I SIMPÓSIO DA BACIA HIDROGRÁFICA DO RIO SÃO FRANCISCO
Integrando conhecimentos científicos em defesa do Velho Chico.

ESTIMATIVA DO TEMPO DE RESIDÊNCIA DA ÁGUA NA BAÍA DE ICÓ-MANDANTES UTILIZANDO SISTEMA DE MODELAGEM TELEMAC-2D

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Resumo

Estudos relativos ao tempo de residência da água na baía de Icó-Mandantes, trecho do reservatório de Itaparica no Nordeste do Brasil são inexistentes. Por esta razão, foram simulados a hidrodinâmica e transporte de água utilizando software TELEMAC-2D, a fim de identificar o tempo de troca na baía. O reservatório tem amplitude de variação de nível de água operacional de 5 m, apresentando elevada disposição de nutriente, que contribuem para a proliferação de algas. Foram considerados cenários com diferentes níveis de água e vazão, utilizando duas malhas não-estruturadas. Na condição inicial, foi distribuído uniformemente um traçador de massa conservadora passiva, para quantificar o tempo de retenção d'água. Foram comparados os resultados considerando: 1) baixo e alto nível de água constante (LWL e HWL, respectivamente); 2) nível de água variável no ano de 2012 (VWL), combinado com vazão de 2060 $m^3.s^{-1}$. Foram obtidos tempos de residência longos (> 1 ano), superior para altos níveis de água e vazões constantes, em comparação com os níveis mais baixos e variáveis. Os resultados não correspondem como valores de tempo exatos, mas servem como ferramenta experimental de suporte à gestão de bacias hidrográficas.

Palavras-Chave: reservatorio de Itaparica; tempo de retenção; processos de troca de água; rio São Francisco

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INTRODUCTION

In the last years, Brazilian government and academic institutions are increasingly concerned about their reservoirs; in particular regarding e.g. climate change and the connected water scarcity, illegalities in water permissions, water quality. Many reservoirs in Brazil were built within the last 50 years, primarily for water storage and energy production, without a conscious environmental plan. Human intervention affects irreversibly water flows natural state, with a huge social and ecological impact. In Itaparica reservoir, located in the semi-arid Pernambuco, Northeast Brazil, climate and land-use changes as well as multiple uses of water lead to water quality problems (Gunkel & Sobral, 2013). Surface water conservation, both for water quality and quantity aspects, is strategic for the sustainable development of the region (Araújo et al., 2003). Therefore, it is necessary to face the social, political and ecological issues with the help of multi- and trans-disciplinary studies, in order to find enhanced management options for the future. This is one of the aims of the INNOVATE project (Interplay among multiple uses of water reservoirs via innovative coupling of substance cycles in aquatic and terrestrial ecosystems), a joint research in collaboration between German and Brazilian institutions. This work is part of the project, dealing with hydrodynamic modeling of Itaparica reservoir.

Object of the study is Icó-Mandantes bay, a shallow eutrophic bay, located approximately in the middle of Itaparica reservoir. A map of the study site can be found in Matta et al. (2014) and a zoom of Itaparica reservoir hereafter in Fig. 1. Previous research in the area showed that exchange with the reservoir main stream hardly occurs, as long as wind is neglected (Özgen et al., 2013; Broecker et al., 2014; Matta et al., 2014). Water multiple uses (e.g. irrigation agriculture), water level fluctuations and shore's desiccation, caused by high evaporation rates (ca. 2,000 mmy^{-1}), overstress the bay, isolating it from the river (Selge et al., 2015). In this work, we simulated hydrodynamics and transport using TELEMAC-2D, in order to quantify the mechanisms and timescales of exchange between Icó-Mandantes bay and the reservoir main stream, according to different water elevations. We conducted a study about water residence times, imposing an initial uniform distribution of a mass-conservative passive tracer, classifying its spreading over time.

