NUMERICAL MODEL STUDY IN ALIMINI LAKE (APULIA ITALY)

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Abstract. The aim of this work is to estimate the impact of a n extra freshwater flux from the Zuddeo channel on hydrodynamic natural processes in the coastal lake of Alimini Grande (Apulia, Italy), and in particular on the currents, residence time and salinity field of the lake through the application of the SHYFEM numerical model. Several simulations have been made, comparing the natural discharge of the Zuddeo channel with a situation of the actual inflow plus a freshwater inflow of 7000000 m^3/year. Wind, tide and discharge of two years (1998-1999), in which all the data was available, have been used. Basin residence times and residual currents have been calculated in order to investigate and understand the hydrodynamic characteristics of the Alimini lake. The results have shown a negligible impact on the basin circulation but not on the residence time and salinity field.

Key words: hydrodynamic model, finite elements, Alimini Lake, brackish lake

1. INTRODUCTION

The study and the estimation of anthropogenic impacts on complex ecosystems, such as coastal lakes considered in this study, requires a knowledge of physical and hydrodynamic phenomena. In this context, mathematical models are a useful tool for investigation, based on the knowledge of the system and on the interactions that occur between the parameters of the system, allows the study and understanding of natural phenomena, also altered by anthropogenic influences. The mathematical models also represent the only way to simulate and predict the effects of any man-made or natural disasters on ecosystems.

The aim of this study is the evaluation of the possible impact of the spillage of waste water in the Alimini Lakes. The numerical model SHYFEM has been used to analyze different scenarios in relation to different flow rates, resulting from sewage treatment, into the coastal lake of Alimini Grande (Fig. 1). The Alimini Lakes is a complex ecosystem consisting of two basins linked by a narrow channel (Strittu); the bigger lake is linked to the Adriatic Sea by a small inlet. This basin should be defined as small coastal lagoon, but its local definition is lake. Several biological and ecological studies have been made on this area which is a Natural Protected Area. The basin directly affected by the increase of fresh water inflow is the bigger lake Alimini Grande. The lake has an area of 1.375 km^2 and a volume of 2.067 10^6 m^3, with average depth of 1.503 m and maximum depth of 3.2 m. The basin communicates with the open sea through a small mouth and receives fresh water from the channels: Traugnano in the northern area, Zuddeo in the western and Strittu in the southern. The model has been applied to investigate the changes in terms of hydrodynamic processes, residence time and salinity caused by an increase of Zuddeo discharge about 700000 m^3/year.

2. METHODS

In this section a description of the 2D version of the numerical model SHYFEM is presented.

2.1. The Hydrodynamic model

The SHYFEM model is a finite element hydrodynamic model that was develop at CNR-ISMAR of Venice for shallow water applications. The model resolves the vertically integrated shallow water equations in their formulations with levels and transports. The horizontal diffusion, the baroclinic pressure gradient and the advective terms in the momentum equation are fully explicitly treated. The Coriolis force and the barotropic pressure gradient terms in the momentum equation and the divergence term in the continuity equation are

