JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 9 2001

WATER QUALITY MODELING AND MANAGEMENT OF THE NILÜFER RIVER, TURKEY

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Our water resources are heavily polluted because of increasing population and industrial activity. Water quality parameters need to be controlled by water quality administrations, especially at big municipalities and industrial areas. The mathematical simulation models QUAL2E and QUAL2EU, developed by the U.S. Environmental Protection Agency, are used for this purpose quite commonly. In this study, the characteristics of this model are described and its application to the Nilüfer River is presented.

INTRODUCTION

The city of Bursa is located in the Marmara region in Turkey. At the present time the Nilüfer River serves as the main route by which wastewaters are transferred out of Bursa and the surrounding area. Outfalls of untreated effluent from both domestic and industrial areas are discharged directly into the river. The catchment of the Nilüfer River drains the northern and western slopes of the Uludað mountain. The main river flows out of the mountains to the west of Bursa, before turning eastwards along the foot of the steep mountain slopes. The river then turns around itself, before flowing into the Simav River. There are many small creeks that feed the Nilüfer along its course through the urban area. Some of these are fed by springs that have been used for water supply; other watercourses flow intermittently after rainfall, or in the spring when they are fed by snowmelt from the mountains.

The land area of Bursa, according to 1987 boundaries, is about 25,000 ha and it is divided into three sub-municipalities. The population is nearly 840,000 according to the 1990 census. The populations in Nilüfer, Osmangazi and Yýldýrým municipalities are about 38,000, 475,000 and 326,000 respectively. The rapid increase of the population has caused uncontrolled development in recent years. About 80 percent of the population lives in residential areas and the others live illegal residential areas. From population projection studies, the future populations of Bursa are about 1,300,000 in the year 2000, 1,800,000 in 2010, and 2,300,000 in 2020 (Gast,1992).

Streamflow gauges in Turkey are operated by the EÝE (Electrical Works) and DSÝ (State Hydraulic Works) while water quality monitoring is carried out by DSÝ and BUSKÝ (Bursa Water and Sewerage Works). Data from these gauges are used mainly for the planning, design and operation of surface storage reservoirs. The DSÝ gauges provide data for only a small part of the overall study area; The EÝE gauge at Geçitköy has a catchment area of 1290 km^2. There are no streamflow gauges downstream of Geçitköy. The EÝE gauge at Geçitköy is the main source of streamflow data for the study. The magnitude of Q (7,10) for the Nilüfer River at Geçitköy, which is traditionally used in surface water pollution and control studies, is estimated to be 0.565 m^3/s.

DSÝ initiated a program of water quality monitoring at locations in and around Bursa in 1984. The sampling points fall into two categories; points upstream of the Doganci Dam, which are used to monitor water flowing into the reservoir, and points downstream of the dam, located throughout the urban and agricultural area. BUSKÝ has also studied the Nilüfer River water quality at the same sampling points. The studies have shown that the Nilüfer River pollution increases from year to year (Karaer and Kestioglu, 1994). After the construction of the Doganci dam, downstream flows are influenced by reservoir regulation and there is no policy of compensation release from the reservoir to control downstream flows.

WASTEWATER PROJECTIONS

Wastewater flow projections are done for the 1990, and for the three target years 2000, 2010 and 2020, taking into consideration land use plans, population projections, and development planning of the city. Average wastewater flow projections according to the two planned wastewater treatment plants are given in Table 1. The wastewater characterization studies are summarized in Table 2. The city was separated in two zones in this study. Domestic wastewater discharges are concentrated in the first zone, while the industrial wastewater discharges are concentrated in the second zone.

