TWO-DIMENSIONAL SIMULATION OF WATER QUALITY OF THE DESCOBERTO LAKE (DF / GO)

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Abstract. *Eutrophication of water bodies is caused by high concentrations of phosphorus and nitrogen causing the decline of water quality. Accordingly, there is a concern to evaluate the quality of water for public supply. This research aims to show the dynamic behavior of the concentrations of these nutrients, dissolved oxygen and water temperature in Descoberto Lake which is the main reservoir of public water supply and environment of the Distrito Federal and neighboring cities, corresponding to approximately 65% of water distributed in the region. The research covered the end of period 2003 to early 2005. It was used for this the model CE-QUAL-W2. This is a two-dimensional model, laterally averaged, for analysis of hydrodynamics and water quality of water bodies. The program uses, among other tools, the concepts of fluid mechanics, modeling by finite differences and environmental flows. Another objective of this study was to evaluate the applicability of the model and the consistency of results for subsequent applications in scenarios predictions.*

Keywords*: Numerical Simulation, Water Quality, Descoberto Lake, CE-QUAL-W2.*

1. INTRODUCTION

You cannot separate the water from the health of a population and the quality of life of the availability and quality of water. (World Health Organization, 1998)

According Lanna (1993) "water resources are important assets of value to promote the welfare of society. " In almost all human activities is closely linked to water as a final or intermediate consumption. By increasing the intensity and diversity of water use, conflicts these users start to emerge. The efficient approach to prevent and manage these conflicts is the use of integrated management of water resources, their control and conservation. These actions must consider a multiplicity of objectives (economic, environmental, social, among others), alternative uses and attitudes such as: irrigation, power generation, supply, etc.

Explore water springs distant centers of consumption increases the cost of transport of water, making its control more difficult. There is thus the importance of studying sources close to centers of consumption, such as the River Basin Discovered in the region under study (Fig.1a). In the northern part of the Basin has been discovered in the dam of Descoberto how the main reservoir for public water supply of the Distrito Federal (DF) (65%) (Fig.1b).

According to the Sanitation Company of the Distrito Federal (CAESB, 2008) the dam of Descoberto since its construction, has lost 17% of the total volume of water. One of the causes was the rapid and disorganized urban occupation, which is depositing large amounts of waste organic material and soil in the bottom of the dam.

The Water Quality Index (IQA) has decreased in recent years. One of the consequences of reducing the wealth of a IQA is a decrease in water quality and the possible increase in account that reaches the public, according to the cost of water treatment, because the Company will use more procedures and reagents to make the water suitable for human consumption, resulting in expensive the final product, the drinking water.

The factors that most influence the contamination are the negative impacts generated by human activities such as deforestation, release of sewage and toxic substances in local expropriated, among others. Cite it as the consequences of human activities insertion of fecal coliform and toxic substances, the siltation, salinisation and eutrophication, which is considered one of the most serious problems experienced in lacustrine environments around the world. To reduce pollution from these actions is essential to planning for sustainable development of the basin.

Accordingly, it is seeking management tools to help in decision-making on such human activities. Cite, among other instruments, the mathematical models for simulation of water quality, much sought option for analysis of scenarios predictions of likely reaction of the body water, facing the impact suffered.

Knowing the loads of pollution entering the pool is important to make sustainable decisions, and the mathematical model we can analyze the water body in question to determine locations of monitoring stations, and discharge of tributaries, choose management techniques to produce scenarios prognoses, among others (Silva, 2006). Similarly, consider the scenarios of the Descoberto lake predictions from numerical simulation software with the CE-QUAL-W2, can bring important results in terms of planning.

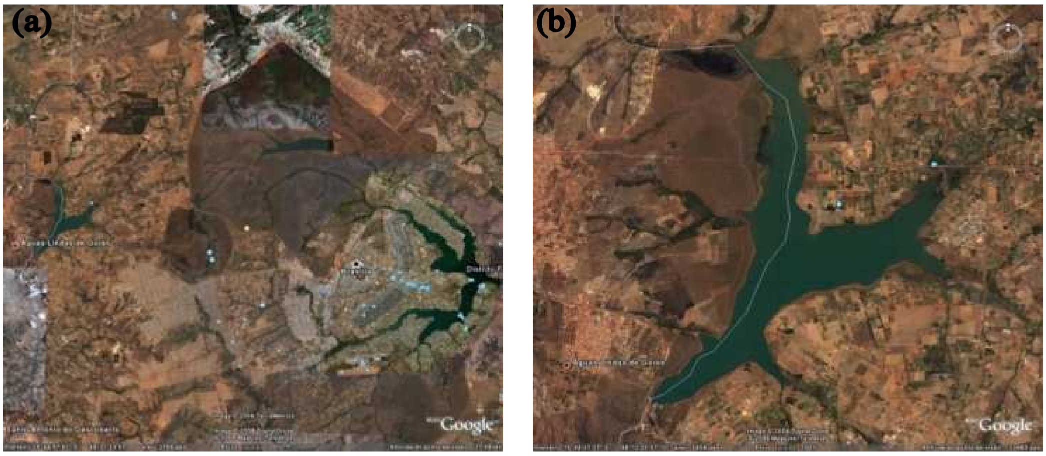

Figure 1. Visualization of the study area. a)Region of Distrito Federal. b)Descoberto Lake GO/DF.
Source: Google Maps. 28 april 2008 < http://maps.google.com.br/>.

