Journal of Coastal Research	SI 39	1432 - 1435	ICS 2004 (Proceedings)	Brazil	ISSN 0749-0208

Understanding Circulation Patterns in Balneário Camboriú's Bight/Santa Catarina State/Brazil Using Numerical Models: preliminary results

C. O. Horita; F. M. P. Tena and A. P. Lima Neto†

†CTTMar
UNIVALI, Itajaí
88302-202, Brazil
cristina@cttmar.univali.br,
franklin@cttmar.univali.br,
guina@cttmar.univali.br

ABSTRACT

HORITA, C. O.; TENA, F. M. P. and LIMA NETO, A. P., 2006. Understanding circulation patterns in Balneário Camboriú's bight/Santa Catarina state/Brazil Using Numerical Models: preliminary results. Journal of Coastal Research, SI 39 (Proccendigs of the 8th International Coastal Symposium), 1432 - 1435. Itajaí, SC, Brazil, ISSN 0749-0208.

In this work a 2DH computational model was applied in Balneario Camboriu's bight Santa Catarina, Brazil. Balneário Camboriú, located in the center-north coast of Santa Catarina, receives a great number of tourists, mainly in summer season. Due to the intense urbanization, water quality problems had been observed in this bight. In order to study these water quality problems, the hydrodynamic behavior must be known. The present study intends to provide preliminary information on the bight's hydrodynamics, showing the effects of the different forces acting in the bight circulation.

ADDITIONAL INDEX WORDS: *2DH hydrodynamic model, SisBAHIA .*

INTRODUCTION

In the last decades, the urban development in coastal areas has intensified, causing a concentration of human beings activities and the industrialization of these areas that appear without a development proposition. Thus, increasing coastal ecosystem deterioration is observed which could be prevented by means of planning and a tidy occupation. The conflict between the resources destruction and our necessities increment can be often minimized by a science based on the management of these resources. Numerical models can play an important role in this management, as they can integrate the physical, chemical and biological processes knowledge of these areas.

Hydrodynamic models are essential components of many computational structures that support the coastal and estuarine management. Actually, the circulation patterns study is usually necessary to accomplish detailed water quality problems, because coastal and estuarine areas are very dynamic, where the net transport depends basically on the local hydrodynamic circulation (TENA, 2001).

The hydrodynamic behavior of most water bodies is extremely complex due to; not only to their irregular geometry, but also to the different flow forcing factors (tide, meteorological data, river flow and density gradients). The hydrodynamic processes comprehension cannot be fully achieved only with field data surveys as it gives just a punctual vision of the system. A more suitable way to comprehend the water bodies flows is the mathematical models adoption, where the phenomena is reduced into a equation system capable of representing water flows in conjunction with environmental data. Those models can be used to represent known or hypothetical situations, allowing diagnostics and forecasts, fundamental to the decision-making.

The mathematical models adoption is the more adequate form to comprehend the water bodies' circulation. Mathematical models can be used to represent known or hypothetical situations, allowing diagnostics and prognostics accomplishment, a fundamental decision tool in accidents situations where pollutants are released to the environment.

Study Area

Balneário Camboriú, located in the center-north coast of Santa Catarina (Figure 1), receives a great number of tourists,