Table 1. Average Wastewater Flows

Year	Central treatment plant				Özlüce treatment plant				Total (L/s)
	Domestic (L/s)	Commercial (L/s)	Industrial (L/s)	Total (L/s)	Domestic (L/s)	Commercial (L/s)	Industrial (L/s)	Total (L/s)	
1990	623.2	118.5	117.7	859.4	45.2	30.0	173.7	248.9	1108.3
2000	1135.8	189.8	203.7	1529.3	193.2	46.1	238.5	477.8	2007.1
2010	1759.7	282.4	287.5	2329.6	384.2	62.4	389.8	836.4	3166.0
2020	2487.4	320.7	309.6	3117.7	624.8	163.9	646.1	1434.8	4552.5

Table 2. Bursa City Wastewater Characterization

Parameter	First zone (Domestic) kg/day	Second zone (Industry) kg/day	Total Kg/day
BOD_5	12875	18787	31644
COD	28668	38149	66817
Total N	270	77	347
Total P	16	3	19
Suspended solids	5441	1527	6968
Oil and Grease	3258	983	4241
Total S	80	2638	2718
Detergents	22	310	332
Flow (m^3/day)	20247	18485	38732
Main Industries	Textile , Automotive, Slaughterhouse		
Main discharge points	Sewerage		

CALCULATION METHODS AND EQUATIONS

QUAL2E is a comprehensive and versatile stream water quality model. It can simulate up to 15 water quality constituents in any combination desired by the user. The model is applicable to dendritic streams that are well mixed. It assumes that the major transport mechanisms, advection and dispersion, are significant only along the main direction of flow. It allows for multiple waste discharges, withdrawals, tributary flows, and incremental inflow and outflow.

The basic equation solved by QUAL2E is the one dimensional advection dispersion mass transport equation, which is numerically integrated over space and time for each water quality constituent. This equation includes the effects of advection, dispersion, dilution, constituent reactions and interactions, and sources and sinks. For any constituent, C, this equation can be written as follows:

$$\frac{\partial c}{\partial t} = \frac{\partial\left(A_X D_L \frac{\partial c}{\partial x}\right)}{A_X \partial x} - \frac{\partial\left(A_X \bar{u} c\right)}{A_X \partial x} \frac{dc}{dt} + \frac{s}{v}$$

where c = concentration (ML^{-3}); A_X = cross-sectional area(L^2); D_L = dispersion coefficient (L^2T^{-1}); u = mean velocity (LT^{-1}); v = incremental volume (L^3) and s = external source (+) or sinks (-) (MT^{-1}). The term on the left side of the equation becomes equal to zero under steady state conditions. The term *dc/dt* refers to constituent changes such as growth and decay. *L*, *T* and *M* are the distance, time and mass units.

The hydrologic balance for a computational element can be written as:

$$(\partial Q / \partial X)_i = (Qx)_i$$

where $(Q_x)_i$ is the sum of the external inflows and/or sections.

The Manning equation is used for hydraulic calculation.

$$Q = \frac{1}{n} A_x R_x^{2/3} J^{1/2}$$

where A_x = cross-section area of the channel or canal (L^2); R_x = mean effective hydraulic radius (L); n = Manning roughness factor; J = slope of the energy grade line; and Q = discharge (L^3/T).

Dispersion is basically a convective transport mechanism. The equation used for the determination of longitudinal dispersion coefficient is:

$$D_L = 3.82\, K\, n\, \overline{U}\, d^{5/6}$$

where D_L = longitudinal dispersion coefficient (L^2/T); K = dispersion constant; n = Manning roughness coefficient; $\overline{U}$ = mean velocity (L/T) and d is mean depth (L).

The model assumes a first order reaction to describe deoxygenation of ultimate carbonaceous BOD in the stream. The BOD function as expressed in the model also takes into account additional BOD removal due to sedimentation, scour and flocculation.

$$dL / dt = -K_1 L - K_3 L$$

where L = the concentration of ultimate carbonaceous BOD, mg/L (M/L^3); K_1 = deoxygenation rate coefficient, temperature dependent (T^{-1}) and K_3 = the rate of loss of carbonaceous BOD due to settling, temperature dependent (T^{-1}).

