IMPROVING WATER RESOURCES PLANNING AND MANAGEMENT INSTRUMENTS – FROM THE PROGRESSIVE WATER QUALITY GOALS TO THE TERRITORY MANAGEMENT

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ABSTRACT: The implementation of the Brazilian National Water Resources Policy emphasizes the systematic planning and management of water resources without dissociating quantity and quality aspects. This also requires strategies that consider appropriate socio-economic-environmental boundaries to encompass the diversity of the Brazilian territory and to promote integration of water resources, environmental planning articulated with land use management, different users and all distinct regional, state and national actors, in a given watershed. This paper highligths the necessity of a technical base for integrated water management that considers also land use and territorial management in critical basins. The environmental regulation allows for the definition of water quality goals defined in a progressive manner to achieve proper restoration of the water body to comply with designated uses. The definition of such restoration steps must be defined in accordance with territorial management perspectives and based on sound technical and scientific methods that include risk analysis perspective.

Key words: Upper Iguaçu Basin, progressive goals, mathematical modeling

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Key words: water resources planning and management, progressive goals, risk analysis and territory management

1. INTRODUCTION

Water resources management in hydrographic basins has been increasingly approached by national and international policies. There have been many advances since the beginning of the Eighties in discussions on topics concerning sustainability and economic and environmental preservation. In this context, the need arises for legal and institutional principles that will ensure the effective use of concepts connected to water resources management. In Brazilian legislation, Law nº 9,433/97 consolidates these principles and its goal is to ensure that current and future generations will have the necessary water available according to quality standards that are adequate for the respective uses, with a view to sustainable development, rational and integrated use of water resources, as well as prevention and defense against natural critical hydrologic events, or those resulting from the inadequate use of resources.

In order to ensure that these objectives will be met, the Law goes further, establishing management tools, including the Water Resources Plans which aim at diagnosing the current situation and creating future scenarios, besides providing a base and guiding the implementation of the National Water Resources Policy. Granting rights and charging for the use of water resources, and classification of water bodies, which aim at ensuring that water will have the quality compatible with the more demanding uses for which it was intended, reducing costs through permanent preventive actions, and the national water resources information system are also instruments established in Law nº 9,433/97.

For the appropriate use of water body quality recovery programs, the instrument involving the classification of the water bodies may be a very effective concept. One of the strategies is to establish progressive goals to implement water clean up measures, which will take into account both the physical and the budgetary restrictions to pay for the cost of interventions in water resources, such as society's will to pay for these interventions.

In basins where the water quality is highly compromised, the strategy to implement clean up measures must be carefully analyzed. An example of this is the Upper Iguaçu basin, in the Metropolitan Region of Curitiba, South Brazil, a highly urbanized region with recent irregular occupancy of flood plains and source areas. Consequently, there have been public supply problems, besides problems with sanitary sewage treatment and urban drainage systems, which do not follow the growth of cities, negatively affecting the environment and people's quality of life.

In order to perform this research, an effort was made not only to understand the different aspects of territorial management of a critical basin such as the Upper Iguaçu, but also to consolidate a consistent data base. This will allow using mathematical models of water quality to investigate the feasibility of implementing water resources management instruments for that basin, emphasizing specially the implementation and calibration of Qual2e model. A significant and substantial part of the effort to consolidate this database is compiled in Porto *et al.* (2007), a project developed in a partnership between USP (São Paulo University) and UFPR (Federal University of Paraná) from 2005 to 2007, which includes the present research. The approach presented here compiles the main results for the methodology used.

2. METHODOLOGICAL APPROACH TO IMPLEMENT AND SIMULATE WATER CLEAN UP MEASURES

The implementation of the National Water Resources Policy guidelines such as the systematic management of water resources is foreseen in Law nr. 9,433/97, without dissociating quantity and quality aspects. This also renders water resources management appropriate to the significant socio-economic-environmental diversity that predominates in Brazilian territory, promoting the integration of water resources management with environmental management and the articulation between water resources planning and land use, different users and regional, state and national planning. These guidelines are based on five instruments: the Water Resources Plans; water body classification according to preponderant water uses; concession of water use rights; charging for the use of water resources; and the water resources Information System.

It is understood that to effectively consolidate these water resources management instruments foreseen in Law nº 9,433/97, investments are needed to train and capacitate the agents, and to try to consolidate a didactic, easily understood database, that is in the public domain. It should be pointed out that to comply with the Law; much research is needed in the field of water resources and management strategies, besides the integration between research done by universities and the appropriate agencies, an integration which is vital to structure the Basin Plans. Although conceptually the Water Quality Classification for rivers and water bodies is a planning instrument to be consolidated by the River Basins Committee, a technical base is needed that will provide information for this consensus building process, aiming at a sensible strategy for its implementation.

The foundation for planning presupposes a set of technical tools needed for a better understanding of how to establish a classification proposal that is practicable and feasible, and above all adaptable to the legal reality established by the tools in force. Figure 1 relates the main stages or studies which are to comprise the water bodies classification process, whichever the strategy to be adopted. These tools are part of a constructive context that culminates with the river basin plan, clearly aiming at constituting goals to ensure the improvement of water quality and its importance in the process of phasing investments through time (Porto *et al*., 2007).

