Research Note: Modeling of the Water Quality of Büyüksu Stream, Bolu, Turkey

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ABSTRACT: The QUAL2E model was applied to the Büyüksu Stream, Bolu, Turkey, to predict the effect of conventional and industrial pollutant sources on stream quality. The model parameters were conditioned using data from eight sampling stations on a 24-km stretch of the stream during a steady-state period between May 2003 and June 2004. The higher biochemical oxygen demand (>50 mg/L) and lower dissolved oxygen concentrations measured (<4.0 mg/L), with their expected values, indicated that the water quality of the Büyüksu Stream was threatened by industrial and domestic pollution. The oxygen-sag curves obtained by the model calculations proved that discharges of the Bolu City wastewater and wood-processing plant effluent were the two primary pollutant sources affecting the stream. Results suggested that the conditioned model can be used as a tool to show the effects of pollutant sources on the Büyüksu Stream and to assess improvements expected by reducing the contribution of pollutant sources. *Water Environ. Res.,* **81,** 325 (2009).

KEYWORDS: stream quality modelling, QUAL2E, water quality management.

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Introduction

Surface water quality is of utmost concern today. Because rivers or streams are the primary inland water resources for domestic, industrial, and irrigation uses, they are among the most vulnerable water bodies to pollution (Carpenter et al., 1998). Thus, it is necessary to prevent and control the pollution of these resources and to have reliable information on the quality of the water (Singh et al., 2005).

The effect of untreated wastewater on aquatic systems has been studied for several years, and the severity of this effect depends on dilution by the receiving water (Spellman, 1996). The zone of impact can be characterized by low dissolved oxygen (DO) and high biochemical oxygen demand (BOD) concentrations, which can be inhibitory to aquatic organisms. As discussed by Campolo et al. (2002), considering only the threshold value of pollutants in the wastewater (independent of the flowrates of the receiving streams or rivers) is not sufficient, because the mechanisms in such sytems are too complex. For effective pollution control and water resource management, accurate identification of the polluting sources and their quantitative contributions and effects are required. For this reason, studies related to water quality and streamflow modeling have recently gained considerable impetus with the development and advent of high-speed computers (Huang and Foo, 2002; Park and Lee, 2002).

Bolu City, located in the western Black Sea region of Turkey, is representative of the green nature of Turkey, with Lake Abant, Yedigöller National Park, and recreational facilities near small lakes, in the forest, and on snow-covered mountains in winter (Figure 1). The city attracts thousands of people every year and can be used as a pilot region to apply green chemistry principles (Lancaster, 2002) to achieve sustainable development for the whole of Turkey. The Büyüksu Stream has supported the livelihood of Bolu City for many years. If the importance of this stream is ignored, the city would soon be lost because of the new industries installed in close proximity. However, currently, the stream functions as a major wastewater sink for the communities and plants located within its basin and is threatened with losing its status as a water source, mostly because of industrial activities, domestic wastewater, urban runoff, and farm wastes. The ecosystem of the stream has been at risk from organic and inorganic pollution because of the waste load inputs that exceed its assimilating capacity.

A previous study by Aktimur et al. (1983) on the Büyüksu Stream showed a severe deterioration in water quality, in terms of chemical and physical contents by industrial or domestic wasteloads at particular points.

The surveys and observations of the stream water quality is insufficient to determine whether the stream is highly polluted, and additional data collected during actual field measurements and estimations determined using mathematical models approved by the authorities are needed. The Qual2E Stream Water Quality Model (Brown and Barnwell, 1987) is considered to be a powerful model for quantifying stream pollution.

This study was conducted to

(1) Identify the waste discharges and their effects on the Büyüksu Stream,
(2) Determine the current state of water quality and pollution levels of the stream,

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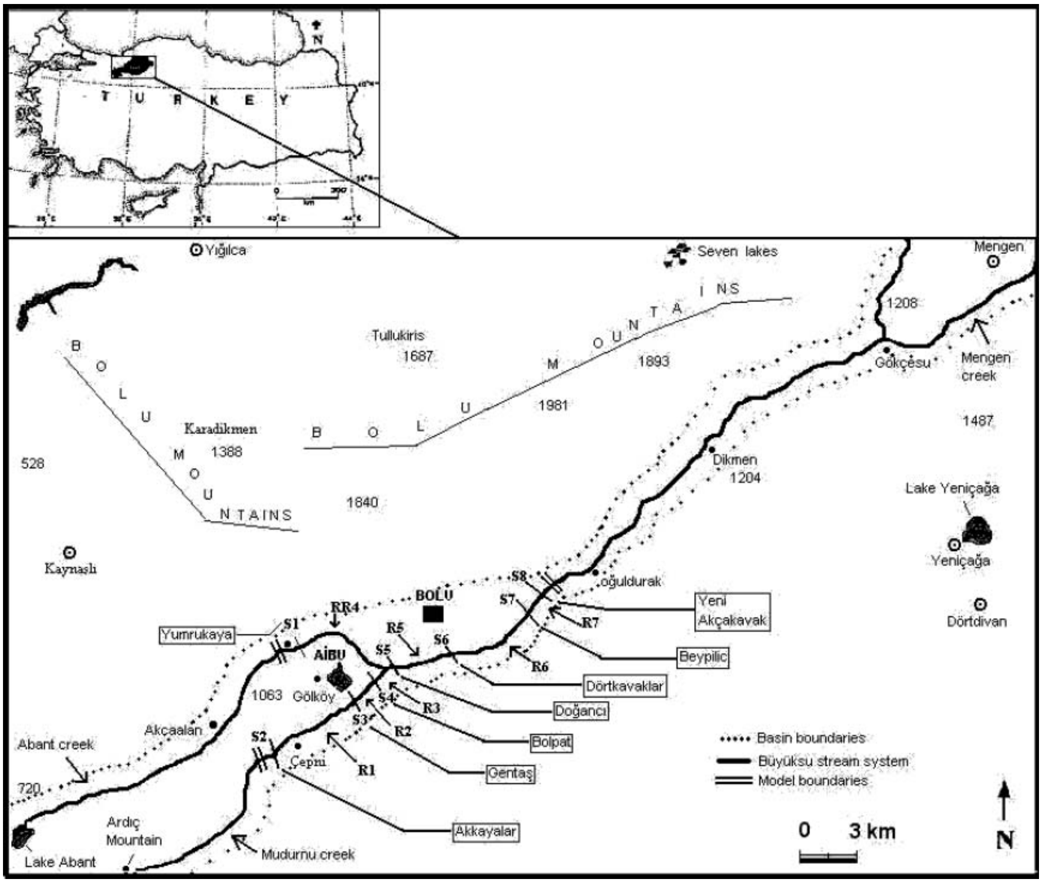