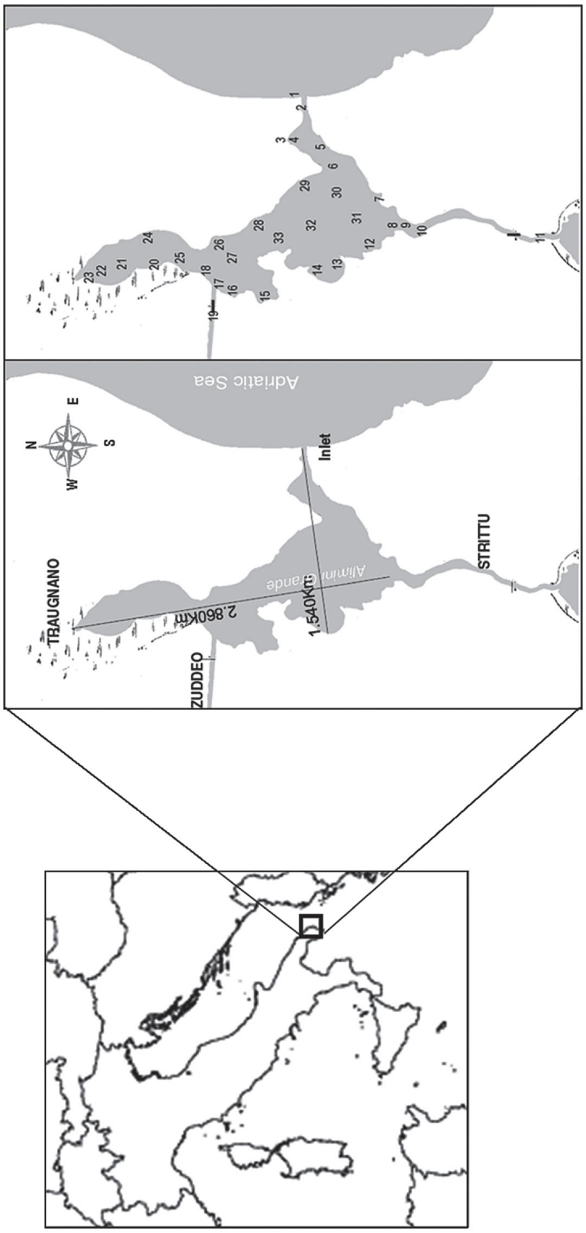

Fig. 1 Location of Alimini Lake and measurement stations

semi-implicitly treated. The friction term is treated fully implicitly for stability reasons due to the very shallow nature of the lagoon. The model is unconditionally stable what concerns the fast gravity waves, the bottom friction and the Coriolis acceleration (Umgiesser and Bergamasco, 1995).

The equations read:

$$\frac{\partial U}{\partial t} - fV + gH\frac{\partial \varsigma}{\partial x} + RU + X = 0 \quad (1)$$

$$\frac{\partial V}{\partial t} + fU + gH\frac{\partial \varsigma}{\partial y} + RV + Y = 0 \quad (2)$$

$$\frac{\partial \varsigma}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} = 0 \quad (3)$$

where η is the water level, U and V the vertically integrated velocities (total or barotropic transport) in x and y direction, g the gravitational acceleration, $H = h + \eta$ the total water depth, h the undisturbed water depth, t the time, R the friction parameter and f is the Coriolis term. The terms X and Y contain all terms like wind stress, the non linear and advective terms and those that need not be treated implicitly in the time discretization as they do not influence the model stability. Details of numerical treatment are given in Umgiesser *et al.* (2004).

The bottom friction term is defined as $R = cB\,|u|/H$. In this formula c_B, the bottom friction parameter, can be assumed either as constant or dependent on the depth through the Strickler formula

$$c_B = \frac{g}{C_z^2} \qquad C_z = k_s H^{1/6} \quad (4)$$

with C_z the Chezy coefficient and k_s the Strickler coefficient.

2.2. Tracer transport and diffusion

The salinity field simulation was based on the transport and diffusion equation, already available in SHYFEM model.

This equation allows to estimate the concentration evolution of dissolved tracer in a water column.

$$\frac{\partial C}{\partial t} + \frac{\partial uC}{\partial x} + \frac{\partial vC}{\partial y} = K_H\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2}\right) \quad (5)$$

$S = \int_{-h}^{\eta} s dz$ where, s is the passive tracer concentration, u and v are the barotropic velocities and K_h is the horizontal eddy diffusivity. (Umgiesser *et al.*, 2004). This module has been used to compute the salinity distribution in the Alimini basin.

2.3. Residence time

The residence time definition considered in this work is given by Cucco and Umgiesser (2006). This variable is defined as the time required for each element of the domain to replace most of the mass of a conservative tracer, originally released, with new water. To compute it we refer to the mathematical expression given by Takeoka (1984 a,b) known as the remnant function. The tracer, initially released inside the lagoon with a concentration of 100%, is subject to the action of the tide and the wind forcing that drives it out of and often again inside the basin through the inlet. The residence time is defined as:

$$\tau = \int_0^t \frac{C(t)}{C_0} dt \quad (6)$$

If the decay of concentration C is exponential,

$$C(t) = C_0 e^{-\alpha t} \quad (7)$$

equation (6) gives $\tau = 1/\alpha$, which is the time it takes to lower the concentration to $1/e$ of its initial value (e-folding time) (Cucco and Umgiesser, 2006). This definition of residence time represents the concept of basin renewal time. In coastal environments, like the brackish lake of Alimini, the renewal time defines the transport time scale for the hydrodynamical processes in the basin. The residence time has been calculated for each element of numerical grid in the simulated scenarios.

