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Water quality modeling of the Medellin river in the Aburrá Valley

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Abstract
Water quality modeling intends to represent a water body in order to assess their status and project the effects of different measures taken for their protection. This paper presents the results obtained from the Qual2kw model implementation in the first 50 kilometers of the Aburrá-Medellín River, in their most critical conditions of water quality, which correspond to low flow rates. After the model calibration, three recovery scenarios (short-term, medium-term and long-term) were evaluated. In the first scenario the sanitation only improved in some streams, in accordance with the Plan of Sanitation and Management of Discharges that was considered. Medium and long-term scenarios, with the operation of the new Water Waste Treatment Plant (WWTP) of the Bello municipality and an increase in the sewage collection, were considered. The obtained results show the positive impact of the operation of the WWTP of Bello in the balance of BOD5, dissolved oxygen and nitrogen.

Keywords: water quality modeling; Aburrá-Medellín River.

Modelación de la calidad de agua del Río Medellín en el Valle de Aburrá

Resumen
La modelación de la calidad del agua busca representar un cuerpo de agua con el fin de evaluar su estado y proyectar los efectos de diferentes medidas que se tomen para su protección. En este artículo se presentan los resultados obtenidos a partir de la implementación del modelo Qual2Kw en los primeros 50 kilómetros del río Aburrá-Medellín, en sus condiciones más críticas de calidad de agua, que corresponden a caudales bajos. Una vez obtenido el modelo calibrado, se evaluaron tres escenarios de recuperación (corto-2años, mediano-5años y largo plazo-10años). En el primer escenario sólo se consideraron mejoras en el saneamiento de algunas quebradas de acuerdo con el Plan de Saneamiento y Manejo de Vertimientos (PSMV), mientras que los escenarios a mediano y largo plazo consideraron la operación de la Planta de Tratamiento de Aguas Residuales (PTAR) de Bello y un aumento en la colección de aguas residuales. Los resultados obtenidos evidencian el impacto positivo del funcionamiento de la PTAR de Bello en los balances de DBO5, oxígeno disuelto y Nitrógeno

Palabras clave: modelación de calidad del agua, río Aburrá-Medellín.

4. Introduction

Surface water bodies, especially those that travel along great cities, when they do not have a complete sanitation system are exposed to receive discharges of several sources. These discharges can alter the balance of the ecosystem, leading to a loss of diversity and to an alteration of the abundance of organisms and deterioration in the physical and chemical quality, which ultimately results in limiting the potential uses of the water. As a tool, in order to evaluate different scenarios to recover the water quality, it the implementation of numerical methods is widely used.

Numerical models for water quality and transportation can reproduce the hydraulic, chemical and biological processes that occur in water bodies by using mathematical expressions that represent these phenomena of interest. These mathematical expressions are approximations, or a simplified version, of the real system, which consider its most important characteristics

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[1,2]. Therefore, the models are valuable tools for assessing the impact of the implementation of strategies and / or measures that seek to improve water quality [3,4,5].

The first water quality models applied to the Aburra-Medellín River that can be found in literature, were conducted by Empresas Publicas de Medellín (EPM) as support models for several projects related with the sanitation of the river. Recently, the environmental authority in the basin of this river (Area Metropolitana del Valle de Aburrá), through its "RedRio" project performed a water quality modeling using the QUAL2K modeling software, in order to evaluate 14 different sanitation scenarios, in other words, to estimate the impact of chemical pollutants in the water body.

The results of the research presented in this paper began with the selection of the water quality model, looking for a model that best represents, or fits, the main characteristics of the river and the modeling needs. The model to be selected should be able to adequately represent the transport phenomena of a highly affected river with continuous discharges of organic matter; the model should also have an adequate mathematical formulation of the physical–chemical processes of interest in the research. Finally, the model should be consistent with the technical and economic capacities available in this research, to acquire the data required by the selected model (both: quality and discharges data). Taking into consideration the reasons above mentioned and having in mind that the main goal is to have a model capable to be used as a decision tool in the river, the QUAL2Kw model, an updated version of the QUAL2K model [5,6,7], was implemented.