Figure 1—Map and location of sampling stations in Büyüksu (Bolu) stream basin.

(3) Apply the Qual2E model to the stream to assess the changes in dissolved oxygen and BOD dynamics along the stream, and
(4) Predict the results and feasibility of possible future changes on stream water quality using the model.

Methodology

Description of Study Site. The Büyüksu Stream (Figure 1) has an annual water capacity of approximately 3×10^8 m^3. The stream basin spans an area of 380 km^2 and has a length of approximately 76.5 km up to Gökçesu (Mengen). Also, it is the largest stream (by area) of the Filyos River Basin. The headwater is located in the southwestern part of the basin, and the stream flows along an east–northeast direction and passes Abant İzzet Baysal University, Bolu City, which has a population of approximately 80 000 people and approximately 20 villages (BİGEP, 2003).

One of the two primary sources of the Büyüksu Stream is Abant Creek, which originates from Lake Abant. The second source is Mudurnu Creek, and it merges with Büyüksu Stream near the Bolpat potato-processing plant (Doğancı village). After joining with Mudurnu Creek, Büyüksu runs approximately 4 km away from the southern tip of Bolu plain at an altitude of approximately 725 m. Depending on the season, the average surface width and maximum depth of the stream varies between 4.5 and 8.5 m, and 35 cm and 1 m (minimum in summer and maximum in spring), respectively. The depth throughout the stream increases toward the downstream region (DSİ, 2001).

Data Collection. Sampling was carried out every 2 months for approximately 1 year (May 2003 through June 2004). The sampling period was decreased to 1 month during summer, to observe the changes in stream water quality more frequently. Sampling stations were chosen where the main industrial and domestic wasteloads and incremental flows were most dense along the stream. Locations of the stations are given in Figure 1 and Table 1. Dissolved oxygen, BOD, and other chemical constituents of the samples were analyzed in the laboratory using wet-analysis techniques (Rump and Krist, 1992). All water samples were kept in containers at −4°C in the dark, and 0.7 mL of concentrated sulfuric acid and 0.02 g of sodium

Table 1—Name and location of the sampling stations on Büyüksu Stream basin.

Station	Code	Distance from headwater of Mudurnu Creek (km)
Yumrukaya village	S1	23.5 (7.5 from junction)
Before Akkayalar spring	S2	22.5
GENTAŞ (waste effluent)	S3	29
BOLPAT (waste effluent)	S4	30
Doğancı village	S5	31
Dörtkavaklar (wastewater effluent)	S6	36
BEYPİLİÇ poultry processing plant	S7	43.5
Yeni Akçakavak (waste effluent)	S8	44.5

azide solution were added to stabilize the chemical content of the samples. Dissolved oxygen meters were used to validate the wet analyses, and compatible results were obtained.

Details of Numerical Models

Qual2E Model. The stream water quality model Qual2E (Brown and Barnwell, 1987) is basically a steady-state model for conventional pollutants in one-dimensional streams. This model, based on the self-purification phenomena, incorporates an oxygen-sag curve analysis using mathematical equations originating from the Streeter–Phelps equation (Streeter and Phelps, 1925). It is used to study the dissolved oxygen characteristics of a stream and describes transportation and transformation processes for BOD and dissolved oxygen. While transport processes resulting from the flow of water include dispersion, diffusion, constituent reactions, and interactions among constituents, transformation processes consist of BOD, nitrogen oxidation, surface reaeration, sediment oxygen demand (SOD), photosynthesis, and respiration.

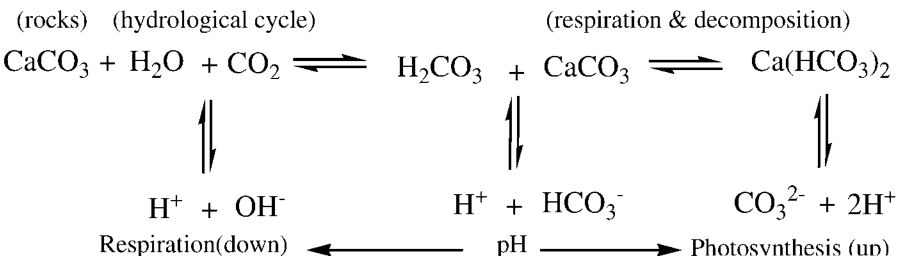
The main governing equations of QUAL2E describe deoxygenation of ultimate carbonaceous BOD in the stream and its relationship to the rate of change of oxygen, as follows:

$$\frac{dL}{dt} = -k_1 L - k_3 L \tag{1}$$

$$dO/dt = k_2(O^* - O) + (\alpha_3 \mu - \alpha_4 \rho)A - k_1 L - k_4/d - \alpha_5 \beta_1 N_1 - \alpha_6 \beta_2 N_2 \tag{2}$$

Where all variables are defined as in Table 2. Each term in eq 2 represents a major source or sink of oxygen that is interrelated with eq 1.

