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Computer Simulation of Oil Dispersion in Rivers in Brazil Following a Spill: A Case Study Involving the Berigui and Iguaçu Rivers

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Abstract: This study analyzed the dispersion of oil leaked from the Presidente Getulio Vargas Refinery in 2000 into the Iguaçu and Berigui Rivers, both in the State of Parana, Brazil. We studied three (3) flow scenarios: the first with the values observed on the day of the accident, the second utilizing peak values and the third, using low flow. We used Computational Fluid Dynamics (CFD) to simulate propagation of the plume. The plume showed a greater spread during the maximum flow of water, while for less flow, less dispersion of oil occurred. These results show that in situations of low flow, adoption of measures aimed at mitigating environmental damage (containment and recovery of spilled oil) are easier than recovery of spilled oil dispersed in the plume at high flow.

Keywords: oil spill, dispersion, Computational Fluid Dynamics (CFD)

1 Introduction

Surface water sources have multiple uses, especially supply for human consumption [14, 1]. Beyond this, other uses also deserve mention because of their importance in agricultural and industrial use, primarily watering livestock and recreation. Water for each of these sectors should be available in quantity, but it is also essential that quality characteristics are appropriate for the use [3].Environmental degradation of water resources has limited the use of potential water sources.

The current commitment of resources, having utilized watercourses that drain urban centers has eliminated sources with great potential to supply metropolitan areas [12]. Degradation of the quality aspects of these water bodies occurs mainly by discharges of wastewater from industrial and diffuse sources [2].

Environmental accidents are also responsible for the deterioration of water resources. The oil spill in the stream in Sardenha, discussed here, occurred in 2000 in the metropolitan region of Curitiba. The spill of oil and its derivatives into water bodies, in addition to causing pollution of these water resources, is responsible for environmental damage. As [5] discuss, oil has characteristics harmful to exposed organisms and may cause chronic effects even in low concentration. These authors also emphasize that the impact of oil spills is not necessarily related to volume, as small leakages can result in considerable damage to the contaminated areas and bodies of water exposed.

The recent problems of quantity and quality, mainly observed in surface waters, showed that availability is not infinite and degradation capacity is limited [7]. Because of this problem, researchers recently have used models to predict degradation of water quality of rivers and lakes from point sources, and highlight problems involving domestic effluents. Although water quality models are common, simulation of the impacts of accidental discharges, such as oil spills, is undergoing development. Study of these models is highly relevant to predict damage to aquatic fauna and water quality, and generate information simulating scenarios of environmental pollution and the effect of mitigation measures on the quality of water resources.

This study evaluates the dispersion in the Berigui and Iguaçu Rivers of 4000 m^3 of crude oil (Cusiana - 41, American Petroleum Institute) for 2 hours in July 2000 in the State of Paraná, Brazil. This study also shows the use of computer simulations as a tool to measure the impacts of such accidents and serves as a contribution to

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mitigation. As well, the study enables prediction of environmental risks from potential hydrological scenarios, such as normal and extreme maximum or minimum.

2 Study Area

This study was performed on sections of the Iguaçu and Berigui Rivers, both located in the State of Parana, Brazil, as shown in Fig. 1). This area is located on the outer boundary of the metropolitan region of Curitiba, close the facilities of the Presidente Getulio Vargas Refinery (REPAR). REPAR is located on the Schist Highway (BR-476) at Km 16 in Araucaria. This is the location that experienced the oil spill from REPAR in July 2000.

The Berigui River begins in the Serra da Berigui Betara mountains and flows into the Iguaçu river. Hence, the Berigui river is a tributary of the Iguaçu river. The Berigui river is approximately 66 km in length. The Iguaçu river is formed by the meeting of the Iraıriver and the Atuba river. The Iguaçu river travels approximately 1320 km before emptying into the Parana river.

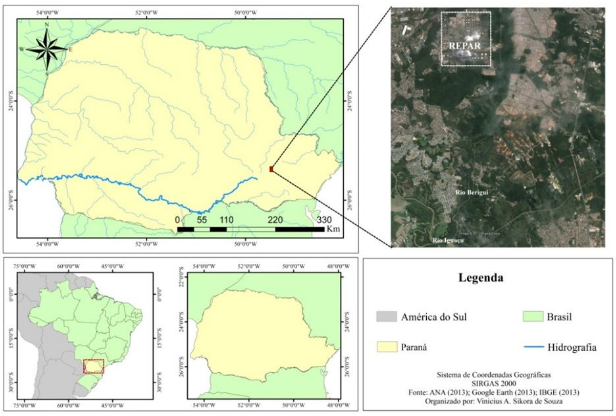

Fig. 1: Location of the Presidente Getulio Vargas Refinery (REPAR) and the Berigui and Iguaçu Rivers