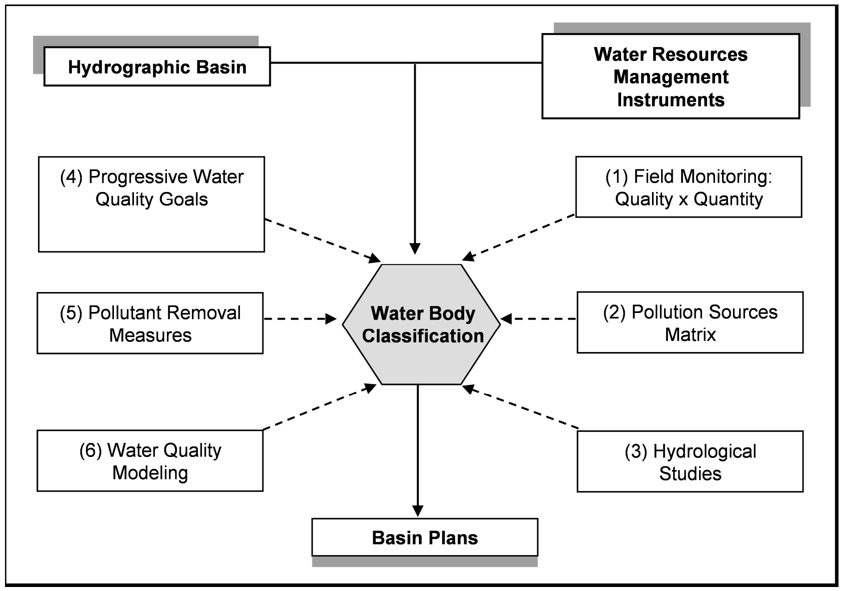

Figure 1. Essential stages to implement a Water Quality Classification

The first mains technical aspects to be addressed are related to **Field Monitoring** (1) that should always relate data on quality and quantity, i.e., it should allow the joint analysis of load removal and reference flow. The **Pollution Sources Matrix** (2) shows the uses and users present in the basin, pointing to the diagnosis of the current situation, and allowing the organization of data in water quality simulations. The hydrological studies (3) are essential for good water resources management and to evaluate the risks of not fulfilling the goals established for water quality. The concept of **Progressive Water Quality Goals** (4) presupposes determining intermediate goals in such a way as to phase the reduction of pollutant concentration in the river over time, in order to achieve the final water quality goal. For each progressive goal it is necessary to have a set of **Pollutant Removal Measures** (5) and, consequently, it is necessary to have investments in order to implement such measures. As a complement, **Water Quality Modeling** (6) allows a more significant evaluation of the transport processes and their effective response in the receiving body system.

The conceptual base to classify water bodies is based on the principles established by CONAMA Resolution 357/05. In its framework, without a clear definition, the possibility is proposed of performing the basin classification using progressive goals. As regards the reality of critical basins, such as the Upper Iguaçu Basin in the Metropolitan Region of Curitiba, carrying out the classification of bodies of water using this new concept necessarily requires an evaluation of how much and where the water clean up measures should be implemented considering the context of budgetary and physical restrictions in the region (Porto *et al.*, 2007).

2.1 Consolidating the diagnosis: field monitoring

The evaluation of water quality presented in the following research is connected to Project: "Critical Basins: Technical Bases to define Progressive Goals for their Classification and Integration with the other Management Instruments", developed in partnership between the UFPR and USP, from 2005 to 2007. This project evaluated the development of methodologies that allow the basins to establish progressive goals for clean up and implementation of the classification plan, working on its conceptual, institutional and technical aspects, applied in the Upper Iguaçu Basin.

As to the water quality parameters, the following were analyzed: concentrations of dissolved oxygen, BOD, COD, total phosphorous, organic nitrogen, ammonia, nitrite, nitrate, total organic carbon and solids fractions,. The methodological procedures were based on routines established in the Standard Methods for the Examination of Water and Wastewater (1998). Complementarily, other parameters were analyzed, such as conductivity, turbidity, pH, temperature and Secchi depth. The flow for each collection day was estimated based on reading the level, when available, and by telemetry.

For field monitoring performed to develop the Critical Basins Project, 6 stations along the main river were selected, over a length of about 107 km, in an area of approximately 3,000 km². Twenty campaigns were performed during the period from June 2005 to July 2006. In order to complement the monitoring data, a second monitoring period with five campaigns was performed from March to August 2008.

2.2 Implementation of the QUAL2E model

In order to implement the Qual2e model, it was necessary to compile a pollution source matrix, e. i., a database for the Upper Iguaçu Basin, detailing 26 sub-basins, covering 14 municipalities (Curitiba and Metropolitan Region), with the area of each basin, length of the tributaries, hydraulic characteristics, use and rate of land occupation, industrial activity, demographic data and sewage collection and treatment system.

Qual2e model can integrate the simulation of several constituents, with a possibility of input from non-point and point sources. The input data were organized in such a way as to meet the model specifications as well as the existing structural limitations, e. i., by pollution sources matrices.

The basic unit of the spatial discretization of each basin is the division of the river stretch simulated into elements of 1km each. In Qual2e model, the balance of each variable is simulated in these computational elements. Each one-kilometer set covers a specific drainage area or incremental area. The hydraulic data (bottom width, roughness, channel and side slope), rate of soil and land occupation and demographic data and sanitary sewerage system were discretized for each incremental area (reaches) when the model is implemented. In the computational model, the location of major users, such as industries (intake and discharge), sewage treatment plants and water treatment plants, besides the untreated domestic sewage and tributaries were properly identified. The topological diagram for the studied stretch of the Iraí and Iguaçu rivers is shown in Figure 2.