Thus, the main objective of this study is using two-dimensional modeling of water temperature and concentrations of phosphorus, nitrogen and dissolved oxygen in Lake Discovered using the mathematical model CE-QUAL-W2, to analyze the dynamic behavior of concentrations of these parameters and the collection of data to support decision making. The article will address some limnological characteristics of the lake, assess the applicability of software CE-QUAL-W2 to the same conditions, to allow the use of the model predictions for creating scenarios.

2. MODELING OF WATER QUALITY

The assessment of water resources in both qualities has a fundamental element of knowledge which deals mainly loads of pollutants generated in the watersheds, and showed the pressures that are exerted on the water bodies as a result of various socioeconomic activities that act on the territory. These pressures determine the quality status of water bodies, and the possible impact that this condition can cause public health or ecosystems. (Pádua, 2004)

Mathematical models for simulation of water quality have become quite sought to enable the analysis of water resource forecasts and alternative scenarios before. The equations governing the quality of these models are the equation of water balance and the conservation of mass, resulting in a partial differential equation. Describes, for example, the hydrodynamics of a river by the equations of continuity and momentum, also known as the Navier-Stokes equations or Reynolds. The simulation models of water quality using equations of advection and dispersion / diffusion to calculate the turbulent transport of dissolved substances in water. (Silva, 2006)

The mathematical model has been the model of Streeter & Phelps (1925), which considers the transport advective and gains and losses of oxygen in the light of reaeration and decomposition of organic carbonaceous matter. Later models incorporated the cycles of nitrogen and phosphorus. In the case of biotic and abiotic variables of the aquatic ecosystem and its physical, chemical and biological agents involved, the models can work with processes of respiration of algae, sediment-water interaction, resuspension, meteorological data, interactions between the food chains, reactions nonlinear kinetics, contributions by diffuse loads, and so on. Due to technological advances, the models use a larger number of constituents of water quality, with modules capable of performing hydrodynamic simulations multidimensional, including physical transport (advection and diffusion / dispersion). (Silva, 2006)

According to Silva (2006) the mathematical models of water quality have evolved in line with the development of numerical methods and computing, the emergence of new environmental problems, and the inclusion of new physical, chemical and biological agents in the aquatic environment.

These models can be classified into deterministic or stochastic, dimensional, two-dimensional or three dimensional. The deterministic generate a single response to a given situation, and are recommended for studies of mechanisms of cause and effect related to the observations of field data. But the stochastic models, also called probabilistic, will depend on a distribution of probability for acceptable answers. As the models have advantages and disadvantages between them, the researcher should choose the most appropriate for your research in order to meet the goals and characteristics of the simulated water body. (Jorgensen, 1988, Thomann and Mueller, 1987; Chapra, 1997)

As already mentioned, the literature is full of simulation models of water quality, with a large number of characteristics and variables likely to simulation, to simulate the water quality of lakes and reservoirs. The model used in this research is the CE-QUAL-W2 version 3.6. This is a bi-dimensional model, longitudinal / vertical, for analysis of hydrodynamics and water quality. Was prepared by the U.S. Army Engineering Research and Development Center, Vicksburg, MS, USA. (Cole & Wells, 2002)

The model has been applied to estuaries, rivers or portions of water bodies, simply specify the prevailing hydrodynamic conditions. Water bodies with various complex dendritic leg or reservoirs can be simulated. The thickness of the layers in the vertical line and the length of segments, to accommodate entries of trainers, may be varied. (Cole & Wells, 2002)

You can use multiple entries, loads of contaminants such as non-point sources, loads of trainers, loads due to atmospheric precipitation and varying loads due to the cleaning of reservoirs for environmental management techniques. (Prates, 2000)

The above model allows the simulation of the concentration of up to 21 constituents than the temperature. Some of the parameters are: solid organic matter, coliform, total dissolved solids, carbonaceous BOD, pH, alkalinity, CO2, iron, DO, ammonia, nitrate, phosphorus, chlorine, algae and dissolved organic matter (Cole & Wells, 2002).

The ability to present a mathematical model, with greater or lesser accuracy, the variation of quality in a body of water is necessarily dependent on the data available for the system studied. (Silva, 2006) For this work will be possible to have field data on water quality, collected by the Graduate Program in Technology and Management (PTARH) (Koide, 2006).

3. METHODOLOGY

The use of a simulation model requires the definition of a conceptual representation of the system to be simulated, must be taken into account the characteristics of the model, the experimental data available and the goals it proposes to achieve. (Miranda et al, 2000)

In possession of the shares of elevations, there are dividing the region into the lake arms, segments and layers. The geometry of the Descoberto Lake was set to a distance of approximately 500.00 m in length, dividing the pond into four arms, longitudinal segments totaling 38, with 14 layers of 2 m in height each. It is important to say that the model does not consider the first and last layer, and the first and last segments of each arm.