2. Theoretical background

The QUAL2Kw model splits the river into segments which are then divided into small subsections known as computational elements. For each element hydrological, thermal and mass balances for each constituent (equation 1) are performed. For each element in the model, a gain or loss of mass can be computed due to the transportation phenomena (advection and dispersion), loads or extractions of external sources (water intakes, wastewater discharges, among others) or internal sources (benthic oxygen demand and biochemical transformations, among others) [7]. The general formula to compute a mass balance of a constituent in water, ci, in section i, is as follows:

$$\frac{d_{ci}}{d_t} = \frac{Q_{i-1}}{V_i} C_{i-1} - \frac{Q_i}{V_i} C_i - \frac{Q_{ab,i}}{V_i} C_i + \frac{E_{i-1}}{V_i}(C_{i-1} - C_i) + \frac{E_i}{V_i}(C_{i+1} - C_i) + \frac{W_i}{V_i} + S_i \quad (1)$$

Eq. 1. Mass balance equation for constituent I, in section i. [4].

Where Qi: discharge in section i (L/day), Qab,i: water intake in section i (L/day), Vi: volume in section i (L), Wi: external load of constituent in segment i (mg/day), Si: sources and discharges of constituent due to reactions and mechanisms of mass transfer (mg/L/day), Ei: dispersion coefficient between sections (L/day), Ei-1,Ei dispersion coefficient between segments i-1, i and i+1 (L/day), ci: constituent concentration in section i (mg/L) and t: time (day).

Mass balance equations are solved under steady state and under uniform flow, using a finite difference method. The final products of the modeling process are curves, which show the variation of the modeled parameters along the streams. The main difference between Qual2Kw and Qual2K is that the first one has incorporated a genetic algorithm to find the optimal values of the kinetic parameters. The genetic algorithm tries to optimize the adjustment rate of the model compared to the observed data. The final software users can choose between a manual input of the values for each parameter to be used in the model or an auto-calibration functionality [8].

3. Materials and methods

3.1. Study area description

Aburrá Valley is located in the center-south of the Department of Antioquia (State) in Colombia. It is situated in the middle of the Central Andes mountain range. Its relative importance is that the city of Medellin is part of it, which is the second largest city in the country as well as the second most important. Nine other municipalities are part of this Metropolitan area (Barbosa, Girardota, Copacabana, Bello, Itagüí, Sabaneta, Caldas, La Estrella y Envigado). The combined population of these cities is around 3 million inhabitants. The Aburrá-Medellín River crosses the valley from south to north. This river crosses the ten municipalities mentioned above, and has become a hub for the historical development of the region [9].

The topography of Aburrá Valley is irregular along its extension. The altitude is between 1300 and 2890 m a.s.l. Medellín, which is the most developed urban core, is located in the central part of the valley within an extension of 8 km [10].

Most of the surface streams and the natural drains of the Aburrá Valley are highly polluted due to direct wastewater discharges, mainly in the central part of the valley. This situation leads to a reduction in the dissolve oxygen levels and to an increase in the levels of organic matter, inorganic matter, and toxic substances [11]. Water quality decreases substantially and with it the quality of life for the people around it.

The Aburrá-Medellín River integrates the municipalities of this valley. It receives about 254 tributaries of a different magnitude, along its 100 kilometer length, from its source point in the top basin, in a place known as Alto de San Miguel (municipality of Caldas), to its confluence with the Rio Grande. The tributaries are relatively short, with steep slopes, deep and narrow channels, high speeds and large sediment transport capacity, which correlate with the high erosive powers [12].

Monitoring stations, the monitoring stations selected in this research to be incorporated into the model are: San Miguel –E1, Before Valeria-E2, After Valería-E3, Ancón Sur without channeling -E4, Ancón Sur with channeling -E5, Before San Fernando-E6, After San Fernando-E7, Aula Ambiental-E8, Ancón Norte –E9 (Fig. 1, Table 1).

After model selection, according to its easy handling and required information [13], historic records from low flows in the river, since the year 2004, were used to run the model [12], since they are related to the most critical conditions of water quality in a flow receiving different types of discharges [14].