pH/Alkalinity Equilibrium Model. pH changes occurring in streams may be interpreted according to reactions and phenomena given by Masters (1991), as follows:



(3)

The measured total alkalinity, carbonate, bicarbonate, and calcium concentrations were input to a Microsoft Excel spreadsheet (Microsoft Corporation, Redmond, Washington) to determine the equilibrium pH values (Chapra and Pelletier, 2003), according to eq 4, as follows:

$$pH_s = (pK_2 - pK_{sp}) + pCa + \log\left(Alk + [H^+]_{act} - \left(\frac{K_w}{[H^+]_{act}}\right)\right) \tag{4}$$

Where

K_2 and K_w = dissociation constants,
Ksp = solubility-product constant for calcium carbonate ($CaCO_3$),
pH_s = saturated pH values,
Ca: actual calcium concentration (mg Ca^{2+}/L),
Alk: total alkalinity in (mg$CaCO_3$/L), and
$[H^+]_{act}$ = actual hydrogen ion concentration.

The pKs and all dissociation constants were corrected for temperature.

Application of Qual2E Model to Büyüksu Stream

Model Setup. The Büyüksu Stream was divided into seven reaches, each of which was subdivided into computational elements of 0.5 km. In total, approximately 24 km of the mainstream was covered. Reaches R1, R2, R3, R5, R6, and R7 were located on the main body of the stream (Mudurnu Creek), and reach RR4 described a tributary, Abant Creek (Figure 2).

In the model, there are two headwater elements (HW1 and HW2) that referred to the starting conditions of Mudurnu Creek and Abant Creek, respectively. Reach RR4 (Abant Creek) between 30 and 31 km is an incremental flow element that added no apparent pollutant load to Büyüksu and only diluted the main stream. There are four point load elements (W1, W2, W3 and W4), representing waste discharges at the Gentaş, Bolpat, Bolu City wastewater, and Beypiliç locations.

Data inputs to Qual2E included both hydrological and kinetic components. Maximum and minimum depth (d) and velocity (u) data sets for each sampling station at corresponding flowrates (Q) were required to solve the rating equations (eqs 5 and 6) (Ning et al., 2001). The calculated hydrological constants and coefficients (a, b, α, and β) for each reach are given in Table 3.

$$u = aQ^b \tag{5}$$

$$d = \alpha Q^\beta \tag{6}$$

The Manning's coefficient (n) varies between 0.015 and 0.15 for smooth and rough-bottom surfaces. In this study, n was taken as 0.04 for all reaches. In accordance with the Flood and Earthquake Emergency Aid Project of Turkey (DSİ, 2001), the value of the dispersion coefficient (K_L) was taken as 80 m^2/s for all reaches.

Kinetic data consisted of reaeration (k_2) and deoxygenation rate (k_1) coefficients. These were corrected for temperature (T) using the Arrhenius equation, as follows:

$$k_T = k_{20}\theta^{T-20} \tag{7}$$

Table 2—Nomenclature for eqs 1 and 2.

O	Dissolved oxygen concentration (mg/L)	A	Algal biomass (mg-A/L)
O*	Saturated concentration of dissolved oxygen at the local temperature and pressure (mg/L)	L	Ultimate concentration carbonaceous BOD (mg/L)
α_1	Fraction of algal biomass that is nitrogen	k_1	CBOD deoxygenation rate (1/day)
α_3	Rate of O_2 production/unit of algal photosynthesis (mg-O/mg-A)	k_2	Reaeration rate (1/day)
α_4	Rate O_2 of uptake/unit of algae respired (mg-O/mg-A)	k_3	Rate of loss of CBOD due to settling (1/day)
α_5	Rate of O_2 uptake/unit of ammonia nitrogen oxidation (mg-O/mg-N)	k_4	Sediment oxygen demand rate (g-O/m^2-day)
α_6	Rate of oxygen uptake/unit of nitrite nitrogen oxidation (mg-O/mg-N)	β_1	Ammonia oxidation rate coefficient (1/day)
μ	Algal growth rate (1/day)	β_2	Nitrite oxidation rate coefficient (1/day)
ρ	Algal respiration rate (1/day)		
		d	Mean stream depth, m
N_1	Ammonia-nitrogen concentration, mass/volume	N_2	Nitrite-nitrogen concentration, mass/volume

Where

k_T = temperature-corrected coefficient;
k_{20} = coefficient at 20°C; and
θ = temperature-corrected constant with values of 1.024 and 1.047 for k_2 and k_1, respectively.

The reaeration rate coefficient at 20°C (k_2^{20}) was estimated by the equation of O'Connor–Dobbins (O'Connor and Dobbins, 1958). This equation is suitable for the Büyüksu Stream, because the stream is shallow, small, and has low flowrates.

The carbonaceous BOD deoxygenation rate coefficient, k_1, was estimated from the mean line in Figure 3 as a function of the average stream depth (Ergen, 1992); these values are also shown in Table 3. To convert 5-day BOD (BOD_5) to ultimate BOD (k_{BOD}), the rate coefficient was assumed to be constant, with a value of 0.23 L/d.

Solids, which can decompose anaerobically or aerobically on settling to the stream bottom, represent another dissolved oxygen sink. The rate of dissolved oxygen depletion resulting from the sediment oxygen demand (SOD; k_3) was taken as 0.2 in this model (Brown and Barnwell, 1987).

Because nitrogenous BOD (NBOD) does not typically begin to exert itself for at least 8 to 10 days, most BOD_5 tests are not affected by nitrification. Thus, nitrogen oxidation was not considered in application of the model.

The model's heat balance required a diurnal heat budget. Data were provided by meteorological observations and solar data (solar constant = 1367 W/m^2) (Chapra and Pelletier, 2003).