3. THE GRID

The computation of physical variables is made by SHYFEM model on a numerical grid. The high resolution of grid was necessary to estimate the hydrodynamic processes of basin and to analyze the system salinity. The grid has 3536 nodes and 6509 elements. Coastal ecosystems often present a complex morphology and finite elements method allow to follow faithfully the system conformation through the variable dimension of triangles. The grid has been obtained from a digital line of lake contour with a resolution of 10 m. The bathymetry data, measured in 1998-1999 (Basset *et al.*, 1998), have been interpolated on the grid elements. In Fig. 2 (a, b) the numerical grid and the bathymetry of Alimini Lake is shown. In this domain the marshy area of Traugnano has been neglected in order to better analyze the sheet of water.

4. FORCINGS

The data, used to force the Alimini basin, have been extracted from different sources.

- The discharge data of channels Zuddeo Strittu and Traugnano are obtained from Basset *et al.* (1998).
- The tide prescribed at the inlet has been calculated using the astronomical components.
- The wind data set applied over all the basin has been obtained from meteorological stations of Otranto and Galatina.

In Fig. 3 (a,b,c) the discharge data for the Traugnano, Strittu and Zuddeo channel are shown. These data have been applied to simulate the natural conditions of the Alimini lake. The increase of discharge is applied only the Zuddeo channel and the increment of flux is about 700000 m^3/year (0.022 m^3/s). The Alimini basin exchanges water with the Adriatic Sea through a little inlet on the eastern side of lake. Unfortunately in the years 1998-1999 measurements of tidal level are not available for the Otranto area. Using the astronomical components (see Tab. 1) the level values have been computed and applied to the inlet. The amplitude of tide fluctuates between ± 10 cm and the period considered is between August 1998 and August 1999.

The wind data set, relative to the Otranto station, was discontinuous and then it has been integrated with data from the Galatina wind station. In Fig. 4 and Fig. 5 the wind speed for 2 years (1998-1999) and two polar plots with dominant directions are presented. Observing Fig. 5, in both years the most frequently wind events had a speed less then 10 m/s whereas the peaks had a speed up to 40 m/s. These high wind velocities have been measured mainly in January and February 1999. The most frequently wind directions were the Tramontana wind, from North and Libeccio and Ponente, from the third quarter (S, SW, W).