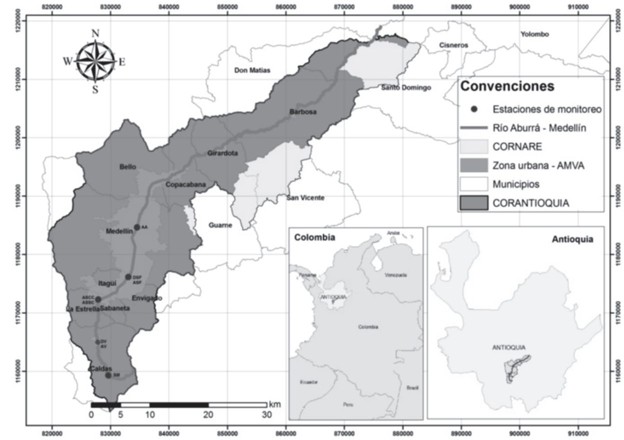

Figure 1. Study Area Location.
Source: [10]

Table 1.
Monitoring Stations used in the model.

Estation	Coordinates		Distance from san miguel
	Latitude	Longitude	Km
Alto San Miguel (SM)	6° 02´ 50.4´´ N	-75° 37´ 09.9´´ W	0.0
Before stream La Valeria (AV)	6° 5´ 46.6´´	-75° 38´ 08.7´´	8,5
After stream La Valeria (DV)	6° 5´ 46.6´´	-75° 38´ 08.7´´	8,6
Ancón Sur without channeling (ASSC)	6° 09´ 07.8´´	-75° 37´ 54.9´´	15,2
Ancón Sur with channeling (ASCC)	6° 09´ 07.8´´	-75° 37´ 54.9´´	15.4
Before San Fernando (ASF)	6° 11' 26.78"	-75° 34' 79.15"	22,7
After San Fernando (DSF)	6° 11´ 43.5´´	-75° 34´ 53.3´´	22,8
Aula Ambiental (AA)	6° 15´ 51.8´´	-75° 34´ 20.4´´	31,3
Ancón Norte	6° 22' 16.21"	-75° 29' 21.29"	48,6

Source: The authors.

Input Data into Qual2Kw model. As a first step the border conditions were set up in the monitoring station (San Miguel). Hydraulic data, temperature, water quality and low flow data were also set up in the other monitoring stations along the river located downstream of the initial station. The model was set up in such a way that the sections in which the river is splitted were adjusted to concur with the sections that were defined by the environmental authority [15] as the most important monitoring stations, because they allow a quick view of the state of the river. Domestic and industrial discharges, as well as tributary streams, were modeled as point sources in the model. Since there are some distributed discharges along the river, which are very difficult to locate and to characterize, and since they have a significant impact on the water, these distributed discharges were included in the model as unmonitored tributaries and the quality was assumed to be the typical composition for residential waste water [16] and for the mass balance.

Table 2.
Modeling Scenarios

Scenario	PTAR Bello	Discharge PTAR San Fernando	% Removal Streams (Bod5 –Tss)
e0	No Operative	70-70	Actual Situation
e1	No Operative	70-70	Variable f(PSMV) 2014
e2	Operative	70-70	40
e3	Operative	50-50	60

Source: The authors.

Model Implementation. The model was set up with low flow data. The time step used to calculate was fixed on 11.25 minutes to avoid numerical instabilities. The numerical methods used were Euler and Newton-Raphson [17]. Level 1 was chosen in order to model the exchanges in the hypothetic zone, because it includes zero and one-order equations for BOD oxidation.

Model Calibration. The algorithm used by the model to calibrate the model constants consists in a genetic searching technique, which involves a set of operators that allows its convergence into an optimal solution [2, 7]. In order to find the set of parameters that better represent the reality of the river, the model was run in such a way that the objective function (weighted squared error) was minimized. The genetic parameters were set as: 125 model runs in a population and 126 evolutive generations.

Water quality scenarios, according with the progress of the Sanitation Master Plan and Discharges Management (PSMV for its acronym in Spanish). Three scenarios were considered in this research, according with the law 3930 of 2010 [18]. In which is formulated, among others, the need to have formulated a management plan of water resources and these management plans must be formulated by the environmental authority, considering during the formulation of the plan different projections for the short, medium and long term (2, 5 and 10 years). The first scenario was simulated by having the discharge of the interceptors of wastewater directly into the river, but assuming a better collection of wastewater in the tributaries according with the goals of the PSMV for the year 2014. Scenarios 2 and 3 were simulated under the assumption of the construction of the south and north interceptor as well as the construction of the wastewater treatment plant of Bello, all of them fully functional. Table 2 presents the summary of the simulated scenarios.