Figure 2 shows the longitudinal discretization of the Descoberto Lake, their arms and their segments, generated by the model. We used standard slope, and the guidelines were obtained from images provided by CAESB. There are dubious positions of some segments, but according to the results there are no influences.

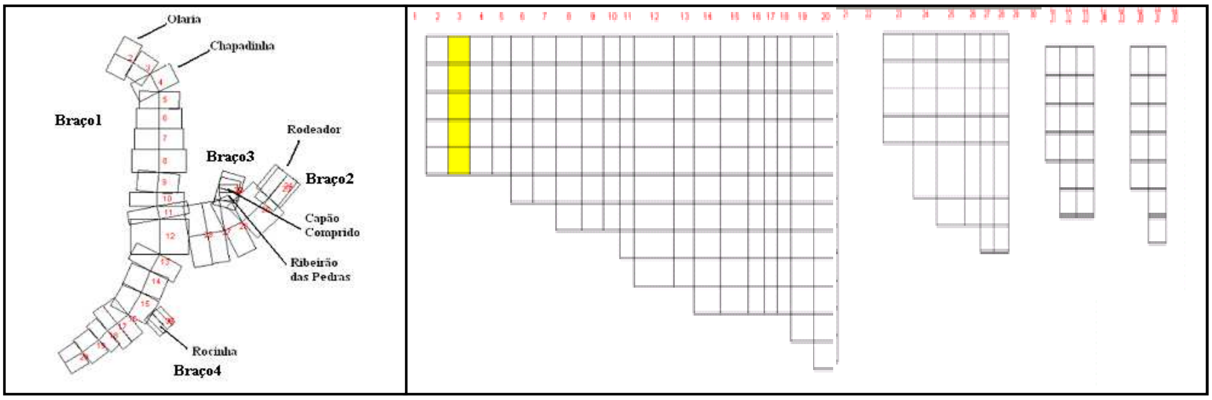

Figure 2. Longitudinal discretization of the Descoberto Lake showing their arms and their segments, generated by the model.

The hydraulic data used were provided by CAESB. The Collection Management and Technical Geoprocessing released the CAESB to review the research reports of studies of hydrological Dam Descoberto published in 2003, part of the project "*Estudos de Concepção e de Viabilidade Técnica e Econômica para Elevação da Crista do Vertedouro da Barragem do Rio Descoberto, do Distrito Federal*" (CAESB, 2003). Another source of data was the report of the project "*Definição De Requerimentos De Resolução Espacial E Temporal Para Monitoramento Da Quantidade E Qualidade Da Água Em Bacias Hidrográficas*" (Koide, 2006). These documents gave details on: flow, temperature, water quality parameters, among others.

Initially, the simulation covered the years 2003 and 2004. Specifically from October 2003 to October 2004. According to documents of the CAESB (2003), the region of the DF has basically two seasons per year, the rainy season, which runs from October to April (summer) and the period of drought, which runs from June to August (winter), which has low rate of precipitation. The months of May and September months are defined as the transition to these stations. Over the summer and winter solstices are very sharp, the spring and autumn equinoxes are not easily seen.

Thus, the study period, for the sensitivity analysis, verification and confirmation, understand the observed data from 10/01/2003 to 12/14/2004. Begins thus in the rainy season of 2003 and ends in the same period in 2004.

4. RESULTS AND DISCUSSIONS

Ideally, a model should be used as a starting point for investigations limnology of a body of water, is continuously refining the data to better understand the system and processes studied. This was the path made by this research. Initially, set up the hydrodynamic parameters, to further enable the model to simulate the water quality parameters. Thus, had the results in the time-scale for comparing observed and simulated data.

4.1. Results of the simulation of flow and water level

The correct entry of data flow helps to reduce possible errors generated during the simulation, because the water level, i.e. its volume is directly related to the transport of mass and consequent change in the concentration of the parameter under study and its physical and chemical reactions. (Souza, 2006)

It appears that the results of the variation in elevation of water in the following 20 are satisfactory, despite the differences noted at the beginning of the simulation. The inconsistencies can be explained by the lack of comparative data of the years under study, was used as average annual increases of documents available in the CAESB (2003). It is important to mention the simulation was configured with the spillway dam of the Uninsured in elevation 30.00 m. Thus, the output stream of water from the lake, in addition to making water and discharge of fund will be poured if the water level is higher than 30 meters above sea level. With this analysis, adjusted the data flow of the river main (Descoberto amount) and its tributaries.

4.2. Results of the simulation of water temperature

As recommended by the manual model, it is evaluating the results of simulated water temperature in the last segment of the lake. It was evidenced by the sensitivity analysis, the influence of flow on water temperature. This is easily explained by phenomena of heat transfer in the water mass. There is a slight discrepancy between the values of water temperature simulated and experimental, this may be due to problems in the flow of the lake, as was previously found mainly in the beginning of the period simulated.