To flow simulation using Qual2e model was adopted the Manning equation method instead of discharge coefficients. A trapezoidal section area with a Manning's roughness coefficient of 0,033 were used according to Porto *et al.* (2007). The incremental flows of each reach were calculated according to the respective drainage area and a single coefficient of specific flow, calculated for different profiles of permanence, determined in the Critical Basins Project (Porto *et al.*, 2007). The flow for 95% of permanence, $Q_{95\%}$, was used as a base of the simulations. The flow observed in the field, i.e., median profile of the collections performed between 2005 and 2008, $Q_{field,}$ as well as the other flow permanence scenarios were calculated from flow $Q_{95\%}$. The specific flows and permanence scenarios used were: $q_{95\%}$ = 2.94 l/s.km², $q_{80\%}$ = 6.00 l/s.km² and q_{mlp} =13.93 l/s.km².

For the input of data quality in the model, the pollution sources matrices were used, based on the Water Clean Up Plan of the Upper Iguaçu Basin (SUDERHSA, 2000), updated and adapted to the structural simplifications that exist in model QUAL2E by the Critical Basins Project (Porto *et al.*, 2007). The pollution sources matrices are characterized by being divided into four large data groups: (i) characteristic data of the basin being analyzed (basin code, river length, and incremental areas); (ii) hydraulic data and flow; (iii) loads (non-point and point sources); (iv) specific water quality model input data (BOD concentration, nitrogen, phosphorus and DO).

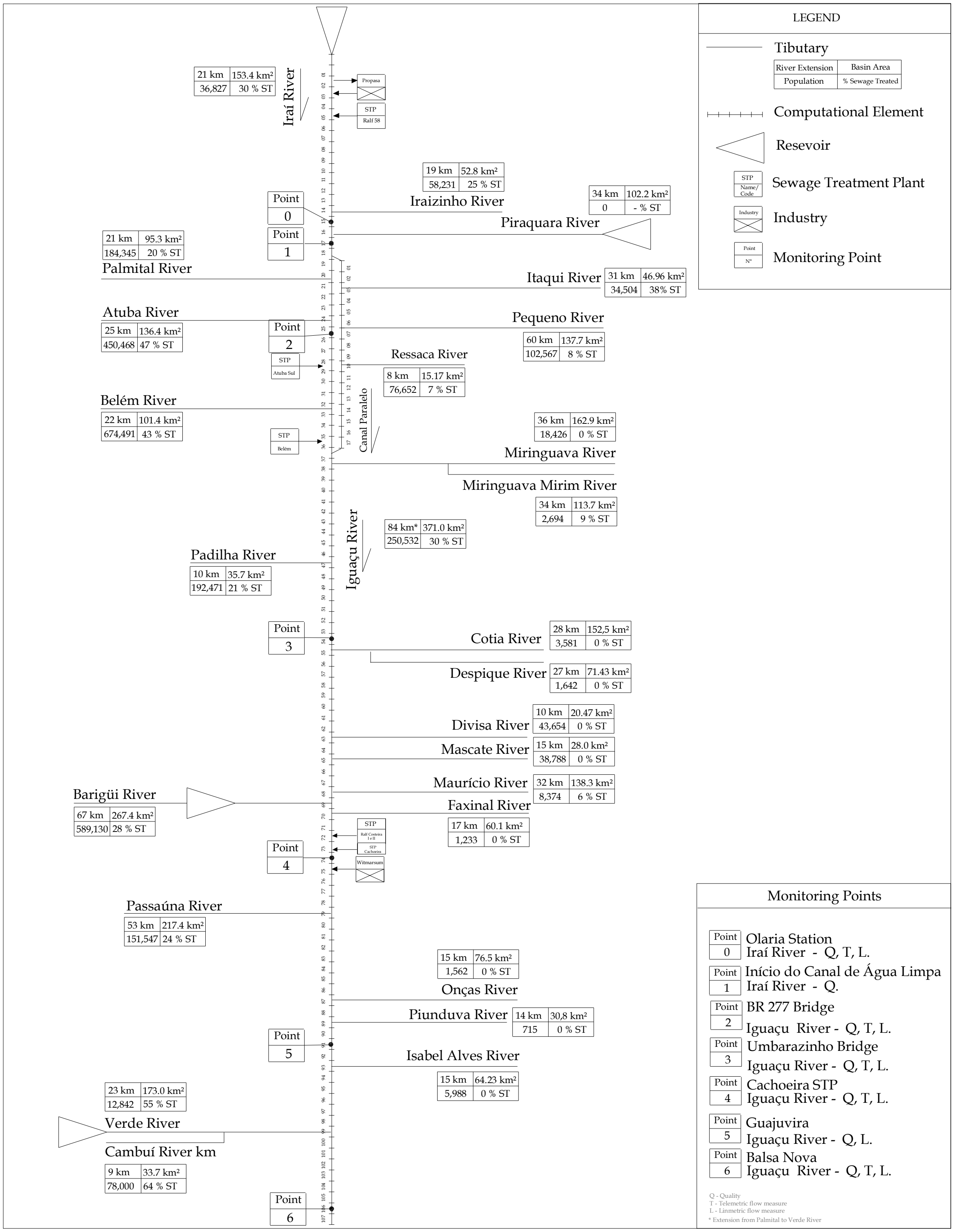

Figure 2. Topological diagram of the Upper Iguaçu Basin, with the location of the main tributaries and monitoring points.