Among the assumptions that were considered in the simulations, the actual discharge of the waste water treatment plant (WWTP), San Fernando, 70-70 and 50-50, means that it is expected that the discharge of the WWTP does not exceed 70 70 mg/L of BOD5 and 70 mg/L of TSS, and so on.

In scenarios 2 and 3, which consider the WWTP of Bello, it is worth mentioning that the percentages in the collection of waste water in the tributaries that still do not have proper sanitation is 40% and 60%. Additionally, in scenario 3 a 5% improvement was assumed by the streams that today have proper sanitation with the implementation of construction works that improve the collection of wastewater.

Obtaining the equation for the BMWP/Col (Biological Monitoring Working Party in Colombia). According to the actual water quality conditions observed in the river it is not possible for the macro invertebrates to colonize the river. For this reason, it was decided to not include in the computation the growth and decay rates, but a variation of the model was used which tried to better represent the specific situation described above in the Aburrá-Medellín River. The BMWP/col is computed by using a piece of code in an Excel Macro that automatically calculates it after the physicochemical variables are computed in the software. To obtain the equation, a matrix was structured with the data collected under low flow periods. The Electrical Conductivity parameter plays a major role in determining the processes related with water quality in this river and for this reason an equation to calculate the BMWP/col must be in terms of this parameter. To be able to include the effects of conductivity in the BMWP/col a regression using dichotomous variables and to validate its representativity it was necessary to evaluate the assumptions that were made; the latter was done with Eviews [19].

4. Results

4.1. BMWP/col equation

When performing a test of hypothesis testing, the p-value of the explanatory variable (for electrical conductivity variable) was 0.104 with a confidence level of 89.9 %. With these values, it is possible to conclude that conductivity does have a significant effect on the BMWP/Col. Additionally, p-values of all dichotomous variables tend to zero, which indicates that they are significant and must be considered when using the equation in each section of the river

4.2. The obtained equation is shown below:

$$BMWP/Col=(- 0.13*conductivity^{0.3} +3.59E1 +2.54*E2 +2.14*E3 +2.82*E4 +2.90*E5+ 2.29*E6+ 2.49*E7+2.58*E8)^{(1/0.3)} \quad (2)$$

4.3. Calibrated Model

In the Figs. 2, 3 and 4 it is possible to compare the results along the river for the modeled parameters (continuous line) against field measurements in the monitoring stations (scattered points) under low flow scenarios.

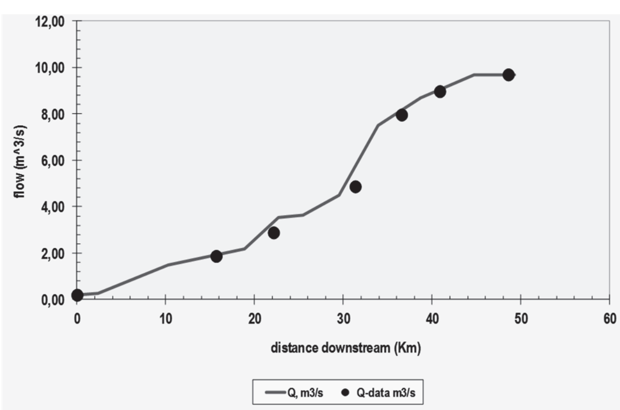

Figure 2. Simulation under low flow discharges (m³/s)
Source: The authors.

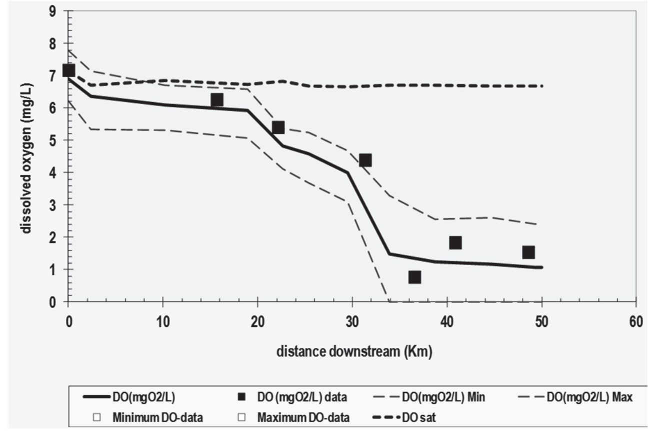

Figure 3. Dissolve Oxygen Simulation (mg/L), low flow.
Source: The authors.