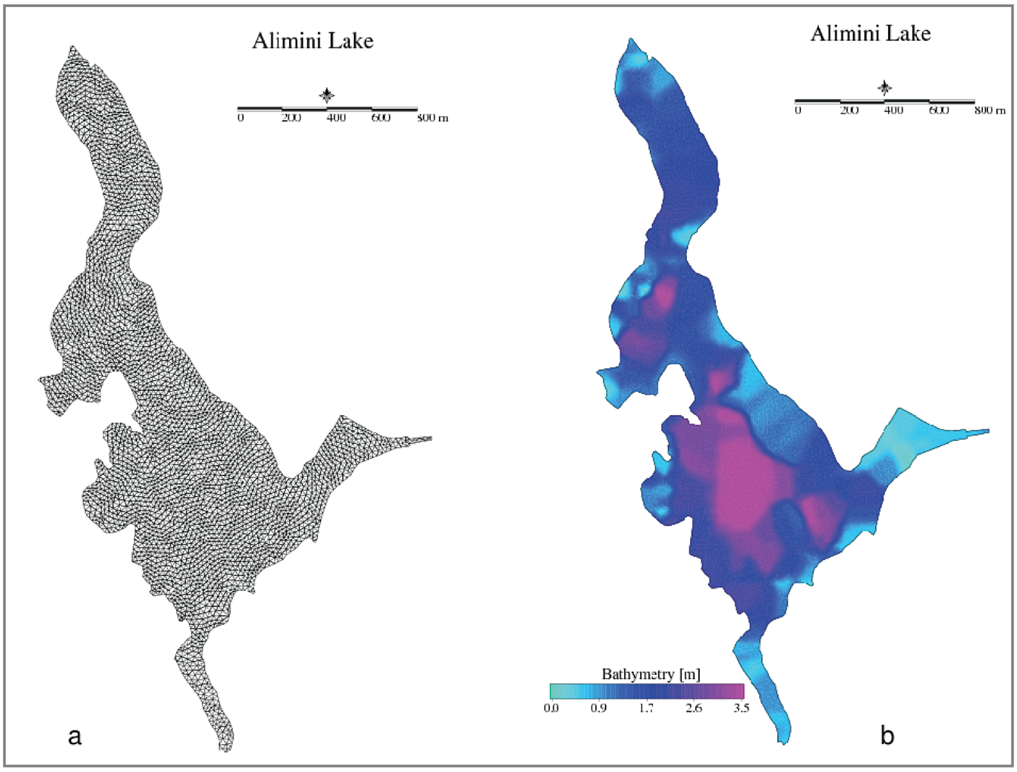

Fig. 2 Numerical grid and bathymetry of Alimini Lake

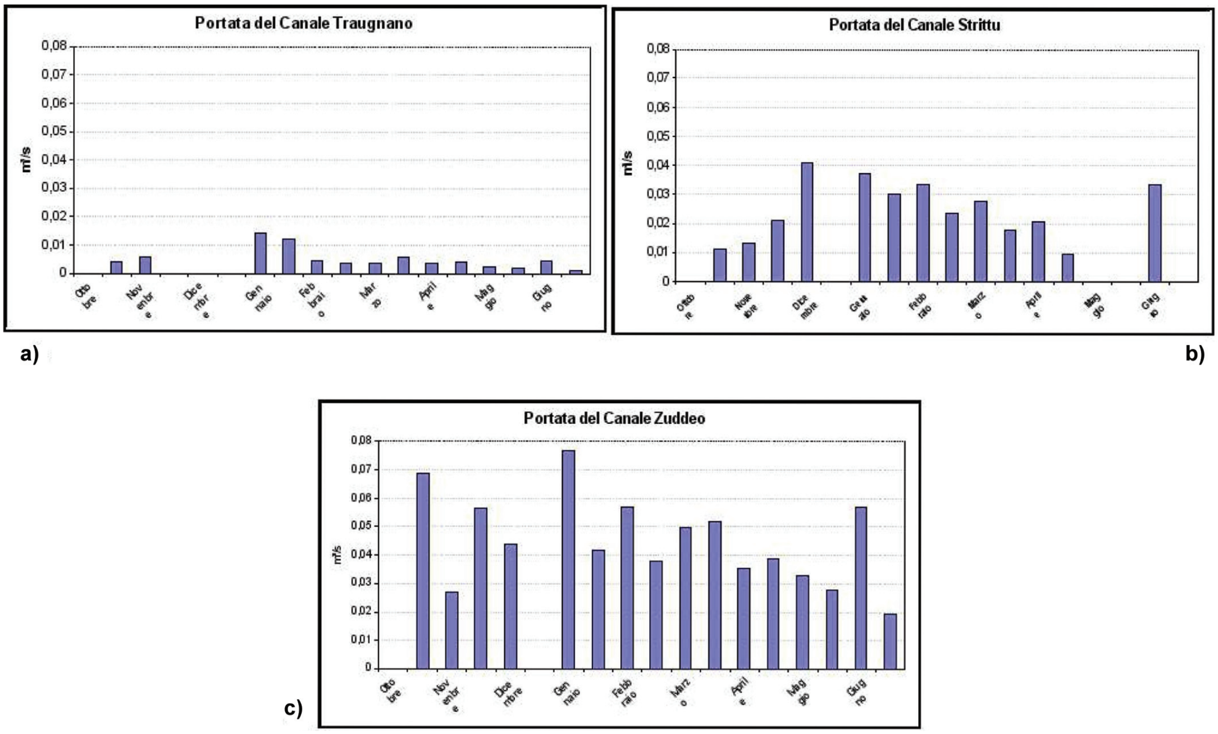

Fig. 3 Discharge of the channels: **a**) Traugnano, **b**) Strittu, **c**) Zuddeo

Constituent	H_0 [m]	g_0 [deg]
M2	6.8	68.83
S2	4.0	80.99
N2	1.2	10.64
K2	1.1	236.33
K1	2.3	50.93
O1	0.9	51.67
P1	0.8	65.34

Table 1 Open boundary condition. Amplitude H and phase g of the main tidal constituents for the Otranto area

