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Modeling Surface Water Quality and Nutrient Correlation with Sediment Oxygen Demand at Dam Water Reservoirs

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ABSTRACT

The work presented here is a model approach based on WASP8 (Water analysis simulation program) a water quality model simulated to represent contaminants at the surface and bottom sediments of Kurtboğazı dam reservoir in Ankara city. However, our water quality output variables: are temperature, nitrate, total phosphorus, total Kjeldahl nitrogen, dissolved oxygen, Chlorophyll a, and ammonia. To ensure the model represents the actual case at the reservoir, the results from the simulation model were calibrated using actual data from the Kurtboğazı dam site, the calibration utilizes statistical techniques. The first method was the goodness-of-fit, R2 between model variables and field data, and the results were in the range of 0.86 to 1.0 indicating excellent linear association. The second technique was the RE, the values of which obtained were less than 1, elaborating acceptable results. The dam reservoir Kurtboğazı had been affected by the negative impact arising from dissolved oxygen depletion in the hypolimnetic layer during stratification periods and that had been well documented. However, the processes of oxygen consumption at the sediment-water interface are still difficult to grasp conceptually and mainly linked to sediment oxygen depletion and the phenomena of sediment oxygen demand SOD. The novelty of this research work is the development of a quality model to predict the reactions of state variables that are occurring at the water body and how they interact with each other and their influence on the overall quality status of the Kurtboğazı reservoir, and the crucial factors influencing the depletion of oxygen at the water column; secondly, the effect of anoxic condition on the benthic flux and the impact of anoxia condition on the ratio of nitrogen to phosphorus ratio at the reservoir. It was evident from the results of calibration that the model successfully simulated the correlation of the parameters influencing the anoxic condition, and benthic flux and ratio shift from nitrogen-limited during the summer to phosphorus-limited at the beginning of winter.

INTRODUCTION

Due to the problem of growing population, many countries in the world are either suffering water shortages (Simon & Hashemi 2018) or will eventually face this issue in the future, to make matters more complicated anthropogenic activities accelerate water resources depletion on a global scale, and there is an increasing emphasis on improving the quality of aquatic ecosystems, and monitoring surface waters have highlighted the need-to-know what factors cause the environmental deterioration (Ozmen et al. 2006), in Turkey, Ankara is considered to be the largest city in the Anatolia region and the second-largest city, with a population of over four million people (TUIK 2008), and there are several dam resources that feed water supply to the city: Çubuk-II, Bayındır, Kurtboğazı, Çamlıdere, Eğrekkaya, and Akba (Tozsin et al. 2015, Magara 1997). Therefore, it is expected that in the coming years there is a decline in the water quality widespread around the world and on a global scale (Kendirli et al. 2009, Kernan & Allott 1999).

Due to the lack of water resources, it has become more difficult to supply sufficient high-quality drinking water to the Ankara metropolitan area (Patil et al. 2008) and the application of technologies and strategies are the available solutions for treating polluted water resources. However, it is worth mentioning that adopting precautionary measures against the pollution of water resources is by far a more efficient and sustainable long-term solution. Water quality management often involves large capital investment. Managers must have means of evaluating and estimating different scenarios, this is where modeling is used to predict various impacts of alternatives on the whole system.

Water Quality Analysis Simulation Program (WASP) is a dynamic segment-based or compartment-modeling program for aquatic systems (Wang et al. 2018), including both the water column and the underlying benthos, which aids the interpretation and prediction of different water quality responses to anthropogenic and natural phenomena regarding quality and pollution control. The software is flexible and capable of simulating a wide range of pollutants in 1, 2, or 3 dimensions and examples are: the estimation of pollution load for the Taipu River (Bilal et al. 2009); total maximum daily load analysis (TMDL) for nutrients in the Neuse River Estuary, North Carolina (Wool et al. 2003a, 2003b); phytoplankton in St. Louis Bay, Mississippi (Camacho et al. 2014); impacts of climate change on water quality of Chungju Lake-South Korea (Park et al. 2013); dissolved oxygen in the Danshui and Chungkang Rivers, Taiwan (Chen et al. 2012); dissolved oxygen depletion in diverted floodwaters of the Elbe River, Germany (Lindenschmidt et al. 2009); eutrophication control in the Keban Dam Reservoir, Turkey (Soyupak et al. 1997). One of the most crucial factors that dominating the aquatic ecosystem's health is oxygen, therefore, it is of paramount importance to predict oxygen levels at lakes and reservoirs as part of an integrated water management system, reaeration from the atmosphere plays a vital role to replenish the DO levels in any water surface system, however, this must counter inflowing waters that transport organic matter into a reservoir, this matter will settle in the sediments along with dead plants and algae. When this material decomposes both chemical oxidation and biological respiration exert a significant oxygen demand on the water column (USGS Science 2020), known as biochemical oxygen demand BOD, and on the sediments, known as sediment oxygen demand SOD (Julie & Lindenschmidt 2017, Panagiotaki & Dimitrios 2015, Papastergiadou et al. 2009, Parlak 2007). Another important fact to consider is the depletion of dissolved oxygen due to the degradation of organic matter in the sediment, eventually, this will cause a release of metals such as iron and manganese, also, nutrients in the form of nitrogen and phosphorus (William 2002) into the water column, therefore DO depletion may also cause the release of toxic substances and anoxic conditions combined with the release of toxic substances can lead to severe water quality problems (Tufford & Hank 1999). Sediment oxygen demand SOD (Li et al. 2021, Mbongowo et al. 2018) is the process impacted on a wide scale by the concentrations of materials in the sediments and overlying water column, nutrient release from the sediment due to mineralization diagenesis of organic materials in bottom sediments, which ultimately contributes to eutrophication and hypoxia (Testa et al. 2013).

Organic matter that settles into the sediments is subjected to several physical and biogeochemical processes (Miroslaw & Piotra 2014, Moltke et al. 2017). Benthic deposits have been known for a long time to cause depletion of oxygen concentration in natural waterways. Microbes consume oxygen when they break down organic matter. Bioturbation is a process in which benthic organisms modify the sediments. Organic matter decomposes and oxidizes, transforming nutrients and releasing them back into the water column. Within a few millimeters to centimeters of the water-sediment interface, sediment oxygen levels drop from bottom water concentrations to near zero, resulting in significant gradients. As oxygen is utilized to fuel the breakdown of organic matter, these gradients contribute to diffusion into the sediments, imposing a sediment oxygen demand (SOD) on the water column. Models of diagenetic processes predicting the effects of SOD on water quality have been difficult to assemble due to the lack of standard methods to accurately measure, quantify, and predict SOD, it is worth mentioning that several factors affect the SOD rate: such as sediment age, surface area, depth of deposit, temperature, water velocity, and chemical and biological differences (Quirós 2004).

With the considerable rise in pollution levels, populations, and the misconduct of natural resources (Ray et al. 2016) it is now of significant importance and a basic fundamental necessity to innovate methods and systems to sustain and minimize the impact of pollution and contamination to the water bodies, by the use of continuous monitoring systems. In this paper a simulation program system, WASP8 utilized in a novel manner to formulate a water quality simulation model that is a replica of conditions and status at the Kurtboğazı dam reservoir site. Water quality models can be effective tools to simulate and predict pollutant transport in the water environment and contribute to saving the cost of labor and materials for a large number of chemical experiments to some degree. Moreover, it is inaccessible for on-site experiments in some cases due to special environmental pollution issues and in the cases of specially protected areas. However, the model developed in this work was calibrated on actual data from the site. The model further investigated the depletion of oxygen and the related phenomena of sediment oxygen demand and the factors affecting this condition and how it is related to benthic flux and the nitrogen-to-phosphorus ratio. The simulated model developed and presented in this research paper is monitoring and evaluation as it provides a base and know-how support for the sustainability of natural resources.

MATERIALS AND METHODS

Characteristics of the Study Area

Kurtboğazı Dam takes its name from the lake on which it was set, situated northwest of Ankara, coordinates at north latitude: 40°16´ & 40°28´ and between 32°37´ & 32°46´ at the east longitude, with a maximum depth of 32 m. Kurtboğazı was constructed as an earth-filled dam with a catchment of approximately 331 km^2. Its basin is smaller than the Sakarya basin, however, the construction of this dam was completed in 1967 and today it is used to supply drinking water to Ankara province. The dam basin and surrounding locations are affected by terrestrial climate; therefore, it is hot and dry in summer; cold, and moderately rainy in summer and winter, respectively (Altin et al. 2010). Meteorological Stations alongside the Kurtboğazı dam basin registered from 1988 to 2006 an average of 30.3 mm in summer, and 35 mm in autumn (Altin et al. 2010). The Basin of the dam has alluvium, hillside, Pliocene sediment, and andesite. Hillside debris covers the andesite formed mainly by rocks. The andesite in this region shows a massive structure and has been subjected to tectonic activity over a long period (Altin et al. 2010). Kurtboğazı dam reservoir is subjected to the growth of cyanobacteria (Turkish Water Pollution Control Regulation. 2004) that results in algae blooms and deteriorates water quality since it contains toxic materials resulting in, taste and odor problems in water occur and those threaten public health (Kali & Güngör 2020).

According to the information we obtained from the General Directorate of Ankara Water and Sewerage Administration -ASKI two main streams are feeding the Kurtboğazı Dam, the first is the Kurt Stream the second stream is known by the name Pazar Stream (Tozsin et al. 2015), (Fig. 1). Due to the importance of the Kurtboğazı dam reservoir as a source of water supply to Ankara city, the General Directorate of State Hydraulic Works-DSI along with the General Directorate of Ankara Water and Sewerage Administration -ASKI had launched many programs and special conservation plans to monitor the water quality of Kurtboğazı reservoir: to protect, improve and ensure sustainable use for it, this was eventually achieved by the distribution of five monitoring stations: K1, K2, K3, K4 and K5 of Kurtboğazı (Fig. 1) (ASKI 2021), two of the sampling points are built on the constantly flowing Pazar stream of the name K4 and K5, and sampling point K1 station was set just before entrance of water into the Ivedik Drinking Water treatment plant to observe water quality of the dam reservoir. The remaining stations K2 & K3 were distributed along the Kurtboğazı dam but I was not able to get the exact locations for the stations from ASKI. Therefore I resorted to the method of approximating their location based on available references and information. According to ASKI, the water samples are taken from the stations on weekly basis but they also have daily measurements. Some tests are performed at the site others are preserved in special conditions to be later delivered to ASKI laboratories for accurate and thorough testing.

Moreover, the available data from ASKI is presented in the appendix, it was also the basis for the calibration where the results are presented in (Table2) for the calibration between model results and the data provided from ASKI collected by stations (K1, K2 …).

Reservoir Water Quality Model

The WASP can be thought of as a dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. The basic program simulates the following processes that change over time: dispersion, point, and diffuse mass loading, advection-dispersion, and boundary exchange (Stolarska & Kempa 2021).

An important issue is that when simulating a quality model you can decide upon the degree of the complexity you choose the model to carry, this implies to increasing the number of state variables means an increase in model complexity. However, for this work, the aim was to establish a sediment oxygen demand SOD model to correlate the different factors and variables that are influencing the oxygen level in the reservoir. To meet the objective of our work the first major step was to establish the water quality simulation model then followed by the SOD model.

The simulation program WASP8 can assess one, two, and three-dimensional systems as well as several types of pollutants. It can be used to examine various water quality issues in a variety of water bodies, including rivers, streams, coastal waters, ponds, estuaries, lakes, and reservoirs. The compartmentalization concept underpins this paradigm. A mass balance equation is presented for each equation. Rapid and full mixing occurs within each compartment. The program model depends on the principle of mass conservation when solving equations, and these equations represent the three primary types of water quality processes: loading; transformation; and conveyance. There are also biological. physical and chemical transformations that play a substantial influence on concentration variability along the water body that manifest in the form of dispersion; advection-dispersion and kinetic transformation (Ranjith et al. 2019).