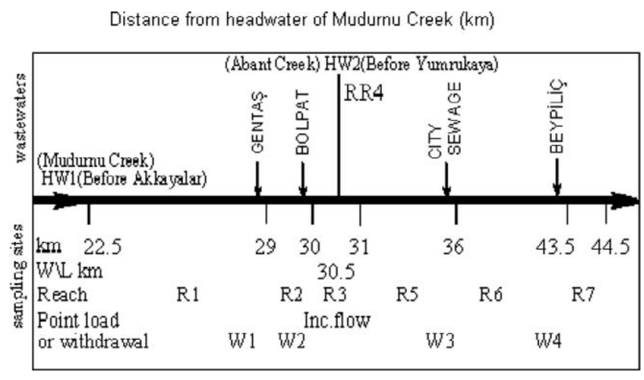


Figure 2—Main body of the stream from headwater of Mudurnu Creek and reaches formed—tributaries, wastewaters, and incremental flows.

Sensitivity Analysis for the Model. The objective of the sensitivity analysis was to determine the contribution of uncertainty sources to the model. These included estimations of reaction rate constants for oxidation of organic material (k_1) and the coefficient for the rate of reaeration (k_2). They were calculated for the July 2003 conditions, according to the flow regime of stream, using the following empirical equations:

O'Connor–Dobbins equation (O'Connor and Dobbins, 1958):

$$k_2(20) = 3.93\frac{U^{0.5}}{H^{1.5}} \quad (8)$$

Owens-Gibbs equation (Owens et al., 1964):

$$k_2(20) = 5.32\frac{U^{0.67}}{H^{1.85}} \quad (9)$$

Churchill equation (Churchill et al., 1962):

$$k_2(20) = 5.026\frac{U}{H^{1.67}} \quad (10)$$

Thackston-Krenkel equation (Thackston-Krenkel, 1969):

$$k_2(20) = \frac{24.9(1 + F^{0.5})u^*}{H} \quad (11)$$

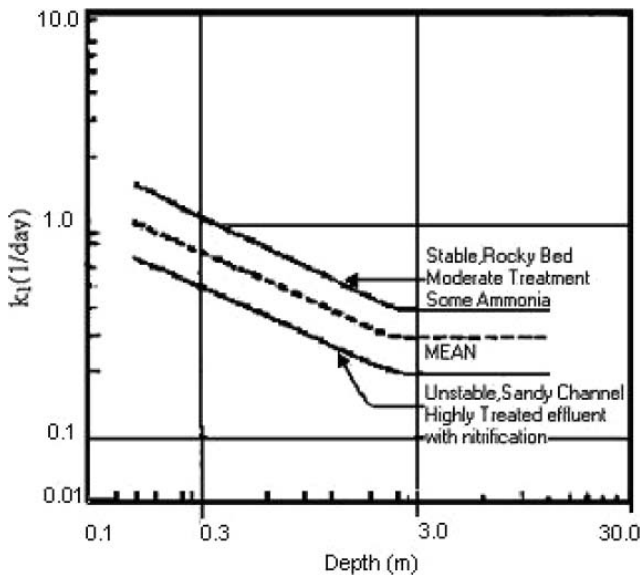


Figure 3—BOD deoxygenation constant k_1 as a function of depth (Ergen, 1992).

Table 3—The hydrological and BOD deoxygenation constants adjusted in the model.*

Constant	Reach R1	R2	R3	RR4	R5	R6	R7	Tributary
a (1/m^2)	0.94	0.43	0.93	0.62	0.58	0.45	0.57	0.56
b	0.54	0.20	0.57	0.37	0.41	0.46	0.47	0.36
α (s/m^2)	0.33	0.35	0.33	0.22	0.43	0.41	0.34	0.23
β	0.35	0.44	0.33	0.40	0.60	0.36	0.38	0.36
Average depth (m)	0.21	0.22	0.24	0.17	0.59	0.54	0.5	—
k_1 (1/day)	1.5	1.4	1.3	1.8	0.4	0.5	0.7	—

* b and β are unitless hydrological coefficients.

Where

U = Stream velocity (m/s),
H = Stream depth (m),
u*= Shear velocity (m/s), and
F = Froude number.

The results show variation in the oxygen-sag curves and are presented in Table 4 and Figure 4.

Improvement of the Conditions at Gentaş and Bolu City Wastewater Discharge Points Using the Model. One of the aims of the modeling study was to predict the consequences of changes in waste treatment and management activities on stream water quality. Thus, the Qual2E model was applied to the Gentaş wood-processing plant and Bolu City wastewater disharges (two primary pollutant point sources) to the Büyüksu Stream. This was done for August, October, and December 2003 and February 2004, when the dissolved oxygen concentrations were at minimum and BOD concentrations were at maximum. This calculation was carried out to test the capability of the conditioned model and assumed that the receiving waters would not exceed the first-class limits for BOD<3 mg/L and dissolved oxygen>8 mg/L (Michaud, 1994).

Results

Measurement and Qual2E Model Results. Büyüksu is a typical upland catchment stream before it enters Bolu City. Its high dissolved oxygen concentrations (Figure 5a) indicate that it is well-aerated in the upper parts of the stream. However, part of the stream is highly polluted, as characterized by high BOD concentrations (>50 mg/L) (Figure 5b), low pH values (Figure 5d) changing between 5.2 and 7.2 at the 3rd station, and elevated alkalinity and hardness levels (Figure 5e). Dissolved oxygen is lower than the critical value (<4.0 mg/L), below which, even fish cannot survive (Michaud, 1994). Precipitation has diluting effects during February to May. City wastewater and discharges from the wood-processing plant, broiler livestock production facilities, and food industries are the primary sources of pollution affecting the stream (Table 5).

The results calculated with the model (Figure 5) indicated that the stream segment most affected by waste discharges was between the 28th and 36th km. The calculated dissolved oxygen concentrations begin to increase after 30th km and again at the 38th km, and two sags in the simulation (calculated) graphs can be easily seen at approximately the 30th and 36th km (Figure 5a). The dissolved oxygen concentrations were typically lower than critical values,

Table 4—Different reaeration (k_2) equations and varying BOD deoxygenation constants for July 2003.