It also examined the vertical profiles of water temperature (Fig. 3) during the period simulated, with the Gregorian and Julian dates and images generated by the model. Dates were selected characteristics of each season: spring, summer, autumn and winter, including the profile of the beginning of the reporting period (October).

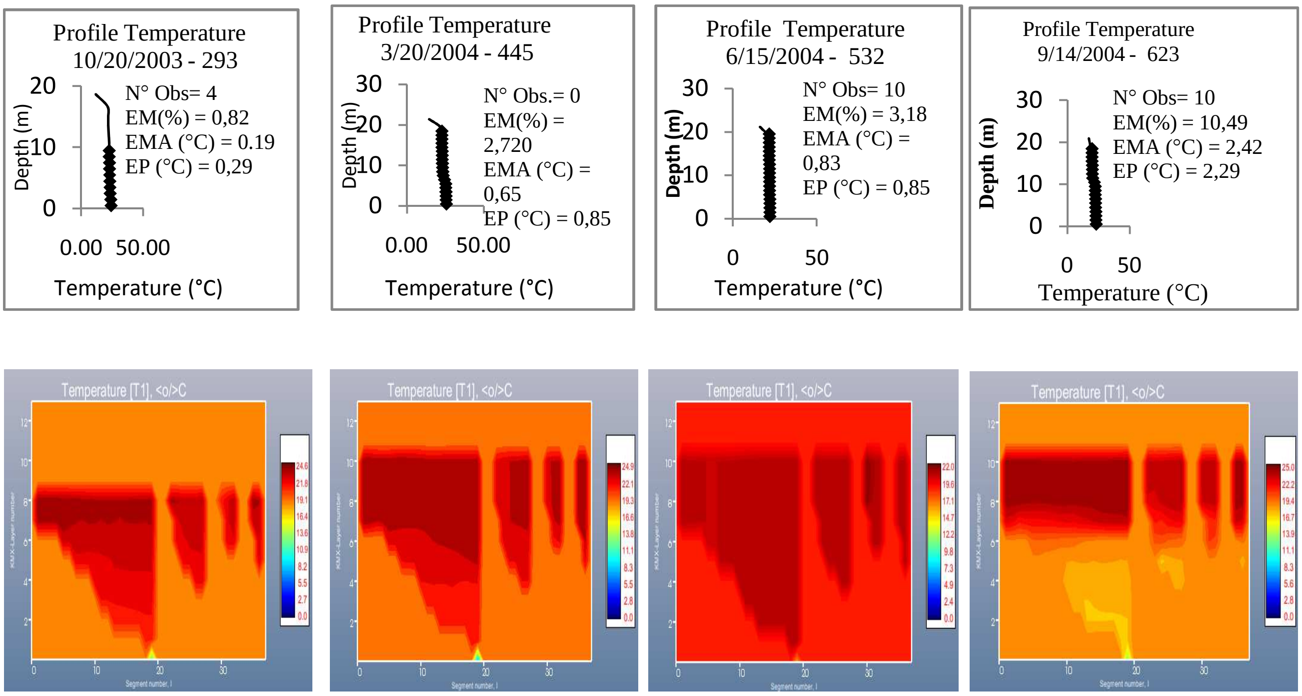

Figure 3. Vertical profiles of water temperature, generated by the model.

According to the graphs above, one can see the consistency of the vertical profiles in the analyzed period. The error associated with a higher profile is the month of September and can be compared with the same period of elevation of water level, where there is greater error apparent. This month is characterized by the transition period from dry to rainy season from the DF.

You can see that in October 2003, March, September and December 2004 is thermal stratification of water column. These months are characteristic of the rainy season (summer), where the surface layers of the reservoir is warm and become less dense than the deeper layers, making the mixture of upper and lower layers. This phenomenon does not occur during the colder months, as observed in June.

4.3. Results of the simulation of water quality

The following are shown in Figures 4 and 7 the values of water quality parameters: reactive phosphorus, ammonia nitrogen, nitrate + nitrite and OD. Compare the results of this research with the experimental data obtained by the project of Koide (2003). These were arranged in graphs with temporal variations and vertical profiles during simulated. All results are equivalent to the segment 20 of the model, i.e. the last segment of the lake discovered. As one might expect some errors associated with the results as accidental errors, random and systematic experimental data relating to, errors related to calibration of the computational tool, and finally to the errors intrinsic to the model. It is interesting to mention that normally are only available for a given simulated measured by months, thereby generating significant errors during the entire period of study.

4.3.1. Dissolved Phosphorus (P-PO4)

The model simulated the dissolved phosphorus on the adsorption of phosphorus to the inorganic suspended solids and sediment by resuspention, including its transport in the body of water and its decay rate of organic matter, which is related to biochemical oxygen demand. Note in Figure 4 results.