3 Hydrological Analysis

The source of data for simulations of possible scenarios was hydrological modeling of the Berigui and Iguaçu Rivers. The time series, both available from the National Water Agency, were gauged by stations 65019800 and 64926000. For the scenario of maximum flow, we used the highest observed in historical data. The other scenario used in the simulations was based on the $Q_{7,10}$ calculated for the rivers. [10] explain that $Q_{7,10}$ is an important parameter in hydrologic studies because it provides statistical estimates of the availability of natural water flow. $Q_{7,10}$ has wide application in planning and managing the use of water as an important instrument of the National Policy of Water Resources of Brazil, The estimate of $Q_{7,10}$, is based on the average flow rate of the mobile-flow daily averages of seven consecutive days of all data series for each season. From these rolling averages, the minimum value is identified for each registration year, thus obtaining a series of annual minimum values. Ordered in increasing value enables calculation of cumulative probabilities of occurrence, averages and standard deviations according to the following equations:

$$Tr = \frac{n+1}{m}, \tag{1}$$

Where: Tr is the back period, n is the number of elements of the sample and m is the placing value in the sample sorted in ascending order

$$Prob = \frac{1}{Tr}, \tag{2}$$

Where: Prob is the cumulative probability of occurrence and Tr is the back period.

$$Q = \frac{\sum_{i=1}^{i=n} Q_i}{n}, \tag{3}$$

Where: Q is the average annual minimum flows seven days, Q_i is the Flows annual minimum flows seven days and n is the number of elements in the sample.

$$S_Q = \sqrt{\frac{(\sum_{i=1}^{i=n} Q_i)^2 - n(Q)^2}{n-1}}, \tag{4}$$

Where: is the Standard deviation of minimum flows seven days, Q is the average annual minimum flows seven days and n is the number of elements in the sample.

Subsequently, they were modeled using the Weibull distribution based on the work of [4]. For this purpose, we used the software R.

4 Simulation

The geometry used in the simulation (Fig. 3) was obtained by the intersection of the transverse and longitudinal profiles of rivers in AutoCAD and subsequent conversion into a 3D block .

In this study, we used the multi-purpose commercial package ANSYS CFX currently developed by ANSYS Inc. ANSYS CFX is the leading CFD software used in South America. The package contains a set of programs for general use in CFD, ANSYS CFX has proven effectiveness in solving flow problems in engineering. The package combines an advanced solver with pre- and post-processors .

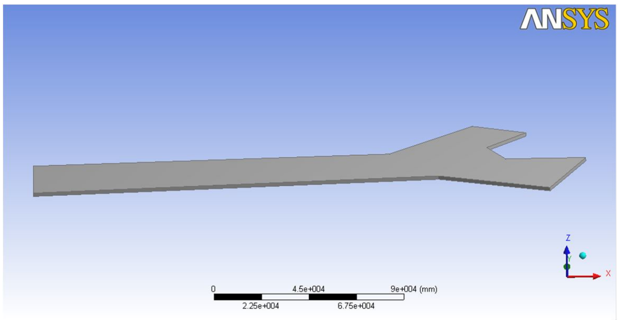

Fig. 2: Geometry used in the simulation

Applying CFD (and thus ANSYS CFX) comprises the following steps:

-Definition of the area of the simulated area. The domain used was created and exported by AUTOCAD; -Discretization of the domain and mesh generation. The domain is divided into points of application of the equations to obtain the numerical solutions. The set of discrete points is called mesh [8]. Figure 3 shows imposition of the mesh onto the geometric figure representing the inersection of the two rivers. The mesh has around 3850 tetrahedral-shaped elements and 1549 nodes formed by intersecttion of the tetrahedrons. The block type (tetrahedron) and the number of elements were chosen after testing to ensure representative results that are independent of the mesh. For meshing, DesignModeler was used.