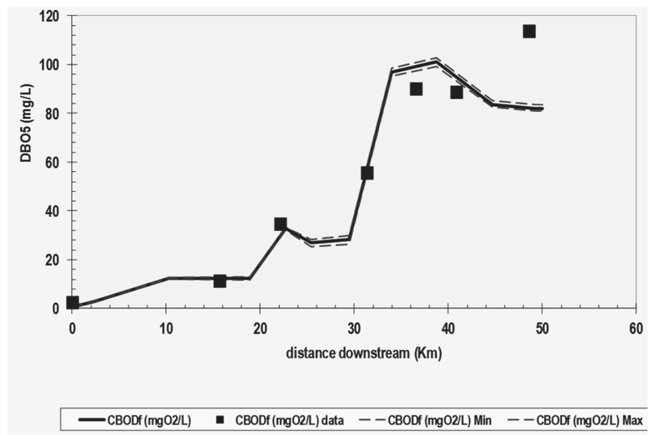

Figure 4. BOD5 Simulation (mg/L), low flow
Source: The authors.

4.4. Evaluation of scenarios

Once the model was properly calibrated, the following alternatives were evaluated: scenario "e0" actual water quality conditions in the Aburrá – Medellín River; scenario "e1" corresponds to the expectations of the water quality conditions in a period of two years. For the input data of this scenario, in some of the tributaries the percentage of sanitation according with the sanitation works projected in the PSMV for the year 2014 were assumed. Scenario "e2" represents the expectations in water quality in a five-year period. Scenario "e3" represents the expectations in water quality over a ten-year period. The percentage of sanitation in the tributaries used in scenario "e2" was 40% and 60% in scenario "e3". Discharges from the San Fernando WWTP were set up as 70-70 and 50-50 for scenarios "e2" and "e3" respectively assuming the future WWTP of Bello was fully functional. From these scenarios, it was possible to obtain the behavior of water quality.

Fig. 5 shows the variation for the BDO5 along the river for the future scenarios that were run (2, 5 and 10 years) assuming pollutant load removal in scenarios 2 and 3 and also with the WWTP of Bello operating. In the same graph, the

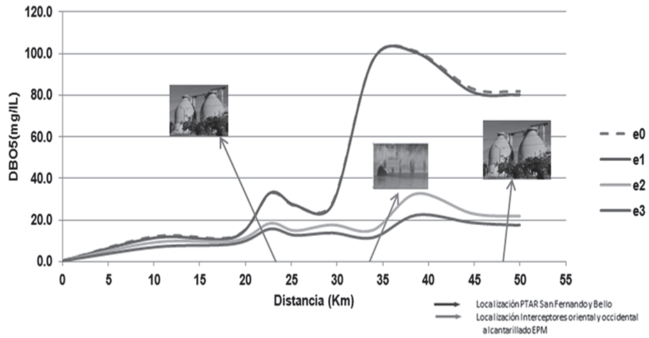

Figure 5. BOD5 behavior in all scenarios
Source: The authors.

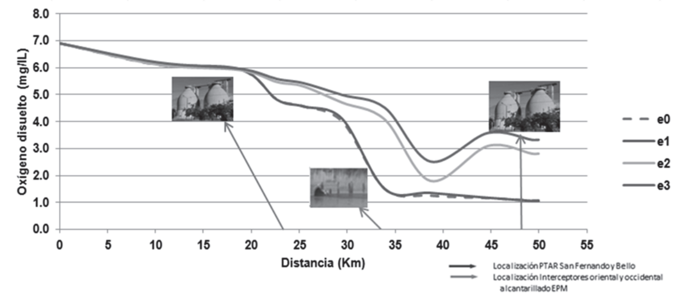

Figure 7. Dissolve Oxygen (DO) profile in the river in all scenarios
Source: The authors.