The simplified differential equation used in the model to describe the rate of change of oxygen is shown below:

$$dO/dt = K_2(O^* - O) - K_1 L$$

where O = the concentration of dissolved oxygen, (M/L^3); K_2 = the reaeration rate in accordance with the Fickian diffusion analogy, temperature dependent (T^{-1}); O = the saturation concentration of dissolved oxygen at the local temperature and pressure (M/L^3); L = concentration of ultimate carbonaceous BOD (M/L^3).

The reaeration coefficient is calculated from the Thackson and Krenkel equation.

$$K_2^{20} C = 10.8(1 + F^{0.5}) \frac{U^*}{d} \cdot (2.31)$$

where F is the Froude number, which is given by:

$$F = U^* / \sqrt{gd}$$

And U^* is the shear velocity:

$$U^* = \sqrt{ds_e g} = \frac{\bar{u} n \sqrt{g}}{1.49 d^{1.167}}$$

where, d = mean depth (L); g = acceleration of gravity (L/T^2) ; S_e = slope of the energy gradient; $\bar{u}$ = mean velocity (L/T) and n =Manning's coefficient.

APPLICATION TO THE NILÜFER RIVER

The model is applied to the Nilüfer River by using a simplified stream network which is shown in Figure 1 to illustrate data input. Using the variables and coefficients which are given in Table 3, Biochemical Oxygen Demand (BOD) and Dissolved Oxygen (DO) simulations at steady state conditions are done for the year 2000. The model can also be run in dynamic mode but it requires real time monitoring.

The simulations for the BOD and DO parameters related to the river length are carried out for

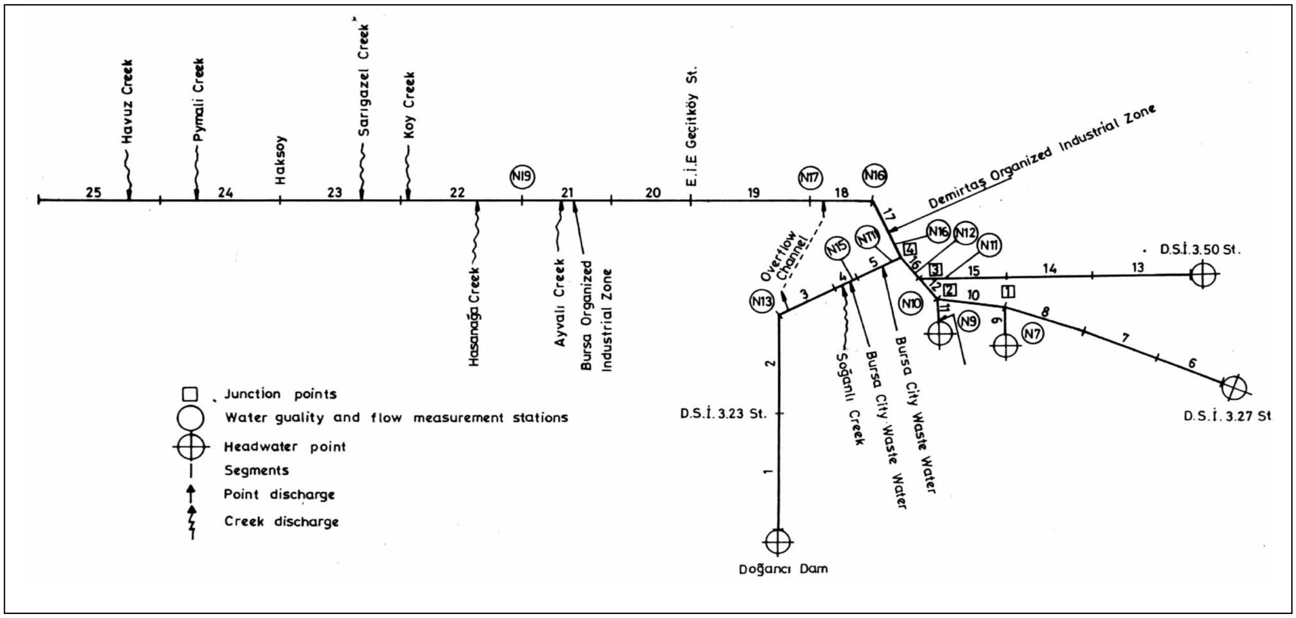

Figure 1. The modeling application network for the Nilüfer River.

