19h International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2015, Barcelona, Spain 22-23 July 2015

OXYGEN DEPLETION MODELING IN A POLLUTED RIVER – TESTING BY AN ACTUAL EXAMPLE

Rajfa Musemić, Almin Halač & Mirela Alispahić
Faculty of Mechanical Engineering, University of Sarajevo
71000 Sarajevo, Vilsonovo šetalište 9, Bosnia and Herzegovina

ABSTRACT
The aim of this paper is to investigate and analyze the dynamics of change of dissolved oxygen in the river. The concentration of dissolved oxygen in the river is one of the most widely used indicators of overall ecological health of body water. The curves of sources and sinks of dissolved oxygen in the river using a modified Streeter-Phelps equation are modeled and tested with set of data by an actual example. The model shows that the dissolved oxygen decreases with increasing distance due to biochemical oxygen demand (BOD). The effects of the following parameters are analyzed: the initial deficit of dissolved oxygen, biochemical oxygen demand due to the oxidation of carbon compounds (CBOD), nitrogen compounds (NBOD), the consumption of oxygen in the sediment (SOD), background BOD from non-point sources and net production of oxygen. The Monte Carlo statistical analysis of data was also performed.
Keywords: BOD, CBOD, NBOD, SOD, Oxygen Depletion Modeling

1. INTRODUCTION
Dissolved oxygen (DO) refers to volume oxygen that is contained in water. Oxygen enters the water by photosynthesis by aquatic biota and by the transfer of oxygen across the air–water interface (aeration). Flowing water is more likely to have higher DO levels than stagnant water because of the water movement at the air–water interface; oxygen–rich water at the surface is constantly being replaced by water containing less oxygen as a result of turbulence, creating a greater potential for exchange of oxygen across the air–water interface. Due to the importance of oxygen in fresh waters, all countries in the world have set water quality standards that require DO concentration of equal to or greater than 5 mg/l most of the time, and 4 mg/l at all times ([1], [4]).

2. METHODOLOGY
Different model types are available to model surface water quality; they vary from detailed physically–based models to simplified conceptual and empirical models. The most appropriate model type for a certain application depends on the project objectives and data availability. In this study, DO and BOD dynamics are modeled using a modified Streeter–Phelps equation [1].
The final modified Streeter-Phelpsova equation has to include the DO sinks (CBOD, NBOD, SOD, initial DO deficit and background BOD), and DO sources (rearation and primary production – respiration). Using the standard principle of superposition (sum of different solutions for each sink and source) for mass balance equation the modified and adapted Streeter–Phelps equation is given as:

$$D = D_0 e^{-k_a x/u} + \frac{k_d L_0}{k_a - k_r}(e^{-k_r x/u} - e^{-k_a x/u}) + \frac{k_n N_0}{k_a - k_n}(e^{-k_n x/u} - e^{-k_a x/u}) + \frac{S}{k_a H}(1 - e^{-k_a x/u}) + \frac{R-P}{k_a}(1 - e^{-k_a x/u}) + \frac{k_d L_b}{k_a} \quad \ldots (1)$$

where D_0 is the initial oxygen deficit; L_0 is initial CBOD; N_0 is initial NBOD; the forth term on the right side is due to SOD; the fifth term is due to respiration - production (R-P); the last term in is due to background BOD caused by nonpoint sources; k_a is reaeration rate coefficient, k_d is the CBOD deoxygenation rate coefficient, k_r is the CBOD deoxygenation plus sedimentation rate coefficient; k_n is the NBOD deoxygenation rate coefficient and t is the travel time in the river. The rate coefficients k_a, k_d, k_r, and k_n are related to oxygen sink and depend upon the properties of the water and other physical, chemical and biological factors.