The matrix was built by dividing each basin analyzed into reaches, corresponding to the contribution areas that exist in each of the 26 sub-basins considered, including the drainage areas of the basins of Irai and Iguaçu rivers, a stretch simulated in this study. In the tributary matrices, water balance and the contribution of organic and nutrient loads were also estimated. The inputs of data on the tributaries were considered point sources in simulating the 107km stretch of Irai and Iguaçu rivers.

The loads were considered by dividing them into domestic, industrial and non-point, each of them identifying the source, effluent flow, BOD and nutrient load such as nitrogen (organic, ammoniacal, nitrite and nitrate) and phosphorus (organic and dissolved), and the removal efficiency (when it occurred). As to the non-point load, the matrices were organized according to the type or use (urban, agricultural and forest) and land occupation rate. The contribution of organic matter, in terms of BOD concentration, was estimated according to Porto *et al.* (2007). Mean values indicated by Chapra (1997) and Von Sperling (2007) were used for the nitrogen and phosphorus contributions.

The point load was estimated both for intakes and industrial effluents and for effluents from domestic sewage. In the case of domestic sewage, the methodology presented by Von Sperling (2006) was used, calculating the effluent flow generated by the population of each incremental area of the basins studied, and the organic and nutrient loads. The overall population was considered with the effluent collected and treated, and also in the case of collection without treatment. The parcel referring to the treated effluent corresponds to the sewage treatment plants located in the basins being studied. As to the untreated parcel, the effluent flow and pollution load were linearly distributed over the respective reaches (areas).

The contribution of domestic sewage with collection and treatment was estimated from the Water Clean Up Plan (SUDERHSA, 2000), and updated by the Critical Basins Project (Porto *et al*., 2007). The sewage treatment plants were considered point sources in Qual2E model, with input of effluent flow data, BOD concentration and respective removal efficiency, and concentration of the remaining fractions of nitrogen and phosphorus. The efficiency of organic matter removal treatment was estimated according to the users' register; for the phosphorus fractions, on the other hand, a removal of 50% was considered, and 20% for ammoniacal and organic nitrogen (Von Sperling, 2007). Dissolved oxygen concentration was considered nil for these discharges.

The load from industrial sources was also estimated from the Water Clean Up Plan (SUDERHSA, 2000), in relation to the contribution of organic matter. The industries were located for each stretch simulated, both for intake and for effluent discharge. In the case of discharge, the values of flow, BOD concentration and efficiency of organic matter removal when they exist are implemented. The concentration of dissolved oxygen was considered nil for these discharges.

2.3 Calibration of Qual2e model

The challenge of Qual2e model calibration (Brown and Barnwell, 1987), presented in this paper for DO, BOD, nitrogen and phosphorus was based on the solution of equations of quantity of movement and energy conservation integrated with the pollution transport equations, taking as simplified representation the balance of organic matter by the coefficients of deoxygenation (K_1), reaeration (K_2), sedimentation (K_3) and sediment oxygen demand (K_4); the oxygen balance by coefficients of ammonia and nitrite oxidation (β_1 and β_2), organic nitrogen decay (β_3), ammoniacal nitrogen released by benthonic fauna (σ_3), organic nitrogen sedimentation (σ_4) and rate of oxygen consumption by ammonia and nitrite oxidation (α_5 and α_6); and phosphorus balance by the coefficients of decay and sedimentation of organic phosphorus (β_4 and σ_5) and inorganic phosphorus released by benthonic fauna (σ_2).

In order to calibrate the model, as was done by Knapik (2006), Porto *et al.* (2007), and Kondageski (2008), attempts were made to adjust the simulated flow curves, DO concentration, BOD, nitrogen (organic, ammoniacal, nitrite and nitrate) and phosphorus (organic and dissolved) at an interval of 25 to 75% permanence of the respective data collected in the field, with an optimum value close to the median.

2.4 Implementation of the water clean up scenarios

Simulation of pollutant removal scenarios aims at evaluating impact in terms of improved water quality after their implementatiton. The measures took into account actions to increase the number of population with sewage collection and treatment, as well as the efficiency of treatment, through the removal of organic and nutrient load from the effluents, in order to analyze the reflex in terms of improved concentration of BOD, ammoniacal nitrogen, total phosphorus and dissolved oxygen, according to the standards established in CONAMA Resolution 357/05.

The hypothesis adopted considered creating sewage treatment plants at the mouth of each tributary, for a percentage of load removal in the year of 2025. Two scenarios were analyzed:

- **Scenario A**: the removal of 70% of organic load (BOD), 70% ammoniacal nitrogen and 85% inorganic phosphorus;
- **Scenario B**: the removal of 95% of organic load (BOD) and nutrients (ammoniacal and organic nitrogen; total phosphorus).

The removal rates for **scenario A** were estimated from the theoretical reduction needed to reduce the concentration for Class 2 (CONAMA Resolution 357/05), in the permanence of the long period mean flow. As to the nutrients, the removal was analyzed only for ammoniacal nitrogen and inorganic phosphorus, according to Von Sperling, 2007.

In **scenario B**, the rate of removal considered was that defined as an ideal removal rate by the Critical Basins Project (Porto *et al*., 2007). This rate of removal means 100% sewage collection and treatment, with a treatment efficiency of 95%.

The evaluation of the results of implementing the clean up measures were evaluated taking into account the permanence curves of concentration of the variables under study. These curves allow identifying the permanence or not of a given variable within the classification classes, for different flow scenarios, and the risk of non-classification associated with each permanence.