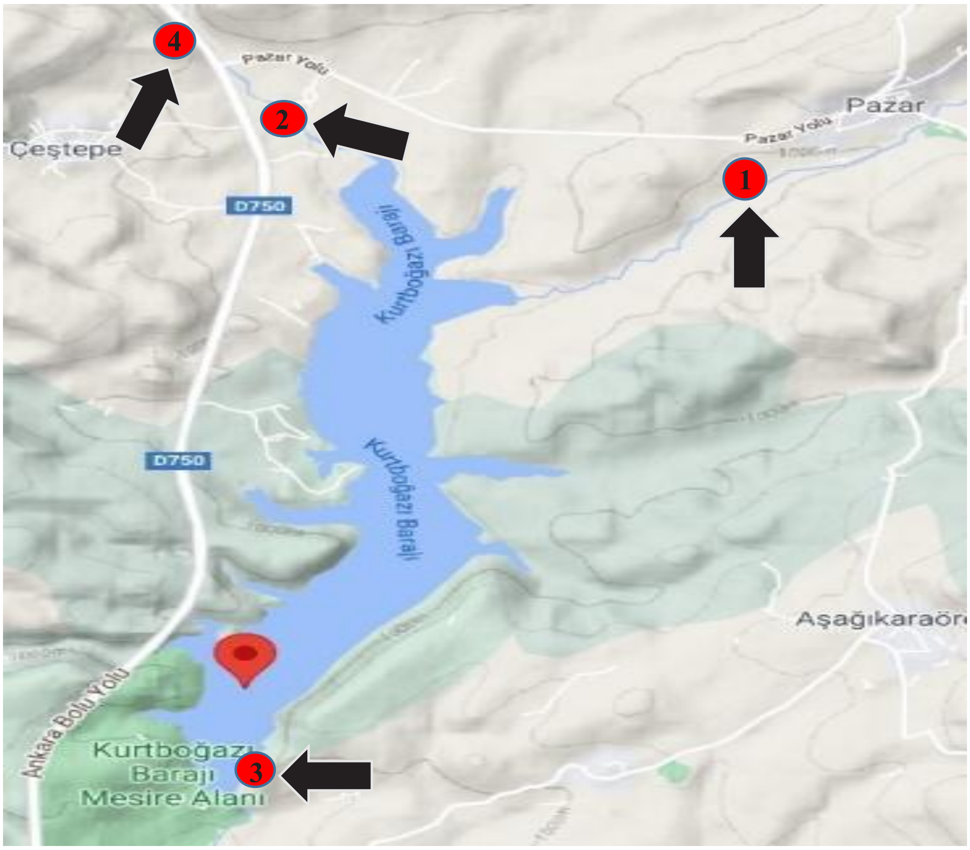


FIGURE LEGEND

1 Point-1 location of Pazar Stream-Feeding to Kurtboğazı reservoir

2 Point-2 is where the Kurt Çay Stream-Feeding to Kurtboğazı reservoir

3 Point-3 is Discharge point of Kurtboğazı reservoir

4 Point-4 of discharge for Water derived from Eğrekkaya dam to Kurtboğazı Reservoir via Inceğez tunnel

Fig. 1: Google map 2021. [Location of study area Kurtboğazı dam reservoir], Ankara Turkey, 40°16' 10.92" N, 32°42'2.16" E, Google Earth.

Table 1: Dimensions of segments.

Segment Name	Length of segment (L)	Width of segment (W)	Area (m^2)= L.W	Volume (m^3) = L.W.depth
1	1136	845	959920	31677360
2	874	816	713184	24248256
3	904	714	645456	20654592
4	1020	670	683400	22552200
5	1224	641	784584	26675856
6	918	568	521424	17206992
7	1064	787	837368	29307880
8	758	685	519230	18173050

Table 2: Model result for state variables at segments 1, 2, and 8 with statistical tests for calibrating simulated results.

State Variable	Segment Number	May 2019	July 2019	Sept. 2019	Nov. 2019	Dec. 2019	R^2	Root mean square error RMSE	Mean absolute % error MAPE	Relative error RE
Tempera-ture °C	1	15	18.7	15.4	13.6	13	0.93	4.3	<88	0.34
	2	17.7	19.1	15.1	13.2	13.1	0.96	4.1	<72	0.32
	8	12.8	17	15.8	11.6	11	0.91	2.5	<40	0.2
Nitrate ($mg.L^{-1}$)	1	250	242	26	63	60	0.97	35.4	<86	**1.86**
	2	525	521	189	60	56	1	129	<33	**1.52**
	8	545	543	376	73	62	0.96	80	<23	**1.78**
Dissolved Oxygen ($mg..L^{-1}$)	1	8	8	8.1	8.7	8.5	0.86	1.7	<22	0.17
	2	9.8	9.7	9.2	8.6	8.7	0.97	1.2	<20	0.1
	8	8.3	8.2	8.5	8.9	9	0.93	0.9	<15	0.19
Chloro-phyll a ($\mu g.L^{-1}$)	1	1.67	1.7	1.76	1.85	1.83	0.97	0.4	<31	0.29
	2	1.87	2.05	2.07	2.11	2.13	0.98	0.6	<24	0.11
	8	0.49	0.51	0.53	0.53	0.54	0.92	1.4	<66	0.69
CBOD ($mg.L^{-1}$)	1	2.09	2.5	2.56	2.93	2.98	0.97	0.24	<12	0.06
	2	2.1	2.42	2.68	2.7	2.6	0.96	0.2	<12	0.09
	8	2.14	2.4	2.7	2.8	2.8	0.98	0.7	<40	0.23
Ammonium ($mg.L^{-1}$)	1	220	231	316.7	337	340	0.98	113.2	<30	0.04
	2	180	195	243	303	304	0.96	13.9	<15	0.05
	8	196.9	196.9	200.5	213	304	1	48.6	<24	0.11
Total Phos-phorus ($mg.L^{-1}$)	1	0.83	0.8	1	0.9	2.95	0.99	0.3	<80	0.45
	2	41	40	38	18.9	16.8	0.93	19.3	<58	0.42
	8	56	50	41	30.1	16.4	0.95	16	<40	0.3
Total Kjeldahl nitrogen (NH_3/NH_4)	1	159	168	221	372	410	0.98	47.6	<18	0.08
	2	177	181	199	380	400	0.88	112.6	<63	0.26
	8	149	156	209	380	384	0.99	11.3	<11	0.04

(Table 2) also displays the calibration result between model and field measurements for the state variables. Using statistical tests as shown in the last four columns:
1. R^2 is a goodness-of-fit measure for linear regression models
2. RMSE is the Root mean square error between the measured and model result
3. MAPE is the Mean absolute percentage error between the measured and model result

Conservation of mass forms the basic fundamental foundation of the Water Quality Analysis Simulation Program WASP theory. The simplest form of writing the mass would be Input system + production= out of the system. A lake or river can be considered a tank reactor and based on that idea the mass balance equation is (Wool et al. 2017):

$$Q_0.C_A+r_A.V=Q.C_A+\frac{dnA}{dt} \quad \ldots(1)$$

From eq. 1, the Q_0 = Inflow ($L^3\ T^{-1}$), Q_A= Outflow ($L^3\ T^{-1}$), at the left side of the equation it refers to C_A= concentration of (A) inflow ($M\ L^{-3}$), Q.CA= concentration of (A) in outflow ($M\ L^{-3}$), r_A = rate at which substances are produced, V= volume (L^3) $\frac{dnA}{dt}$ = the number of moles of a substance A.

From the point of temporal and spatial input to the point of export and mass conservation in space and time, the model controls and assesses every component of water quality, when temporal and spatial fluctuations in constituent concentration are taken into consideration, a finite-difference equation is used for each segment, and, he finite difference form of the equation of mass balance is deduced for a 1D reach for ease of application, the concentration is computed for each segment. The initial value for each segment at time zero is the final concentration calculated from the previous segment. The dissolved components in a body of water represent the three primary categories of water quality processes as shown below (Wool et al. 2017):

$$\frac{\partial(AC)}{\partial t} = \frac{\partial}{\partial x}\left(-u_x\, AC + E_x\ A\ \frac{\partial(C)}{\partial t}\right) + \mathrm{A}\ (S_L + S_B) + \mathrm{A}\ S_K \quad \ldots(2)$$

Where C is the concentration of water quality ($g.m^{-3}$), t is time in (day), U_x is the longitudinal velocity ($m.day^{-1}$), E_x is the longitudinal diffusion coefficient ($m^2.day^{-1}$), S_L is diffusion loading rate ($g.m^{-3}\ day^{-1}$), S_B is boundary loading rate including upstream, downstream, benthic, atmospheric ($g.m^{-3}.day^{-1}$), S_k = transformation term (total kinetic transformation rate; positive is a source, negative sink, ($g.m^{-3}.day^{-1}$) for variable i in a segment) and A is cross-sectional area (m^2). Eq. 2 emphasizes that any mass enters a system must, by conservation of mass, either accumulate within the system or exit the system also Completely Mixed Flow Reactors (CMFRs) which means control volumes for which spatially uniform properties may be assumed (Wool et al. 2017):

Accumulation = S imports –Sexports+Ssources –Ssinks …(3)

There are many processes of physical and chemical perspective affecting the available dissolved oxygen in the water body and thus, eventually controlling the dynamic environment for the aquatic system, this involves phytoplankton, nutrients, Biochemical oxygen demand, and dissolved oxygen (Ranjith et al. 2019):

$$\frac{\partial c_b}{\partial t} = K_a\,(c_{sat} + c_6) - k_d\left(\frac{c_6}{k_{BOD} + c_6}\right) c_1 - \frac{SOD}{D} + G_{P1}\left[\frac{32}{12} + 4(1 - P_{NH3})\right] c_4 - \frac{32}{12}\ k_{1R}\, c_4 \quad \ldots(4)$$

Where, C_6 = DO ($mg.L^{-1}$), C_5= CBOD ($mg.L^{-1}$), C_{sat} =saturated concentration of DO ($mg.L^{-1}$), C_1=ammonia-nitrogen ($mg\ N\ L^{-1}$), k_d = de-oxygenation rate (day^{-1}), k_{BOD} = half-saturation constant for dissolved oxygen DO. D = depth of water (m), SOD = sediment oxygen demand ($mg.m^{-2}.day^{-1}$), P_{NH3} = preference for ammonia term, k_a =re-aeration rate (day^{-1}) G_{p1} = phytoplankton growth rate (day^{-1}), C_4= the phytoplankton biomass in carbon units ($mg.C.L^{-1}$), and k_{1R} = phytoplankton respiration rate (day^{-1}) (Ranjith et al. 2019).

However, the increase of anaerobic reactions in the underlying sediments and aerobic respiratory processes in the water column will lead to a decrease in DO. On the other hand, Phytoplankton growth, and re-aeration result in an increase in DO and sediment oxygen demand, but the respiration of phytoplankton respiration and oxidation of CBOD result in loss and decrease of DO. In the WASP8 model, the State variable interactions in advanced eutrophication include: Phyto is phytoplankton as carbon, NO_3 refers to nitrate, NH_4 is ammonium, PO_4 is ortho phosphorus, CBOD is carbonaceous biochemical oxygen demand, DO is dissolved oxygen ON is organic nitrogen, OP is organic phosphorous, DOM is dissolved organic matter, SS is inorganic suspended solids (Ranjith et al. 2019) and (Wool et al. 2017).