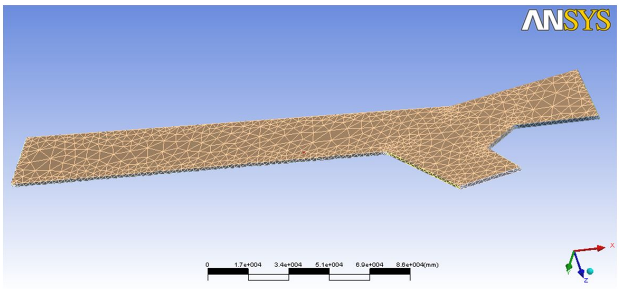

Fig. 3: Mesh used in the simulations in the river and Iguaçu Berigui

- Introduction of the conditions for solving equations. After meshing, the next step involved introduction of boundary conditions required for solving the equations. Boundary conditions are specified in Table 1, along with the physical properties of the fluid and the flow parameters specific to the problem to be solved. This step also established that flow in the rivers is permanent. In addition, the surfaces of the sections in the rivers was assigned a Manning Number 0.02. This value is within the range measured by [6]. Manning Numbers for rivers in the region vary from 0.0185 to 0.0310. Finally, the turbulence model used in the simulations was the k - epsilon, which solves two transport equations: turbulent kinetic energy, k, and the rate of energy dissipation. The k - epsilon model has shown good results for various application areas [9]. To introduce the necessary conditions for solving the equations we used CFX - Pre.

Table 1: Fluid properties

Properties	Water	Oil
Density (Kg/m^3)	997	814,6
Viscosity (Pa.s)	0,0009	100

- Resolution of the equations. To solve the equations using the conditions set in the previous step, we used CFX - Solver. - Visualization of the results. The results are visualized using graphs in the program CFX - Post.

5 Results and Discussion

As noted previously, three scenarios were employed in these simulations. The first involved the same magnitude of flow as the day of the accident (July 16, 2000). The second involved the maximum flow observed in historical series, and the third, values of $Q_{7,10}$ for each of the streams. Table 2 shows values of the flows used in the simulations.

Table 2: Flow values used in the simulation scenarios

Scenarios	Iguaçu river ($m^3.s^{-1}$)	Berigui river ($m^3.s^{-1}$)
Flow Day Accident	26,40	3,58
Maximum Flow Rate	71,35	17,70
$Q_{7,10}$	12,09	2,41

Fig. 4 shows results obtained for the three scenarios. Simulated concentrations are presented along the river in the form of volume fraction. Volume fraction is the volume ratio of oil on the surface of rivers. Figure 4 indicates that the first and last scenarios showed the lowest rate of dispersion of the oil. Expressed in volume fraction, the concentrations along the river remained close to 1. Concentrations were slightly lower than that near the boundary between the water coming from the Iguau river and the Berigui river, due to the increased velocity of the Iguau river. In contrast to these scenarios, case B (conditions of maximum flow), had the highest rate of longitudinal dispersion with concentration fractions mainly between 0,046 and 0,100.

High flow conditions favor longitudinal dispersion, while low flows, such as $Q_{7,10}$, do not favour longitudinal

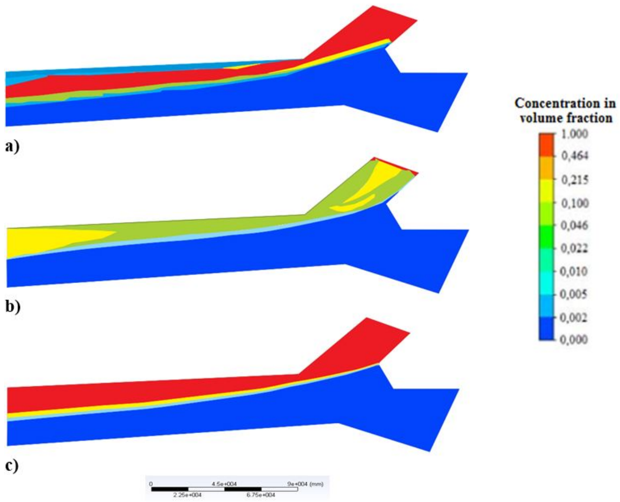

Fig. 4: Volume fraction of oil flow conditions observed on July 16, 2000 (a), maximum flow rate (b) and $Q_{7,10}$ (c) for the Berigui and Iguau Rivers

dispersion. [11] explains that the process of transport and dispersion of pollutants in a body of water considers the velocity of the receiving body, location of the pollutant source in relation to the river, and the dispersion coefficient. Thus, for the same position of the source of pollution for all scenarios, the velocity of the water and longitudinal dispersion coefficient are responsible for greater or lesser spread of the plume of contamination. For the cases studied, the high flow velocity, associated with high flow rate, led to a greater dispersion of oil.

As explained by [13], for a spill into a watercourse having considerable turbulence, dispersion of the oil is facilitated and its presence in such environments is ephemeral, or a few days. However, in adverse hydrodynamic conditions having low turbulence, effective dispersion and the oil is retained for a longer time. High volume retained in a location of limited area prevents recovery of the biota.

Although greater retention in an environment is detrimental to recovery of localized biota, this factor prevents spreading of the oil slick to other locations. Thus, conditions of high water flow rates (simulation ”b”) can create greater environmental damage than scenarios ”a” and ”c” because of greater ability to contain and recover spilled oil.

