



Development of a neuro fuzzy modelling tool for a decision support system in desalination in coastal zones

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ABSTRACT

The advances in models based on fuzzy neuronal logic networks in field of water quality in the last few years have been quite significant. This article develops a decision tool based on this methodology that allows the analysis of instant and seasonal behavior of brine discharge from desalination plants into the sea. This is to establish management measures to maximize discharge dilution and thereby reduce brine impact on the receiving medium. Over 70% of the increase in salinity of the affected area can be explained by just three significant variables: one associated to brine discharge, one associated to seasonality and one associated to climate conditions.

Keywords: ASDECO; Brine discharge; Brine plumes; Brine dispersion forecast system; Support tool for decision making; Desalination; Neural network; Fuzzy logic; Dilution

1. Introduction

The placement of the brine generated in desalination processes by means of reverse osmosis is one of the main problems confronting the desalination industry. Brine discharge in coastal areas is an appropriate solution, but it must be carried out in an environmental way by complying with authorized regulations.

In Spain, in the last few years, there has been a spectacular increase in the use of inverse osmosis in the desalination process of sea water. In most cases, environmental

brine impact has been evaluated from contrasted models such as CORMIX, which is useful in the design phase but limited in the operation phase. Also, deterministic models do not yet have the necessary capacity to solve the complex problem of transport and brine diffusion in the marine environment. This slow development is partly caused by the lack of experimental data from the natural environment.

One of the objectives of the ASDECO Project (Automated System for Desalination Dilution Control) is the evaluation of salinity variations in the marine environment over periods of time. This information can be used to improve the applicability of deterministic models, but

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until this is possible, it would be very convenient to have a mathematical tool that allowed this information to be used for predictive tasks in real time.

An interesting possibility has become available with the current development and application of models that combine fuzzy inference systems and artificial neuronal networks in the water quality field. Even though mathematical models based on neural networks have been successfully used in fields such as hydrology and coastal engineering, it hasn't been that successful in the water field. The main reason for this is that a great amount of information that is difficult to obtain is required. However, the benefits in environmental aspects have continued to increase. Currently, these models of this kind have been used to build a system to predict the water level in a reservoir [2], to predict the appearance of pesticides in wells with limited information [6] and also to mould nutrient loads in water masses [4].

In transport and brine dispersion, the physical processes of turbulent mix are predominant in chemical and biological ones; therefore, the application of models based on fuzzy logic can be viable provided if there is enough information.

2. Objectives

The main objective of this research, which is integrated in the ASDECO program, is to develop a computational requirements tool that, given the brine discharge levels and the environmental conditions, can predict salinity evolution in the marine environment.

The data available comes from two sources: from historical registers for 2006 and 2007 gathered in the Environmental Vigilance Programs (PVA) and from the measuring instruments for salinity, currents, swells, winds, etc installed in one of the buoys of the ASDECO system. The buoy is located in the influence area of the brine discharge of Desalination Plants I and II of Alicante (Spain). The characteristics of the discharge as well as the ASDECO system have already been described in previous reports (Annual Report 2008).

Due to the wide availability of data and the current difficulty of using turbulent dispersion classic models, a computational tool based on neural and fuzzy systems has been developed as support to the alert system installed by ASDECO.

3. Description and implementation of models

The tool used is based on adaptive neuro-fuzzy inference systems (ANFIS), which is a neural fuzzy Sugeno-type model that is implemented by Matlab. It is an application that combines fuzzy logic with neural networks.

Fuzzy systems are formed by input and output variables, fuzzy rules and an inference method that allows

obtaining the output values when the input values are known. When the inference method used is a neural network, the tool is called as adaptive neuro fuzzy inference system (ANFIS). This system is used to create or improve fuzzy inference systems based on Takagi–Sugeno rules. In this kind of inference, rule's consequences are linear combinations of the input variables and the output is a weighted linear combination of the rule's consequences. On one hand, fuzzy inference systems provide an intuitive mechanism to represent knowledge using If-Then rules helped by an expert choice; on the other hand, neural networks are highly adaptive and have an extraordinary learning ability. Using tools that combine these two methods constitute an efficient mechanism to model real systems. This is because a method that learns from the input data is provided and the expert choice is included.