Table 3: Model Variables, Coefficients and Initial Conditions

K_1	0,3 day^{-1} (T = 20 °C)
K_2	Trackson and Krenkel
K_3	0.0
Flow	Manning equation (n=0.028, trapezoidal)
K (Dispersion coefficient)	60
K_4(sediment oxygen demand)	0.0
Constant downstream condition	-----
Basin altitude	100 m
Longitude (degree)	29.04
Latitude (degree)	40.11
Headwater 1 flow	0.15 (m^3/s)
Headwater 2 flow	0.10 (m^3/s)
Headwater 3 flow	0.10 (m^3/s)
Headwater 4 flow	0.10 (m^3/s)
Headwater 5 flow	0.10 (m^3/s)
Point 1 flow	0.51 (m^3/s)
Point 2 flow	0.51(m^3/s)
Point 3 flow	0.51(m^3/s)
Point 4 flow	0.41(m^3/s)
Point 5 flow	0.47(m^3/s)

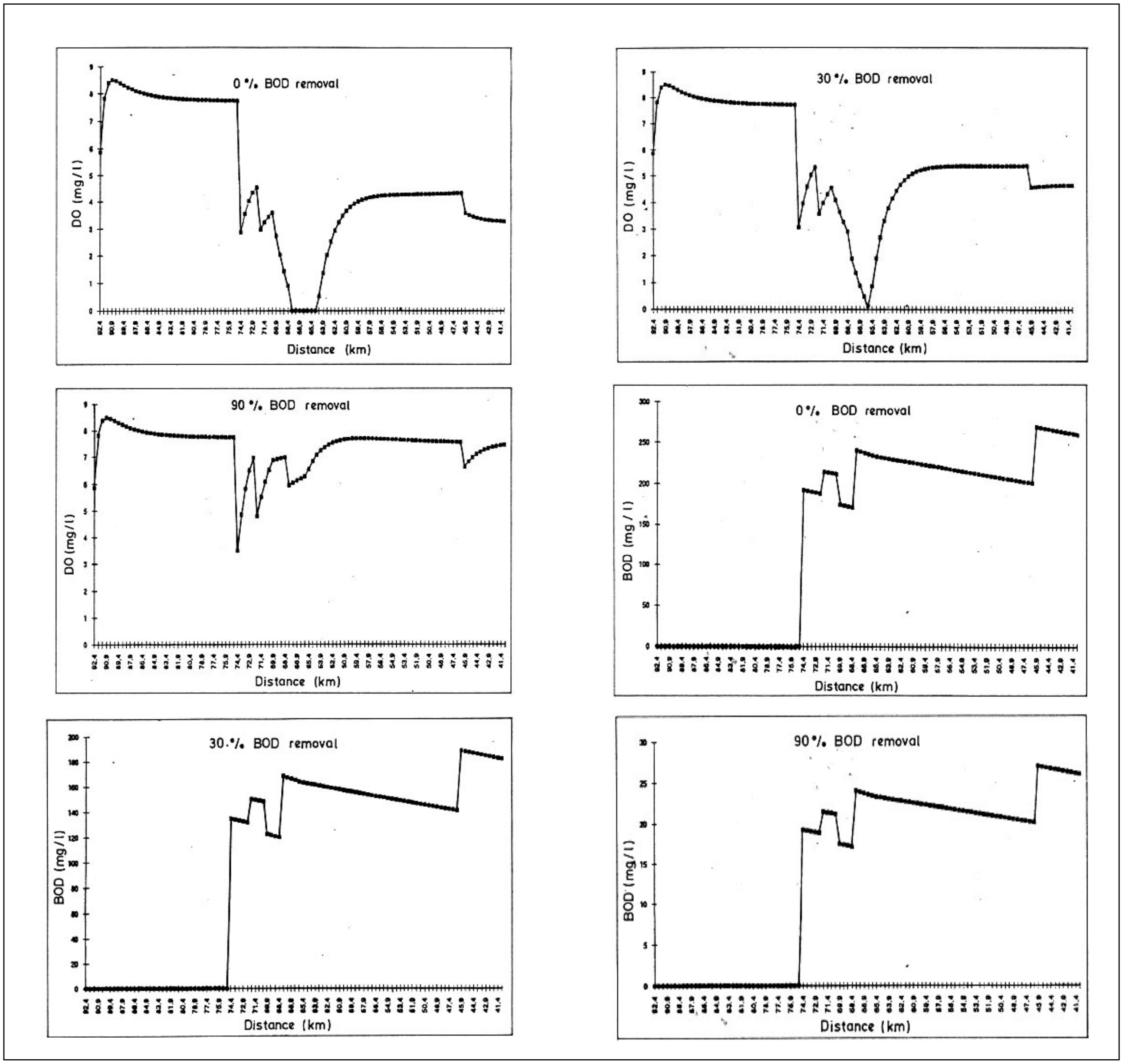

Figure 2. BOD and DO variations along river segments.

0 percent BOD treatment, 30 percent BOD treatment and 90 percent BOD treatment of the point discharges. It is assumed that there is no significant pollution input before point discharges into the river. The BOD and DO variations along the river segments are shown in Figure 2.

According to the classification of inland surface water by Turkish Water Pollution and Control Legislation submitted on September 4, 1988, there are four groups : Class I : high quality water (8 mg DO/l and 4 mg BOD/l), Class II : low pollution (6 mg DO/l and 8 mg BOD/l), Class III : polluted water (3 mg DO/l and 20 mg BOD/l), and Class IV (<3 mg DO/l and >20 mg BOD/l).

The simulation results as shown in Figure 2 are compared with the aforementioned legislation and it is seen that the discharges of the effluents into the river without treatment caused anaerobic conditions (Class IV) at some distances. Also 30 percent BOD removal is not acceptable in terms of