Waste water discharge impact modeling with QUAL2K, case study: the Zayandeh-rood River

Nader Nakhaei

Amir Etemad Shahidi

International Environmental Modelling and Software Society (iEMSs)
2010 International Congress on Environmental Modelling and Software
Modelling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada
David A. Swayne, Wanhong Yang, A. A. Voinov, A. Rizzoli, T. Filatova (Eds.)
http://www.iemss.org/iemss2010/index.php?n=Main.Proceedings

Waste water discharge impact modeling with QUAL2K, case study: the Zayandeh-rood River

Nader Nakhaei (1), Amir Etemad Shahidi (2)
(1) Nader_Nakhaei@civileng.iust.ac.ir
(2) etemad@iust.ac.ir

Abstract:
One of the most significant hydrological resources are rivers (especially for drinking water). Stream simulation or modeling is a common cost-effective way for water quality monitoring and predicting the future quality of rivers and streams.
This paper describes and demonstrates the application of the U.S environmental protection agency's water quality model, QUAL2K, to The Zayandehrood River, one of the biggest Rivers in Iran and Middle East, and also a way to increase dissolved oxygen in order to optimize the water quality, simulation of affixing a weir and even more. First of all, the river's hydraulic factors such as roughness are precisely calibrated and subsequently with the first set of data according to biochemical oxygen demand and dissolved oxygen the model is calibrated. In the next step along with above mentioned calibration, validation is done with the second set of data. Afterwards to find out if weirs will ameliorate water quality, a critical condition applied with 20% increase in loads which enforced to the model to simulate effect of weirs on the water quality in this predicament. Investigation of results in calibration and especially validation showed that zayandehrood's water quality is poor downstream of industrial areas due to waste water discharges and dissolved oxygen is even under 5 mg/l in downstream hence biochemical oxygen demand is high downstream of industrial plants. On the other hand simulating affect of weirs in critical conditions indicates that this method will increase dissolved oxygen (DO) downstream of the weir.

Key words: QUAL2K, Local oxygenation, Zayandehrood River, Weir

1. INTRODUCTION:

A big amount of agricultural, municipal and industrial wastewaters discharges to water bodies around the world. These discharges of degradable wastewaters in water bodies result in decrease in water quality generally and particularly DO (Dissolved Oxygen) concentrations. According to above mentioned problems of wastewater discharges, it is important to manage the water quality of hydrological sources and predict the impact of contaminants on them. Rivers and streams are one of main sources that suffer a big amount of pollutant loads and wastewater around the world.
Mathematical models are a way to describe relations between waste loads and water bodies and to describe concentration of each contaminant due to the receiving water body's characteristics.
One of widely used mathematical models for streams and rivers is USEPA's QUAL2E-UNCAS (Brown and Barnwell, 1987). Several inadequateness of Q2E has been reported during these years which lead to developing a new version. Qual2k is the newest version of Qual series which developed to cover limitations of previous versions. Although, Qual2k is limited in simulating streams and rivers quality in a one-dimensional steady state condition, it includes DO interaction with fixed plants and it taken bottom algae into account with CBOD (Carbonous Biochemical Oxygen Demand).

A water quality modeling study on The Nakdong River in Korea performed by both Qual2k and Qual2e, displayed that the latest version of these series were more accurate due to field measurements than the former one (Park and Lee, 2001). Another application of Qual2k for water quality modeling in The Bagmati River showed that, the model represented the field data pretty accurate. In this study various water quality management options taken into account to control DO, such as pollution loads modification and local oxygenation (by affixing weirs). Apparently local oxygenation is effective in raising DO levels (Kannel et al, 2006). The Qual2k can not take groundwater contribution of stream into account. Therefore, in some cases contaminant's concentration underestimates (Azzellino et al, 2006).
The Zayandehrood River, located in hearth of Iran, is simulated with Q2K model. A former study with Q2E which applied on The Zayandehrood River showed that industrial, municipal and agricultural wastes decrease the concentration of DO and increase concentration of CBOD in some reaches. However, it has been reported that lack of hydraulic data and inaccurate quality measurements was a problem. In this report The River had been divided into 8 reaches (Abrishamchi et al, 2005).
The QUAL2K has been chosen for this study because; the flow condition is almost steady in The Zayandehrood River.
However, few studies have reported on simulating the water quality of The Zayandehrood River, but, there is little information available on giving quality control management options. Another advantage of this investigation is that The River is separated in 18 reaches which is more detailed and accurate in compare with former studies.
In this study with two sets of more detailed hydraulic data and relatively more accurate field measurements data of DO and CBOD that are newer than previous studies on this case, the River first and foremost has been calibrated and then validated. Due to poor condition of water quality which have been generated from first step (low DO concentration), it is necessary to control the situation with performing different ways of management in order to prevent the quality from worse situations. A way that applied in this simulation is local oxygenation with weir which has been a good choice for improving water quality levels by increasing the amount of DO. The main purposes and objectives in this investigation were: to test the model's ability on simulating stream's quality, to diagnose wastewater discharges impact on streams, to take the affect of local oxygenation into consideration.