In this case, a programming developed in modeling the continental water quality has been adapted [4].

There are two fundamental reasons for using this tool in the model. The parameters that can influence the dilution of a brine plume in the sea can be of very different types with a highly non-linear relationship due to interaction with each other. Also, the transformation of parameter field data does not provide statistically significant results which would allow the use of other more traditional regression models.

Before using this application, one of the first decisions to be taken is to define the objective function and the significant variables. The objective function is the increase of salinity in the area affected by the brine discharge. From other studies [1], it has been determined that base salinity in this area is 37.5 psu. These studies also state that the quality objective to fulfill in the area to protect is that the maximum increase can reach 1 psu for areas where there is *Posidonia oceanica*, and 2 psu in the case of *Cymodocea nodosa*.

As first option, with the aim to develop a predictive model as easy as possible, we thought to use only two significant variables: those associated to the brine discharge and those associated to environmental variables. The first refer to discharge flow and its excess salinity with respect to the base salinity. This is expressed in a combined form, which is known as excess salt load over the salinity in the sea. The second refer to swell, which is represented by significant height, wave period and direction. In addition, the number of explanatory variables that can be used depends on of the number of available data. In this first phase of the study the number of valid data did not allow more than two explanatory variables.

4. Results

4.1. Model adjustment with data from the Vigilance Programme 2006

First, a series of preliminary tests were carried out

using the historical registers of 2006 from the Environmental Vigilance Programs in the area affected by brine discharge. The purpose was to evaluate the possible viability of the parameters according to the results and then to make the decision to apply the model with the new data obtained by the ASDECO system. For 2004, there are different CTDs in the area of influence of brine discharge that register salinity in the perimeter of protection of *Posidonia oceanica*. In Fig. 1 we can see the location of the sensors which, for different reasons, have moved over time, from positions A1–A6 to L1–L5. The data used in this section is related to station A3 of the PVA 2006, since it was verified that this station gathers the influence of the plume of brine discharge more directly than other stations.

The first simulations were carried out using the input of excess salt load as one of the variables to represent the excess salinity with respect to the base salinity of the sea and the day of the year of the discharge as another one to represent seasonality. The number of data used was three hundred, distributed at regular intervals in the year 2007. Two hundred were used for the training phase while the last one hundred served for validation/prediction. A total of eleven membership functions, making combinations thereof to be reduced the average quadratic error functions were tested. During the training we paid particular attention to the risks of overtraining, fixing the number of iterations in 20–30. Finally, the employed membership functions were a total of five Gaussian type, which provided quadratic errors under 0.49. The first results are shown in Fig. 2.



Fig. 1. Location of stations and distribution of *Posidonia oceanica* (Annual Report 2006).

The increase of salinity measured in the area and the one simulated by means of ANFIS is quite close with a regression coefficient R^2 0.719. This shows that salt load is a key factor just as expected. Since the model has limitations due to the number of registers available, the experiments were limited to three variables. Based on these results, another parameter representing hydrodynamics in the area under study was added to the model. This variable, maximum wave height was selected and the changes and the results in the model are shown in Fig. 3. As expected, there is an inverse relation between the salinity of the plume observed in the station A3 and the maximum wave height. This relation leads to a reduction of approximately 0.75 psu/m of increase in the maximum wave height.

4.2. Model adjustment with data from the Vigilance Programme 2007

During 2007, the active CTDs are found in positions L1–L5 and have more data available for these sensors than in 2006. This is relevant because stations that are farther away from the discharge provide results that are closer to the actual measured results. This is true even though additional parameters are influencing the results of the model.

4.3. Model adjustment with ASDECO data 2008–2009

The data provided by the sensors installed in the SADO I buoy by the ASDECO control, follow-up and alarm prototype started to be available in October 2008. The data became more uniform in February 2009.