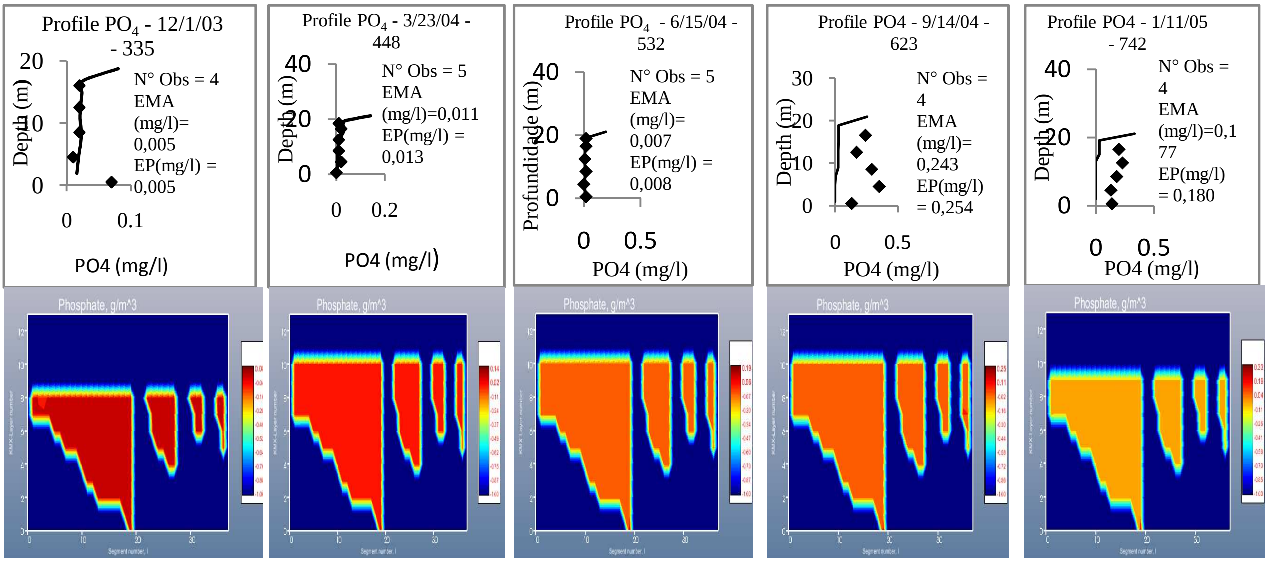

Figure 4. Profiles of concentration of phosphate near the dam, simulated by the model CE-QUAL-W2 version 3.6.

The concentration of P-PO4 ranged from 0.00 mg / l at 0.21 mg / l in the layer just below the water surface. The resolution of CONAMA 357/05 "provides for the classification of bodies of water and environmental guidelines for the framework and establishes the conditions and patterns of release of effluents, and other measures." It was discovered in the lake as a body of water belonging to Class 2 of fresh water, which can target:

> "supply for human consumption after conventional treatment, the protection of aquatic communities, the primary contact recreation such as swimming, water skiing and diving, as Resolution CONAMA no. 274 of 2000, the irrigation of vegetables, fruit plants and parks, gardens, fields of sports and leisure, with which the public may have direct contact, and the aquaculture and fishing activity." (Res. CONAMA 357/05)

According this resolution, only the values of total phosphorus in lotic environments are available. Note that the concentrations of reactive phosphorus observed by Koide (2006) in the profile of the pond reaches a concentration of 0.35 mg / l, especially in September, which are above the allowable limit for total phosphorus for water bodies of Class 2. This is mainly due to the transition period from dry to rainy season, in which a decrease of water level by concentrating the loads on the shell.

Comparing the simulated with the observed values, there are significant errors in the concentrations of P-PO4, a special in the rainy season. The probable explanation for this result, apart from experimental errors and model, is the possibility of diffuse loads originated from rainwater runoff from the municipality of Águas Lindas de Goiás and environment, and domestic sources, agricultural and industrial sewage, not included in the model.

The loads of phosphorus are significantly higher in the characteristic of the municipality have a high rate of population growth, especially in recent years. Thus, the sources lay untreated household synthetic detergents in the reservoir, and the marginal agricultural activities to the lake to throw their loads diffuse. For vertical profiles, the EMA (mean absolute error) ranged from 0.005 mg / l at 0.243 mg / l, while the standard error ranged from 0.005 mg/l at 0.254mg/l.

4.3.2. N-ammonium (NH_4)

According to statistical studies, we used the rate of nitrification (NH4DK) of 0.005 day^{-1}. In the case of the existence of anoxic conditions during simulated, using the value of 0.005 day^{-1} for the coefficient related to the release of ammonia nitrogen by the sediment (NH4REL). Figure 5 shows the simulated results of the concentration of ammonia-N during the period studied the vertical profiles in the water column.