2. STUDY AREA AND METHOD

2.1 Study Area

The Zayandehrood River is one of the biggest rivers in Middle East which located in the center of Iran around Isfahan city. It emanate from Dimeh spring which is located within 140 km distance from Isfahan. The river's length is about 360 km with a drainage area around 4200 km^2 (Figure 1). From The Zayandehrood Reservoir an adjusted flow is releasing and till Kaleh Bridge it is clean because of mountainous area and also due to no discharge. Water flows in a valley in this reach and agricultural farms are not distributed in these parts.

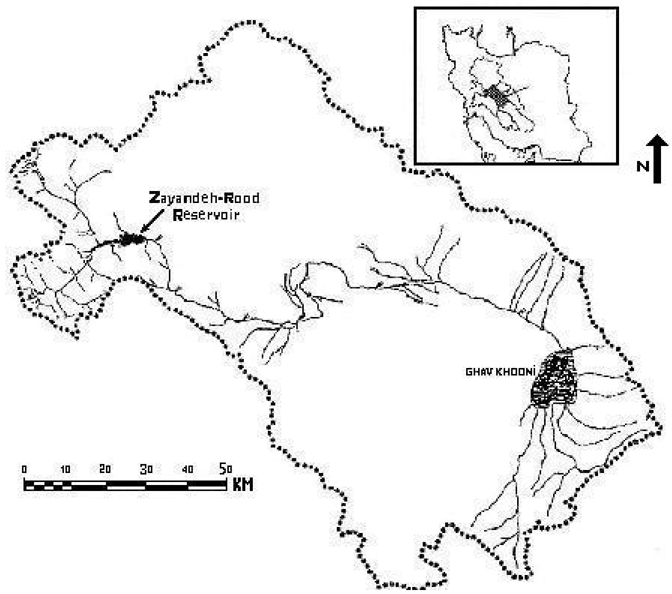

Figure 1- The Zayandehrood River location and drainage area

As above mentioned condition, water will stay clean until Kaleh Bridge but after this area various pollutant loads are discharges to river and the quality becomes really poor. Afterwards, the Zayandehrood River will flow toward the Varzaneh village and after that it will divide into several branches and run through Ghav-khooni Swamp and finally drains into it.

There are so many big and small industrial plants that pollute the river directly or indirectly. Not only they discharge their waste with an incomplete treatment into the river, but also, Bunch of them discharges their raw waste.

In parallel with above mentioned discharges, some other plants may not discharge their waste into the river but the contaminants may leak to the river by polluting the ground water sources. There are several cities and villages along the river which discharge their raw or partially treated wastewater into the river (Abrishamchi et al., 2005).

The Abshar Treatment plant which located in east of Isfahan city discharge municipal wastewater of Isfahan and some other smaller cities around after treatment but this plant's output is poor because of low capacity as some times raw waste discharges to the river. From this point onwards the quality of water begins to decrease rapidly as DO concentrations become low and CBOD rise.

These problems and Zayandehrood River's vital role indicate that a water quality management required for this situation in order to predict the future quality and also to impede the water quality of getting worse.

2.2 Modeling tool

In The Qual2k model the River will be divided into several reaches and each reach will be divided into equal segments. These segments are model's shortest parts of simulation. This model can simulate fate and transport of so many parameters and contaminants such as temperature, BOD, DO, phytoplankton, various kinds of nutrients, PH and etc.

Qual2k has a general mass balance equation (1) for a constituent concentration C_i in a water column of reach i:

$$\frac{dc_i}{dt}=\frac{Q_{i-1}}{V_i}c_{i-1}-\frac{Q_i}{V_i}c_i-\frac{Q_{ab,i}}{V_I}c_i+\frac{E_{i-1}}{V_i}(c_{i-1}-c_i)+\frac{E_i}{V_i}(c_{i+1}-c_i)+\frac{W_i}{V_i}+S_i$$

Where Q_i = Flow at reach i (m^3/s), $Q_{ab,i}$ = Abstraction flow at reach i (m^3/s), V_i = Volume of reach i (m^3), W_i = Loading of pollutant to reach i (mg/s), S_i = Sources and sinks of the pollutant including reactions and mass transfer ($mg.s/m^3$), E_i =Dispersion coefficient between reaches i and i+1 (m^3/s), E_{i-1} = Dispersion coefficient between reaches i-1and i (m^3/s) and t= time (s).