The increase of salinity produced in the control point where the buoy was located (according to excess salt load and maximum wave height) is currently being studied. Also, the introduction of new parameters has been attempted in order to achieve better results from

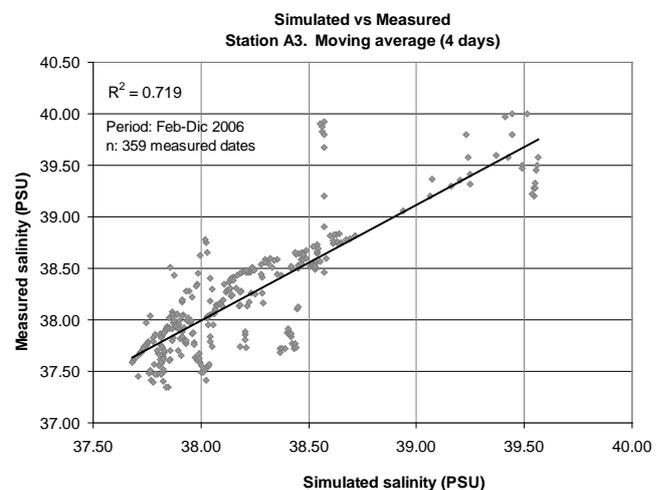


Fig. 2. Results for salt load for A3.

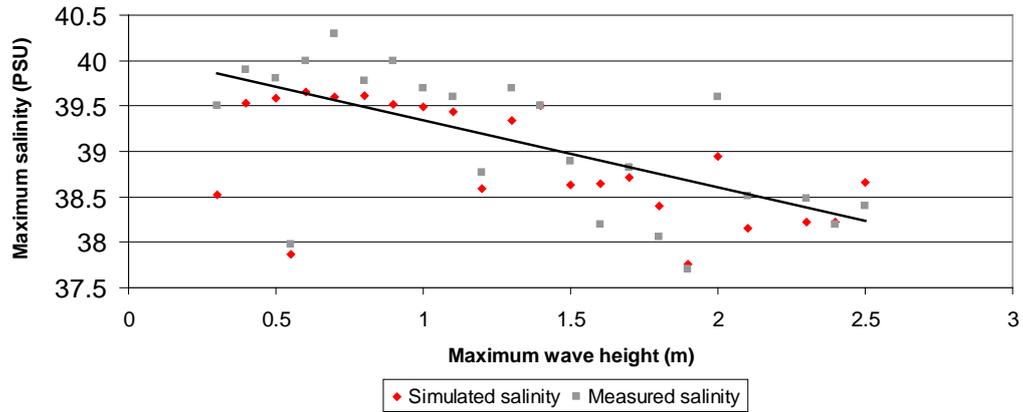


Fig. 3. Results for salt load and swell for A3.