Reach	Reaeration equations (k_2) 1	2	3	4	BOD deoxygenation rate constant (k_1) (1/day)
1					1.5
2					1.4
3					1.3
4	Owens-Gibbs equation	Churchill equation	O'Connor–Dobbins equation	Thackston Krenkel equation	1.8
5					1.0
6					0.4
7					0.5

Reach	BOD deoxygenation rate constant (k_1) (1/day) 1	2	3	Reaeration constant (k_2)
1	1.7	1.5	1.3	
2	1.6	1.4	1.2	
3	1.5	1.3	1.1	
4	2.0	1.8	1.6	O'Connor–Dobbins equation
5	1.2	1.0	0.8	
6	0.6	0.4	0.2	
7	0.7	0.5	0.4	

Table 5—Results of dissolved oxygen, BOD, pH, alkalinity, and hardness analysis measured in July 2003. Locations shown underlined show the points just after the wastewater discharges. The "*" shows the headwaters of the Büyüksu (Bolu) stream system. In general, suspended solids per capita contribution is given as 0.08 and 0.06 kg/d BOD.

	Station	S1*	S2*	S3	S4	S5	S6	S7	S8
Physical variables	Flowrate (m^3/s)	0.210	0.146	0.22	0.183	0.410	1.539	1.613	1.545
	Width (m)	5.30	3.00	3.50	2.90	5.70	6.90	6.50	6.30
	Depth (m)	0.410	0.230	0.260	0.270	0.320	0.660	0.580	0.530
	Velocity (m/s)	0.308	0.213	0.242	0.226	0.263	0.338	0.428	0.463
	Temperature (°C)	22.4	21.3	26.5	24.5	21.1	22.3	21.2	21.5
	pH	9.24	8.70	7.23	8.32	8.23	8.76	8.92	8.86
Chemical variables (mg/L)	Dissolved oxygen	9.4	9.0	1.8	3.8	4.1	2.3	8.5	8.7
	BOD_5	1.60	1.80	225	93.0	80.0	98.0	6.4	7.3
	Bicarbonate	265	347	486	368	389	732	357	364
	Carbonate	17.4	0.0	0.0	0.0	0.0	10.1	13.9	12.3
	Total alkalinity (as $CaCO_3$)	522	569	762	623	639	1096	633	638
	Calcium	62.3	76.1	89.3	63.1	96.3	132	92.3	84.5
	Magnesium	18.2	20.1	22	7.3	20.1	22.8	22.6	17.6
	Total hardness (as $CaCO_3$)	231	273	262	228	323	452	323	242

except those calculated in September and October 2003. This is the result of low-flow conditions in the stream associated with waste discharges from the plants in large quantities. The significant decrease in dissolved oxygen concentrations is especially noted in the months that are deficient in rain. The locations where dissolved oxygen (<4 mg/L) and BOD (>50 mg/L) concentrations were critical can be seen easily in Figures 5a and 5b.

pH/Alkalinity Model Results. Equilibrium (calculated) pH values were estimated using inputs of measured parameters, such as alkalinity and hardness, to the pH/alkalinity model. The calculated pH values for all sampling months were lower than those measured in field (Figure 5d). Only for the months in which the stream water temperature was quite low were the measured and calculated values close. This difference between calculated and measured pH values resulted from several factors. Equilibrium pH calculations indicated that the stream water was buffered well. Different types of wastewater discharges did not cause a change in pH of the stream water. In addition, large differences between measured and calculated values indicated a high saturation index of the stream water. Because the stream water was supersaturated with respect to calcium carbonate, some of the calcium carbonate may have precipitated as the sample was being transported to the laboratory for analysis, thereby leading to an increase in pH. At other locations, especially, at the 3rd station, low-flow conditions (Figure 5c) and the low pH values of the wood- and food-processing plant wastewater discharges decreased the pH levels of the stream. Alkalinity values and comparison of measured and calculated pH values for July 2003 are presented in Figures 5d and 5e.

Improvement to Water Quality as Predicted at Gentaş and Bolu Wastewater Discharge Points. Improvements in water quality, as predicted by the model, are apparent in Figure 6. In examining these results, it is clear that the stream water quality would improve if the effects of industrial and domestic wastewater discharges were reduced or the discharges were treated. An increase in water quality limits to first class (BOD <3 mg/L) from the existing third and fourth classes (BOD > 12.0 mg/L) (Michaud, 1994) could be attained. Also, it should be taken into consideration that this is only a prediction by use of a powerful mathematical model; of course, it is very difficult and expensive to reduce the pollution to such a low level both for dissolved oxygen and BOD concentrations in the stream water.

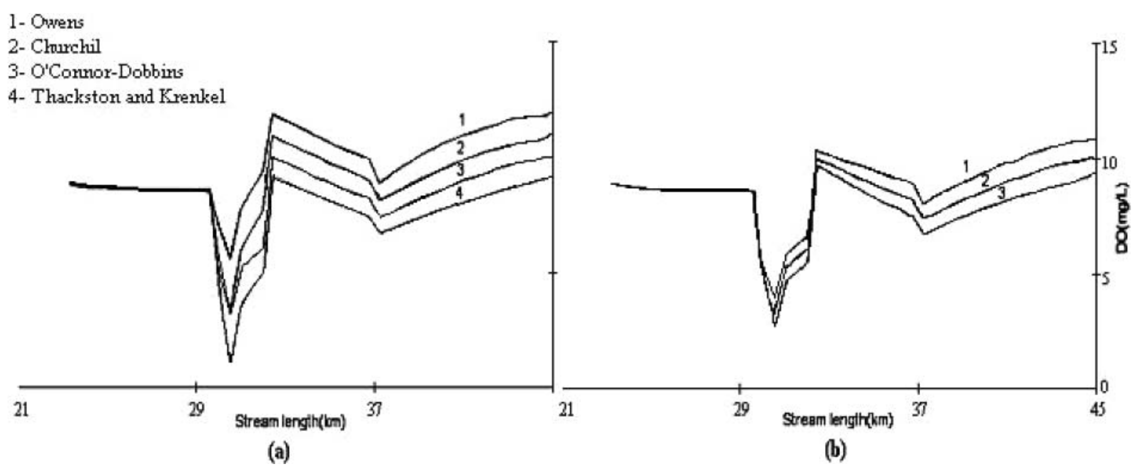


Figure 4—(a) Changing of dissolved oxygen values in July 2003 by using (a) different reaeration (k_2) equations, and (b) different deoxygenation constants (k_1).