2.3 Method

The Zayandehrood River has been divided into 18 reaches according to field measurements of the River's characteristics. All the reaches are divided into several elements which they are roughly 1km each. Actually, there are 9 measuring points that measure the River's characteristics: depth, width, velocity and flow (Table1). Destination between each of these points is considered as two reaches that the slope of these two are equal but rivers width in them are different due to mentioned measuring points.
There are two set of data from dry and wet season which applied to calibrate and validate the model. After these two steps, a 20 percent increase will be applied to waste loads because; it will help the modeling to be more realistic about future population and also industrial and agricultural development around Isfahan city. With this condition applied to the model a critical scenario will be simulated. From this part onwards, water quality management option (local oxygenation) will be taken into account.

Reach\ Measuring point upstream	Length (km)	Width (m)	Slope
1\Tanzimi	25	63.7	0.0022
2	25	58.5	0.0022
3\Zamankhan	31.5	58.5	0.0021
4	31.5	44	0.0021
5\Kaleh	13.65	44	0.0026
6	13.65	41.5	0.0026
7\Dizicheh	2.31	41.5	0.0017
8	2.31	44	0.0017
9\Lenj	14	44	0.0018
10	14	36	0.0018
11\Moosian	17.5	36	0.0013
12	17.5	15	0.0013
13\Choom	17.5	15	0.00077
14	17.5	15	0.00077
15\Shahkaram	35	15	0.00077
16	35	7	0.00077
17\Varzaneh	15.75	7	0.0008
18	15.75	7	0.0008

Table 1- Reaches and measuring points with details

3. RESULT AND DESCUSSION

3.1 Model calibration

The model has been calibrated with field measurements data of January 2003 which was a dry weather season in this investigation. First of all as long as the Q2K model needs all parameters of the Maning formula, it is necessary to calibrate the maning factor (n. roughness).
In order to do so, with available data of flow and depth of measuring points at January 2003 the Hydraulic calibration has been applied and estimated roughness of each reach has been calculated.
Afterwards, according to DO and CBOD field measurements of January 2003, the model has been calibrated. An acceptable match of model and field data can be seen. The result showed after Kaleh bridge that industrial loads discharge to The River, DO concentration starts to drop slightly (Figure 2) ,while, BOD concentration undergo a sharp increase (Figure 3). The model has been underestimated the DO concentration. As it has been mentioned, it happened in former studies in dry weather season because of underground water contribution.

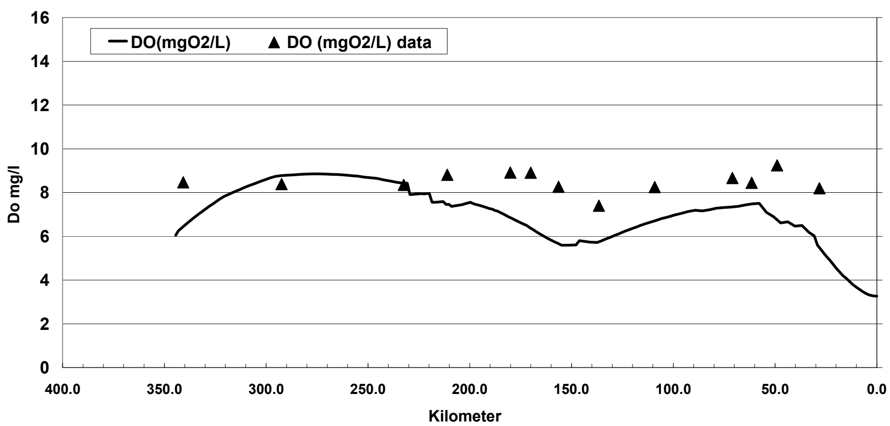

Figure 2- DO concentration (mg/l) January 2003 (Calibration)