MATERIAL AND METHODS

Modeling tools

The bathymetry of the model was set up using measured data mapping, conducted by echo sounder profiling during different field campaigns, performed between 2012 and 2014 (Selge et al., 2015). The data were imported and elaborated with the help of Janet (Smile Consult GmbH), an efficient tool to generate and edit grids for numerical simulations. TELEMAC-2D, a module of the TELEMAC-MASCARET system (Laboratoire National d'Hydraulique et Environnement (LNHE), part of the R&D group of Électricité de France), was used as processor. It is a powerful integrated modeling tool for free-surface flows and it solves the two-dimensional shallow water and transport equations with complex algorithms mainly based on the Finite Element Method, computing the water depth, the two velocity components and the depth averaged concentration at each point of the mesh (Hervouet, 2007). After each computation, the results were examined with the help of ParaView, an open-source multi-platform data analysis and visualization application (Ayachit, 2015).

The mathematical model used is the two dimensional shallow water and transport model. Full explanation of the governing equation can be find in (Matta et al, 2016). We did not take into account reactive transport.

The computational domain has an area of around 100 km^2: it covers Icó-Mandantes bay and it includes a part of São Francisco River, concerning the inflow and the outflow (Fig. 1). São Francisco river, the longest in Brazil with about 2,914 km length, crosses the area and it is interrupted in its flow by the Luiz Gonzaga dam, forming the Itaparica reservoir: a large basin of about 828 km^2, with a regulated mean flow of 2,060 m^{3}s^{-1} and a mean water elevation of 302.8 m a.s.l.

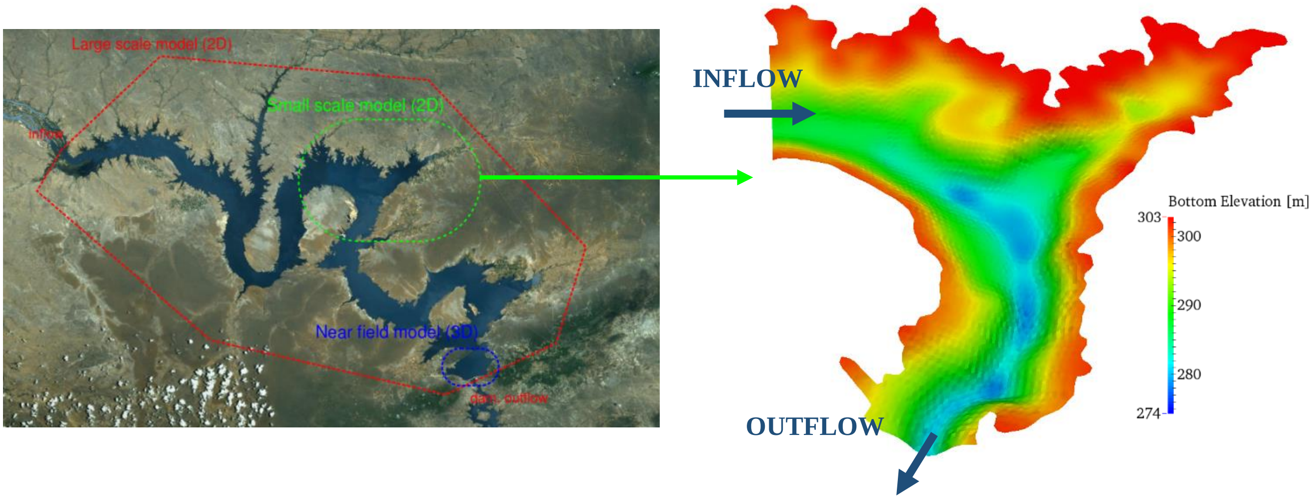

Figure 1 – Itaparica reservoir (*left*) and bathymetry of the model (*right*)

RESULTS AND DISCUSSION

Until now, modeling studies to define retention times in Icò-Mandantes bay have not yet been conducted. In general, residence time for a natural river flow can be simply determined after Chapra (1997). Using this formula we could obtain a value of about 2 months for Itaparica reservoir, considering the mean water level of 302,8 m a.s.l. and the mean dam-controlled discharge of 2,060 m^{3}s^{-1}. In more complex cases, as our study area, no constant flow through is ensured and the problem depends on many variables. Several methods can be used, as Lagrangian Particle Tracking (Banas et al., 2005).