3. CASE STUDY OF THE UPPER IGUAÇU BASIN

The case study was developed based on the dynamics of the reality of land use and occupation in the Upper Iguaçu basin, in the Metropolitan Region of Curitiba. The sources of the Upper Iguaçu basin are in the Serra do Mar mountains. The main river extends for about 107 km until the boundary of the Metropolitan Area of Curitiba, with a drainage area of about 3,000 km^2. In the current research, 26 sub-basins were used to characterize the Upper Iguaçu Basin. The main tributaries of the respective basins are: Atuba, Belém, Cambuí, Cotia, Despique, Divisa, Faxinal, Iraí, Iraizinho, Isabel Alves, Itaqui, Mascate, Maurício, Miringuava, Miringuava Mirim, Padilha, Palmital, Passaúna, Pequeno, Pianduva, Piraquara, Ressaca, Rio das Onças and Verde.

The population in the basin is approximately 3 million, distributed throughout 14 municipalities. The basin studied concentrates about 25% of the overall population and 30% of the urban population in the state, with low rates of sewage collection and treatment. Since this is a highly urbanized region, it has been undergoing a process of irregular occupation of flood plains and headwater areas, especially on the right bank of Iguaçu River. As a consequence of this process, there have been problems concerning the water supply system, the treatment of sanitary sewage and the urban drainage systems, which do not keep up with the growth of cities, negatively affecting the environment and people's quality of life.

The simulation plan adopted in this study was divided into two stages: simulation to calibrate the Qual2e model (Brown and Barnwell, 1985) and simulation of water clean up scenarios. In the first stage, water quality modeling was applied to the Iguaçu river considering the tributaries as point sources, whose contributions were estimated in the simulations performed by Knapik (2006) and Porto *et al.* (2007). The next stage involved a study of the tributaries when the water clean up scenarios were configured.

The simulations to calibrate the model involved sensitivity analysis, model simulation and calibration. In the sensitivity analysis, the simulations were performed investigatively involving the coefficients that rule the behavior of variables. In this stage, 14 model coefficients were analyzed, as presented in Knapik (2009).

After the identification of coefficient sensitivity, the variables dissolved oxygen, BOD, nitrogen and phosphorus were simulated. Initially, in order to analyze the methodology of load estimation, the nitrogen and phosphorus concentrations were simulated separately. For these simulations, the pollution sources matrices, initially prepared only for organic matter, were adapted with nitrogen and phosphorus inputs, both from point and non-point sources. Model calibration was performed based on information from the literature, with coefficient adjustment by trial and error.

BOD modeling involves biological and physical processes to remove organic matter from the water column. Carbonaceous deoxygenation, represented in Qual2e model by coefficient K_1, is a biological degradation process which involves the consumption of the oxygen present in the aquatic environment. On the other hand, the physical removal of organic matter occurs through the sedimentation process, represented in qual2e model by coefficient K_3. Values ranges indicated in the literature were evaluated for both coefficients (Bowie *et al.*, 1985; Chapra, 1997; Von Sperling, 2007). K_1 was also analyzed in laboratory, through Winkler BOD method (APHA, 1998).

Modeling in nitrogen, for the organic, ammoniacal, nitrite and nitrate fractions, was based on two processes: conversion and removal. In the conversion, the decay of organic nitrogen to ammoniacal nitrogen (β_3) and nitrification (β_1 and β_2) were simulated. One of the forms of removal of this nutrient simulated in Qual2e model is sedimentation of organic nitrogen, represented by coefficient σ_4. The nitrogen input was simulated by noon-point and point sources, and the release of ammonia from the benthonic fauna (σ_3).

A simplified simulation of the concentration of total phosphorus, and also of nitrogen, was performed, since interaction with algae was not included, because the concentration of chlorophyll-*a* in the environment studied was not very significant, as shown in the field monitoring results. In the balance of the phosphorus concentration only the decay of organic phosphorus to inorganic, β_4, the release of dissolved phosphorus from the benthonic fauna, σ_2, and the loss of particulate phosphorus from the water column by sedimentation, σ_5 , were considered.

Modeling of dissolved oxygen performed by Qual2e model (Brown and Barnwell, 1987), allows the analysis of interactions of the presence of organic matter, nitrogen, phosphorus and algae in the water body. In the present study, as shown in the previous items, interaction between algae and nitrogen and phosphorous and, consequently, the relationship between chlorophyll-*a* and the concentration of dissolved oxygen were not simulated. Thus, the factors that directly influence, in this case, the consumption/release of DO in the water body are: carbonaceous deoxygenation (K_1), atmospheric reaeration (K_2), sediment oxygen demand (K_4), ammonia and nitrite oxidation (β_1 and β_2), and oxygen consumption rates in the nitrification process (α_4 and α_5), referring to the mass balance of the organic matter and nitrogen. Three coefficients directly involved in the calibration of dissolved oxygen were not altered, since the values used are subject to the calibration of the BOD and nitrogen concentration (K_1, β_1 and β_2). As to the other coefficients, two were more sensitive, K_2 and K_4. Thus, a constant value was used for K_4, α_4 and α_5, according to indications from the literature, and different combinations were evaluated for the reaeration coefficients available in Qual2e model. The results of calibration for BOD, ammoniacal nitrogen, total phosphorus and dissolved oxygen are shown in Figure 3. The coefficients used to calibrate the model are in Table 1.