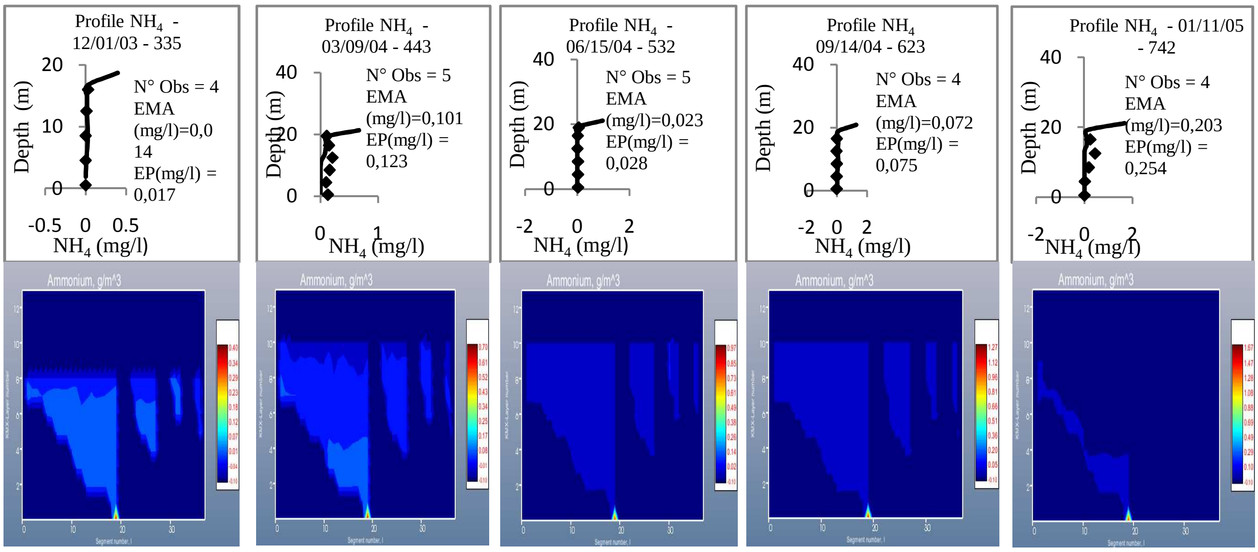

Figure 5. Profiles of concentration of ammonia-N, near the dam, the simulated model CE-QUAL-W2 version 3.6.

The values of ammonia-N had been measured between -0.07 mg / l and 0.17 mg / l. However, the results of modeling included the interval between 0,004 mg / l and 0.15 mg / l for the temporal variation of the concentration near the dam of the Uninsured. As for the vertical profiles, variations of the measured concentrations were between -0.03mg/l and 0.45 mg / l, but the results of the simulation values were between 0.00 mg / l and 1.27 mg/l.

To assess the levels of qualification of the results to the CONAMA 357/05, breaks down along the middle of the lake pH, due to the decoupling of the constituent in its free form, with that context, a characteristic toxic and harmful to the cup d ' water and biota (Souza, 2006). According Koide (2006), the pH values during simulated remained below 7.5 and the concentrations of ammonia, both measured as simulated, remained below the limit for Class 2, which is 3.7 mg/l.

It appears that during the period simulated, the simulated concentration of ammonia-N is below the measured values, except in the deepest regions of the lake, which are possibly involved with resuspension of sediments, thereby increasing the concentration of the fund. The reason for this fact is due possibly to errors associated with the quantity of experimental data available, the experimental errors and model. As regards the vertical profiles, the EMA ranged from 0.01 mg / l at 0.20 mg / l, while the standard error was between 0.02 mg / l at 0.25mg / l.

Another source of error is in the effluent loads from urban and rural areas. There is, clearly, the figures relating to the vertical profiles, the increase of the concentrations measured during the rainy season from October to April, when probably the loads of nutrients, urban and rural, are carried to the lake and its tributaries, mainly near the dam.

4.3.3. Nitrate + Nitrite (NO_3+NO_2)

As already stated above, the nitrate and nitrite ions are computed together in a single variable. It was found that NO_2 + NO_3 suffer great influence of the parameter of nitrification, as was to be expected. Then, they were established after analysis and adjustment, the values of NO3DK of 0.03 days^{-1}, where the presence of anoxic conditions in the system, the value of NO3S of 0.01 m / day.

Figure 6 shows the simulated results and measured values, obtained close to the dam discovered, with its temporal variation in the surface in vertical profiles.