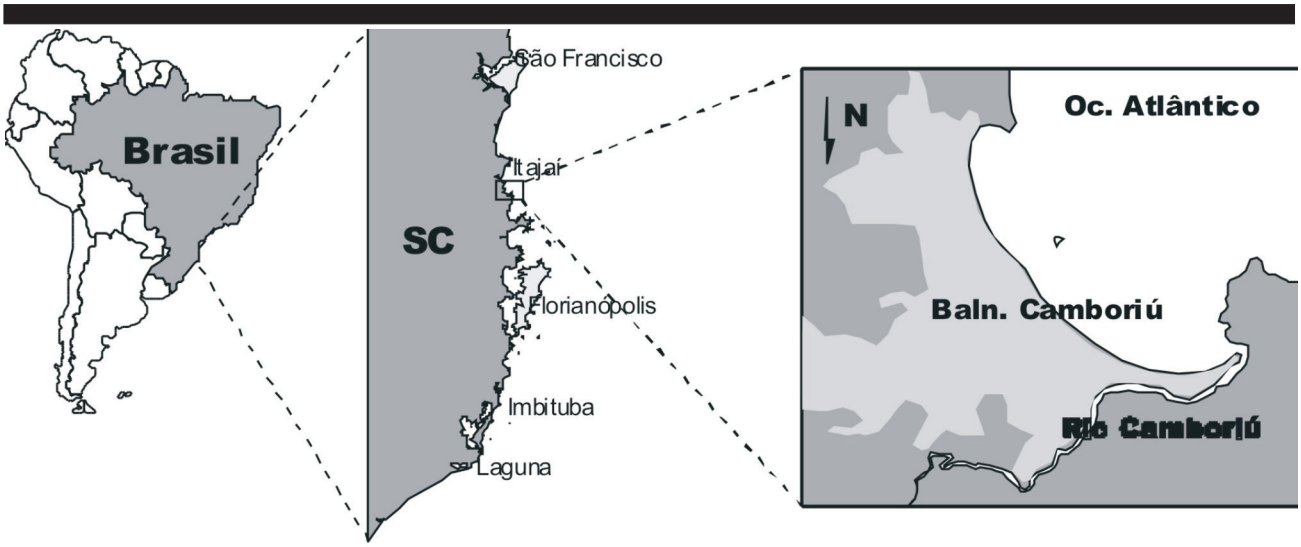

Figure 1. Study area localization.

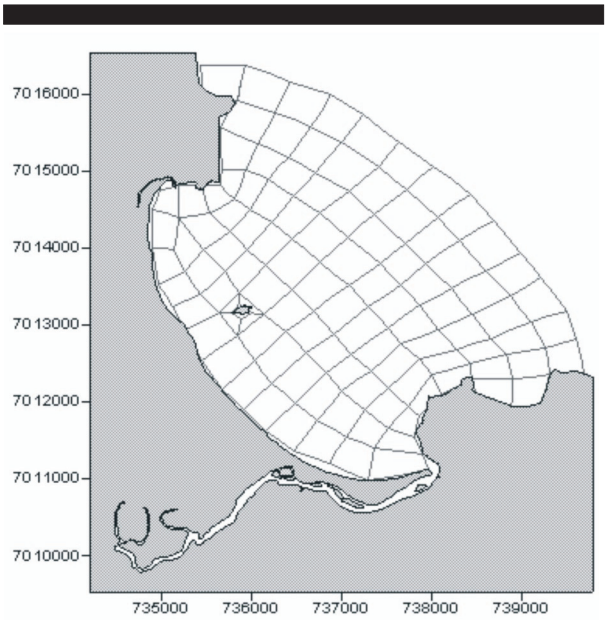

Figure 2. Finite element mesh domain discretisation.

mainly in summer season. From a fixed population of 70 thousands inhabitants, its population reaches 250 thousands in the summer (IBGE, 2001). Due to the intense urbanization, water quality problems had been observed in this bight caused by the Camboriu's river and Marambaia's channel discharge and by undercover sewage in the pluvial drainage system, that discharge in several points along the beach (HORITA and CARVALHO, 1999).

Numerical Model

The modeling concept involves the use of approximations that simplify the studied problem, focusing the main phenomena that act in the water body. In this study, the interest was the circulation hydrodynamics forecast in the coastal area of Balneario Camboriu's bight. In the interest scales, the applicable circulation is the caused by long period forcing factors, as tides and winds.

With a hydrodynamic model, the circulation patterns can be defined by the current velocities and by the seawater elevation, for different conditions of bathymetry and forcing factors.

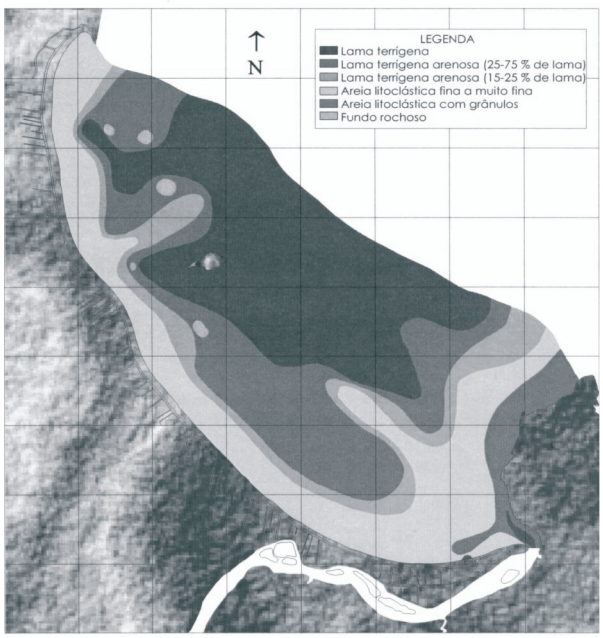

Figure 3. Balneario Camboriu's bight bed granulometry chart.