Table 1 Coefficients used to calibrate model QUAL2E, for the simulation of BOD, DO, nitrogen and phosphorus

Coefficient	*Unit*	*Meaning*	*Used value*	*Range*[(1)]
K_1	1/d	BOD decomposition rate	0,1	0,02 – 3,4
K_2	1/d	Reaeration rate	[(2)]	0,0 – 100
K_3	1/d	BOD settling rate	1,2	-
K_4	$g/m^2.d$	Sediment oxygen demand	1,5	-
β_1	1/d	Ammonia decay rate	0,1 e 0,3	0,1 – 1,0
β_2	1/d	Nitrite decay rate	0,8	0,2 – 2,0
β_3	1/d	Organic nitrogen decay rate	0,1 e 0,4	0,02 – 0,4
β_4	1/d	Organic phosphorous decay rate	0,35	0,01 – 0,7
σ_2	$mg\_P/m^2.d$	Dissolved phosphorous source	0,1	-
σ_3	$mg\_N/m^2.d$	Ammnia source	0,25	-
σ_4	1/d	Organic nitrogen settling rate	0,08	0,001 – 0,1
σ_5	1/d	Organic phosphorous settling rate	0,2	0,001 – 0,2
α_5	mg_O/mg_N	O_2 uptake per unit of NH_3 oxidation	3,5	3,0 – 4,0
α_6	mg_O/mg_N	O_2 uptake per unit of NO_2 oxidation	1,14	1,0 – 1,14

[(1)] Values suggested by Bowie *et al.* (1985) Brown and Barnwell (1987), Chapra (1997), Von Sperling (2007) and/or limits of Qual2e model;
[(2)] A combination of the following equations (available in Qual2e model to calculate coefficient K_2) was used: O'Connor and Dobbins (1958), Owens *et al.* (1964), Thackston and Krenkel (1966), Tsivoglou and Wallace (1972), cited by Brown and Barnwell (1987).

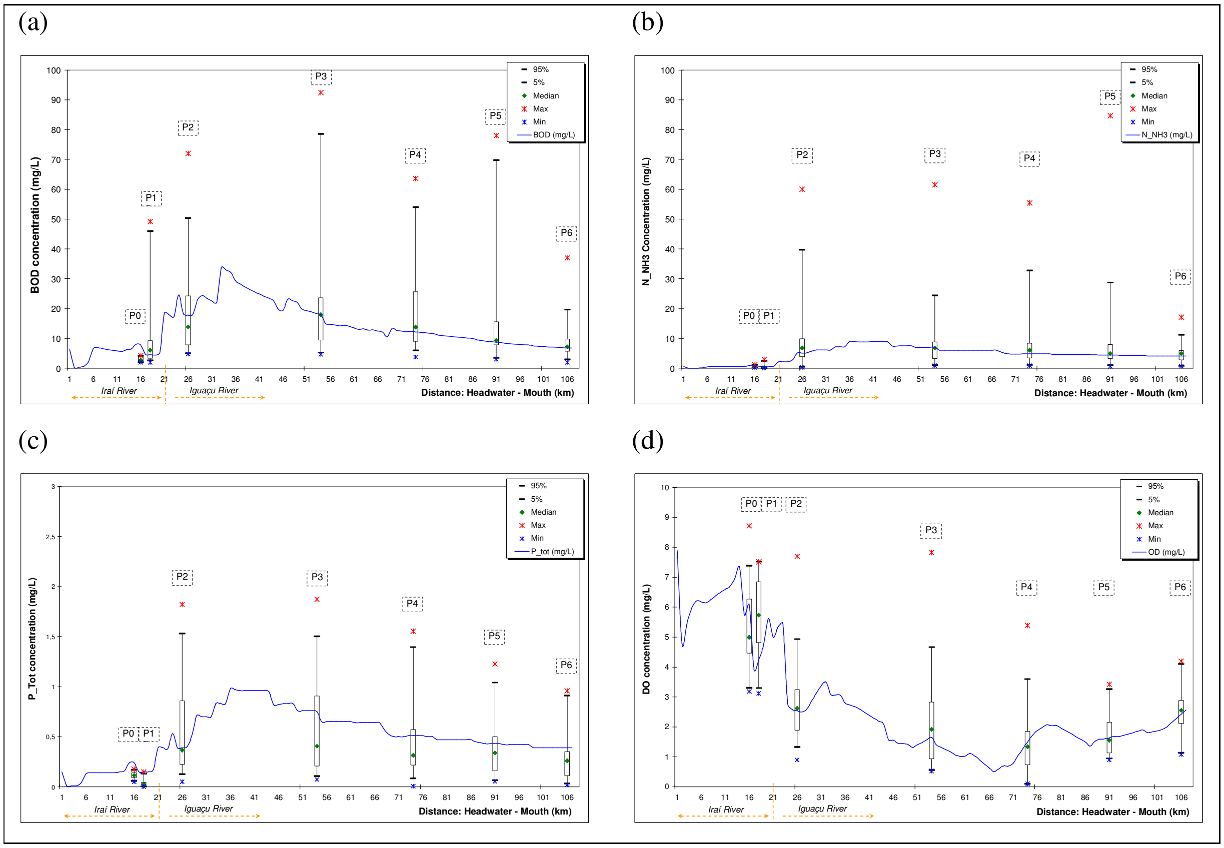

Figure 3. Calibration curves for the concentration of BOD (a), ammoniacal nitrogen (b), total phosphorus (c) and DO (d), with the Box plots of the monitoring data from 2005 to 2008 at points P0 to P6