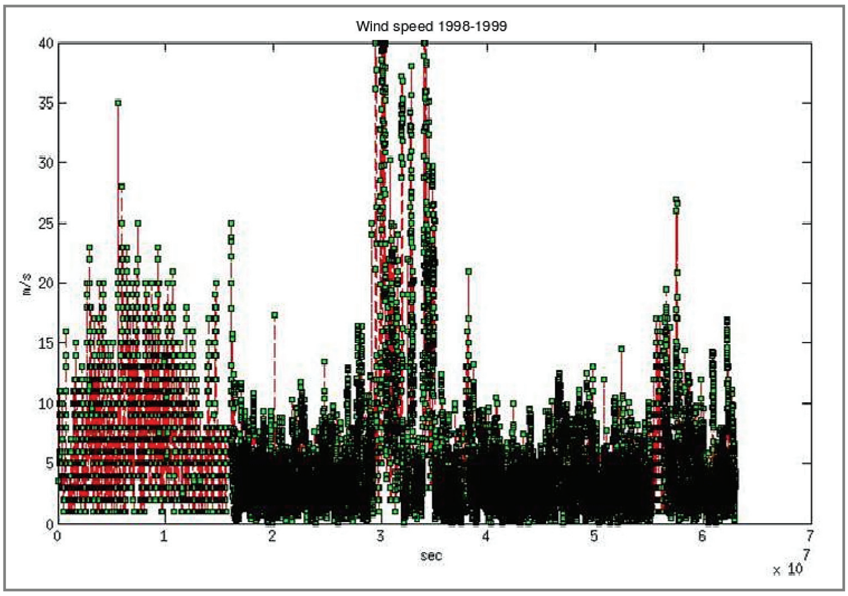

Fig. 4 Wind speed measured from Areonautica Militare at Galatina and Otranto stations

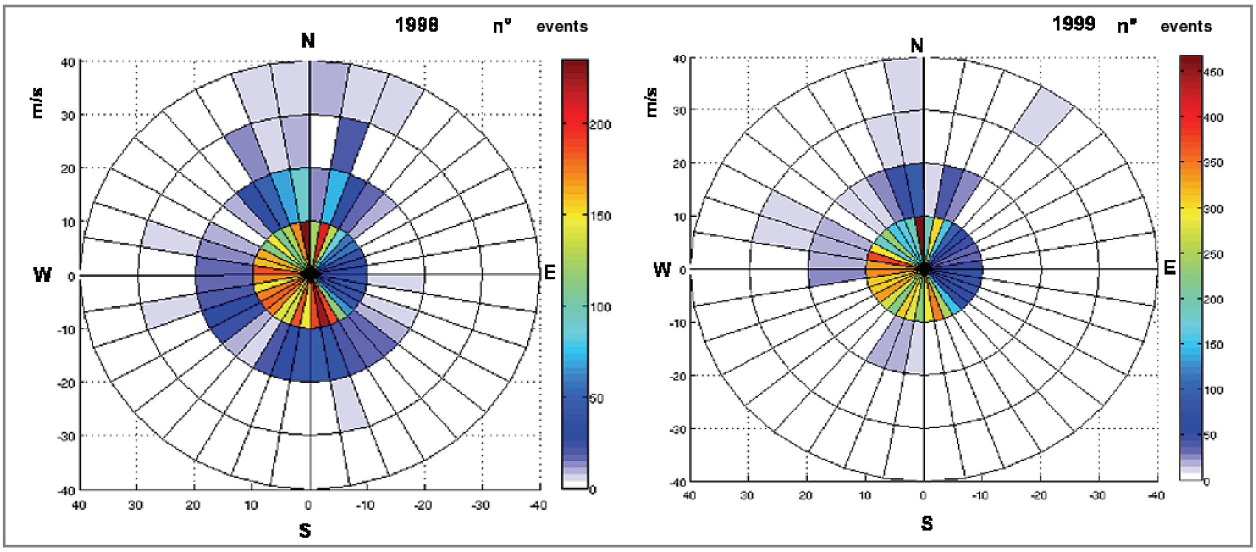

Fig. 5 Wind polar plots of years 1998 and 1999

In order to simulate the salinity distribution in the basin, the rainfall and evaporation data sets have been used. The rain data have been extracted from work of Basset *et al.* (1998) (Fig. 6a) and an estimate of evaporation on Taranto area (Fig. 6b) has been used since solar radiation data in the Otranto area have not been found for the simulation period.