2DH Model

As the water column stratification in study area is usually weak the relevant flow is quasi horizontal and the horizontal pressure gradients due to surface slopes are much bigger than due to horizontal variations of density, the model used in this study does not include pressure gradients due to density gradients.

Based on these suppositions, the governing equations are depth integrated, reducing the problem dimension. At each time t, the 2DH model computes the depth averaged current velocities in x and y directions, $u(x, y, t)$ and $v(x, y, t)$, and the seawater elevation $z = (x, y, t)$ in each (x, y) point of the domain (ROSMAN, 1987).

The depth averaged equations, known as the shallow water equations, can be written as follows:

- Mass conservation equation or continuity equation:

$$\frac{\partial \eta}{\partial t} + \frac{\partial u_i H}{\partial x_i} = 0 \quad (i, j = 1 \text{ and } 2) \tag{1}$$

- Xi momentum conservation equation:

$$\begin{aligned} &\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -g \frac{\partial \eta}{\partial x_i} + \\ &+ \frac{1}{\rho} \frac{1}{H} \left[\frac{\partial}{\partial x_i} (H \tau_{ij}) + \tau_i^S - \tau_i^F \right] + f_i u_j (1 - \delta_{ij}) \end{aligned} \tag{2}$$

where for a large scale flow, u_i is the flow velocity component in the x_i direction, $\eta(x, y, t)$ is the free surface position. $H = h(x, y) + \eta(x, y, t)$ is the instantaneous water column high, being $z = -h(x, y)$ the bed position. The term $f1 = -f2 = 2\Omega \text{sen}\theta$ is the Coriolis coefficient, where is the Earth rotation velocity, and θ the latitude angle (negative in the South hemisphere). τ_i^S and terms are the surface and bottom friction stress, g is the gravity acceleration and ρ the water specific mass.

The depth averaged lateral turbulent tensions, τ_{ij}, are essential to obtain models with good predictive capacity. In the present study, they are modeled as follows:

$$\begin{aligned} &\frac{\tau_{ij}}{\rho} = (K_{Hf} + K_V) \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) + \\ &+ \frac{\Lambda_k^2}{24} \left(\left| \frac{\partial u_i}{\partial x_k} \right| \frac{\partial u_j}{\partial x_k} + \frac{\partial u_i}{\partial x_k} \left| \frac{\partial u_j}{\partial x_k} \right| \right) \end{aligned} \tag{3}$$

where K_{Hf} is the horizontal turbulent diffusion *momentum* coefficient; K_V is the horizontal dispersion momentum coefficient. Λ is a parameter concerning with the filter width used in the turbulence averaging.

Boundary Conditions

There are two types of boundary conditions: closed and open boundaries. The water body margins and possible tributaries feature the closed boundaries. In this kind of boundary, a value is assigned to the component flow normal to the domain outline; usually the margin is considered impermeable and the value imposed is zero. Beyond this prescription, it is necessary to prescribe a tangential component, usually zero, to parts of the land boundaries that represent rivers or tributaries.

The open boundaries normally feature the water masses limits, representing a model limit, but not a real limit of the water body. Usually, in outflow situations, free surface elevation is prescribed along the open boundaries. However, in inflow situations, it is necessary to prescribe another boundary condition, commonly the imposition of a null velocity component tangential to the boundary.

The equation system of the shallow water circulation model is solved using numerical techniques, as it does not have a known analytical solution. The differential equations time discretization uses implicit schemes of finite differences of $(t)^2$ order and the spatial discretization, uses sub parametrical finite elements, with quadratic interpolation to the flow variables and linear interpolation to the geometry. This scheme is of $(x)^4$ order potentially (ROSMAN, 1987).