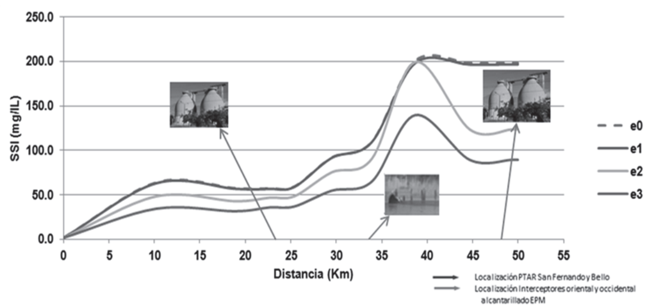

Figure 6. SSI behavior in all scenarios
Source: The authors.

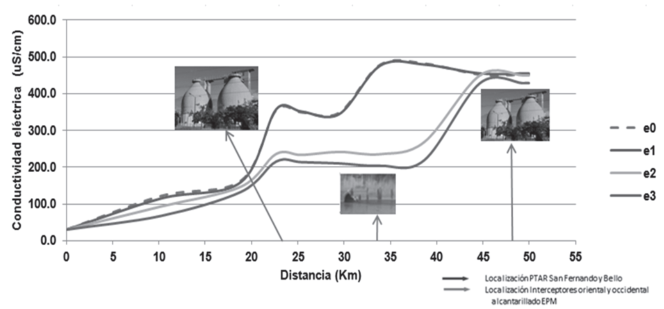

Figure 8. Electrical conductivity profile in the river in all scenarios
Source: The authors.

actual scenario is presented. By comparing these scenarios, a notorious recovery in the water quality of the river is observed once the WWTP enters into operation. From this analysis it is clear the importance that the WWTP plays in the Sanitation Plan of the river to help in the recovery of the physicochemical water quality of it.

Fig. 6 shows the variation of inorganic suspended solids (ISS) along the Medellin-Aburrá River according to the predictions of the modeling. It can be seen that in terms of ISS in the river the recovery is not as significant as the one modeled for the BOD. Which can be explained with the large contribution of ISS that is being received from the tributaries and in many of them the origin is not from the domestic wastewater, but from mining in the tributaries and deforestation processes in their upper parts, so despite its removal in the proposed scenarios, concentrations remain high.

For the evaluated scenarios OD profile along the river, is shown in Fig. 7. In this graph it is possible to see a recovery near to the Moravia sector (Kilometer 34), this is due to the closure of the interceptors located in this point of the river and the startup of the WWTP of Bello. This situation is more evident in scenarios 2 and 3 (i.e., projections at 5 and 10 years).

Fig. 8 shows the results for electrical conductivity for the different scenarios simulated. The highest values of conductivity correspond to scenarios e0 and e1 (current and year two) due to the low remotion rates. The lowest values of conductivity were in scenarios e2 and e3 (years five and ten) where the WWTP of Bello is operating. The discharge of the future WWTP in Bello causes the conductivity to increases and moves northwards.

Like the ISS parameter, there is not a significant recovery in conductivity, as it was obtained for BOD near to km 48 of the river. This is due to the lack of real data about removal percentages for this variable with the WWTP of Bello operating.

Fig. 9, shows the results from the model for BMWP/Col in the different scenarios. From this graph, a marked deterioration in km 10 is observed, which corresponds with the place where the tributaries Chuscala, La Miel y La Valeria enters into the river, then a recovery is achieved near km 15. In km 23, BMWP/Col reduces again; in these kilometers is located the discharge of WWTP San Fernando. From this point the biological component that represents this BMWP/Col, shows a slight improvement until km 33 where the parameter decreases again due to the discharge of "K-33 Interceptors" of waste water at this point for scenarios 0 and 1 (current and 2 year scenarios). From this point, there is a constant trend in this variable in the more critical stretch of the river.

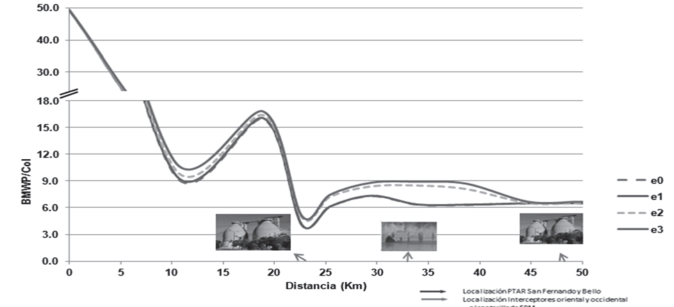

Figure 9. BMWP/Col profile in the river in all scenarios
Source: The authors.