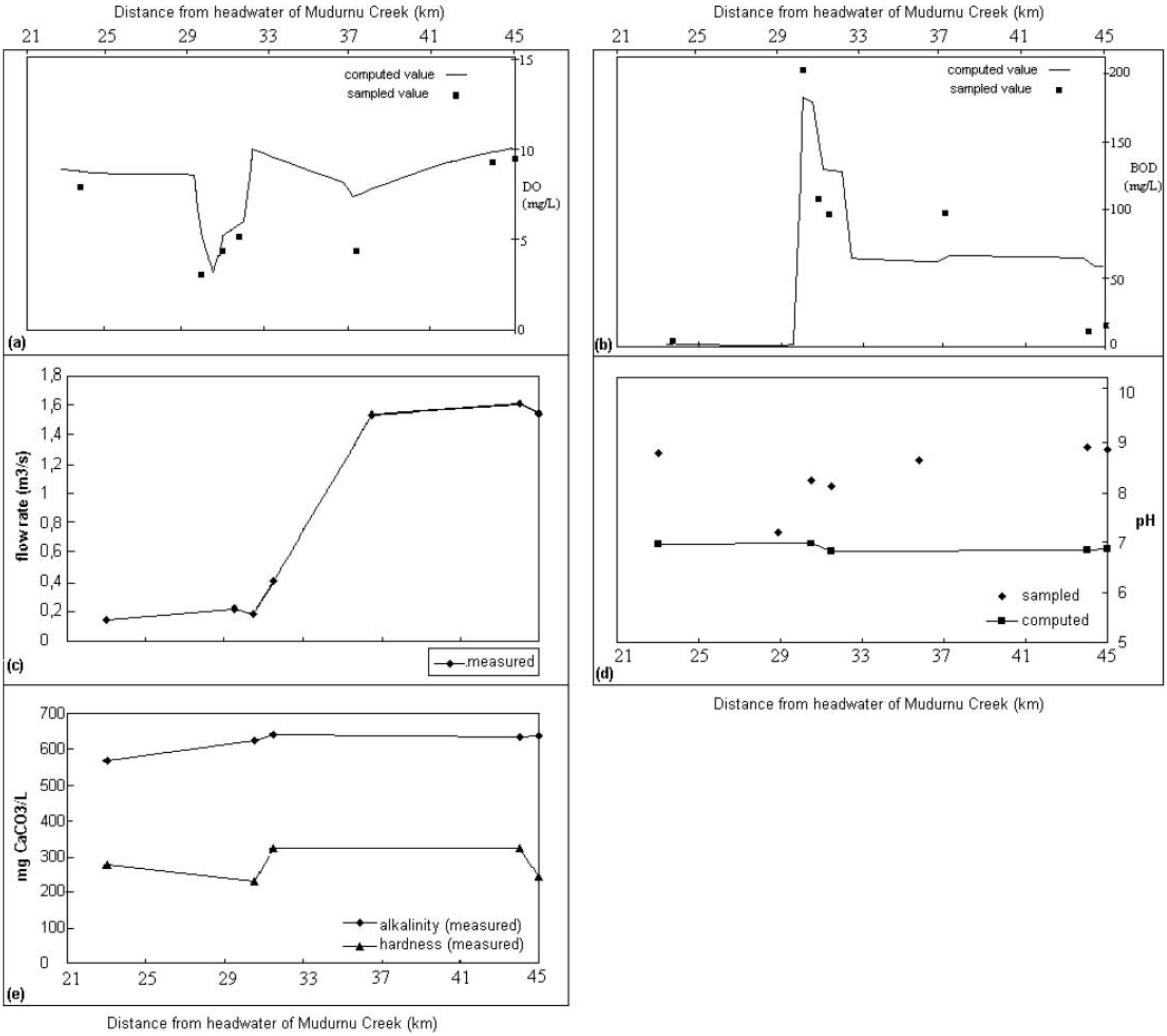


Figure 5—For July 2003, (a) dissolved oxygen concentrations; (b) biochemical oxygen demand concentrations; (c) measured flow (discharge) rates variations along the stream; (d) saturated and measured pH levels along the stream; and (e) alkalinity and hardness levels, in terms of millgrams $CaCO_3$ per liter.

Discussion

There are two well-resolved sags (30th and 36th km) in Figure 5a; the sharp one is the result of the wood-processing plant waste discharge, and the broader one is the result of the Bolu city wastewater discharge. When Figures 6a and 6d were examined starting from August, October, and December 2003 to February 2004, it is seen that these two sags start developing in August and reach a minimum in October. By the effect of seasonal precipitations, these two sags begin to broaden starting from December to February. This trend is directly proportional to the meteorological conditions and/or stream flowrates, as shown in Figure 7. This means that seasonal influences are critical and must be taken into consideration when interpreting the results.