In this study, a mass-conservative passive tracer with concentration equal to 10 was set as initial condition (t = 0) in the whole bay, while zero concentration in the rest of the domain. More specifically, the value of 10 was assigned to each point of the mesh, which had the x- coordinate higher than 560,157 m (Fig. 2, left). A mean wind of 5.5 ms^{-1} blowing from South-East with an angle of 140° (Matta et al., 2014), a Strickler bottom friction coefficient of 30 m$^{0.33}$s^{-1} (Cirilo, 1991) and evaporation equal to 5.479 mmd^{-1} were chosen for each case studied. We assumed velocity diffusivity and diffusion coefficient equal to 10^{-4} m^{2}s^{-1}.

The limitation applied to the grid points for the initial conditions (x > 560,157 m) was used as well to distinguish the results related only to the bay. This means that the number of nodes belonging to the bay are 1,383 and 2,932 for LWL and HWL, respectively. In order to provide an approximated value of residence time for each scenario, the results were divided in different intervals. In particular, if the initial value at t = 0 was c = 10, we counted how many nodes fit to a certain concentration interval after each saved time step, i.e. concentration higher than 9, between 8 and 9, between 7 and 8, between 6 and 7, including the extremes of the interval, and coming with this procedure until the interval of concentration lower than 1. The time at which all points of the bay belonged to this latter interval, was defined as the approximated water residence time. It means that after that time, all points of the bay have a concentration lower than 10 % of the initial value.

Constant water level scenarios

A low water level of 300 m a.s.l. and a high water level of 304 m a.s.l. were imposed as constant water elevation for low water level (LWL) and for high water level (HWL) at the outflow boundary, respectively, and a controlled discharge of 2,060 m^3s^{-1} as boundary condition at the inflow from Itaparica. We run the simulations for 2 years, assuming a constant water elevation for the whole computation. As we can observe from the results in Tab. 1 and Fig. 2 (*right*), the concentrations inside the bay after 6 months have an amount of ca. 40 % and 60 % of the initial value for LWL and HWL, respectively.