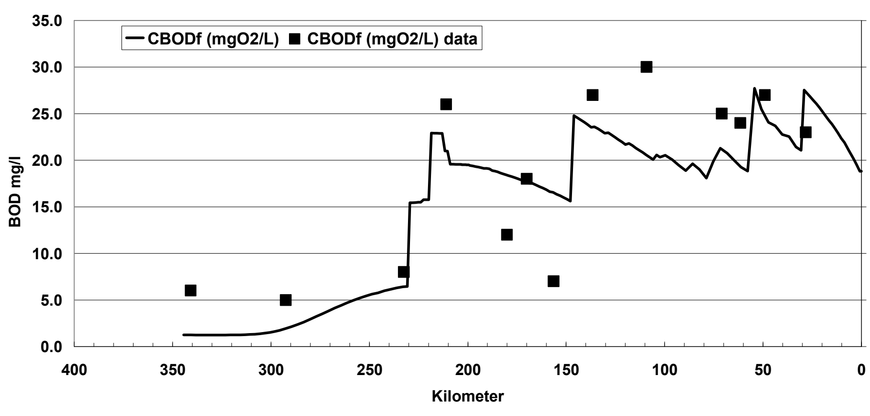

Figure 3- BOD concentration (mg/l) January 2003 (Calibration)

3.2 Model validation

The next step is to verify the model with calibrated parameters. In order to do so another set of data from August 2004 (wet weather season) has been applied to the model.
DO and CBOD simulation in this part showed a pretty good match with measured data. Same as calibration, a gradual reduction in DO concentration is happening after kaleh area (Figure

3), hence, CBOD amount is going up dramatically after this area (Figure 4), all because of big amount of municipal, agricultural and particularly industrial loads. As it can be seen the Do concentration is under 5 mg/l in roughly half of river's length which is really poor. This amount of DO is not suitable even for fisheries survival and it is in class 3 of USEPA's surface water quality classification. This class of water quality can only be use for agricultural purposes.

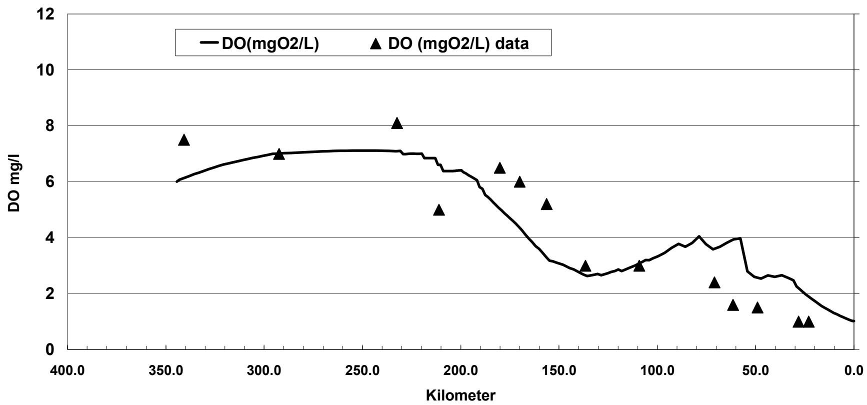

Figure 4- DO concentration (mg/l) August 2004 (Validation)

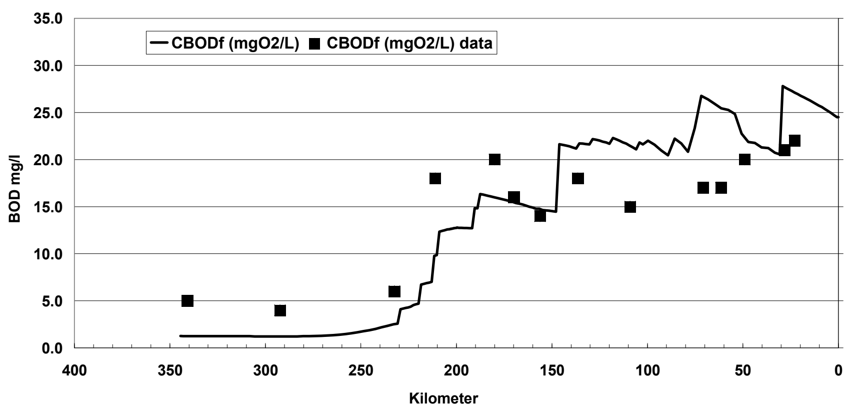

Figure 5- BOD concentration (mg/l) August 2004 (Validation)

3.3 critical situation scenario

To estimate future quality of the river, at this step, 20 percent increase is applied to all loads and from 182 km from downstream of The Zayandehrood River, DO concentration is under 5 mg/l which is in class 3 of USEPA's mentioned classification (agricultural purposes only). To solve this problem and to increase water quality, local oxygenation is considered as a solution.