Based on eq. 4, it can be arranged in the following form (Ranjith et al. 2019):

$$\frac{\partial c_5}{\partial t} = a_{OC}\, k_{1d}\, c_4 - k_d\left(\frac{c_6}{k_{BOD}+c_6}\right) c_5 - \frac{V_{s3}(1-F_{d5})}{D}\, c_5 - 3\, k_{2d} + (K_{NO3} + c_6)\, c_2 \quad \ldots(5)$$

Where a_{oc} = oxygen to carbon ratio = 32/12 ($mg\ O_2\ mg^{-1} C^{-1}$), k_{1d} = phytoplankton death rate (day^{-1}), k_d = CBOD deoxygenation rate (day^{-1}), k_{2d} = denitrification rate (day^{-1}), K_{NO3} = half saturation constant for oxygen limitation for denitrification ($mgN.L^{-1}$), F_{d5} = dissolved fraction of CBOD, V_{s3} = settling velocity of organic matters ($m.day^{-1}$) and c_2 = nitrate nitrogen ($mg.L^{-1}$).

There is an important point to clarify regarding BOD measurements that may be affected by the decay of algal carbon and algal respiration. Thus, this requires corrective measures taken toward the internally computed value in the model and also given by (Ranjith et al. 2019):

$$BOD_5 = c_5(1 - e^{-k_{dbot}}) + \frac{32}{12}\, c_1(1 - e^{-5k_{nbot}}) + a_{0c}\, c_4\,(1 - e^{-5k_{1R}}) \quad \ldots(6)$$

Where c_5 = the internally computed CBOD ($mg.L^{-1}$), C_1 = the internally computed NH_3, ($mg.L^{-1}$), C_4= the phytoplankton biomass represented as carbon units ($mg.L^{-1}$), a_{0c}

= the oxygen to carbon ratio = 32/12 (mgO_2. $mg^{-1}.C^{-1}$), k_{dbot} = deoxygenation constant rate (day^{-1}), k_{nbot} = nitrification constant rate (day^{-1}) and k_{1R} = the algal respiration rate at 20°C (day^{-1})

Phytoplankton phosphorus in eq. 6 the term c_4 represents the dissolved inorganic phosphorus which is taken up, stored, and converted to biomass during the growing phase of the phytoplankton (William 2002). Will be re-written to include the mass of phytoplankton after it undergoes respiration and death (Ranjith et al. 2019):

$$\frac{\partial(c_4\, a_{PC})}{\partial t} = \left(G_{p1}\, D_{p1} - D_{p1} - \frac{V_{S4}}{D}\right) a_{PC}\, c_4 \quad \ldots(7)$$

Where a_{pc} is phosphorus to carbon ratio (mg $P.mg^{-1}.C^{-1}$), G_{p1} = phytoplankton growth rate (day^{-1}), D_{p1} = phytoplankton death rate (day^{-1}), V_{s4} = phytoplankton settling velocity ($m.day^{-1}$), a_{pc}= Biomass in (mg) converted to both non-living inorganic ant of inorganic and organic matter. There is a connection between inorganic and organic phosphorus via a sorption-desorption mechanism, non-predatory mortality, and endogenous respiration return phosphorus to particulate organic form. Organic phosphorus is converted to dissolve inorganic phosphorus at a temperature-dependent mineralization rate. Non-living organic phosphorus must be decomposed by bacteria or mineralized into inorganic phosphorus before phytoplankton may use it, eq. 7 becomes (Ranjith et al. 2019):

$$\frac{\partial(c_3)}{\partial t} = \left(\left[a_{pc}\, D_{p1}\,(1 - f_0\, p)\right]c_4 - k_{83}\left(\frac{C_4}{K_{mpc}+C_4}\right)\right)c_8 - G_{p1}\, a_{pc}\, C_4 \quad \ldots(8)$$

Where c_3 = phosphate phosphorus ($mg.L^{-1}$), c_8 = organic phosphorus ($mg.L^{-1}$), f_{op} = phytoplankton recycled to the organic phosphorus, f_{d8} = fraction dissolved organic phosphorus, k_{83} = mineralization of dissolved organic phosphorus (day^{-1}), K_{mPc} = the half saturation constant for phytoplankton ($mg.CL^{-1}$) and V_{s3} = organic matter settling velocity ($m.day^{-1}$).

However, in many research papers, ammonia is preferred in the form of ammonia nitrogen. The phytoplankton nitrogen is gained during growth and lost during death. The settling velocity V_{s4} = settling velocity ($m.day^{-1}$) and a_{nc} refers to the fact that for every mg of phytoplankton carbon consumed or lost there is an equivalent of nitrogen being generated so, there is nitrogen to carbon ratio = 0.25 $mgN.mg^{-1}.C^{-1}$ as shown in eq. 9 below (Ranjith et al. 2019):

$$\frac{\partial(c_4\, a_{nc})}{\partial t} = \left(G_{p1} - D_{PT} - \frac{V_{S4}}{D}\right) c_4\, a_{nc} \quad \ldots(9)$$

The process of respiration for the phytoplankton may use a fraction of nitrogen at the cell denoted by f_{on} is organic, while (1-f_{on}) is in the inorganic form of ammonia nitrogen. For the phytoplankton to be able to use nitrogen the latter must undergo a process of mineralization or what is known as decomposition by bacteria. Organic nitrogen (c_7) is acquired by phytoplankton death and dissipated by mineralization and settling, on the other hand, ammonia nitrogen (c_1) is acquired through the process of phytoplankton mortality and dissipated by nitrification & phytoplankton growth nitrate-nitrogen (c_2) is gained via nitrification and lost through phytoplankton growth and de-nitrification, eq. 10 below the display (c_7) or organic nitrogen, while (c_1) refers to ammonia nitrogen and (c_2) is nitrate nitrogen, (Ranjith et al. 2019):

$$\frac{\partial(c_7)}{\partial t} = D_{P1\,(a_{nc}\quad f_{on})}\, c_4 - K_{71}\left(\frac{c_4}{k_{mpc}+c_4}\right) - \left(\frac{v_{s3(1-f_{d7})-}}{D}\right) c_7 \quad \ldots(10)$$

The equation for (c_1), and (c_7) shall be presented below in eq.11 and eq.12 (Ranjith et al. 2019):

$$\frac{\partial(c_1)}{\partial t} = D_{P1}\ a_{nc}\ (1-f_{on})\ c_4 - K_{71}\left(\frac{c_4}{k_{mpc}+c_4}\right) c_7 - k_1\,\partial\left(\frac{c_6}{k_{nit}+c_6}\right)c_1 - G_{p1}\ a_{nc}\ p_{NH3}\ c_4 \quad \ldots(11)$$

$$\frac{\partial(c_2)}{\partial t} = k_{12}\,\partial\left(\frac{c_6}{k_{nit}+c_6}\right) c_1 - G_{p1}\ a_{nc}\ p_{NH3}\ c_4 \text{-}\ k_2\, D\left(\frac{k_{NO3}}{k_{NO3}+c_6}\right)c_2 \quad \ldots(12)$$

Where (c_7)= organic nitrogen ($mg.L^{-1}$), (c_1)= ammonia nitrogen (mg L^{-1}), (c_2) = nitrate nitrogen ($mg.L^{-1}$), f_{on} =dead phytoplankton recycled ON, k_{71} = The ON mineralization rate (Day^{-1}), f_{d7} = Fraction of dissolved organic nitrogen, kmN = Michaelis value for ammonia preference ($\mu gN.L^{-1}$), k_{mPc} = half saturation constant for phytoplankton limitation of phosphorous recycle ($mgC.L^{-1}$), K_{NO3} = half saturation constant of oxygen de-nitrification ($mgO_2.L^{-1}$), k_{12} = nitrification rate (day^{-1}) and k_{2D} =

Denitrification rate (day^{-1}). The WASP8 model also takes into account the temperature effect for all first-order reactions in the model by eq. 13.

$$K(T) = k(20)\,\Theta^{T\text{-}02} \quad \ldots(13)$$

Where K (T) = the reaction rate (day^{-1}) at temperature T (°C) and θ = the temperature coefficient for the reaction.

Modeling Kurtboğazı Reservoir

According to the information obtained from the ASKI report, field data was collected at specific locations at the monitoring stations in the Kurtbogazi dam (ASKI 2021), and physico-chemical properties of water at the stations were provided by ASKI: K1, K2, K3, K4, and K5. This data was for one year which included the surface and sediment analysis at some stations. According to ASKI, the sampling frequency was weekly, and the method of sampling was according to Standard Methods for the Examination of Water and Wastewater (ASKI 2021). The simulation program WASP8 is generally based on the principle of mass conservation as viewed in eq. 2. This principle requires that the mass constituent being investigated must be accounted for, and the model traces each water quality constituent from the point of spatial and temporal input to its final point of export, conserving mass in space and time. To accomplish this task, there are important input data that must be defined by the user: Simulation and output control, model segmentation, advective portraying the transfer of matter and initial concentrations (Ray et al. 1996), boundary concentrations, waste loads, kinetic parameters, and constants. The simulation model will be tracking the movement and transformation of environmental parameters that are involved in the interaction of the Kurtboğazı reservoir. These parameters are Biological oxygen demand BOD (Kali & Güngör 2020) which measures the potential of water to deplete the oxygen. In other words it's the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in as total kjeldahl nitrogen (TKN) is essential for living organisms to function and excess amount of these nutrients cause eutrophication and oxygen depletion; total phosphorus (TP) levels provides reliable information on the water body quality and trophic state; nitrate (NO_3) if the water body has exceeded nitrate this will eventually cause eutrophications and plant bloom, this large amount of plant growth depletes oxygen from the water and negatively affecting aquatic life; phytoplankton (Chlorophyll a) monitoring chlorophyll levels is a direct way of tracking algal growth and insuring it does not exceed permissible levels and lead to algae bloom; dissolved oxygen (DO) it is a key factor to determine the health state of a water body; ammonium (NH_4) are monitored as increased concentrations of ammonium can enhance the growth of algae and aquatic plants the bacteria can also convert high ammonium to nitrate (NO_3) in the process of nitrification, which lowers dissolved oxygen. There are also other data requirements to be entered before running the model, for example, the weather parameters in the form of air temperature, dew point, wind speed, and solar radiation, (Ankara Çabuk Turkey Weather History 2020).

As explained earlier the model is a set of expanded control volumes, or "segments," that together represent the physical configuration of the water body. These segments are provided to help users interpret and predict water quality responses to natural phenomena and man-made pollution for various pollution management decisions since WASP is a dynamic compartment where individual compartments can interact with each other and undergo dynamic remodeling for aquatic systems, including both the water column and the underlying benthos (Ambrose 2017 and). The Kurtboğazı reservoir is divided into 8 segments (Fig. 2) for the surface layer. However, these segments will have a subsurface layer below them as part of the water column. Also, there is the surface benthic and subsurface benthic that make up the sediment bed. The total number of segments will be 16. For each segment surface and subsurface, water dimensions with areas and volumes are given in (Table 1). The same concept was also applied to sediment beds for surface and subsurface benthic, based on the segment division in (Fig. 2). The dimensions were derived in length and width and the last two columns are for the area and volume of each segment, as listed in (Table 1). These dimensions are required to be entered into the model as part of the input procedure.

Execution of Model and Development of Results

Our selected simulation period for this work is from 1/1/2019 to 1/1/2020, the reason for selecting this date is because the available data that was sent from ASKI was at this time frame, according to the municipality of Ankara Water and Sewerage Administration –ASKI (2021), Altin et al. (2010), and Tozsin et al. (2015) there are two inlet points to Kurtboğazı reservoir as shown in (Fig. 1), known as Kurt and Pazar. These will represent segment 1 and segment 2 in the model respectively. The discharge point from Kurtboğazı is the Dam point which corresponds to segment 8 in the model. The reason for selecting these specific segments is because they correspond to effective location points such as inlet and outlet points at the reservoir. As for the remaining observation stations, they correspond to other segment numbers as presented in (Fig. 2). Observation stations K1, K2, K3, K4, and K5 represent segment 8, segment 7, segment 5, segment 2, and segment 1 respectively. However, our work will focus on segments 1, 2, and 8 as mentioned earlier.