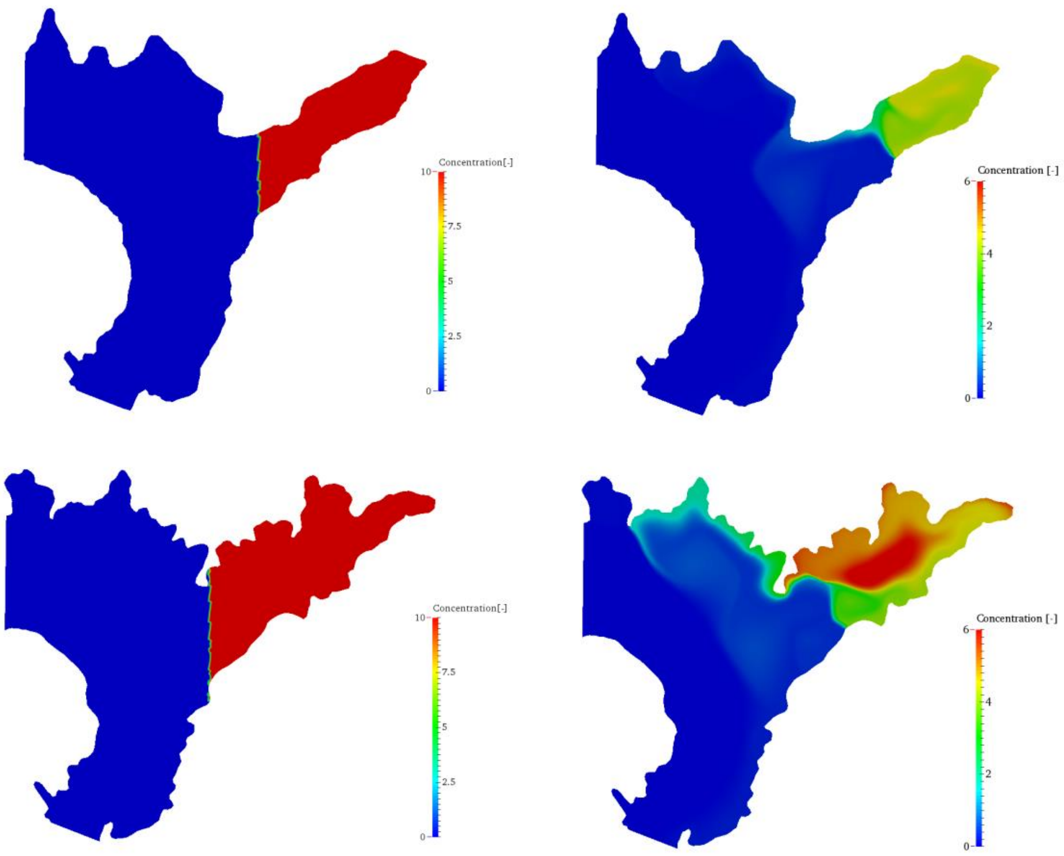

Figure 2 - Spreading of the mass-conservative passive tracer concentration at zero time (*left*) and after 6-months simulation (*right*) for time-constant LWL (*above*) and HWL (*below*).

Variable water level scenario

The previous scenario was applied considering a variable water level over the year 2012 in Icó-Mandantes bay, in order to approach more accurately the reality (Fig. 3).

We used daily data water levels (m a.s.l.), which are available on CHESF website (Companhia Hidro Elétrica do São Francisco) and we observe data between 2012 and 2015. Since the area is suffering in the last years for a dry period, which is simulated in the previous paragraph with the LWL case, we choose the most variable year in that time period: 2012, in particular between the 17th of January 2012 and 17th of January 2013. The discharge was kept constant to the mean 2,060 m^3s^{-1} for the entire computation.

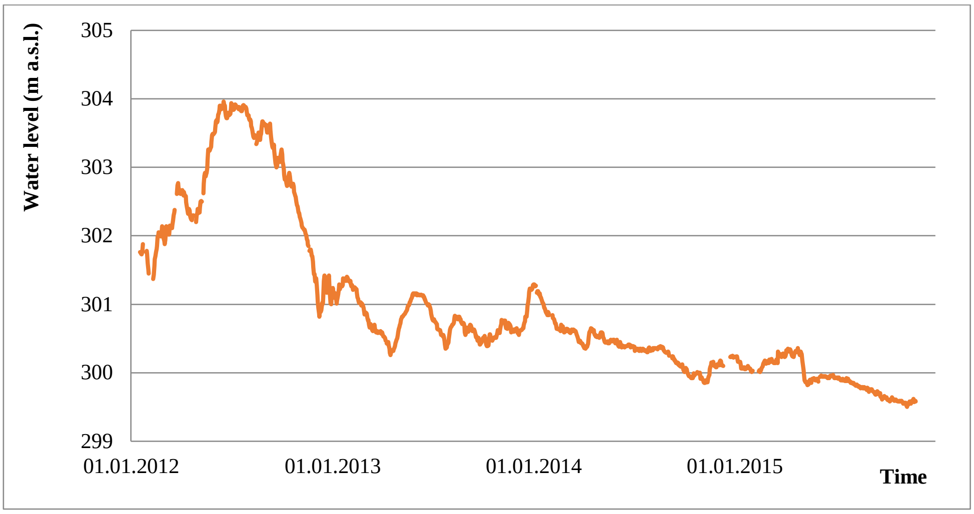

Figure 3 - Outflow boundary conditions variable in time: water elevation [m a.s.l.].

The results show that the residence time remain very high (> 1 year) and they are overall in accordance to the LWL case (Tab.1 and Fig. 4). Variable water level and constant discharge do not increase relevantly water exchange between the bay and the main stream. Indeed, retention graphs of Fig. 4 show that concentrations lower than 10 % are approached the soonest after 1 year (red line). After 2 years the LWL and VWL curves overlap.

Table 1 - Approximated values of water residence time, modeling a uniform distribution of mass-conservative passive tracer as initial condition in Icò-Mandantes bay. The values indicate the time at which each point of the bay has a concentration lower than 10 % of the initial one.