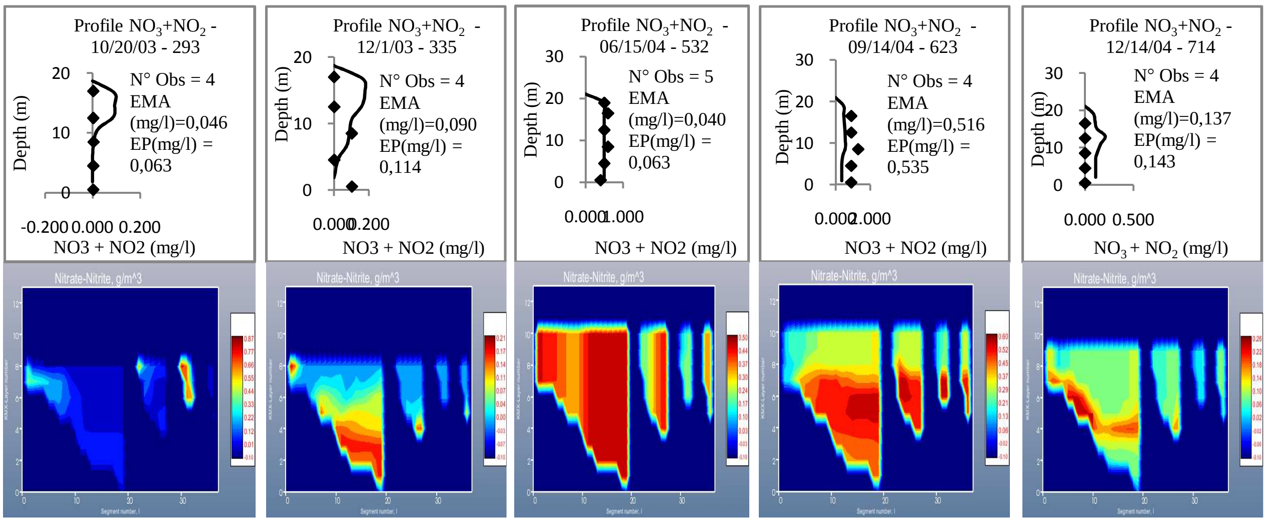

Figure 6. Profiles of concentration of nitrate + nitrite, near the dam, simulated by the model CE-QUAL-W2 version 3.6.

Observe that the minimum concentration of nitrate + nitrite measure is 0.000 mg / lea maximum is 1.404 mg / l. But the simulated values ranging from 0.000 mg / l and 0.577 mg / l. According to the CONAMA Resolution 357/05, to the Class 2 of water, both measured and simulated values were found within the required standards, ie below 10mg / l. Statistical analysis showed that the EMA ranged from 0.040 mg / l at 0.516 mg / l, while the EP (percentage error) ranged from 0.063 mg / l at 0.535 mg / l.

According to previous discussions on the results obtained for water temperature, we observed the stratification of the water column of the lake in summer months as described. Figures of the vertical profiles (Fig. 6) there is in October and December to stratification resulting from changes in temperature in the region. The upper layers become warmer, therefore less dense, and the cooler lower layers and more dense. This phenomenon makes it difficult to mix the water column, also stratifying the concentration of constituents such as NO_x, unlike what happens in June.

There is a discrepancy comparing the experimental data with simulations, especially in September, when the transition from dry season to rainy season. Increasing the concentration of NO_x is probably the decrease of water level, contributing to a greater concentration of pollutants in the water column.

As the rainy season, the addition of experimental errors, intrinsic to the type and quantity of data entered in the simulation, may be associated with loads of tributaries flow of urban and rural. Basically, it is correct to affirm the presence of loads of nutrients originated from marginal areas, especially the right side of the reservoir, which is known of the existence of the local farmers. Thus, during the rain, a lot of loads of nutrients is released into the lake by rain water.

4.3.4. Dissolved Oxygen (OD)

According to statistical analysis, was used for the simulations the coefficient of deoxygenation (KBOD) the value of 0.25 day^{-1}, the temperature coefficient of Arhenius (TBOD) from 1.0147; DBO5 the relationship with biochemical oxygen demand last (RBOD) of 1.85, and the sediment oxygen demand (SOD) was between 0.5 to 1.7 for g/m2.dia segments.

According to the recommendations of Cole & Wells (2003), and statistical analysis, using the following stoichiometric relationship to the degradation of organic matter: CBODC equal to 32%, CBON equal to 6% and CBODP equal to 0.4%.

It is important that a concentration of OD have influences interactions of chemical, physical and biological characteristics of the environment, as air temperature and water, nitrification, decomposition of organic matter and water velocity of the wind, among others. Thus, the error comes from one of these parameters affect the final outcome of the OD. The results obtained by simulation of dissolved oxygen and their experimental data are presented in Figure 7.