The adopted mathematical modeling approach was subjected to a thorough calibration before its use for determining the sediment oxygen demand, with this intention. The results

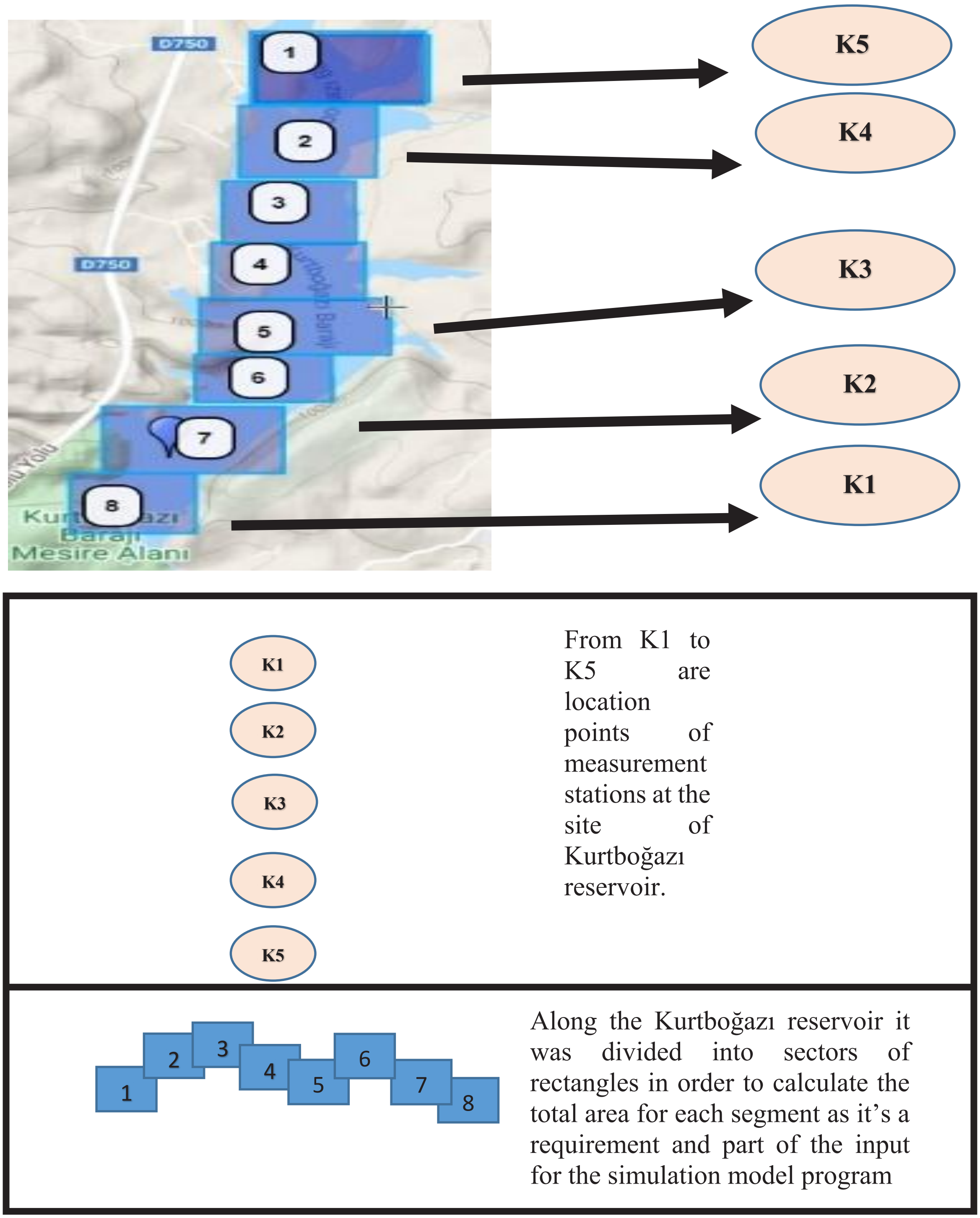


Fig. 2: Google map of Kurtboğazı reservoir with segments, Ankara Turkey, 40°16’10.92” N, 32°42’2.16” E, Google Earth, date accessed 1/3/2021, google.com/maps.

obtained from a series of calibration runs were compared with prescribed sets of field measurements. The purpose of executing calibration trials for specified periods was to find a suitable combination of numerical values for the model parameters and hence to obtain an acceptable match between model predictions and field data. The results of calibration were checked using statistical tools such as constrained regression analysis and the root mean of the square error will be presented in the results section. The calibration parameters based on total phosphorus, total Kjeldahl nitrogen, CBOD, and dissolved oxygen that was used are presented in (Table 2). However, it's important to point out that calibration is not limited to the above-mentioned parameters, it may include other state variables depending on the existing conditions of the water to be simulated.

Modeling Sediment Oxygen Demand (SOD)

After calibration of the model, the work will focus on the simulation of the sediment oxygen demand SOD model, as it's the rate at which dissolved oxygen is removed from the water column in surface water bodies due to the decomposition of organic matter in the bottom sediments, and it includes both the respiration rates of benthic communities and the chemical oxidation of reduced substances in the sediment. Since there is no available data on laboratory tests for the sediment at the Kurtboğazı reservoir we model the SOD then for the calibration of the result an equation was used by Sharma (2012), Sediment oxygen demand SOD is the rate at which dissolved oxygen is removed from the water column in surface water bodies due to the decomposition of inhibited organic matter at sediment, and it includes both the respiration rates of benthic communities and the chemical oxidation of reduced substances in the sediment, several factors affect the SOD rate, such as sediment age, surface area, depth of deposit, temperature, water velocity, and chemical and biological differences (Chen & Lung 2012) and (Fig. 3) is a conceptual drawing of the SOD and at sediment and water column. Since there are no available

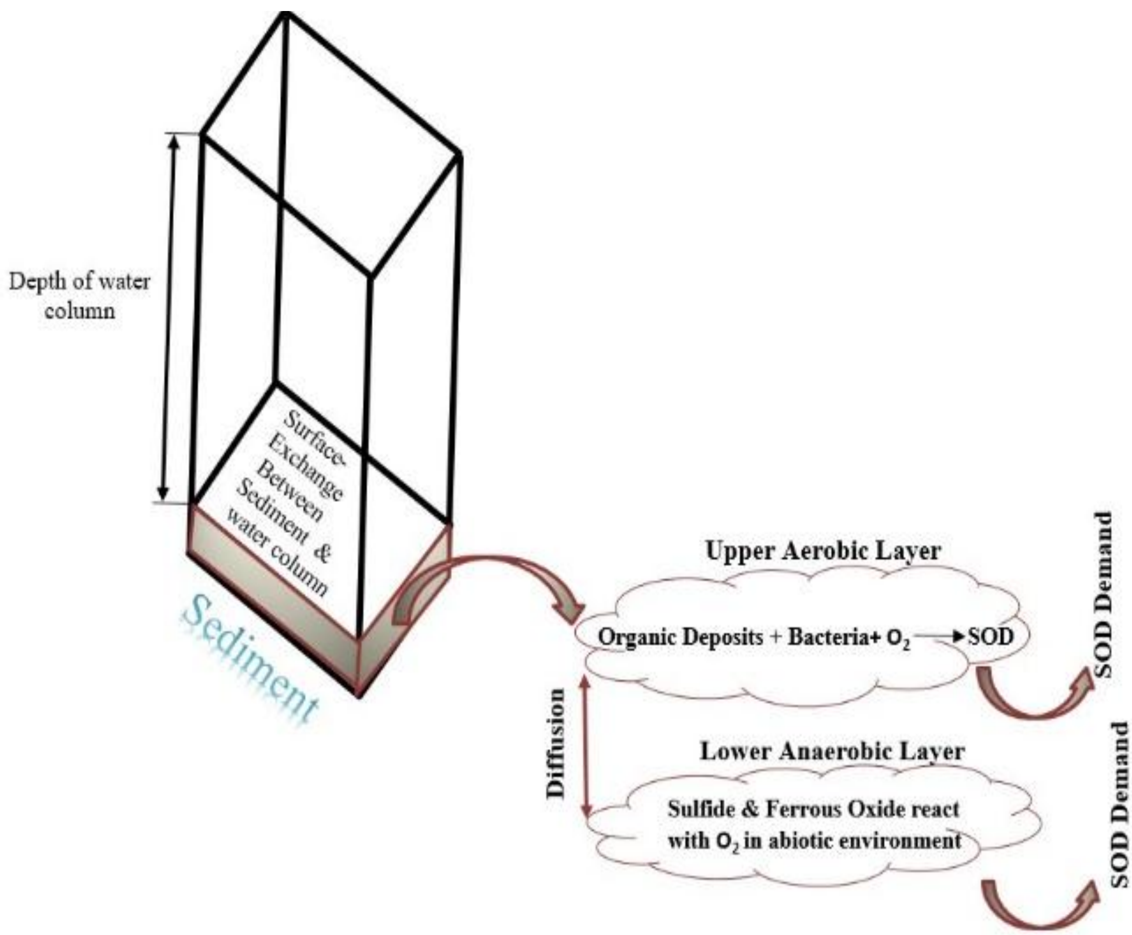


Fig. 3: Conceptual drawing of sediment oxygen demand between sediment and water column at Kurtboğazı dam reservoir.

data of laboratory tests for the sediment at the Kurtboğazı reservoir we are going to first model the SOD using the calibrated water quality model developed in this work then for the calibration of the result alternative steps are to be taken which will be explained in the following paragraphs, according to (Sharma 2012) the sediment oxygen demand could be calculated from the Total organic carbon (TOC) using the equation 14 (Sharma 2012).

$$SOD\ (g\ m^{-2}\ day^{-1}) = 0.0302 \cdot TOC + 0.0845 \quad \ldots(14)$$

Using the result from our model for TOC and applying it to eq. 14 and the results of segments 1, 2, and are given in (Table 3).

RESULTS

Kurtboğazı Dam Reservoir Simulation Model

The novelty of this work is to do with the fact that this simulation tool has not been used before for the Kurtboğazı reservoir water quality monitoring program, in general. This study focuses on anoxic and oxygen depletion due to stratification (Mahmud 2009) and sediment oxygen demand which increase in the summertime.

However, of the utmost important point to be emphasized at this stage is the difficulty I endured in the process of acquiring the data from the official institute in Turkey regarding one year of Kurtboğazı reservoir field data, obtained from the observation stations controlled by ASKI, for that I had to undergo a complex, lengthy and very exhausting process, having said that I consider myself lucky to even be able to obtain these data, and, in defense for the forthcoming situation regarding the limited availability of field data, there may be two directions of arguments: the first was initially confirmed by the ASKI official institute that in the last five years, the conventional data has been consistent, and no unusual or out-of-date data has been observed. Several additional parameters were employed in the model's calibration process, and the findings are shown in (Table 2). The results provided excellent variance in the dependent variable with readily available field data.

Once the model was executed, it was subjected to a thorough calibration before its use for determining the sediment oxygen demand. With this intention, the results obtained from a series of calibration runs were compared with prescribed sets of field measurements. The results of calibration were then checked using statistical tools as presented in (Table 2) of the model. Results starting from May to the end of the year 2019 included all the state variables: temperature, nitrate, dissolved oxygen, total phosphorus, chlorophyll-a, total Kjeldahl nitrogen, CBOD, and ammonium at segments 1, 2, and 8. The last four columns are applying the statistical analysis methods to check the accuracy of model results with actual measured data from the site, the first method used is R squared R^2 which is a statistical measure of how close the data are to the fitted regression line between measured field data and the model result and from (Table 2) our range for the state variables is between 0.86 and 1.0 according to (Moriasi et al. 2007), higher values indicating less error variance and are acceptable, inspection of (Table 2) Root mean square error RMSE is the root mean square error of approximation its absolute measure of fit, our range result for RMSE from 0.2 to129 according to (Mielke & Berry 2001, U.S. EPA 2003) and (Burger et al. 2008) RMSE has no clear interpretation or related measures, and therefore calibration of our model will not be based on these techniques, the column of mean absolute percentage error MAPE resulting to be a very large value even though the model appears to fit the data well, this is because MAPE divides the absolute error by the actual data when the values are at times closer to 0 can greatly inflate the result of MAPE. The last column of (Table 2) is the relative error RE between simulated and measured data. RE are all less than 1 which indicates good results according to Hazewinkel (2001). Except for the Nitrate which is: 1.86, 1.52, and 1.78 for segments 1, 2, and 8 respectively. So, another test was performed only on this data of nitrate to ensure the model results are performing well since the R^2 for Nitrate

Table 3: SOD result from simulation of model with SOD from the equation at segments 1, 2 and 8.

