 10 km North of La Pletera.

The GLM (General Lake Model), developed by Hipsey et al. (2014), computes vertical profiles of temperature, salinity and density by accounting for the effect of inflows/outflows, mixing and surface heating and cooling. GLM incorporates a flexible lagrangian layer structure similar to the approach of several 1-D lake model designs (Imberger and Patterson 1981; Hamilton and Schladow 1997). The lagrangian design allows for layers to change thickness by contracting and expanding in response to inflows, outflows, mixing and surface mass fluxes. The model accounts for the surface fluxes of momentum, sensible heat and latent heat using the commonly adopted bulk aerodynamic formulae.

Using the bathymetry and the daily water depth, the water volume of the lagoons were determined. With this information, GLM has been used to evaluate the different water fluxes: inflows, outflows, rain and evaporation by adjusting them to the daily known water volume. This process has been developed through the following steps: Firstly, the totals inflows and outflows have been estimated from the known water volumes. Secondly, the evaporation fluxes have been calculated from the model and took into account together with the rain fluxes in order to get the new inflows and outflows due to total water intrusions in the lagoons. Finally, the model was run with these new inflows and outflows to corroborate that the total volume and the experimental temperature and salinity values adjust to experimental values.

3. RESULTS AND DISCUSSION

In Figure 2a the values of the real volume estimated from the water levels of the lagoon Life B compared to GLM volume values have been represented. These results are the first step of the GLM, in which the total of inflows and outflows has been estimated to assess the water budget in the lagoons. According to Figure 2, the model fits better when the volume of the lagoon is higher and is more difficult to adjust when volumes are small, i.e, during summer.

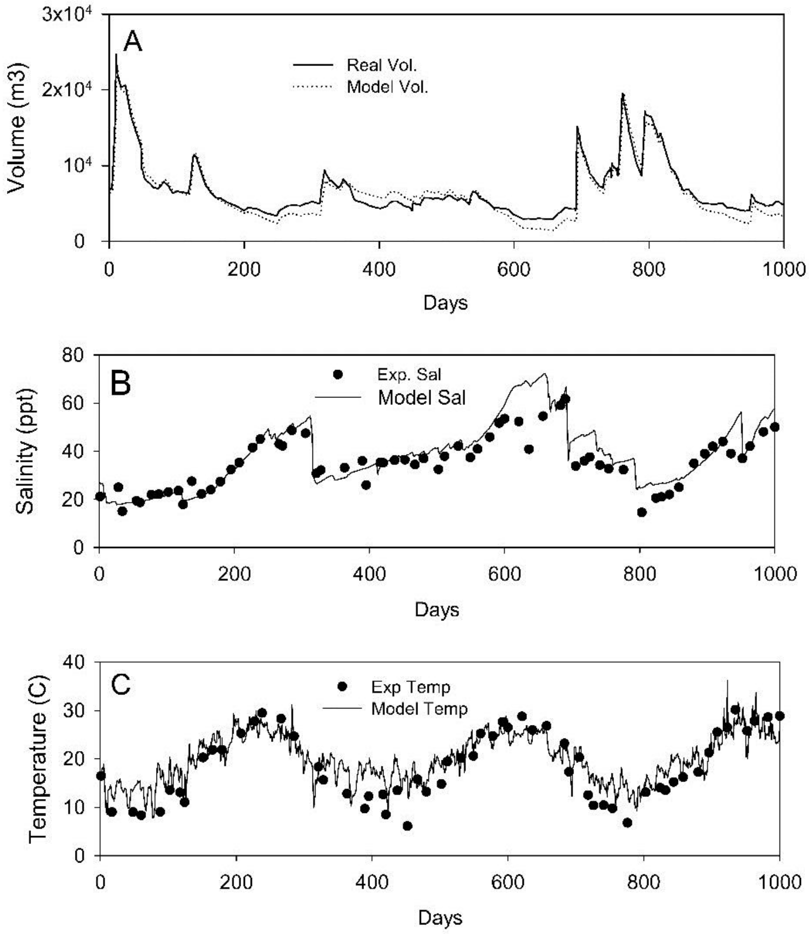

Figure 2. GLM results compared to field data in Life B lagoon (from November 2014 to September 2017): a) Real volume vs. GLM volume (in m^3); b) Real salinity vs. modeled salinity (in ppt); and c) Real surface temperature vs. GLM surface temperature

The following step has been to adjust GLM with the experimental values of temperature and salinity. To do so, the temperature and the salinity values of the inflows are required. Therefore the temperature and the salinity values of the inflow are set up to fit the known experimental values of the lagoons. Considering the results obtained by Menció et al. (2017), a solution composed of both groundwater and seawater was considered as inflow. In summer inflow salinities are set to 25-30 ppt, indicating that most of the inflow water is from sea origin. However in the rest of the seasons salinity changes to ~15 ppt, indicating a 50% mixture of marine water and groundwater.