6 Conclusions

Based on these results, simulations using computational fluid dynamics are a powerful tool for analyzing the impacts generated by accidents involving spillage of oil into water bodies.

Conditions of extreme flow at the time of the accident would also hinder analysis of the affected body of water.

The worst-case scenario for modelling would be the seasonal situation in what we have maximum flow leading to damage to biota and the shoreline, and the spill response measures should have increased the number of containment barriers to provide the greatest mitigation of the problem.

References

[1] Brasil. Lei n. 9.433 de 08 de janeiro de 1997. Institui a Poletica Nacional de Recursos Hıdricos, cria o Sistema Nacional de Gerenciamento de Recursos Hıdricos, regulamenta o inciso XIX do art. 21 da Constituição Federal, e altera o art. 1 da Lei n. 8.001, de 13 de março de 1990, que modificou a Lei n. 7.990, de 28 de dezembro de 1989. Diario Oficial da União, Brasılia, n. 29, pp. 470-474, 09 jan 1997, Seção 1.

[2] Grant, S. b. et al.(2012). Taking the waste out of wastewater for human water security and ecosystem sustainability. Science, Vol. 337, No. 6095, pp. 681-686.

[3] International Conference on Water and Environment - ICWE. (1992). The Dublin statement on water and sustainable development. IN: ¡www.inpim.org/?les/Documents/DublinStatmt.pdf¿. Accessed: Jan. 24, 2013.

[4] Leme, E. A.; Chaudhry, F. H. (2005). Vazão mınima do vale medio do rio Jaguari Mirim. Revista Brasileira de Recursos Hıdricos, Vol. 10, pp. 127-136.

[5] Leme, D. M.; Morales, M. A. (2007). ”Avaliação da qualidade de aguas impactadas por petroleo por meio de sistema-teste biologico (Allium cepa) - Um estudo de caso”. IN: 4 Congresso Brasileiro de Pesquisa e Desenvolvimento em Petroleo e Gas, Campinas - SP.

[6] Martoni, A. M.; Lessa, R. C. (1999). Modelagem hidrodinâmica do canal do rio Parana, trecho Porto São Jose - Porto 18. Parte II: Calibragem do modelo. Acta Scientiarum, Vol. 21, No. 4, pp. 961-970.

[7] Miranda, R. G.; Pereira, S. F. P.; Alves, D. T.V. (2009). Qualidade dos recursos hıdricos da Amazônia - Rio Tapajos: Avaliação de caso em relação aos elementos quımicos e parâmetros fısico-quımicos. Rev. Ambiente e agua, Vol. 4, No. 2, pp. 75 - 92.

[8] Pinheiro, L. A. R.; Cunha, A. C.; Cunha, H. F. A.; Souza, L. R.; Bilhalva, J. S.; Brito, D. C.; Brasil Junior, A. C. P. (2008). Aplicação de simulação computacional a dispersão de poluentes no baixo rio Amazonas: Potenciais riscos a captação de agua na Orla de Macapa-Amapa. Revista Amazônia: Ciência e Desenvolvimento, Vol. 4, No. 7.

[9] Shilton, A. (2001). Studies into the hydraulics of waste stabilisation ponds. Palmerston North: Massey University. Dissertation (Doctor of Philosophy in Environmental Engineering), Massey University, 280 p.

[10] Silveira, A. S., Moura, R. M. P., Andrade, N. L. R. (2006). Determinação da q7,10 para o rio cuiaba, Mato Grosso, Brasil e comparação com a vazão regularizada apos a implantação do reservatorio de aproveitamento multiplo de Manso. Revista de INGENIERA SANITARIA Y AMBIENTAL.

[11] Soares, P. A. (2011). Estimativa e aplicação dos coeficientes de dispersão longitudinal e de reaeração em corpos de agua naturais. Dissertation (Master in Environmental Engineering) Blumenau University, Blumenau, Brazil.
[12] Soller, J. A.; Schoenb, M. E.; Bartrandc, T. (2010). Estimated human health risks from exposure to recreational waters impacted by human and non-human sources of faecal contamination. Water Research, Vol. 44, No. 16, pp. 4674-4691.
[13] Szewczyk, S. B. O. (2006). Processos envolvidos em um derramamento de oleo no mar. Dissertation (Doctor of Physical Oceanography), Rio Grande University.
[14] Tomasoni, M. A.; Pinto, J. E. S.; Silva, H. P. (2009). "A questão dos recursos hıdricos e as perspectivas para o Brasil." GeoTextos, Vol. 5, No. 2, pp. 107 - 127.

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