	Month	DOC-Model	SOD-from Equation	SOD-from Model		Month	DOC-Model	SOD-from Equation	SOD-from Model		Month	DOC-Model	SOD-from Equation	SOD-from Model
Segment 1	July	0.94	0.11	0.52	Segment 2	July	1.1	0.12	0.5	Segment 8	July	1	0.11	0.48
	Aug.	0.96	0.11	0.42		Aug.	1.1	0.12	0.46		Aug.	1.09	0.12	0.47
	Sept.	1.18	0.12	0.4		Sept.	1.26	0.12	0.39		Sept.	1.17	0.12	0.41
	Oct.	1.24	0.12	0.39		Oct.	1.24	0.12	0.39		Oct.	1.22	0.12	0.38
	Nov.	1.24	0.12	0.39		Nov.	1.24	0.12	0.38		Nov.	1.26	0.12	0.36

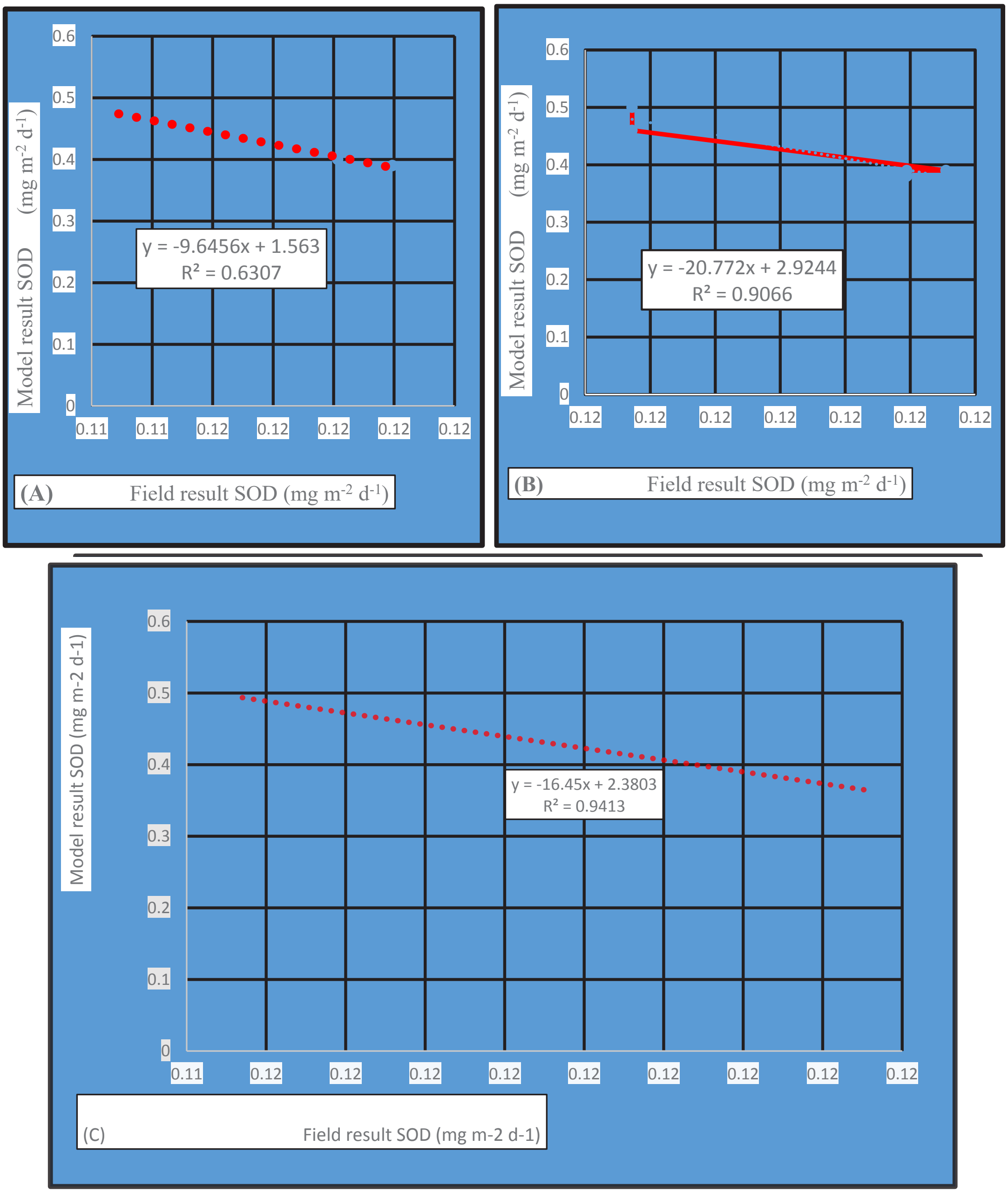


Fig. 4: Statistical test R^2 for SOD model and SOD equation. (A) R^2 =0.63 calibration result for segment 1, (B) R^2 =0.91 calibration result for segment 2, (C) R^2 =0.94 calibration result for segment 8.

results is high. The results of NSE for the state variable of nitrate were 0.9, 0.84, and 0.92 for segment 1, segment 2, and segment 8 respectively, according to Moriasi, 2007 NSE > 0.75 is very good.

In (Table 2) of the model, the result starting from May to the end of the year 2019 for the state variables include temperature, nitrate, dissolved oxygen, total phosphorus, chlorophyll-a, total Kjeldahl nitrogen, CBOD, and ammonium at segments 1, 2, and 8. The last four columns are used to show the results of calibrating the model results with actual data obtained from the site. By applying statistical techniques, we can determine the accuracy and apply the statistical analysis methods to check the accuracy of model results with actual measured data from the site. The first method used is R squared (R^2). Our range for the state variables is between 0.86 and 1.0 and the second test from (Table 2) was the Root mean square error (RMSE), which is the root mean square error of approximation. The last column of (Table 2) is the relative error RE between simulated and measured data, RE is all less than 1 except for the Nitrate which is: 1.86, 1.52, and 1.78 for segments 1, 2, and 8 respectively. So, another test was performed only on this data of Nitrate to ensure the model results are performing well since the R^2 for Nitrate results is high. The results of NSE for the state variable of nitrate were 0.9, 0.84, and 0.92 for segment 1, segment 2, and segment 8 respectively. The simulation process of the Kurtboğazı dam reservoir does not require daily input to the WASP8 system. As mentioned before, there are certain requirements of input data as part of the configuration pattern to build the system representing the actual state case and circumstances for Kurtboğazı reservoir. In addition to this, the user may have an allowance of daily prediction outcomes from the simulation model of different state variables depending on the initial purpose of the model.

Sediment Oxygen Demand SOD

Since there is no available data for sediment oxygen demand SOD at the site, we need to ensure that our model result is representative of SO. At the site we used an equation from Sharma (2012) (eq. 11). The results are presented in (Table 3) for segments 1, 2, and 8 respectively, and displayed in (Fig. 4). However, the next step would be the calibration of results using R^2 and RE to compare the SOD model and SOD from the equation with results in (Table 4) and (Fig. 5).

The model successfully simulated the sediment oxygen demand and the results which display high values for R^2. For segment 1, the R^2=0.63, segment 2 the R^2=0.91, and for segment 8 the R^2=0.94. The reason that R^2 is much lower in segment 1 than in the other locations could be because segment 1 is the inlet point arriving from the Inceĝez tunnel to Kurtboğazı reservoir and there could be unaccounted nutrients that are entering the reservoir and causing the different SOD values. According to Santhi et al. (2001) and Van et al. (2003) values of R^2 greater than 0.5 are considered acceptable.

Internal Nutrient Loading

The model also simulated other phenomena occurring at sediment that contributed to increased levels of SOD at segment 8 or the measuring station at site K1. An overall dissolved oxygen deficiency at the water column, as in internal phosphorus from anoxic sediments, affected water column nutrient concentrations and ratios of total nitrogen over total phosphorus or TN: TP at the reservoir, in that perspective another parameter PO_4 flux to the water column in (mg P.m^{-2}.day^{-1}) would increase the internal loading release and thus decrease DO at the reservoir. Nutrient flux rates from the sediment represent the net result of various microbiological, chemical, and hydrodynamic processes. This cycle coincides with the development of anoxia in the overlying water. Phosphorus release involves the development of anoxia in the water column, resulting in the creation of reducing conditions in the sediments, with associated changes in the iron-phosphorus complexes, in an oxidizing environment. Iron is in the insoluble ferrous form and the formation of iron in the soluble ferric form with the release of bound phosphorus is usually marked by the development of anoxia condition. These results are in line with previous results (Dunalska et al. 2004) all the ratios of TN: TP is based on the model result presented in (Table 5). Internal Phosphorus from anoxic sediments affected water column nutrient (ElçI et al. 2008) concentrations and ratios of total nitrogen to total

Table 4: Statistical tests of R^2 and RE used to describe accuracy between the SOD model and SOD equation.

Diagenesis Model	Segment	R square	RE relative error
Sediment oxygen demand SOD	Segment 1	0.63	0.73
	Segment 2	0.91	0.71
	Segment 8	0.94	0.61

Table 5: Ratio of total nitrogen to total phosphorus simulated by the model at segment 8.

Month	TN	TP	Ratio=TN:TP ratio	Note
7	156	50	3	Ratio<9 N limited
8	209	41	5	Ratio<9 N limited
9	380	30.1	13	<9 Ratio <22
11	384	16.4	23	Ratio> 22 P limited