Figures 2b and 2c show the predicted surface salinity and temperature values obtained with the GLM compared to the experimental ones. It can be seen as the GLM reproduces fairly well the main trends of the salinity and temperature. However, it has to be taken into account that One Dimensional models cannot reproduce horizontal processes that may occur in the lagoons. A similar process has been undertaken for lagoons Life A and Life C.

The evolution of experimental and simulated salinity in Life B has been plotted in Figure 3. According to this Figure, the model reproduces fairly well the increase in the salinity in dry periods and the decrease in salinity caused by the inflows that occurred mainly in winter and autumn during important cyclonic events.

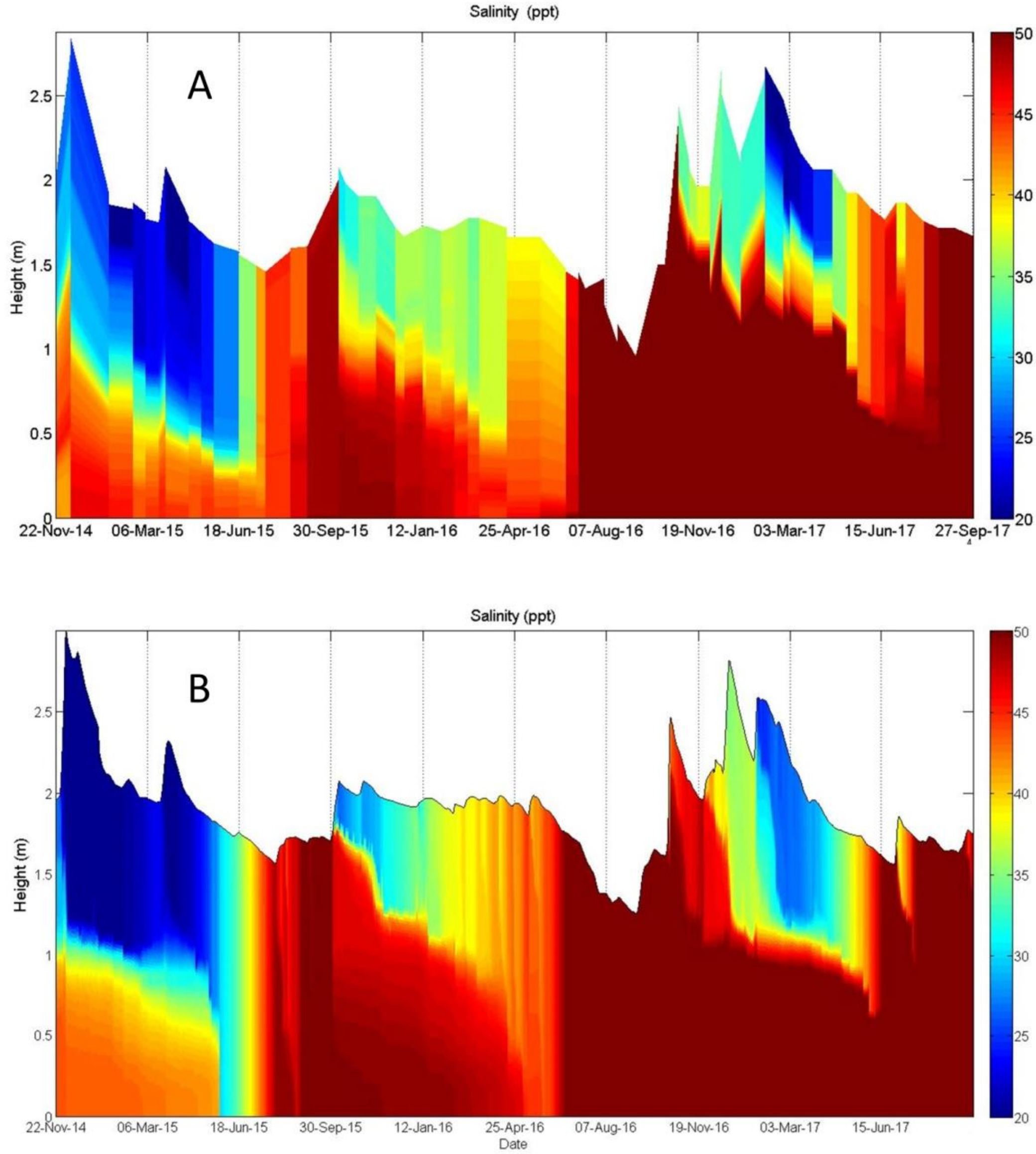

Figure 3. Evolution of salinity in Life B during the study period (November 2014-September 2017): a) Experimental results and b) Results obtained with the GLM