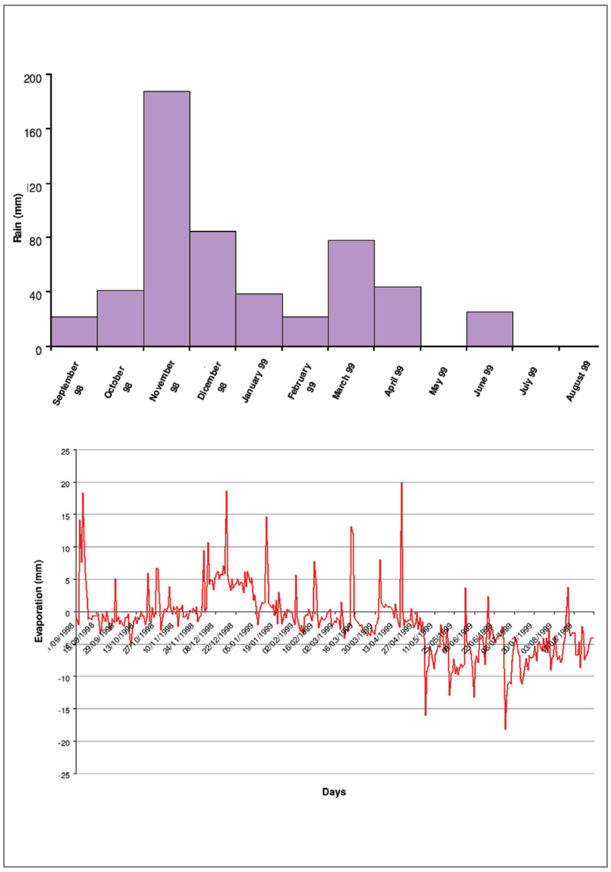

Fig. 6 Rainfall and evaporation input data

5. SIMULATION RESULTS

In order to understand the hydrodynamical processes of the Alimini basin and to estimate the effect of Zuddeo discharge increase on these processes and on salinity, two scenario have been simulated. The simulations have been run with natural discharge of Zuddeo and with discharge increased of 700000 m^3/year. In this phase the forcings of wind, rivers discharge and tide described above have been used. The simulation period was one year, from August 1998 to August 1999. This time interval coincides with the field campaign carried out from Lecce University to collect salinity data (Basset *et al.*, 1998).

In order to study the hydrodynamic response of the Alimini basin to the increment of Zuddeo discharge, the residual currents have been analyzed. The difference between the reference situation and the one with increased flow, in January 1999, is shown in Fig. 7. The residual currents have been computed for each month between August 1998 and August 1999 but the most important variation is visible in January 1999. The map shows residual currents with speed of the order of mm/s. Therefore the speed current variation can't be consider significant.

The salinity distribution has been investigated in the same period of the hydro- dynamic simulations. The model results has been compared with the average salinity of basin obtained from measurements collected in 33 stations (see Fig. 1) between August 1998 and August 1999. In Fig. 8 the evolution of average salinity of the measurements, the reference condition and the condition with the increased flow of Zuddeo are shown. From the comparison between the two time series of reference condition and measurements, it is possible to appreciate the good reproduction of the salinity trend obtained by the model. Some problems have been found for the months of December, January and February

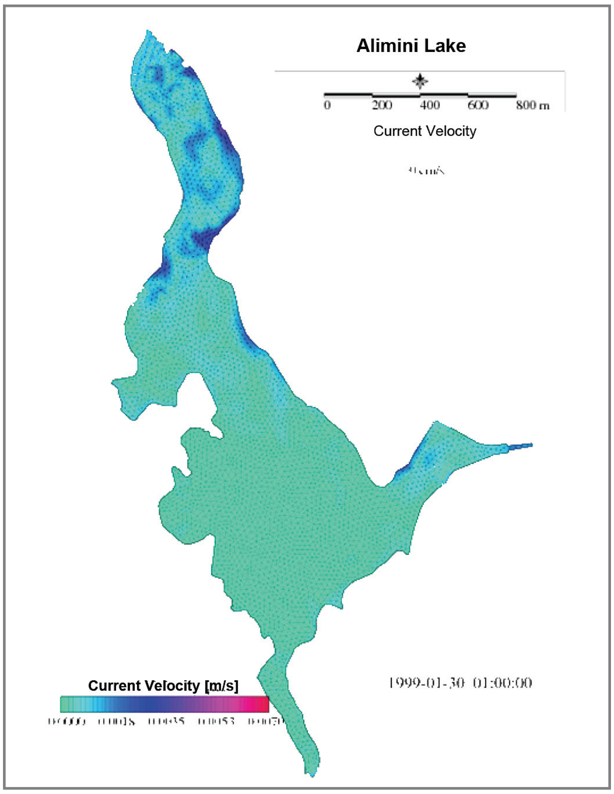

Fig. 7 Difference of residual currents in the Alimini basin computed in January 1999 between natural flow of Zuddeo channel and increased flow