The sharper sag results from the overlap of the two sags for the discharges of wood- and food-processing (Gentaş and Bolpat) plants. The broader one, near the end of Figures 6a to 6d, corresponds to that of a broiler production plant. Moreover, background dissolved oxygen concentrations in Figures 6a to 6d before and after the appearance of the sags is approximately 10 mg/L. This result showed that the stream is purifying itself over such a short distance. This should be noted, because the ratio of chemical oxygen demand to BOD of the waste discharged to the stream is high, and the model considers only biodegradable wastes.

The sag obtained with model (Figure 5a) for the city wastewater discharge was broad (i.e., high variance) in agreement with the measured dissolved oxygen concentrations. The dissolved oxygen concentrations decrease and then increase exponentially (fluctuation). The sag obtained with model (Figure 5a) for the wood- and food-processing plant discharges, however, decrease and then increase sharply (i.e., small variance). This could be the result of

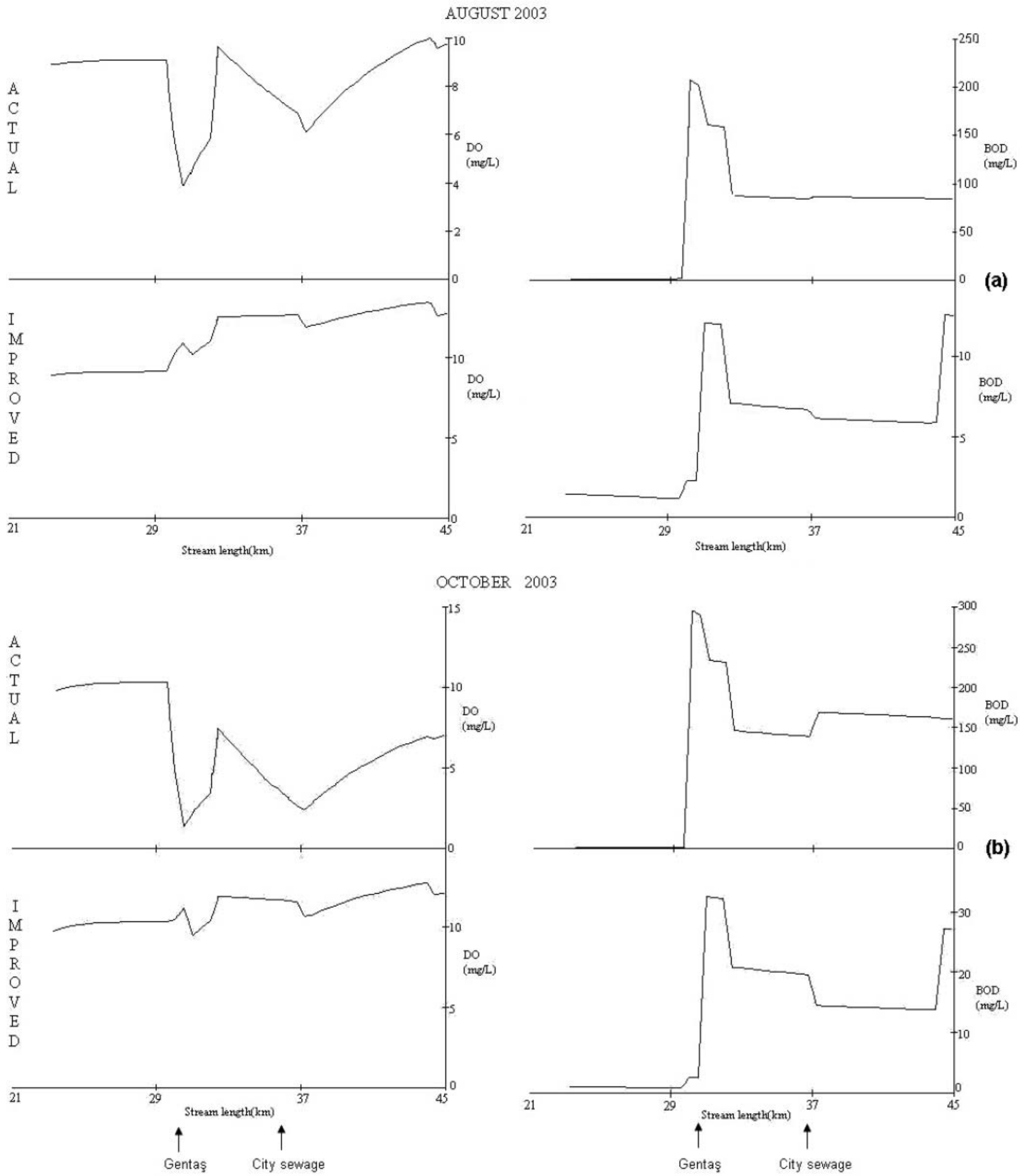


Figure 6—Dissolved oxygen (mg/L) and BOD (mg/L) simulations under improved conditions at Gentaş and Bolu City wastewater discharge points compared with actual measurements (August, October, and December 2003 and February 2004).