Besides, during humid seasons (mainly from autumn to spring) stratification is observed in Life B lagoon, showing salinity values between 20-38 ppt in the upper layer, and values ranging 45-50 ppt in the bottom of this lagoon. This stratification has been also obtained with the GLM results, which also reproduces well the high salinities observed in Life B lagoon during the first cyclonic events, produced just after the main dry periods (Figure 3).

In order to analyze in more detail these hydrological and salinity dynamics, in Figure 4a the relative volume (calculated as the volume of the lagoon divided by the volume of the initial day) of the three lagoons for the period June 2015 - September 2015 has been represented. It can be seen a higher decrease of the relative volume of water in Life A compared to the other lagoons. In contrast, a slight increase in water levels and relative volumes have been detected in Life B and Life C lagoons, caused by the scarce rain episodes registered in this period (with volumes of < 30 mm/event), and also by the low atmospheric pressure values detected in some other periods (Pascual, 2017).

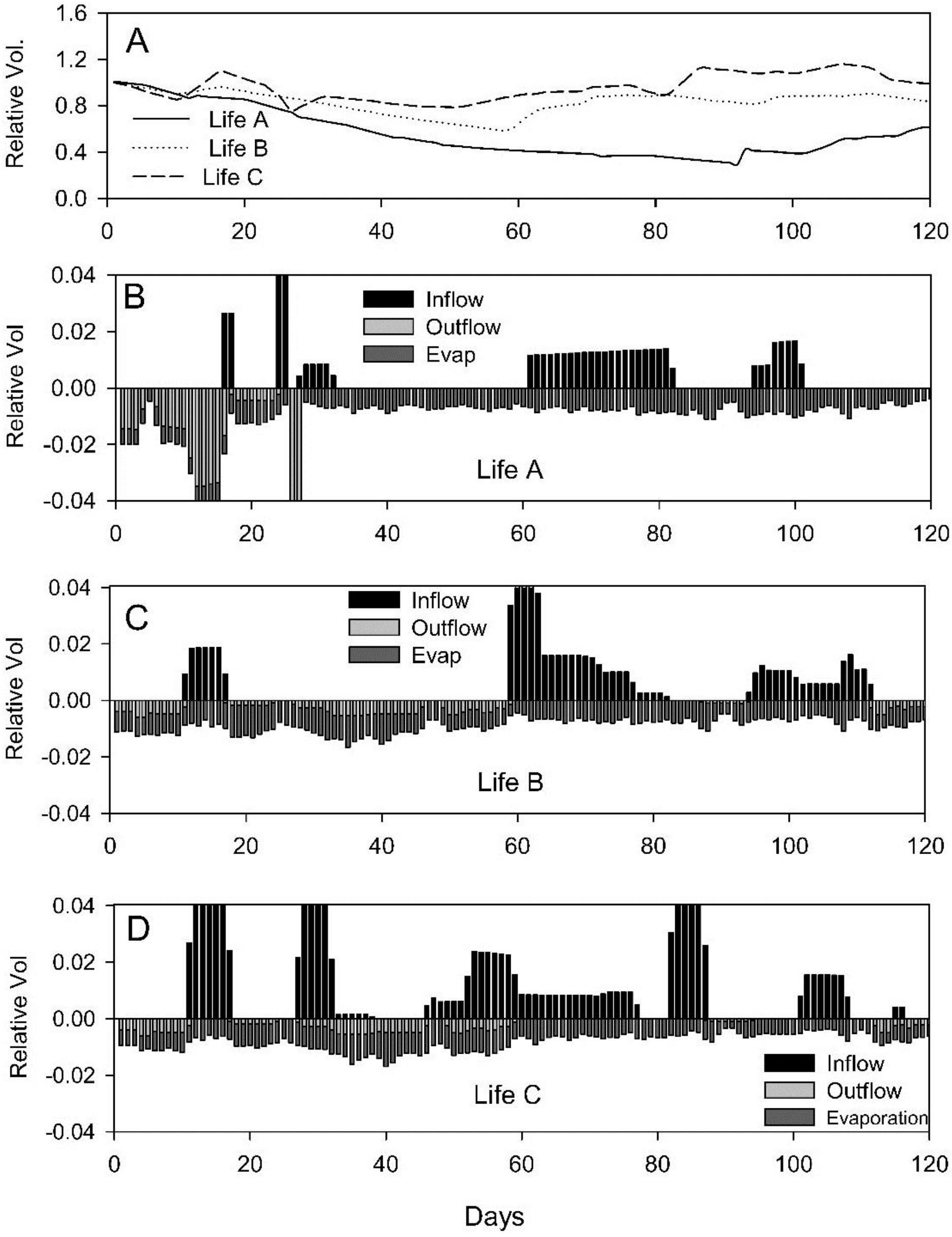

Figure 4. a) Relative water volumes (normalized to the volume of water of the 1st of June of 2015) in Life A, Life B and Life C lagoons from June 2015 to September 2015; and b), c) and d) Inflows, outflows and evaporation volumes of water, per unit of lagoon volume (Relative water volumes), from June 2015 to September 2015 for Life A, B, and C

Besides, in order to fit the GML results to experimental data measured in the lagoons, the inflow salinity values in Life A and Life B lagoons, during the period represented in Figure 4, had to be set around 35-40 ppt, while in Life C lagoon was fixed around 25-30 ppt. These salinity values are similar to the ones of the bottom of the lagoon (see Figure 3 for the case of Life B) and also coincide with the salinities of the water outflows. Therefore, these results point out that the first groundwater inflows into these lagoons, mostly occurring during autumn cyclonic storm events, present similar characteristics to summer water outflows of these lagoons to the aquifer. In particular, water inflow ()

In Figures 4b, 4c and 4d, the estimated inflows, outflows and evaporation fluxes, per unit of volume in the lagoons have been represented. It can be seen that water inflows in Life C are higher than in the other lagoons, showing that this lagoon in summer presents, a different behavior than the other lagoons. It can also be seen that from July to September, i.e., from day 30 in Figure 4, Life A only losses water by evaporation; however Life B and C have water outflows of ~1-2 litters/day.