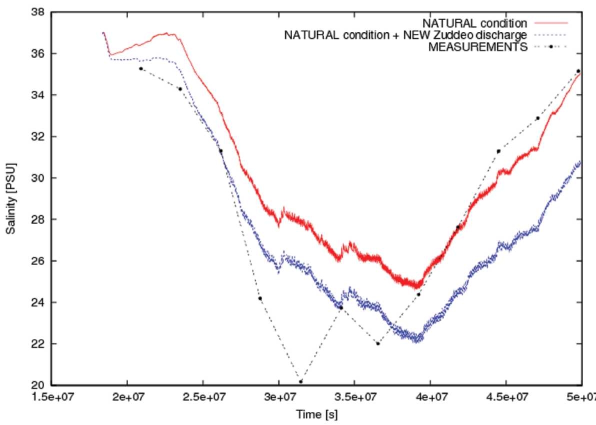

Fig. 8 Spatial average of salinity values: comparison between measurements and model results in the two flow regimes

1999 where the model presents an overestimation of salinity values. This problem can be due to several causes. The evaporation data used for the simulations was relative to the Taranto area because data for the Otranto area was not available in the simulation period. The data was not specific for the investigated area and this can produce the problem in the salinity computation. An other problem of the basin not consider by the model is the wind direction in the period that presents overestimation. In this period the main wind direction is from the North. In this real situation the little inlet of Alimini lake is obstructed by sediments and fresh water can accumulate in the lake. This process is not simulated by model that shows salinity values higher than in the real case.

The influence of the increased Zuddeo discharge on salinity of the basin has been also investigated (Fig. 8). The results shows a decrease of the average of salinity value about of 2 psu, in comparison with the previous simulation.

In the following figure (Fig. 9) the difference between the areal distribution of average salinity in both situations is represented. The impact of the Zuddeo discharge increase (700000 m^3 /year) is particularly visible in the northern and central area of the Alimini basin. The increased flow causes a decrease of salinity values up to a maximum of 3.5 psu.

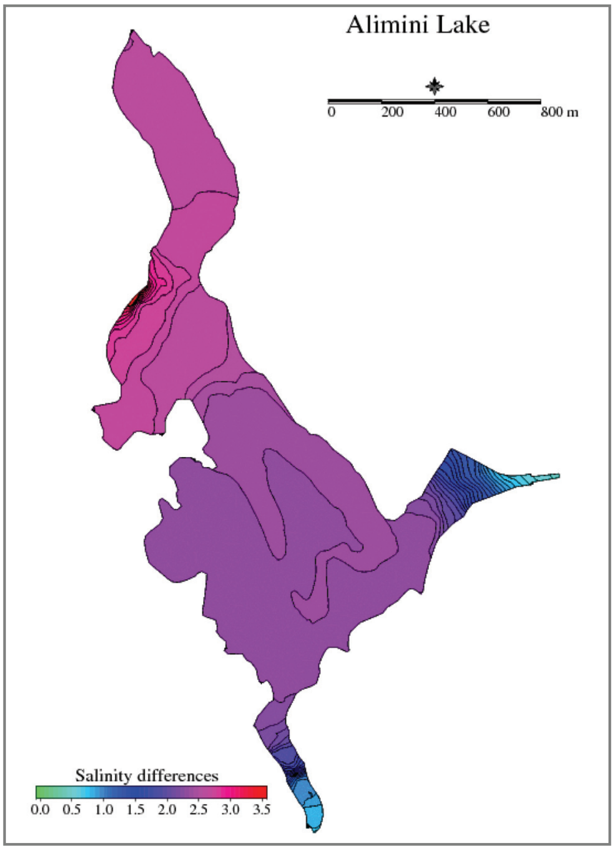

Fig. 9 Map of salinity differences between natural condition and with increased Zuddeo discharge

In the Fig. 10 the time series of the average residence time of the basin are shown. The average residence time of basin reaches values of 160 days, in natural condition. This value is due to the small dimension of inlet that presents a bathymetry of 1 m and an inlet width of 10 m. The influence of discharge increase of the Zuddeo channel on the residence time is about 10 days lower than the residence time found in natural condition. The spatial differences between the natural situation and with the new discharge of Zuddeo channel are presented in a map (Fig. 11). Observing the figure, the central area of the Alimini lake, with new Zuddeo discharge, shows a difference of some days in comparison with the natural condition.