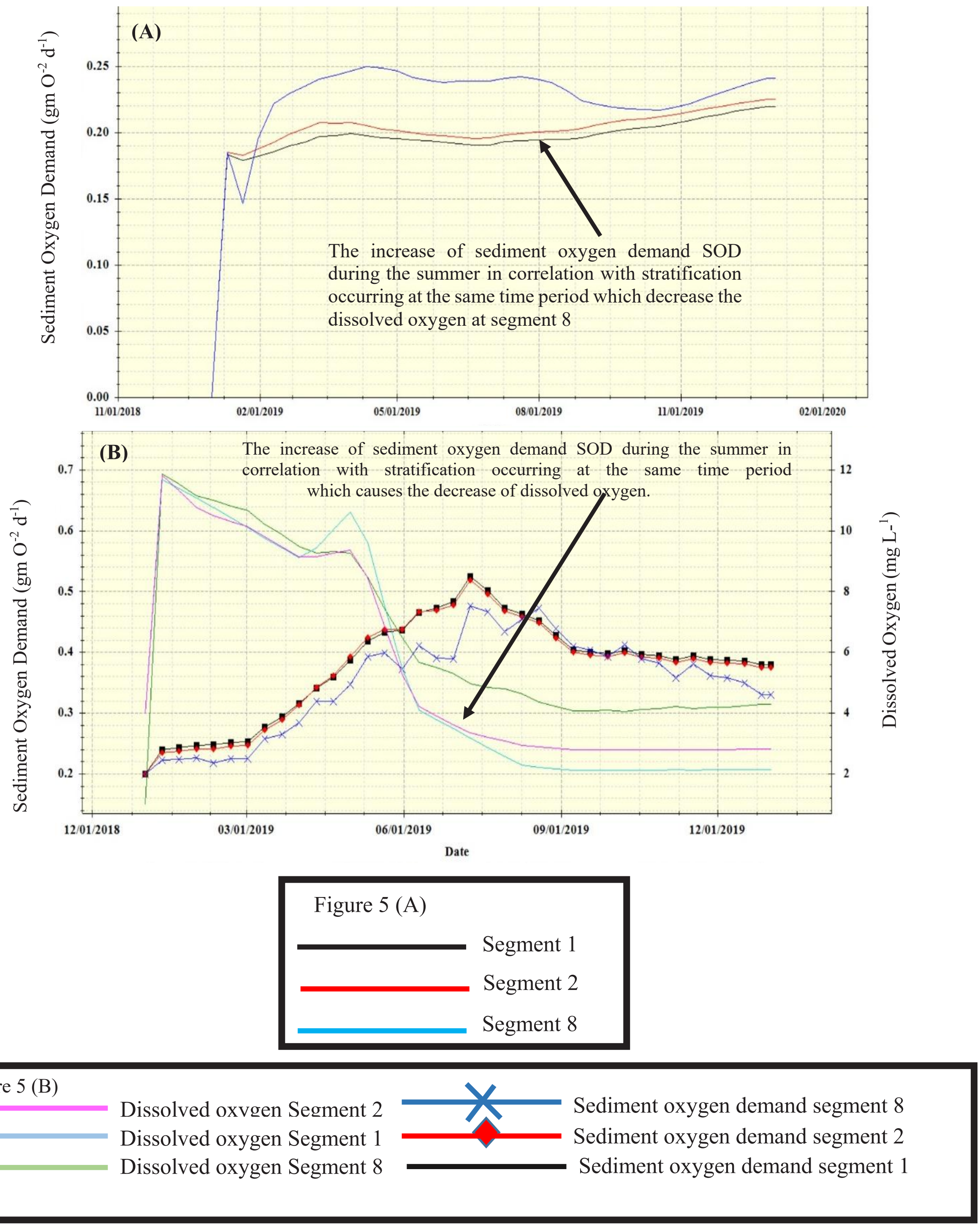


Fig. 5: SOD from the model at Kurtboğazı dam for the segments 1,2 and 8. (A) display the SOD of segment 8 being higher than in segment 1 and 2 specifically in the summer time with an increase of SOD due to stratification. (B) significantly show highest SOD cause lowest values in dissolved oxygen at water column

phosphorus or ratio of TN: TP at the reservoir (Benoit et al. 2006) and (Nikolai & Dzialowski 2014): If TN: TP ratio > 22 indicates Phosphorus limitation. TN: TP ratio <9 indicates Nitrogen limitation and if 9< TN: TP ratio<22, it indicates P and N co limitation. As the temperature disparity between the warmer layer above and the cooler layer below increases in the late summer, the thermocline, a layer of water more frequently observed in a big body of water, decreases.

Model Validation

Calibration always trains the model for certain hydrological conditions, which are those resembled by the observed data When used in so-called "out of sample settings," i.e., hydrological conditions that differ considerably from those referred to in calibration, the model may offer less desirable results in terms of what resulted from calibration. This is a key practical issue that may have a detrimental influence on the reliability of engineering design, because of the uncertainty that affects hydrological models, validation is always important in model simulation design. After calibration and before utilizing it in reality, the literature has proposed more extensive validation techniques, such as cross-validation applications. This type of testing is known as validation. The word validation is often used in hydrology and environmental modeling to describe a technique for examining the performance of simulation and/or forecasting models. In the scientific environment, the word validation has a broader definition that includes any method that aims to test a procedure's capacity to fulfill a certain scope. In other words, it's the degree needed for the model's intended purpose or application, and this is achieved by determining the representative output of our simulation model. This is achieved by tracing the intermediate results and comparing them with observed outcomes. This method involves investigating the intermediate interaction between key variables in the system. In our case, the dissolved oxygen and sediment oxygen demand is selected as it has a high influence on the overall system. By utilizing the correlation coefficient we trace the correlation of SOD DO, temperature, and chlorophyll a with other state variables and compare with the outcome, to reach this notion Pearson's coefficient was used to measure validity, its correlation is widely used to validate the strength of an existing linear relationship between variables, and it assesses the linear relationship between quantitative variables (Zhuhua et al. 2019, Ernst et al. 2009). Pearson's correlation coefficient is a way of determining if two variables have a close relationship, it is defined as the quotient of the covariance and the standard deviation of two variables as shown (Table 6) shows the outcomes of the calculations, the segment that was selected is segment 8, the reason for this choice is due to the fact segment 8 represents the discharge point from the reservoir and according to site field data it's the critical point where the seasonal stratification and oxygen depletion occurs seasonally. The sediment oxygen demand has a high correlation with dissolved oxygen, temperature total phosphorus, and nitrate, and this result is confirmed by many studies earlier that nutrients can increase eutrophication and later on increase SOD (Mackenthun et al. 1999, Micelis et al. 2005, Belo et al. 2008, Rong et al. 2016). Dissolved oxygen is correlated with a SOD of 0.77 and temperature of 0.79 this is in accordance with previous studies (Lantrip et al. 1987, Hupfer & Lewandowski 2008, Sharma 2012, Wei-Bo et al. 2012, Akomeah & Lindenschmidt 2017). The DO and the nutrients' total phosphorus (0.66), and nitrate (0.65), have a moderate association. Previous studies supported this finding (Lindenschmidt et al. 2009, Rong et al. 2016, Bierlein et al. 2016, Julie & Lindenschmidt 2017), as given in (Table 6) there is also a weak correlation between dissolved oxygen and chlorophyll 0.28 (Chen et al. 2019) and a high correlation between dissolved oxygen and sediment oxygen demand 0.77 while the CBOD and dissolved oxygen are negatively highly correlated -0.70 (Oskar et al. 2020), which is often observed the inverse strong relation between CBOD and dissolved oxygen (Chowdhury et al. 2014, Lindenschmidt et al. 2017, Chai & Draxler 2014). Our model was validated based on the concept of using Pearson's correlation coefficient and the

Table 6: Application of Pearson correlation to variables at segment 8.

State variables	Sediment oxygen demand	Dissolved oxygen
Dissolved oxygen	0.77	
Temperature	0.89	0.79
Total Phosphorus	0.89	0.66
NO_3	0.96	0.65
CBOD	-0.68	-0.70
Chlorophyll a	-0.7	-0.28
Sediment oxygen demand		0.77

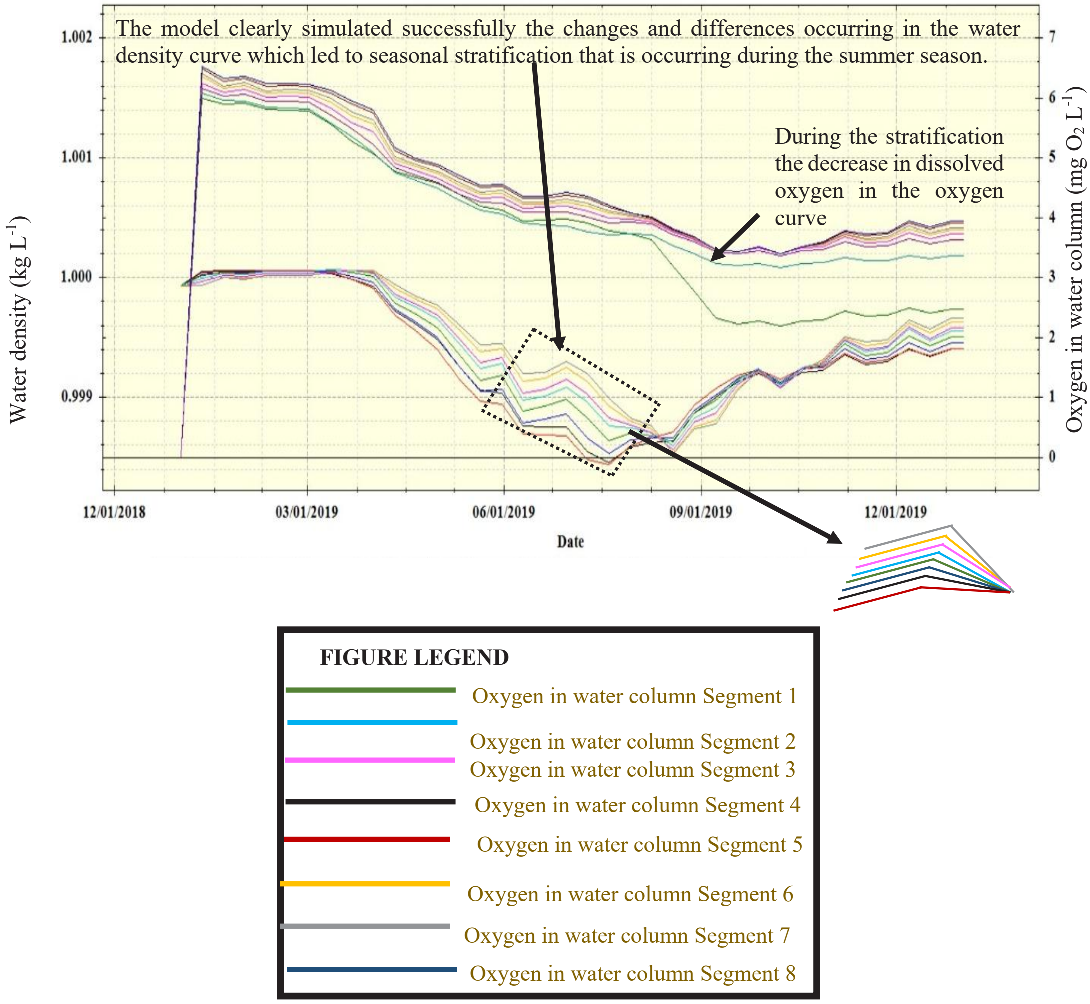


Fig. 6: Water density and dissolved oxygen level in the water column along with the dissolved oxygen for all 8 segments.

state variables in the model, which we checked and validated with previous research.

DISCUSSION

As stratification is a process of generating thermal layers in a reservoir or a lake in summertime, the water temperatures at the upper layer become warmer while the bottom layer is colder. This leads to an increase in the differences in the temperatures between the upper layer and bottom layer. In the case of temperature differences, it results in differences in densities, thus resulting in thermal stratification (Mahmoud 2009, Şebnem 2008), the recurrence was successfully simulated by our model as presented in (Fig. 6). According to previous research (Chen et al. 2019, Jin et al. 2006, 1998, Pan et al. 2009, Schlezinger 2010, Testa et al. 2013, Haan et al. 1995). From the simulation result of our model and by examining (Fig. 7), we conclude that with increasing total phosphorus and peak maximum value of total phosphorus; water temperature; Nitrate; dissolved oxygen corresponded to the highest SOD value.

Mineralization of nitrogen includes the processes by which organic compounds are decomposed and converted to ammonium and nitrate. The formation of complex nitrogen compounds occurs due to their assimilation and immobilization. The major nitrogen-related processes that occur in the aquatic environment are ammonification, nitrification, and denitrification.

The model simulated is shown in (Fig. 8). At observation station K1 or segment 8 in the model, the impact of anoxic conditions on the SOD and fluxes for ammonium, nitrate, and phosphorus is shown in graph 8 (A) of nitrate benthic flow and the negative sign indicates the movement of nitrate from the water column to sediment in summer at station K1 or segment 8 for the same graph 8 (B) PO_4 benthic flux displayed a seasonal cycle with elevated fluxes in the spring and summer and reduced fluxes in the fall. Reaching a minimum in the winter, this cycle coincides with the development of anoxia in the overlying water. Finally, the examination of graph 8 (C) displaying the dissolved inorganic phosphorus benthic flux, shows an increased movement of available phosphorus from sediment to the water column as anoxic conditions rise in summer and ammonium benthic flux variability is observed in spring and summer. On the whole, the reduction in flux to sediment in summer reflects a temperature or biological community dependency.