DO in some points. The treatment efficiency of 90 percent BOD removal gives acceptable results for DO concentration in comparison to legislative standards. However, BOD concentrations along the river reach exceed the standards (>20 mg BOD/l) even for 90 percent BOD removal efficiencies for point discharges. Therefore, higher BOD removal rate is required for the acceptable BOD concentration in the river.

CONCLUSIONS AND DISCUSSION

The hydrologic and hydraulic data for the application studies are provided by the DSÝ, BUSKÝ and EÝE; but the coefficients and constants are taken from the default values of the model by selecting the best fit parameters. The necessary data for the exact calibration of the model are not present. Due to these limitations in data availability, simulations are carried out for three discharge scenarios for point sources along the Nilüfer River: a) no BOD treatment, b) 30 percent BOD treatment, and c) 90 percent BOD treatment for the year 2000. It is found that BOD treatment efficiency of point sources should be higher than 90 percent to meet the standards of Class I quality water, even though the BOD treatment efficiency of 90 percent meets quality Class II quite adequately. This model can be used for effective water management studies in a river with adequate data.

ACKNOWLEDGMENT

This study was sponsored by Dokuz Eylül University Research Foundation, Project No. 0908.94.02.02. The hydrologic and hydraulic data were provided by the BUSKÝ and DSÝ Regional Offices. The author is pleased to acknowledge the assistance of staff at the BUSKÝ and DSÝ offices.

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