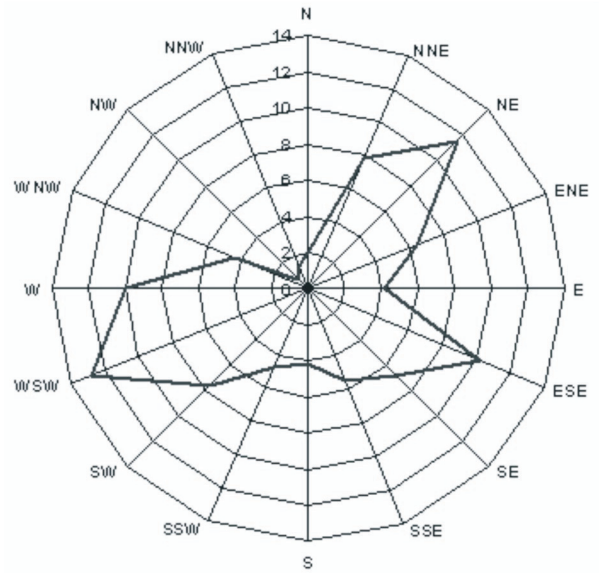

Figure 4. Wind rose for the time series used in the simulation.

METHODS

The methodology used to study Balneario Camboriu's bight circulation patterns was developed in the following stages: (i) pre-processing; (ii) processing 2DH hydrodynamical model application.

Pre- processing

The input data necessary to run the model is presented in this item. Data concerning domain definition, bathymetry, bottom roughness, wind, harmonic constants and discretisation mesh.

Domain Definition and Discretization Mesh

The domain definition was made based on the IBGE map (1:284.530) of Camboriu's river and Balneário Camboriú's bight. Digitizing was done with SURFER® and a linear regression was made to transform the SURFER® local coordinates into UTM coordinates. Determined the boundary domain, a finite element mesh was build in the software ARGUS®, with 112 elements and 456 nodes, being 63 on closed boundary and 27 on open boundary, as shown in Figure 2.

Bathymetry and Bottom Roughness

The information related to bathymetry was obtained from 1800 DHN's nautical chart and related to bottom roughness from ALVES JR. (1998), as shown in Figure 3. Digitizing was done with SURFER® in the same way that in the item just above.

Wind

The wind data used in this work was obtained from SCHETTINI *et al*., 1999, comprehending a time series from June/1996 to December 15th of the same year, with an hour intervals. To define the prevalent wind a Fotran® routine was build to determine the Wind Rose, which is presented in Figure 4.

Processing

The computational model SisBAHIA®, used in this work, brought in the pre-processing data, and through SURFER® interpolation routines roughness and depth values were determined to each mesh node.

Beyond these data, it is necessary to impose a forcing factor to generate circulation in the domain. In this case, tides and wind were used as forcing factors, and the local astronomical tide was simulated by 28 harmonic constants.

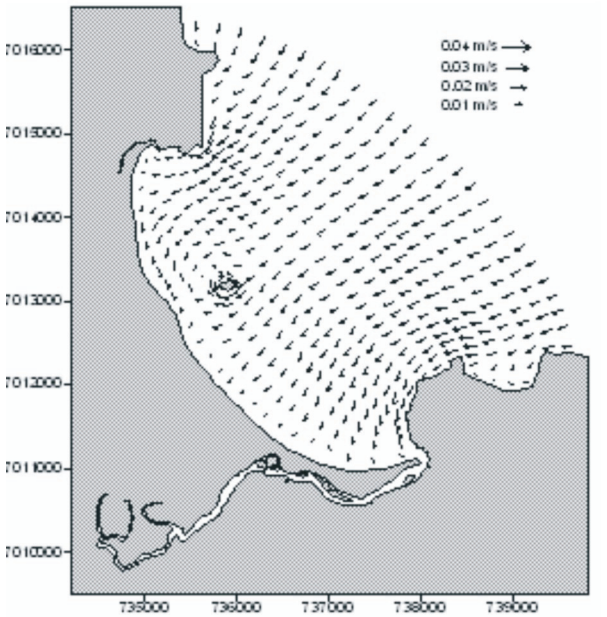

Figure 5. Circulation patterns in Balneário Camboriú's bight, in a ebb tide period without wind.

Four circulation scenarios were simulated for a 15 days period, so that a spring and neap tide would be included: (i) without wind; (ii) with usual wind; (iii) with extreme wind.

RESULTS

The simulation results could be presented in two forms, temporal and spatial results. The former shows the surface water elevation and the *x* and *y* velocity components in pre-defined stations for all the simulation period, and the latter shows current velocity values in *x* and *y* directions for all the domain at one specific simulation time.

As the domain is not big the wind is unable to pile the water, so no significant variation is observed in temporal results. In this way, only spatial results will be presented.

From Figure 5 to Figure 7 the meaningful time instants are presented to neap tide periods, for each simulated scenario.