Our model displays (Table 5) the TN: TP ratio shift from N limited during the summer to P limited at the beginning of winter, and the results are in accordance with previous

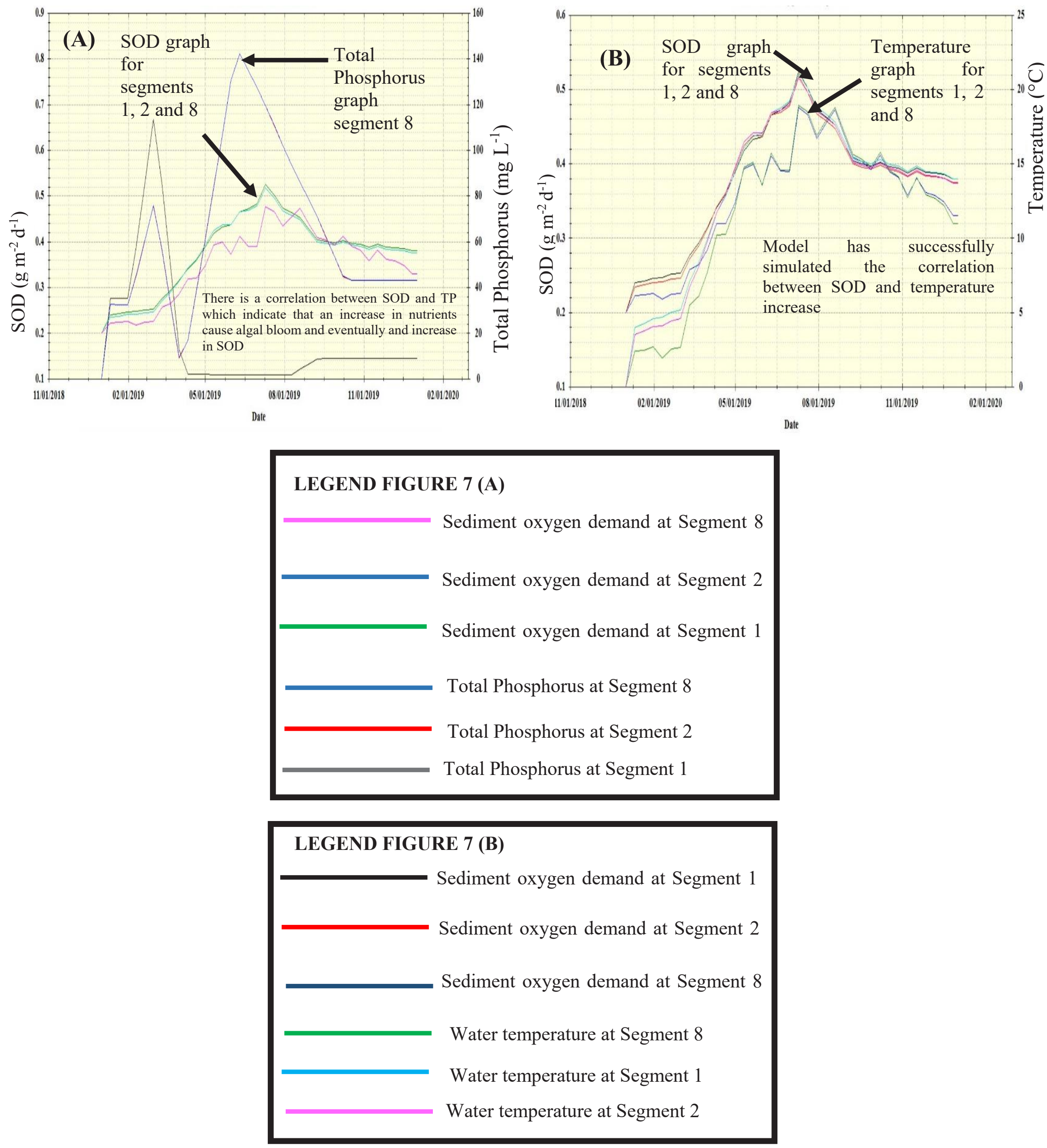


Fig. 7: The state variables that influence the sediment oxygen demand according to our model simulation result.

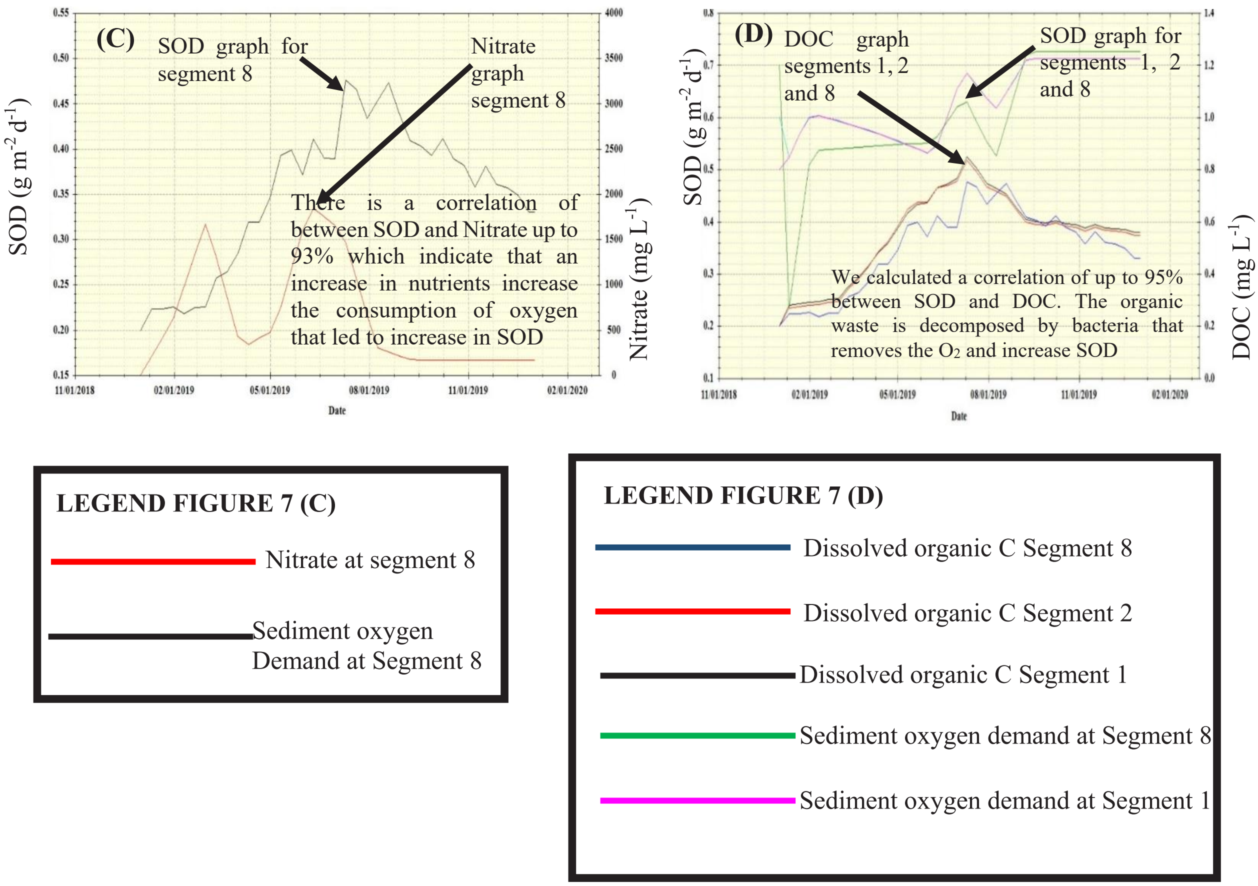


Fig. 7: (continue) the state variables that influence the sediment oxygen demand according to our model simulation result.

research (Jensen & Anderson 1992 & Rahman et al. 2008). Internal P can build up in the hypolimnion and help to lower TN: TP ratios and potentially create N limiting conditions in the epilimnion, this was confirmed by previous studies that have similarly shown that internal Phosphorus loading can play an important role in late season P concentrations and algal blooms (Bierlein et al. 2016, Coppens et al. 2020). The increase of N_2 gas in the water column during the stratification phase, which explains why the N was limited for the TN: TPN ratio at that time, can be seen as another significant signal from the results of the simulated model by examining the denitrification flux from sediment in (Fig. 9). Finally, the curve in (Fig. 10) explores the DO probability for segment 8, showing in detail that dissolved oxygen below 2 (mg.L^{-1}) was only less than 3 percent of the time during the anoxic period and this is in alignment and accordance with field results from ASKI (2021)

CONCLUSION

- As a valuable numerical tool for numerical modeling of river water quality and temperature evolution, a full hydrodynamic and water quality model has been developed to estimate complicated temporal relationship situations in each of the physical processes that exist in real-life environments. Kinetic equations, for example, are physical processes, to this end, tributaries, abstractions, and heat fluxes are provided to simulate the yearly change in water depth, discharge, and temperature. A finite difference method was used to solve the resultant system of equations volume composition that promotes consistent and conservative performance solutions across all flow regimes.
- The suggested model may correctly and reliably depict the reality of the interactions between hydrodynamics and quality parameters after it is thoroughly calibrated and validated, as a result, the integrated model can estimate water quality in a variety of settings, this tool may be valuable to the entities delivering this service since it will allow them to decrease and accurately identify the placement of the quality measurement stations.