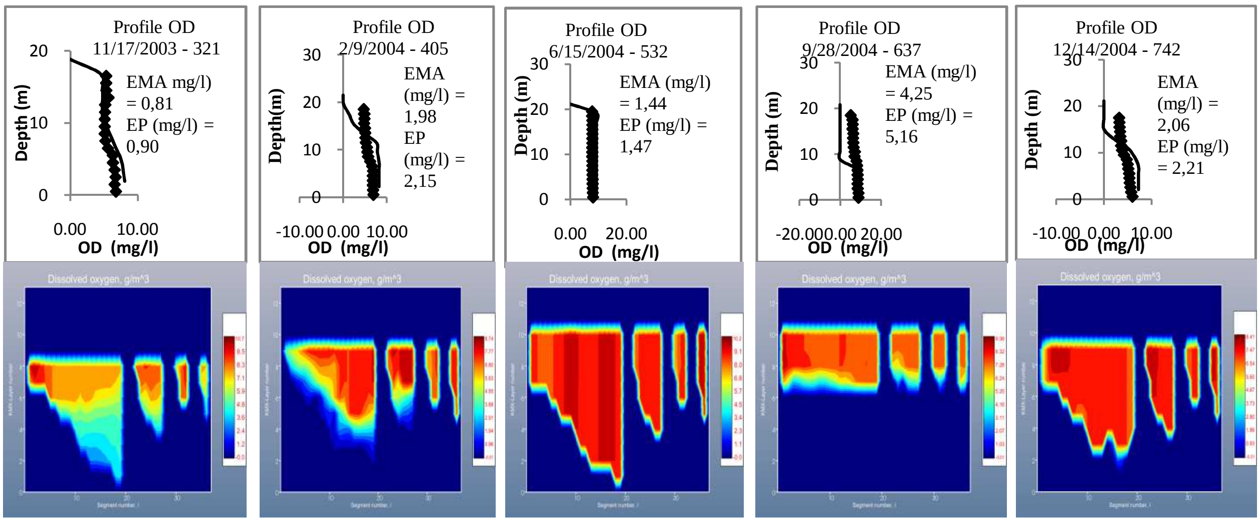

Figure 7. Profiles of concentration of OD, near the dam, simulated by the model CE-QUAL-W2 version 3.6.

The experimental variation of the concentrations of DO near the water surface, during the period under review covered the range of 5.58 mg / l at 7.89 mg / l. According to the CONAMA Resolution 357/05, the pattern of OD for Class 2 water bodies should be ≥ 5mg / l O_2, ie, the tank meets the requirements.

The EMA between simulation and measured data was 0.75 mg / L and the EP of 0.89 mg / l, for the amount of experimental data available. Noting the case that the greatest differences are found during periods of rain between the months of October to April. The sudden drop of OD at the end of simulated period can be explained by an erroneous entry of organic matter, probably evidenced by errors in input data flow in the lake environment, causing the consumption of this OD.

The experimental values of OD for the vertical profiles were 3.31 mg / l at 7.95 mg / l. But the simulated results, covering values between 0.00 mg / l and 9.31 mg / l. Thus, the EMA ranged from 0.81 mg / l at 4.25 mg / l, while the EP ranged from 0.90 mg / l at 5.16 mg / l. Note that the lower values are found in lower layers of the water column. The biggest possibility is that the OD available in these layers is consumed by benthic and resuspended demand of this nutrient, and organic matter in the fund.

Moreover, it appears that in January, October, November and December occurring thermal stratification with separation layer (s) in the water column. Thus, explain the differences found in the concentrations of OD in their depths obtained by simulation.

5. CONCLUSIONS

This research has shown the problem of eutrophication of water bodies, which is the quality loss of body water with the increase of available nutrients in the aquatic environment and can cause algae to bloom followed by the decrease in the rate of OD, killing fish , bad odor among others. In this context the objective of the study was to model the bi-dimensionality temperature and water quality of Lake of the Uninsured, with emphasis on the parameters phosphorus, nitrogen and OD, to the creation of data to support decision making in order to contain the process of eutrophication body of water, enabling simulations of future scenarios of reservoir.

To carry out the simulation, verification, calibration and verification of the model were used experimental data obtained by the reports of the project: "Defining the application spatial and temporal resolution to monitor the quantity and quality of water in river basins" (Koide, 2006) and "Studies on Design and technical and economic feasibility for the spillway crest elevation of the dam the river discovered, the Federal District" (CAESB, 2003).

As the hydrodynamic characteristics of the reservoir has been found that satisfactory results of the flow and elevations of water level, after reaching the hydrodynamic stability. The elevation of water level had a mean absolute error of approximately 1% in the segment near the dam of the reservoir.

According to the modeling of water quality parameters, there are the following conclusions:

- the temperature of the water, the first parameter to be simulated, it had an error of 5.64%. Showed the great influence of solar radiation in water temperature and the flow of the tributaries and their values control. It was verified the usefulness of positive vertical profiles generated by the model, both its numerical output data, as the graphic display. The thermal stratification during the simulated period was easily analyzed graphically, including the results of other parameters.

- It is known that the distribution of oxygen in the water affects the solubility so expressive of many inorganic nutrients. The changes in the availability of nutrients possibly generate an anaerobic environment, also influence the results of other parameters, especially in recent months simulated. The average error of the concentration of DO was 0.75 mg / l for the results of the upper layer of the lake. The average errors for their vertical profiles ranged from 0.81 mg / l and 4.25 mg / l.
- The PO_4, N-ammonia and NO_x may have influences and errors associated with data control, the scarcity of experimental data and diffuse loads, these caused by household waste, industrial and mining not computed in the model. The EMA's concentration was respectively 0.024 mg / l, 0.043 mg / l and 0.348 mg / l, corresponding to the superficial layer of the segment related to the dam of the lake.
- As expected, the highest concentrations of nutrients were observed in general in the months covering the rainy season. Confirming that the greater the flow of its tributaries, the greater will be the entry of pollutants loads. And it was the possible existence of diffuse loads not included in the model, which generated errors between simulated and experimental data.

Despite the difficulties encountered during the process of implementing the model and data errors generated, believes that the application of the CE-QUAL-W2 version 3.6 of the Descoberto Lake, succeeded to the methodology used and the results achieved in process.

6. ACKNOWLEDGEMENTS

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