5. Discussion

In terms of BOD5, in the first 19 km, there are no significant changes in the behavior of this parameter between the current and proposed future scenarios, with a slight peak near Km 10, where tributaries La Miel, La Valeria and La Chuscala enter the river (Fig. 5). La Chuscala tributary receives the discharge of a collector of wastewater in the Mandaly neighborhood (municipality of Caldas), which has a high concentration of organic matter as a product of the agricultural and domestic activities that occur in this watershed. By comparing scenarios e1, e2 and e3 with the actual scenario it is evident that BOD5 concentration has variations in the first kilometers with removal percentages between 40% and 60%, respectively. Therefore, all the efforts in these kilometers should be directed towards the completion of the collectors of domestic wastewater [3], which are planned by the municipality of Caldas and with actions focused on water resource protection.

Future scenarios show a significant decrease in the concentrations of BOD5, compared with the current conditions scenario e0.

It is remarkable the reduction that is observe between km 33 and km 48, as a result of the connection of the sewer interceptors of EPM with the projected WWTP of Bello. Also, with the removal of load in terms of BOD5 in some tributaries such as La Rosa, La Madera, El Hato, La Garcia, La Señorita, Rodas and Piedras Blancas, which are located in this section of the river.

The results support the need to continue with the works to collect the wastewater and with the construction of the WWTP Bello, in order to reduce the load in terms of BOD5, and to continue with the cleaning of the tributaries, to collect wastewater and to prevent direct discharge to the water source, similar effects are presented by Holguín for the Cauca River in the city of Cali [20].

The increase in solids that occurs around km 10, can be explained as a result of the arrival into the river of the tributaries La Minita, La Miel, La Valeria and The Chuscala (Fig. 6). These tributaries introduce large amounts of suspended solids into the water as a result of erosive processes generated in the upper parts of these watersheds and from the direct input of wastewater from the municipality of Caldas through collectors, which are still disconnected from the WWTP in San Fernando.

The increase in the Inorganic Suspended Solids (ISS), close to km 29, is a response of the tributaries that arrive in this section of the river, such as Altavista, La Picacha and La Hueso, which are very important tributaries in terms of distributing solid loads into the river. The high content of solids in these tributaries is not only due to erosive phenomena in the streams but is also related with poor land planning as well as soil uses in the catchments, also in these tributaries the mining to extract construction materials is high. In Km 33, the simulation for future scenarios (specially e3) shows a clear reduction in the load of solids. This reduction can be the result of the connection of the interceptors to the future WWTP of Bello and therefore a reduction of the direct discharges into the Aburrá–Medellín River. In addition, the reduction can be explained due to the significant reductions in discharges in the tributaries. In the base scenario (e0), there is no change in the model for the amount of solids in the river. For scenarios e2 and e3, there is an increment in the solids concentration, basically for the arrival of some tributaries to the river: El Hato, La García and la Madera. In these tributaries, despite the fact they are modeled with a reduction in pollutants, the reduction is not enough to make a significant change in the water quality, due to the high concentrations of solids that they have. Such concentrations are not mainly associated to the domestic wastewater, but with the mining in order to extract construction materials.

Despite discharges of wastewater from the municipality of Caldas, dissolved oxygen is presented in the river until km 15 (Fig. 7). This is because the slope of the river in this segment promotes the oxygenation of the water body. Later, in the river a reduction in the oxygen concentration is observed, with the lowest concentrations around the location of the discharges of the interceptors, which transports much of the wastewater of the region near km 33 (Metro's Caribe Station). From that point, a slight recovery occurs and then decreases again due to an increased load that does not allow re-oxygenation, despite the fact that the slope at this point is still significant and the presence of hydraulic jumps in this part of the river. Between km 33 and km 48 the most critical section of the river is located, which is consistent with the behavior of BOD5 and solids, reflecting the impact of the income of wastewaters into the water body, which deteriorates its quality [17,21]. It is necessary to remark on the fact that despite the improvement of sanitation in the tributaries as it was set up in the model for scenarios e2 and e3, a significant recovery for future values of dissolved oxygen in the critical section of the river is not seen. Aiming to find an ideal scenario, in which the levels of DO were acceptable in the critical section, it was found that it is necessary to collect a minimum of 80% of the wastewater to achieve this goal.