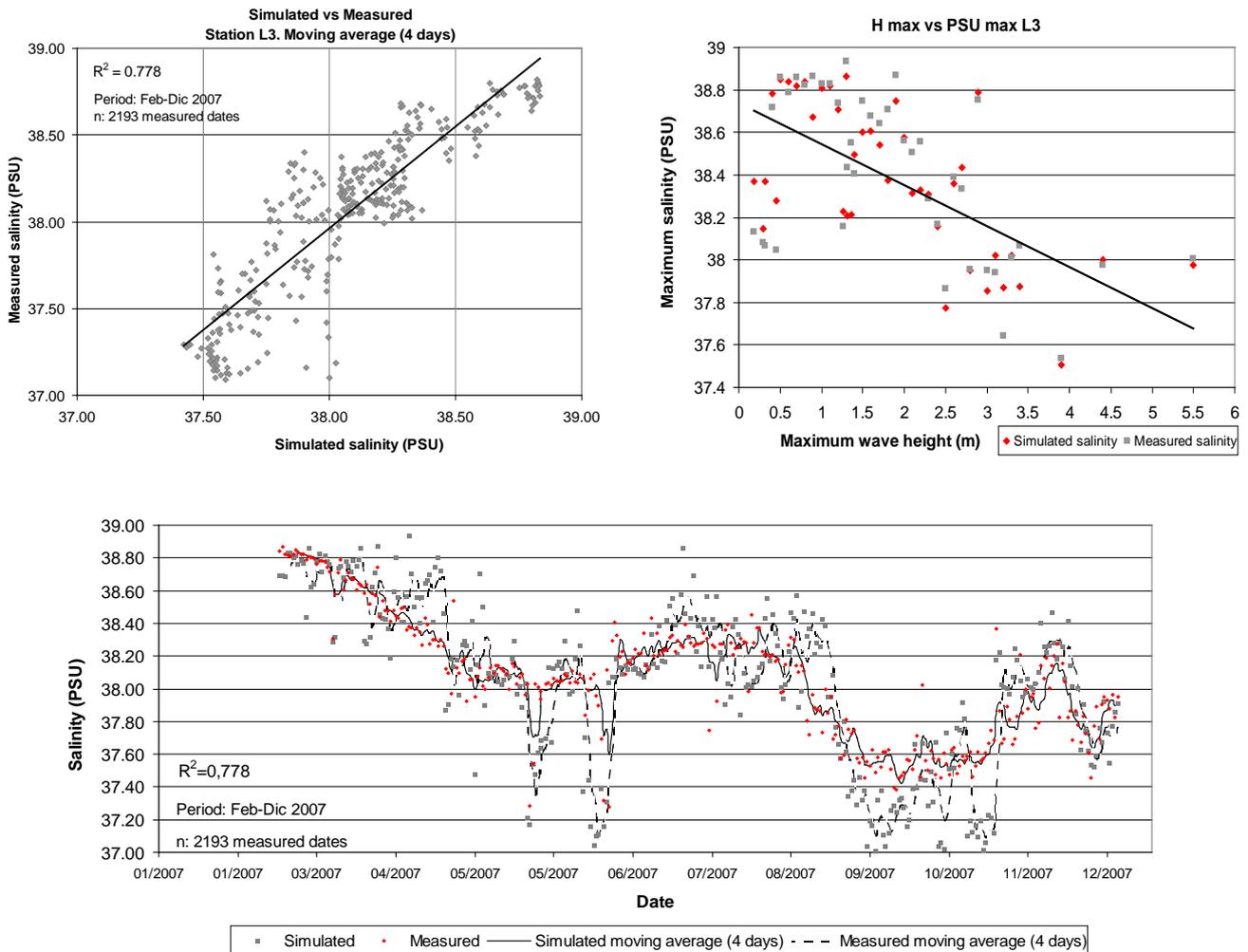


Fig. 4. Results for salt load and swell for L3.