3.4 quality control management option: local oxygenation

To control this kind of situations an option that considered in this study is local oxygenation. The goal is to increase DO concentration to more than 5 mg/l according to mentioned classification and 7 weirs have to be affixed to The Zayandehrood River to achieve this goal (Figure 6). The type of weir that has been chosen to simulate is regular step. Details of each weir can be seen in (Table 2).

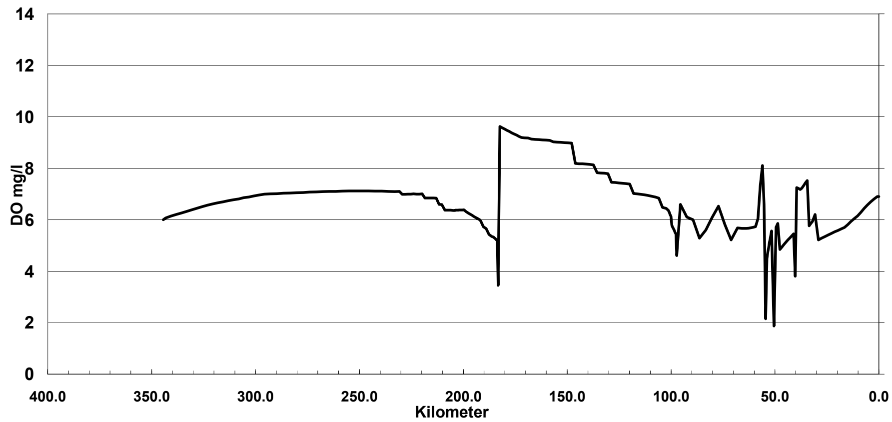

Figure 6- DO concentration with 20% increase of loads and local oxygenation

From 60km of The River, because of low flow and velocity, several weirs needed to move DO concentration up to 5 mg/l. height of each weir is approximated due to upstream and downstream depth of the weir's location to have an optimum output.

Weir	Location (Km)	Height (m)
1- Regular step	183	1
2- Regular step	97	1
3- Regular step	55	0.5
4- Regular step	54	0.5
5- Regular step	51	0.5
6- Regular step	50	0.5
7- Regular step	40	0.5

Table 2- weir details

Apparently, Local oxygenation is an acceptable way to improve water quality in streams and it can help rivers to endure bigger loads of degradable wastewater since DO amount is more.

4. CONCLUSSION

Water quality management has become a serious anxiety for environmental engineers. Wastewater discharges to water sources is climbing up these days and this situation is in desperate need of control and management.
Qual2k modeling software is a common mathematical model to control water quality of streams. This model has been used to simulate DO and BOD concentration in The Zayandehrood River in Iran. Calibration and validation that applied with field measurement data, demonstrate that this River has been in a poor quality condition and needed some management option. However, Qual2k in calibration and validation procedure showed that this model is perfectly reliable in modeling Streams when detailed and complex data are not available due to acceptable match with measured data. To be more realistic about future condition, 20 percent increase applied to waste loads which is an acceptable raise due to population increase and industrial development. This critical scenario leads to local oxygenation in order to increase water quality. 7 weirs have been simulated to move DO concentration up to at least 5 mg/l. this investigation performed that local oxygenation can be an authentic option for water quality management.

5. REFRENCES

A.Azzellino , R.Salvetti , R.Vismara , L.Bonomo, 2006, Combined use of the EPA-QUAL2E simulation model and factor analysis to assess the source apportionment of point and non point loads of nutrients to surface waters. *Science of total environment 371 (2006) 214-222*

A.Abrishamchi , M.Tajrishy , P.Shafieian , 2005,Uncertainty analysis in qual2e model of zayandehrood river, water *env research* 77 , 279(2005)

Brown, L.C., Barnwell, T.O., 1987. The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS (EPA/600/3-87-007). U.S. Environmental Protection Agency, Athens, GA, 189 pp.

Chapra, S.C., 1997. Surface Water Quality Modeling. McGraw-Hill, New York.

Haghighi.M.R , A.Abrishamchi , Ebolghasemi , Ghoreishi , 1997, Water quality assessment and pollution sources of zayandehrood river, technical report, isfahan university of tech.

Prakash Raj Kanne, , S. Lee, , Y.-S. Lee, S.R. Kanel, G.J. Pelletier 2005*,* Application of automated QUAL2Kw for water quality modeling and management in the Bagmati River, Nepal , *ecological modelling* 202 (2007)-517

Seok Soon Park, Yong Seok Lee ,2002, A water quality modeling study of the Nakdong River,
Korea, *Ecological Modelling 152 (2002) 65–75*