The study is carried out for River Bosna, located in the middle of Bosnia and Herzegovina region. Along the River Bosna, the major sources of pollution are domestic and industrial waste water and agricultural drainage. The river is divided into several segments; in each of them there is one measurement station (MS). Raw water samples are collected from Reljevo measurement station, where river's maximum flow rate is $Q_{\max}$= 77 m^3/s with its maximal wideness of watershed 45 m and maximal depth of 1.7 m; maximal velocity is $v_{\max}$= 1.00 m/s [2]. Data collected at Reljevo station are: Q= 33,4 m^3/s; T= 10.1 °C; dissolved O_2 is D_{sat}= 8.42 mgO_2/l; saturation O_2 is 75 % and nitrates concentration are 2.87 mgNO_3/l.

Initial deficit of DO can be calculated as:

$$D_0 = \frac{D_{sat}}{\frac{\%O_2}{100}} - D_{sat} \qquad \ldots (2)$$

For given data initial deficit of DO is equal 2.8 mg/l. Initial NBOD is calculated from stoichiometric conditions for nitrates concentration and its concentration value is equal 3.8 mg/l.

Reaeration rate coefficient can be calculated by the O'Connor-Dobbins formula [1], like:

$$k_a = 3.93\frac{v^{0.5}}{H^{1.5}} = 2{,}85\ \text{day}^{-1} \qquad \ldots (3)$$

where v=v_{av} = 0.7 ms^{-1} is average velocity of the river ($v < v_{\max} = 1$ m/s) and H = 1.1 m is river depth.

Taking into consideration the pollution and land configuration of the River Bosna we adopted initial CBOD value as 10 mg/l. All other necessary data are adopted from literature [1], on the base of recommendations and similar geology - fluvial conditions.

Table 1. Data adopted from literature [1]

Parameters	Adopted value	Comments
SOD, S	5	For areas of intense pollution is in range 5-10 gm^{-2}day^{-1}
Net primary production, (P-R)	10	For streams and rivers daily average value is in range 0.5-10 mgl^{-1}day^{-1}
Background DO deficit, L_b	1	For rivers is in the range of 0.5–2 mg/l
CBOD deoxygenation rate coefficient, k_d	0.5	For rivers is in the range of 0.05–0.5 day^{-1} at 20^{o}C with temperature correction factor $\theta = 1.048$
NBOD deoxygenation rate coefficient, k_n	0.5	For rivers is in the range of 0.05–0.5 day^{-1} at 20^{o}C with temperature correction factor $\theta = 1.08$
CBOD deoxygenation plus sedimentation, k_r	1	For rivers is in the range of 0.5–5 day^{-1} at 20^{o}C with temperature correction factor $\theta = 1.04$

Based on the Thomann Mueller' (1987) suggestion, the deoxygenation rate coefficients are corrected to the temperature changes like [1]:

$$k_d = k_{20}\Theta^{(T-20)} \qquad \ldots (4)$$

Rate coefficients are: k_d= 0.31 day^{-1}, k_n= 0.23 day^{-1} and k_r = 1 day^{-1}.

3. MODELING, RESULTS AND DISCUSSION

The curves of sources and sinks of dissolved oxygen in the river are modeled by Simile v6.4 [3]. The implementation of the model in Simile is given on the Figure 1.