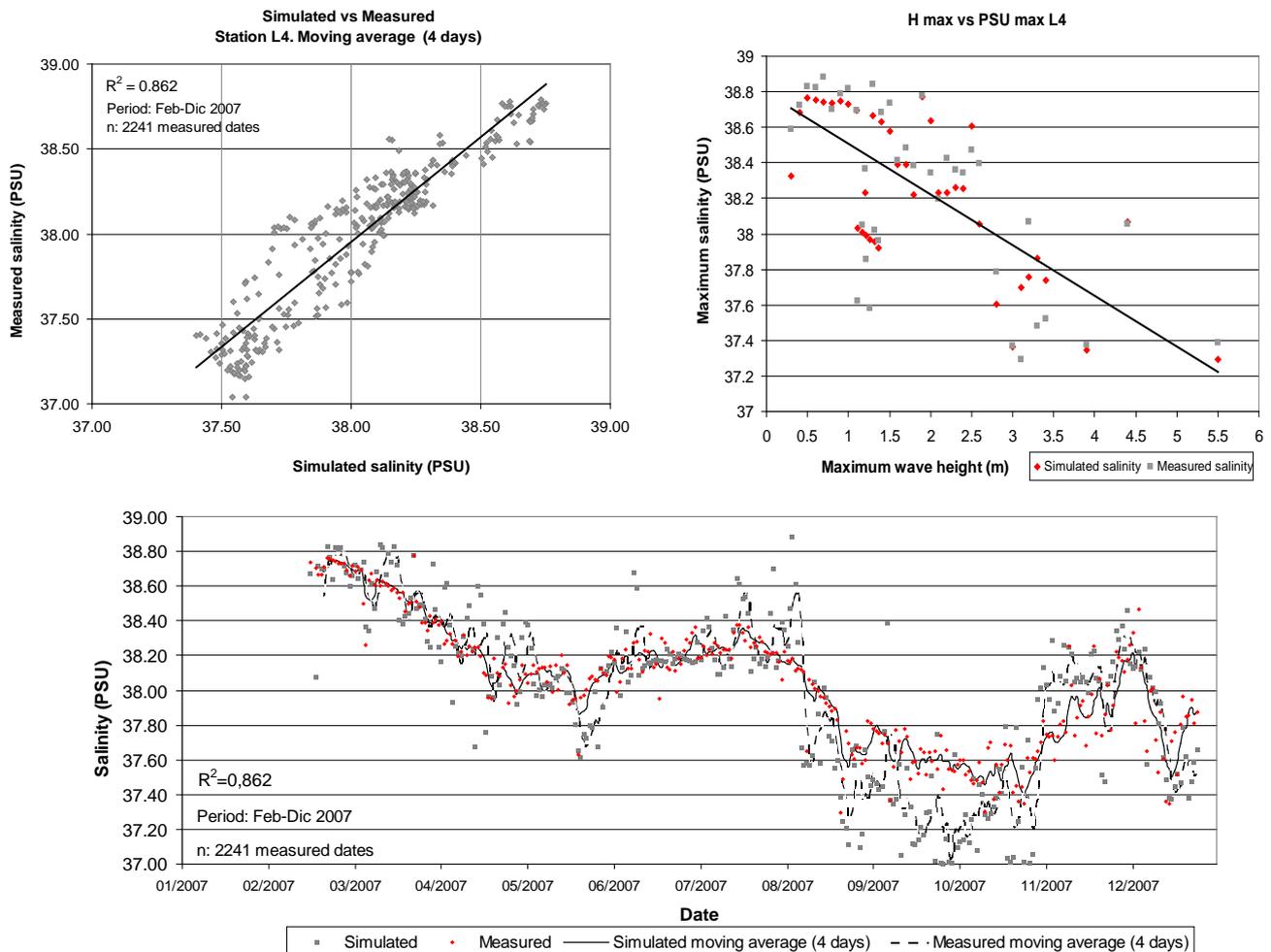


Fig. 5. Results for salt load and swell for L4.

the model and the standardization of other parameters. Other variables besides maximum wave height have been introduced to define the specific behaviors of the brine plume: the significant wave height, the wave period, the intensity of the wind up to 10 m of height, the direction of the wind up to 10 m height and the direction of the swell.

Finally, it is necessary to introduce a parameter that represents previous sea states since the salinity accumulated in the seabed on a specific day is not just a consequence of the climate conditions of that day, but of an accumulation of previous sea states. Thus, the longer the period calm, the lower the energy of dispersion accumulated. This results in a lower mix and a lower dilution of the plume. In contrast, extended storm periods will cause great turbulence, thus favoring the mix.

5. Conclusions

A decision tool has been presented in this work that allows the analysis of instantaneous and seasonal brine

discharge behavior. A fuzzy logic application that is combined with neural networks has been developed and applied to the environmental management of desalination plants to predict increase of salinity in the perimeters of the *Posidonia oceanica* to be protected. With this application, measures can be taken to maximize brine discharge dilution and, thereby reduce its impact on the marine environment.

Research has proven that the most influential environmental variables in salt concentration are the wave height (within the climate scenario), brine discharge, the increase of salinity with respect to base salinity of the receiving medium, and the dilution relations.

These results show that the model predictions are fulfilled. The increase of salinity is higher when the parameter that represents the excess salt load is higher. The increase of salinity is lower when the maximum wave height is higher. It is worth mentioning that the maximum wave height does not explain the average dispersion condition of the plume in the sea nor the decrease

peaks of specific salinity. For prolonged periods of calm, the increase of salinity with respect to the base salinity is high, while for large wave heights the plume undergoes more dispersion.

These results demonstrate that the application of neural fuzzy types such as ANFIS can be an acceptable option for the follow-up and control of brine discharge into the sea. This is true at least until the deterministic models finally correctly represent the turbulent dispersion processes in transport and brines dispersion in real time.

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