Finally, in Table 1 there are represented the main fluxes per unit of volume of the water lagoons, determined during June 2015 - September 2015. These fluxes are calculated in cubic meters per day per lagoon volume. A very different behavior of Life A compared to the other lagoons is clearly seen. This lagoon shows a higher evaporation flux and also a smaller water circulation. Differences between Life B and Life C are not so pronounced; however a higher water circulation, and a smaller evaporation in Life B, compared to Life A can be appreciated. Differences in evaporation between lagoons can be explained by differences in the ratio S/V. A higher S/V ratio means a higher evaporation.

Table 1. Lagoon characteristics and relative daily averaged results of the GLM water budget, for the June 2015-September 2015 period

Lagoon	Life A	Life B	Life C
Lagoon Surface/Lagoon Volume (S/V; m^{-1})	3.88	2.57	1.77
(Inflow-Outflow)/Volume (10^{-3} day^{-1})	-0.17	4.23	5.00
Evaporation/Volume (10^{-3} day^{-1})	-12.43	-7.27	-6.59
Rain/Volume (10^{-3} day^{-1})	2.41	1.42	1.01
Total Water Budget/Volume (10^{-3} day^{-1})	-10.19	-1.61	-0.58

4. CONCLUSIONS

In conclusion, results obtained with the GLM model provide us a comprehensive understanding of the hydrological and hydrochemical dynamics in the Pletera salt marsh lagoons. Also, the results here presented are in accordance with those observed by Menció et al. (2017), who by using hydrochemical and isotopic models, together with GLM, established that the salinity of La Pletera lagoons depended on two distinct processes: 1- mixing of freshwater and sea water occurring within the lagoons or in the aquifer; and 2- evaporation. However, this new study goes a step further, depicting that lagoon inflows after the main dry periods show higher salinities than sea water, and similar to those observed in the bottom of the lagoons during dry periods. This situation could be explained if during these first cyclonic storm events a return of the high salinity water, which was previously lost as output by infiltration from the lagoons to the aquifer, occurs. In addition, differences in salinity among lagoons could be explained not only by a distinct ratio S/V, but also by a slightly higher water circulation in Life C lagoon. This knowledge poses new research challenges, such as to understand nutrient dynamics in this aquifer-lagoons system, or how climate change will modify the water budget and salinity dynamics in La Pletera lagoons.

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