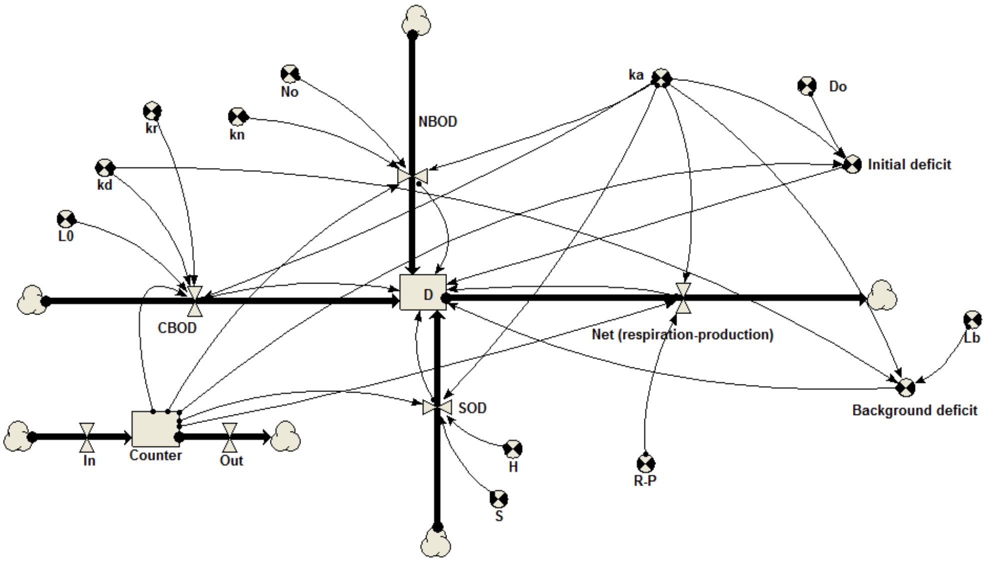

Figure 1. Model of sinks and sources of DO implementation in Simile

The results of calculation with data taken for MS Reljevo are shown in Figure 2.

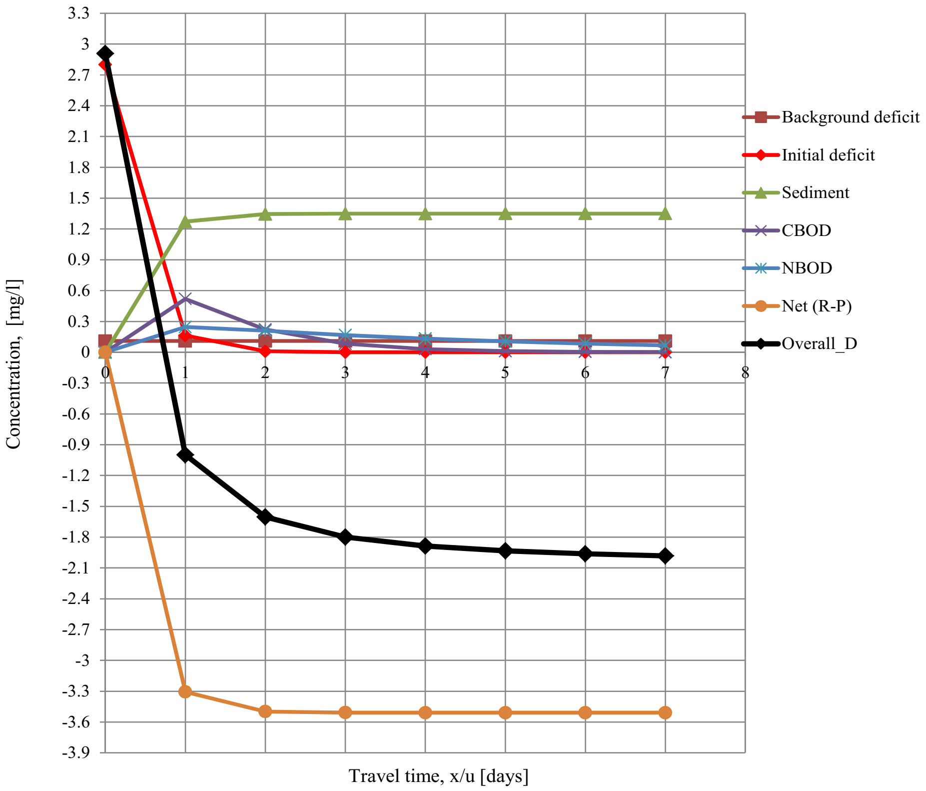

Figure 2. Sources and sinks of DO deficit at Reljevo MS

Dissolved oxygen deficiency at the beginning (D_0), and CBOD (L_0) concentrations of the water, critical time (t_{cr}), and critical dissolved oxygen deficiency (D_{cr}) values are calculated and given in Figure 2. Model includes the assumption that v, S and L_b are constant throughout the entire selected segment of the river. Results of simulation show that critical point occurs at travel time of 1 day (D_{cr} is 2.9 mg/l). After that critical point, dissolved oxygen deficit concentration, CBOD and NBOD concentrations start to decrease until balance is obtained. The overall BOD at critical point is 2,9 mg/l<4mg/l, which means that this value is within the standards.