Using the calibrated model, water quality simulations were performed in the Iraí and Iguaçu rivers for three flow profiles ($Q_{95\%}$, $Q_{80\%}$ and Q_{MLP}), for the years 2005 (diagnosis) and 2025 (prognosis), a period considered in studying the definition and application of progressive goals by the Critical Basins Project (Porto *et al.*, 2007). Water quality was diagnosed using the database of the Critical Basins Project (Porto *et al.*, 2007), which analyzed demographic aspects, collection and treatment of sewage, industrial activity and urban occupation for the period from 2005 to 2025. In this study, analyses were performed based on estimates of organic loads, and nutrient loads based on population growth for the same period of analysis. For the 2025 prognosis, no increase was considered in the collection and treatment of sewage at the active sewage treatment plants. In order to consolidate the case study, an example of application of mathematical modeling integrated to the concept of progressive goals was performed.

An example of the results of simulations of water clean-up scenarios (A and B) are presented in terms of permanence of BOD, ammoniacal nitrogen, total phosphorus and dissolved oxygen (Figure 4), in classes 2 and 3 of CONAMA Resolution 357/05, for monitoring point P2, located in the Iguaçu river in the municipality of São José dos Pinhais, on the boundary with Curitiba, downstream from the Atuba river mouth. This point has a drainage area of approximately 625.5 km^2, including the basins of the Atuba, Iraí, Iraízinho and Palmital rivers, and the initial part of the Iguaçu river basin. In demographic terms, this area has approximately 810,000 inhabitants, and a projection of 1.1 million inhabitants in 2025, with percentages of sewage collection and treatment in the range of 20 to 47% in 2005, according to a survey performed by Porto *et al.* (2007).

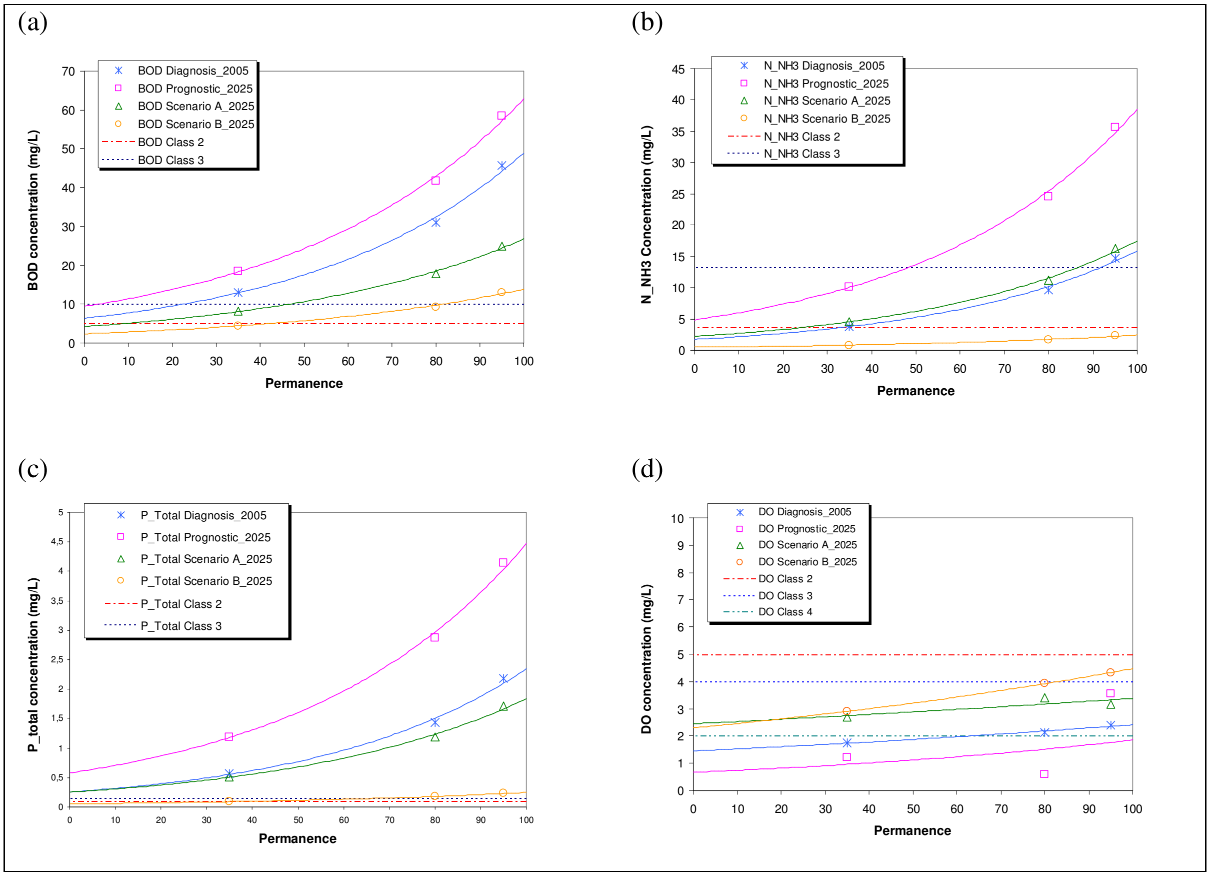

Figure 4. Monitoring point P2: permanence in classes 2 and 3 of CONAMA Resolution 357/05, for a concentration of BOD(a), ammoniacal nitrogen (b) total phosphorus (c) and DO (d).