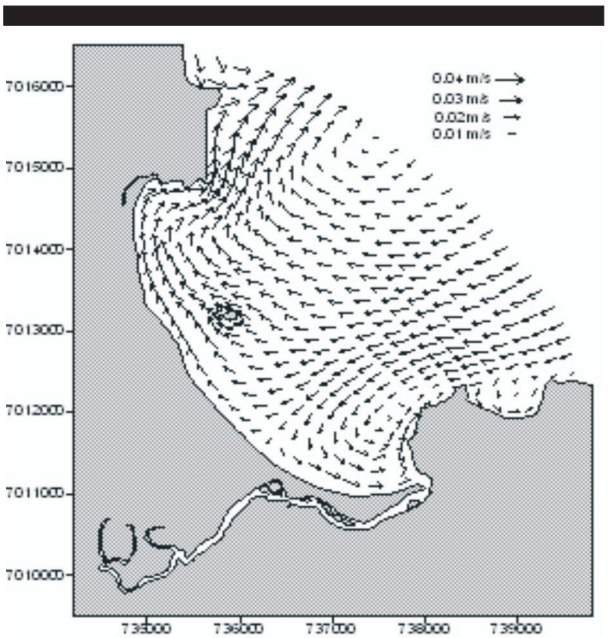

Figure 6. Circulation patterns in Balneário Camboriú's bight, in a ebb tide period with usual wind.

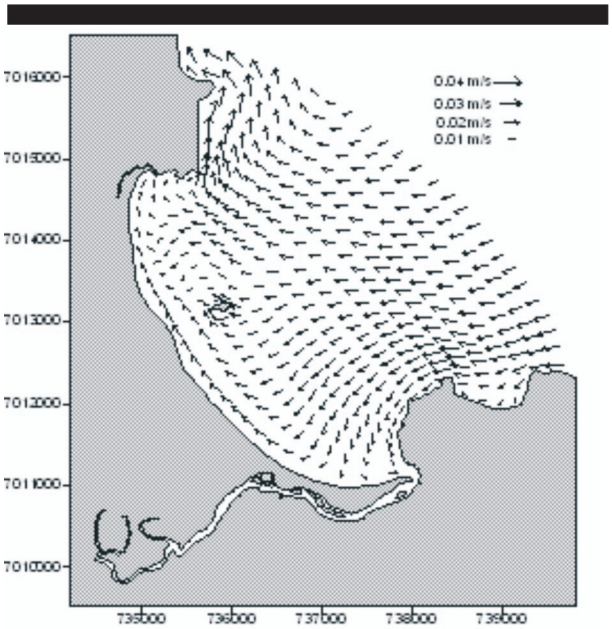

Figure 7. Circulation patterns in Balneário Camboriú's bight, in a ebb tide period with extreme wind.

CONCLUSIONS

In this work a 2DH circulation model was implemented to Balneário Camboriú's bight, in order to study circulation patterns caused by long period forcing factors as tides and wind. The results showed that both forcing factors has influence on the circulation patterns, and after an appropriate calibration it can be used as an important tool to help managers taking decisions.

This work will be continued with data acquisition to calibrate the numerical model.

LITERATURE CITED

ALVES JR, L. A. and ABREU, J. G. N., 1998. Estudo da Geomorfologia Submarina da Enseada de Balneário Camboriú, SC. Itajaí, Santa Catarina: Universidade do Vale do Itajaí, PROBIC final report.

HORITA, C. O. and CARVALHO, J. L. B. DE, 1999. Uma Alternativa para a Melhoria da Qualidade D'água na Enseada de Balneário Camboriú SC. *XIII Simpósio Brasileiro de Recursos Hídricos* (Belo Horizonte, Minas Gerais, Brazil).

IBGE. Brazilian Institute of Geography and Statistics. Data base. Available in: http://www.ibge.gov.br. Acessed in September 2001.

ROSMAN, P. C. C., 1987. Modeling Shallow Water Bodies via Filtering Techniques. Massachussets, Boston: Massachussets Institute of Technology. Ph.D. Thesis.

SCHETTINI, C. A. F.; CARVALHO, J. L. B. DE and TRUCCOLO, E. C., 1999. Aspectos Hidrodinâmicos da Enseada da Armação de Itapocoroy, SC. *Notas Técnicas da Facimar*, v. 3, 99109.

TENA, F. M. P., 2001. Desenvolvimento de um Algoritmo Eficiente para a Equação de Águas Rasas baseado no Método do Elemento Móvel. Rio de Janeiro, Rio de Janeiro: Federal University of Rio de Janeiro. DSc. Thesis. 80p.