Simulation for another location 100 km downstream from Reljevo MS, measurement station located at Zenica city, shows similar behavior regarding the dynamics of change of DO (Figure 3.).

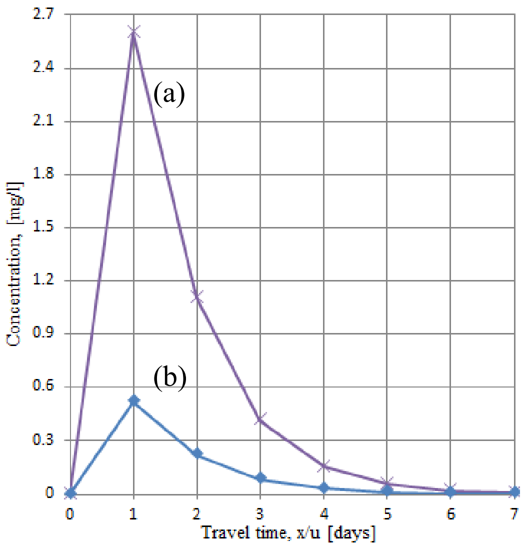

Figure 3. The curves of CBOD for different values of initial CBOD, (a) L_0= 50 mg/l (b) L_0= 10 mg/l

The Figure 3. shows the CBOD changes for different initial values of CBOD, related as 1:5. The both curves of CBOD show the increase till to the critical point, but, after that criltical point their values decrease downstream until they reach the equilibrium value. This fact confirms that initial CBOD has significant effect on the total (overall) BOD.
The performed Monte Carlo analysis was not relevant because we took measurable values that were already averaged in the observed time interval.

4. CONCLUSION

Water samples were periodically taken from Reljevo MS (cca 12 km from the river spring) and Zenica MS (cca 112 km from the river spring) between Mart (2000) and Octobar (2005). The temperature values change between 6.5ºC in Mart (the lowest value) and 16.5ºC in August (the highest value) for Reljevo and between 7.0ºC in Mart (the lowest value) and 22.5ºC in August (the highest value) for Zenica MS. The DO values of the water samples for spring season (Mart, April, May and Jun) reach highest value due to the lower river temperature and some hydro geometric properties of Bosna Stream. Annual average DO values of the water samples collected from Reljevo (8,42 mg/l) and Zenica (7,5 mg/l) shows that river has first class water quality in terms of dissolved oxygen concentration (DO $\geq$ 7.50 mg/l) and temperature (T$\leq$ 5-25ºC) [2]. The results of modeling at both selected segments of the river show that the river makes self-cleaning up after two-three travel days downstream.

5. REFERENCES

[1] Jerald L. Schnoor: Environmental Modelling - Fate and Transport of Pollutants in Water, air, and soil, The University of Iowa Iowa City, Iowa, 1996.
[2] Alma Imamović: Ekološke determinante održivog upravljanja vodenim ekosistemima u kontekstu međunarodnih trendova, PhD Thesis, University of Sarajevo, 2013.
[3] www.simulistics.com
[4] R. Musemic, A. Basic: Ecological and Chemical-Physical Indicators of land Water Quality with Sustainable Protection Measures, Proc. 13th International Research/expert Conference "Trends in the Development of Machinery and Associated Technology" TMT 2009, Tunisia, pp 309-313, 2009
[5] John Wainwright, Mark Mulligan: Environmental Modelling, Jonh Wiley & Sons, Ltd First Edition, Department of Geography, King's College London, UK, 2004.