Scenarios e0 and e1 return the highest values of electric conductivity along the river, due to the low removal percentages for this variable (Fig. 8). These results show a sustained increase in the concentration value that occurs from km 15 to km 33 near the location of the interceptors. Results that can be associated in large part to the city domestic discharges , which are not yet transported into a WWTP. It is also important to note that the electrical conductivity is a dynamic parameter with a different peak in time for each monitoring station depending on the time of day and it is closely related to human activity in the city. Scenarios e2 and e3 show a decrease in electrical conductivity, due to the projected connection of the interceptors to the WWTP of Bello, demonstrating the recovery that the river would have in this segment with the implementation of the PSMV. However, for these two scenarios, the most critical conditions are given by the discharge of the WWTP of Bello, which because of the significant volume of water to be discharged in this plant generates a significant impact on the river.

Overall, the impact of the more significant tributaries of the river on the macro invertebrate community were observed, highlighting the variable BMWP/Col as an indicator to complement the physicochemical analysis of the river (Fig. 9). To recover the diversity and abundance of macro invertebrates (biological quality) in the channelized segment of the river, it is necessary not only to recover the water quality of the river and its tributaries, it is also necessary to implement other strategies associated with the hydraulics of the channel [22,23]. Measurements such as the reduction of the water velocity (a variable that was not considered in the calculations due to the lack of information) must be implemented. What is concluded here is that despite the operation of the WWTP there is still a missing component to improve and it is the availability of natural habitats and colonization substrates and to have structures to protect them [24].

6. Conclusions

Analyzing the results of the model in terms of BOD5, the reduction of this parameter is clear, the highest reductions are achieved when the interceptors were simulated to be connected to the future WWTP in Bello, this was done in scenarios 2 and 3. Scenario 1 only presents a small reduction in concentration of BOD5 due to the sanitation in the tributaries according to the PSMV until the year 2014. This reflects the right decision of EPM to prioritize investment to the construction of the treatment plant to improve the quality of the river. This action is suggested in Colombia due to the limited resources available for reorganizing current and / or treatment wastewater plants [25].

In terms of suspended solids, alternatives e2 and e3 allow reductions in the concentration of this parameter, mainly due to the proposed reduction in the tributaries. Scenario e1 is the worst scenario in terms of solids due to the low reductions assumed on it. It is important to remark that the most critical section of the river for water quality in terms of BOD5 and ISS is located from km 29 to km 48. This situation has a direct relation with the arrival of some main tributaries on the river such as: La Hueso, La Iguaná, Santa Elena, La Rosa, La Madera, El Hato, La García, La Señorita y La Seca, among others. Even though, in the simulated scenarios a certain removal of pollutants was assumed for the sanitation in these tributaries, the assumed percentage was not enough to fully recover the river, especially in terms of ISS. These results show that despite all the efforts that can be made in terms of infrastructure to collect and to treat wastewater, simultaneously, it is essential to initiate actions focusing on environmental education and culture [26], regulatory/incentive policies, proper management of quarries and mining, prevention and mitigation works to avoid erosion and also a suitable land use scheme [27].

Finally, according to the variation obtained from BMWP/Col River's profile in the different scenarios modeled, it is difficult to reach values higher than 15 in the urbanized section, which allow the classification to change from "heavily contaminated (<15)" to "very polluted (16-35)" (ranges established in the biotic index) [28,29]. From the results of the model for the different scenarios it was observed that even though the improvement in water quality on the river and its tributaries and the interconnection of the interceptor with the future WWTP of Bello, the increase in BMWP/col index is minimum. This situation leads to the conclusion that parallel to the improvement in water quality of the tributaries, changes are also required in the hydraulic of the river to create proper conditions that favor the development of the entire life cycle of organisms. So, it is necessary to improve the availability of natural substrates of colonization and structures that enhance its protection.

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