Like the monitoring point P2, the condition of not performing load removal establishes a level of organic pollution (BOD) of 58 mg/L in 2025, for a reference flow of 95% permanence, and a measure of 18 mg/L, which is less restrictive for a flow with 35% of permanence (Figure 4a). Scenario A ensures goals that are consolidated by the effective reduction of the 25 mg/L load in 2025 for a permanence of 95%, and despite the reduction of BOD concentration, the condition of classification in class 2 is not fulfilled. At this point, especially, the goal of classification in class 2 for BOD in relation to the scenarios analyzed, involves a risk of not meeting the class of 90% for scenario A and 57% for scenario B. As to nutrient concentration, the reduction of the nitrogen load adopted in scenario B enables classification in class 23 for the ammonia concentration (Figure 4b), with a reduction of the concentration of 36 mg/L in 2025 and $Q_{95\%}$, to less than 3 mg/L. In scenario

A, whose load reduction was simulated only for the ammoniacal fraction, the concentration in 2025 was higher than the diagnosis for 2005. In this case, the contribution of organic nitrogen to the decay processes may have influenced the final concentration of ammoniacal nitrogen. For total phosphorus (Figure 4c), the risk of not meting class 2 is high (60%), even for the reduction measures proposed in scenario B, with a load removal efficiency of 95%. As a result, the concentration of dissolved oxygen does not present significant gains, and remains mainly in class 4 concentrations in both scenarios (Figure 4d).

According to the results, it is useful to point out the effects of environmental degradation due to water pollution, mainly considering the organic/domestic characteristic of the pollution source matrix in the Upper Iguaçu Basin, Metropolitan Region of Curitiba. The 40 km stretch downstream from the mouth of Irai river clearly shows the condition of the Palmital, Atuba, Belém, Padilha and Barigui river basins , with high rates of urbanization and occupation. In common, these rivers drain a large part of the urban network of Curitiba and the Metropolitan Region, with a population of approximately 2 millions, and percentage of sewage treatment between 20 and 50%. Clearly, this region lacks a plan for effective water clean up measures, especially with regard to reducing the inflow of organic load.

The stretch between points P0 and P1, located in the Irai river, has a strong vocation for urban supply, with quality conditions compatible with the use of the water resource, and from the perspective of a stricter classification. For the other control points, the importance of dilution for better water quality is observed, but with classification conditions still far from the ideal scenario. From the point of view of progressive goals in this case, the classification status is only perceptible if the effect of concentration reduction is analyzed for the 20 years of the study, even though the adequate levels to ensure good water resources quality have not yet been reached.

4. IMPLICATIONS FROM THE PERSPECTIVE OF WATER RESOURCES MANAGEMENT

This research highlights conceptual aspects that are relevant in issues involving water resources management. The Brazilian Law 9,433/97 advances by establishing fundamentals and instruments for their integrated, decentralized and participatory management. In this context, the principles that guide this strategy must be understood as a different focus from the traditional inspection and control mechanisms. A new form of technical approach is needed to meet the demands imposed by that legal instrument. For instance, questions that must still be answered: what parameter or set of parameters will represent the real conditions of pollution, subject to the dynamics of the pollution source matrix, considering that it varies in time and in space; how to integrate hydrologic variability with the water quality conditions; how to interpret point and non-point pollution. As regards the pollution source matrix, its update and optimization, associated with field monitoring and mathematical modeling of water quality are essential for the manager to identify the weaknesses and potentials of a river basin.

In addition, to comply with the legislation, the historical series of water quality data must be as broad and consistent as the hydrological series. Thus, it is essential to invest not only in training and capacity building of technicians, but also in implementing the monitoring stations. Further, it is necessary to improve and control the quality of laboratory tests and procedures and techniques, since errors or uncertainties have an impact on the statistical analysis of data, and consequently, on the diagnosis of water quality.

5. CONCLUSIONS

In this research, the main objective was to integrate field monitoring into the implementation and calibration of a water quality model, Qual2e, to define and simulate progressive load removal goals, considering the Brazilian Resolution for classification of water bodies in the Upper Iguaçu Basin, South Brazil.

The effects of pollution for different flow conditions ($Q_{95\%}$, $Q_{80\%}$ and Q_{MLP}), and the prognosis for 2025 confirm the state of environmental degradation of Irai and Iguaçu rivers, simulated in this study, and the tributaries that drain the more urbanized part of the Upper Iguaçu Basin, including Palmital, Atuba, Belém, Padilha and Barigüi rivers. The organic and nutrient load removal measures analyzed in this stretch indicate that even with significant sewage collection and treatment rates (95% efficiency for 100% collection in scenario B) there is still a risk of remaining outside class 2, according to Brazilian Resolution CONAMA 357/05..

This research helped consolidate the water quality diagnosis in the Upper Iguaçu Basin, using the combination of water resources management tools such as water quality monitoring in Iraí and Iguaçu rivers, with the load estimates (pollution source matrix) and flows (hydrological studies) and simulation and calibration of model Qual2e for dissolved oxygen, BOD, nitrogen and phosphorus. These tools are essential to define progressive goals when drawing up the river basin plans in order to ensure water quality improvement compatible with the uses and according to the possibilities of investment.

Finally, it is important to point out that the method to construct processes for water body classification should be performed according to the real needs and desires of current society. Thus, the inclusion of water quality modeling in the water resources management process is essential to achieve this objective.

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