6. DISCUSSION AND CONCLUSIONS

The study conducted on the basin of Lake Alimini Grande had, as its objective, the analysis of hydrodynamic effects of a possible increase in the channel Zuddeo discharge due to spillage of water treatment. In the first phase of the study, differences in the residual velocity in the order of mm/s between the reference situation and with the addition discharge of 700000 m^3/year from the treatment plant are found. These discrepancies can be considered negligible compared to the average hydrodynamic of the basin.

The simulations performed for the calculation of salinity have a qualitative nature because of lack of data of measured evaporation for the year '98 '99, but the results obtained with the model show a good agreement with the trend of the average salinity of the basin. The peak of fresh water, visible in the data during the months of December '98, January February and March '99, is not well represented by the model. This error in the model results can be caused by two reasons: the evaporation data are not specific of the area and the period under review, and the accumulation of sediments at the mouth that occurs in cases of strong wind from the north, creating a buildup of fresh water in the basin, can not be simulated by the model The increase in the low of the Zuddeo channel generates lower values of salinity that may arrive at a difference of 3.5 psu especially in the area of marsh Traugnano.

The residence time differs by about 10 days between natural scenario and with the increased flow from the Zuddeo channel. Therefore, the increased flow of fresh water still seems to contribute to a decrease in the average residence time.

The results reached in this study show a useful model application to better understand the possible consequences of human interventions.

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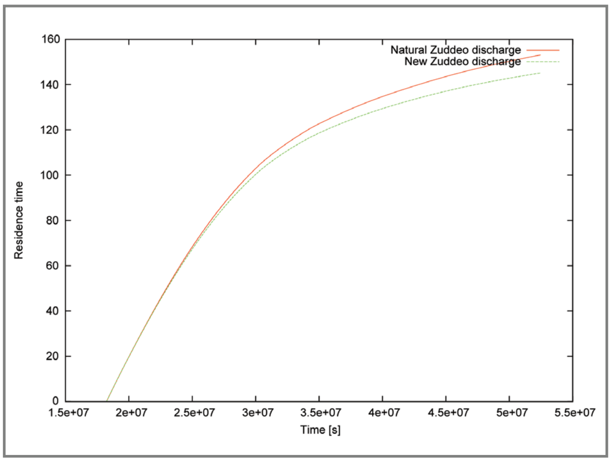

Fig. 10 Residence time of basin. Natural condition in red and with increased discharge of the Zuddeo channel in green

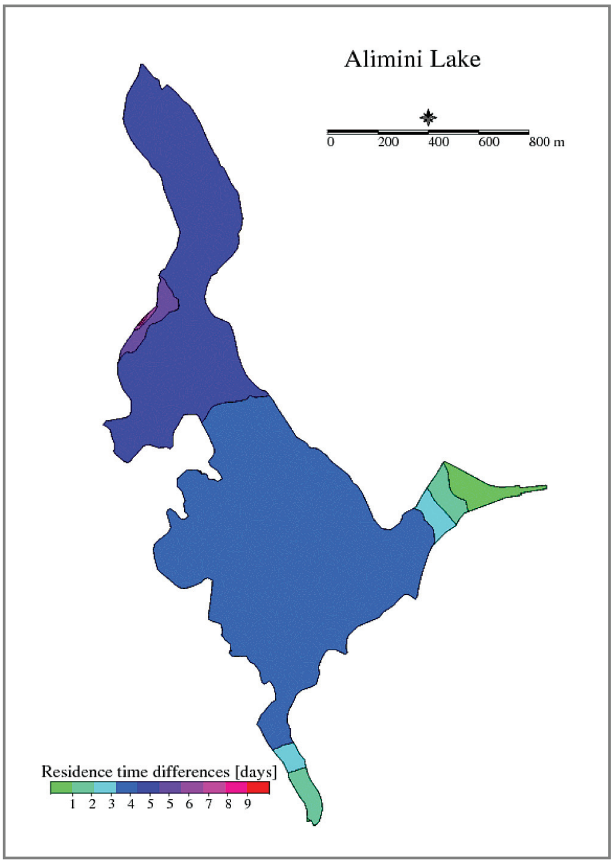

Fig. 11 Differences of residence time in the Alimini basin, computed in the whole simulation period, between increased and natural flow of Zuddeo channel

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