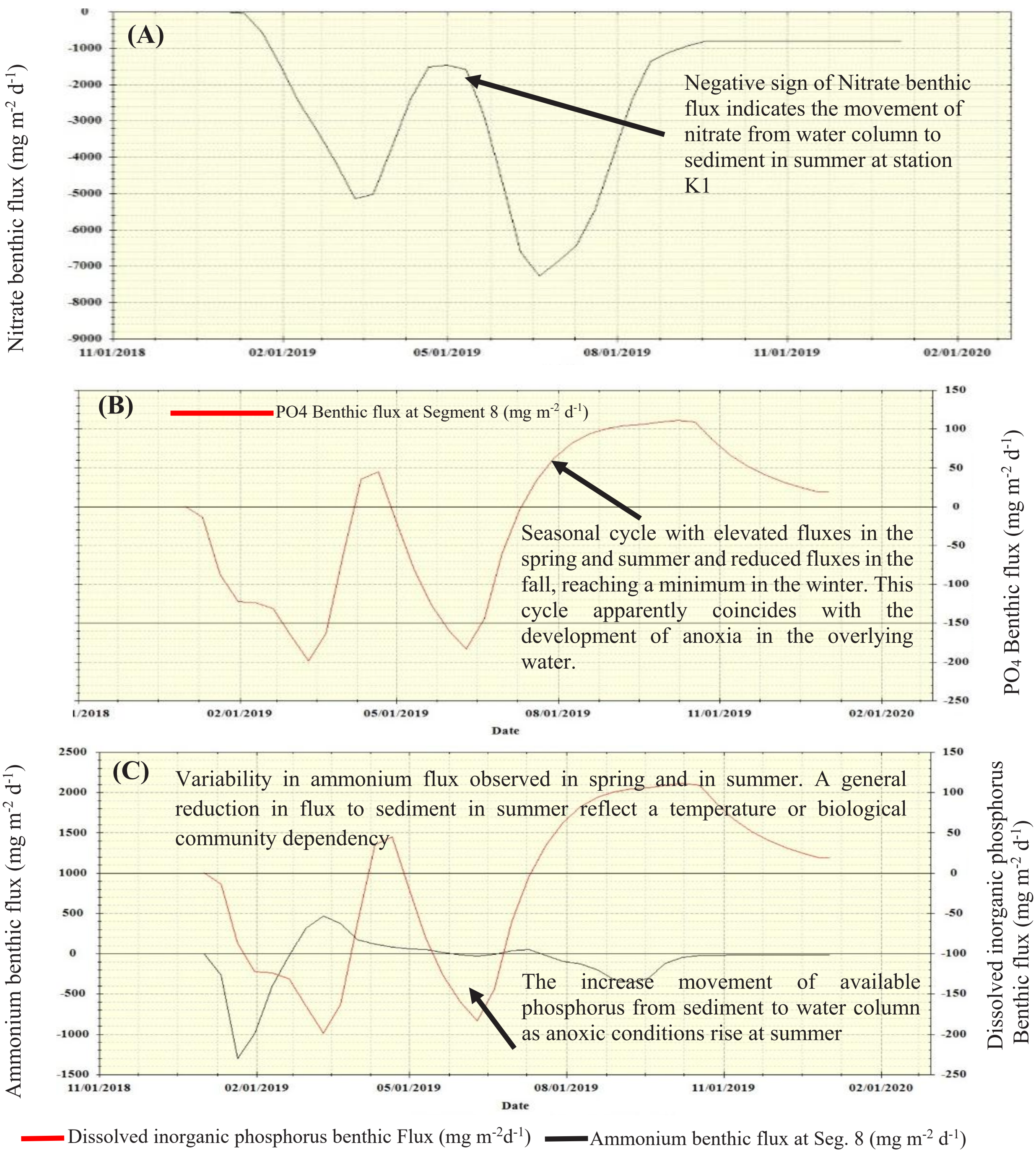
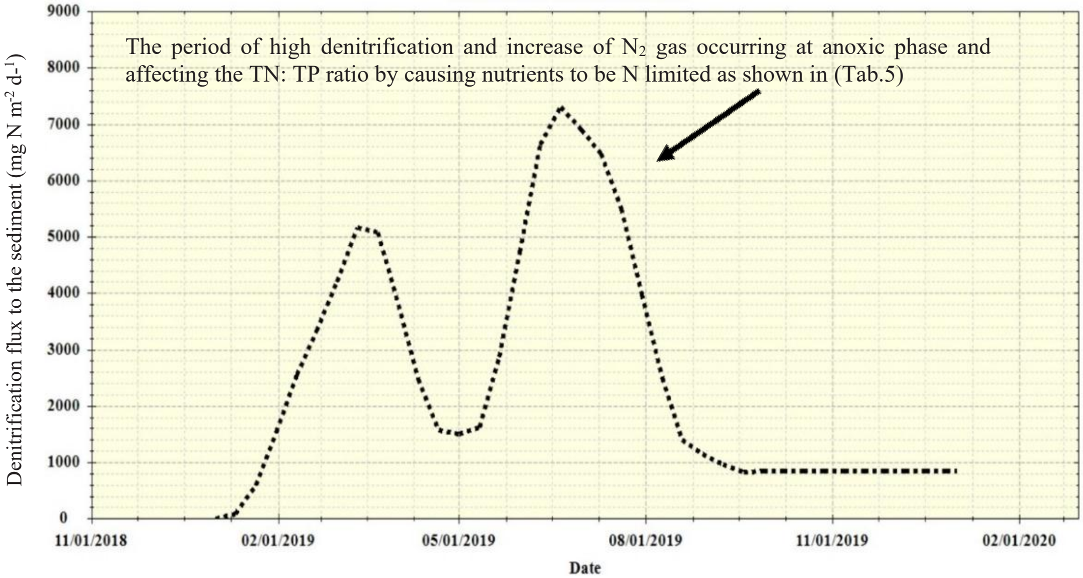


Fig. 8: The effect of anoxic conditions on the SOD and fluxes for ammonium, nitrate, and phosphorus at observation station K1 or segment 8 in the model.

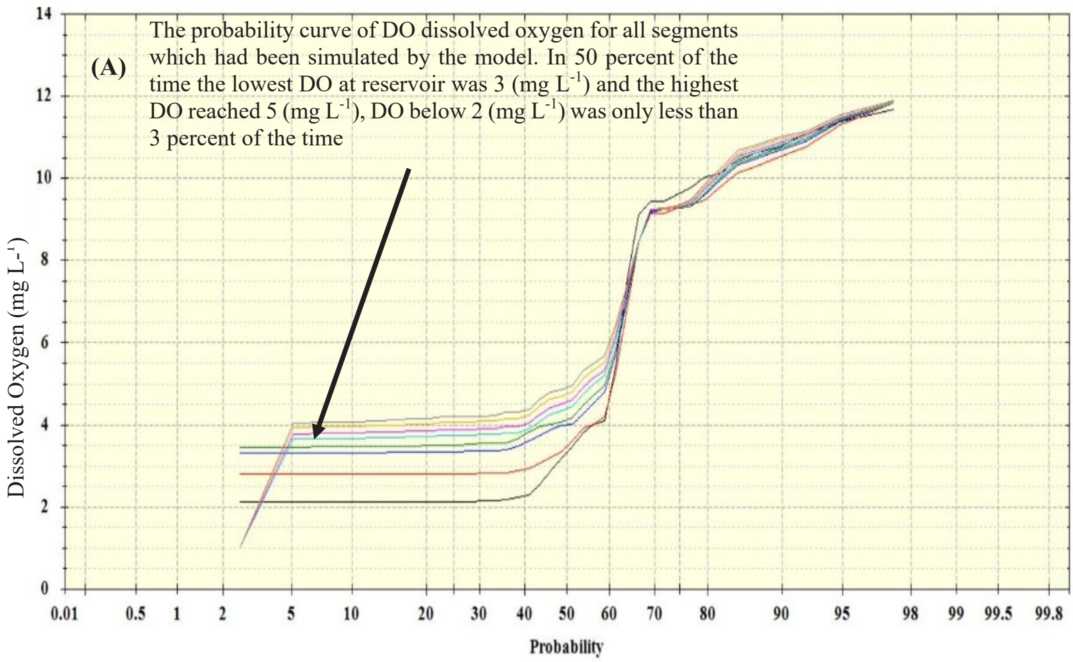
- The effect of anoxic conditions on nitrate benthic flux causes the movement of nitrate from the water column to sediments in summer at station K1 or segment 8, regarding the PO_4 benthic flux at seasonal cycle with elevated fluxes in the spring and summer and reduced fluxes in the fall, reaching a minimum in the winter. This cycle coincides with the development of anoxia in the overlying water.
- As for the effect of anoxic conditions on inorganic phosphorus benthic flux, it increases the movement



LEGEND FIGURE 9

Denitrification flux to the sediment (mg N m^{-2} d-^{1}) at segment 8

Fig. 9: Denitrification flux at anoxic phase from sediment to water column at segment 8.



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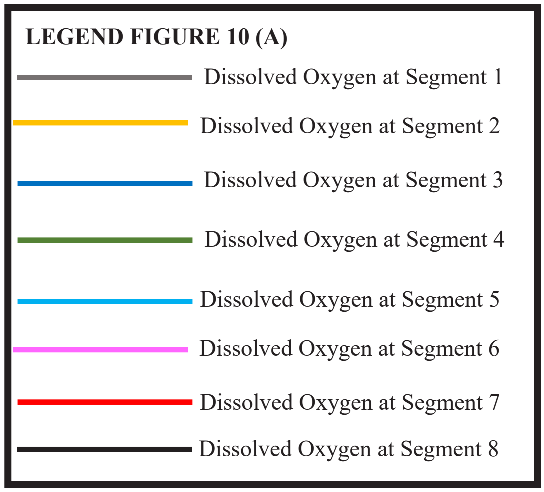

Fig. 10 A: Probability curve and simulated model result for dissolved oxygen for all segments of the model.

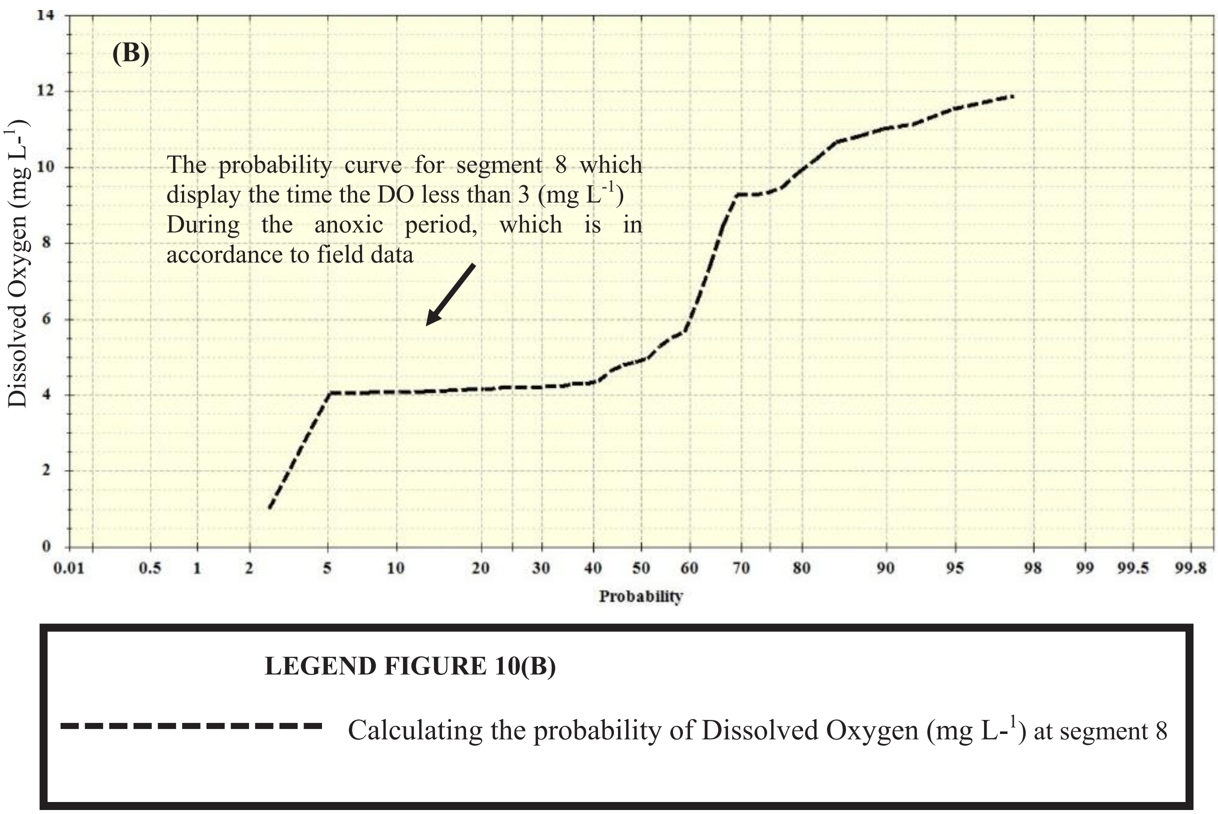

Fig. 10 B: Probability curve and simulated model result for dissolved oxygen for all segments of the model.

of available phosphorus from sediment to the water column as anoxic conditions rise in summer and ammonium benthic flux variability is observed in spring and summer. A general reduction in flux to sediment in summer reflects a temperature or biological community dependency - the period of high denitrification and increase of N_2 gas occurring at an anoxic phase and affecting the TN: TP ratio by causing nutrients to be limited as simulated by the model.

- In segment 8, there is a positive association between SOD and dissolved organic carbon, total phosphorus, temperature, and nitrate, which is evidenced by the anoxic situation and oxygen depletion that took place over the summer.
- The probability curve of DO dissolved oxygen for all segments had been stimulated by the model. 50 %, of the time the lowest DO at the reservoir, was 3 ($mg.L^{-1}$) and the highest DO reach 5 ($mg.L^{-1}$), dissolved oxygen below 2 ($mg.L^{-1}$) was only less than 3 percent of the time.
- Our model was further validated using the Pearson correlation coefficient with results that were in accordance with previous research and model work, which confirmed the validity of our model results.

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