Water level condition	Water residence time [days]
LWL	545
HWL	725
VWL	545 (695 *)

** Between 545 and 695 days, 58 points gained a concentration higher than 10% of the initial value.*

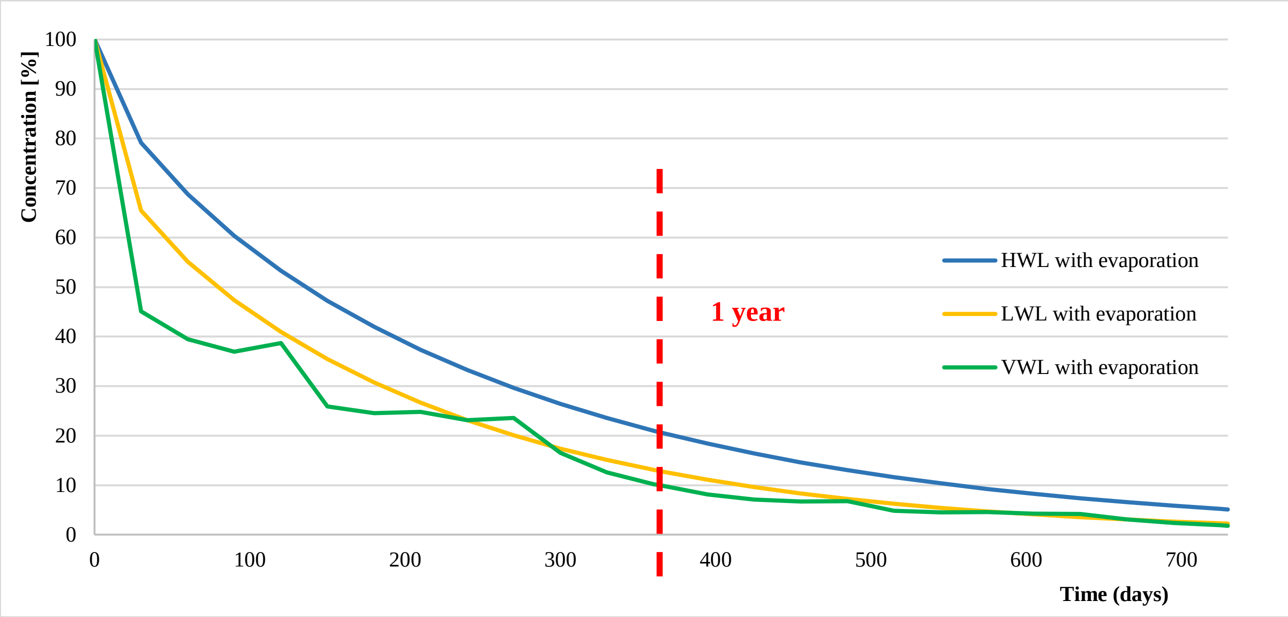

Figure 4 - Decrease of tracer concentration inside the bay [-] vs. time [days].

CONCLUSIONS

Exchange processes between Icó-Mandantes bay and Itaparica reservoir main stream, Northeast Brazil, were investigated for low and high constant water level conditions (abbreviated as LWL and HWL, respectively), for a variable water level (VWL) or variable discharge over the typical year 2012, using the TELEMAC-2D modeling processor. We tried to quantify water residence times of the bay, subjected to evaporation of ca. 5.479 mmd^{-1}, in order to support future management decisions of the reservoir. We simulated the spreading of a mass-conservative passive tracer uniform distribution, imposed as initial condition with concentration 10, just inside the bay. Tracer was retained longer for HWL compared to LWL. After 2 years of computation, assuming constant water elevation for the whole time frame and considering evaporation, we still registered 5 % of the initial value inside the domain for HWL and 2 % for the LWL and VWL.

The results of this study consists in an alternative experimental approach, in order to quantify approximately retention times in a complex domain as Icò-Mandantes bay. This serves as an additional tool for local companies and decision makers, which can be helpful regarding water quality control, water level regulation of the reservoir, placements of new pumps for irrigation agriculture or of a new net cage aquaculture system. Currently, TELEMAC-3D is used to study wind-inducted flow and nutrient emissions in the bay not only in two dimensions, but also considering the vertical direction (Z).

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