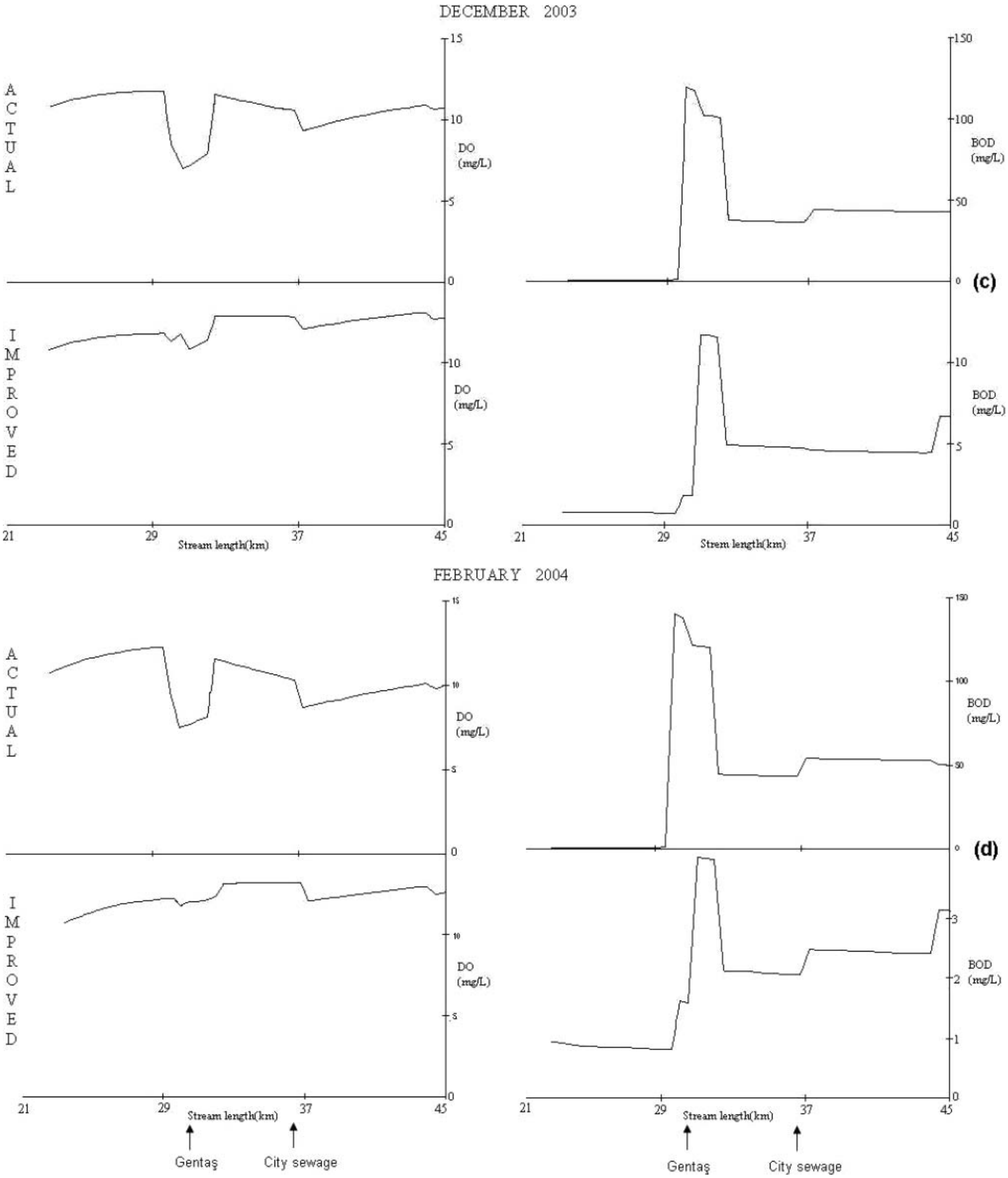


Figure 6—(Continued)

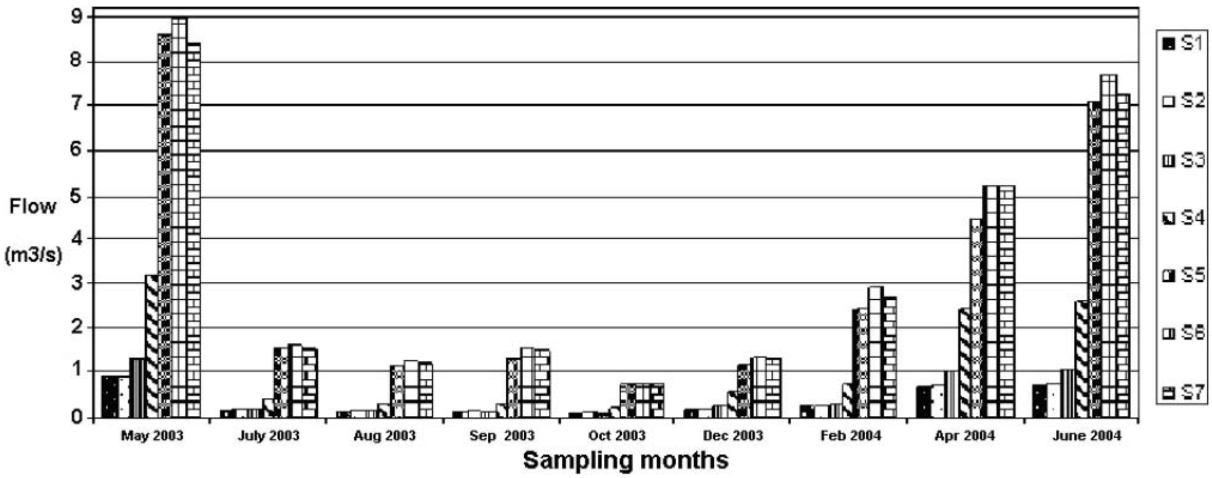


Figure 7—Variation of flowrates in Büyüksu from May 2003 to June 2004.

an incorrect assumption of a small longitudinal dispersion for the stream and/or a mistake in stream segmentation at this region. Abant Creek (RR4) enters the main stream between the 30th and 31st km (Figure 2), and no apparent waste load entered with its water. Thus, it was assumed that its water only has a dilution effect on the main stream water, and this caused an increase in dissolved oxygen levels. This effect is fairly evident at the 32nd km of the main stream in the actual dissolved oxygen concentrations (Figures 6a to 6d).

When actual BOD data were examined (Figure 6c), a well-resolved peak can be seen in December 2003. The sharp peak contains a shoulder because of the food-processing plant (Bolpat) discharge. After the discharge of wastewaters of the wood- and food-processing plants and city wastewater, the BOD concentrations did not decrease to the levels that existed before these wastes mixed in. The actual BOD concentrations remained high, ranging from a low of 130 mg/L BOD to a high of 300 mg/L (Figures 6a to

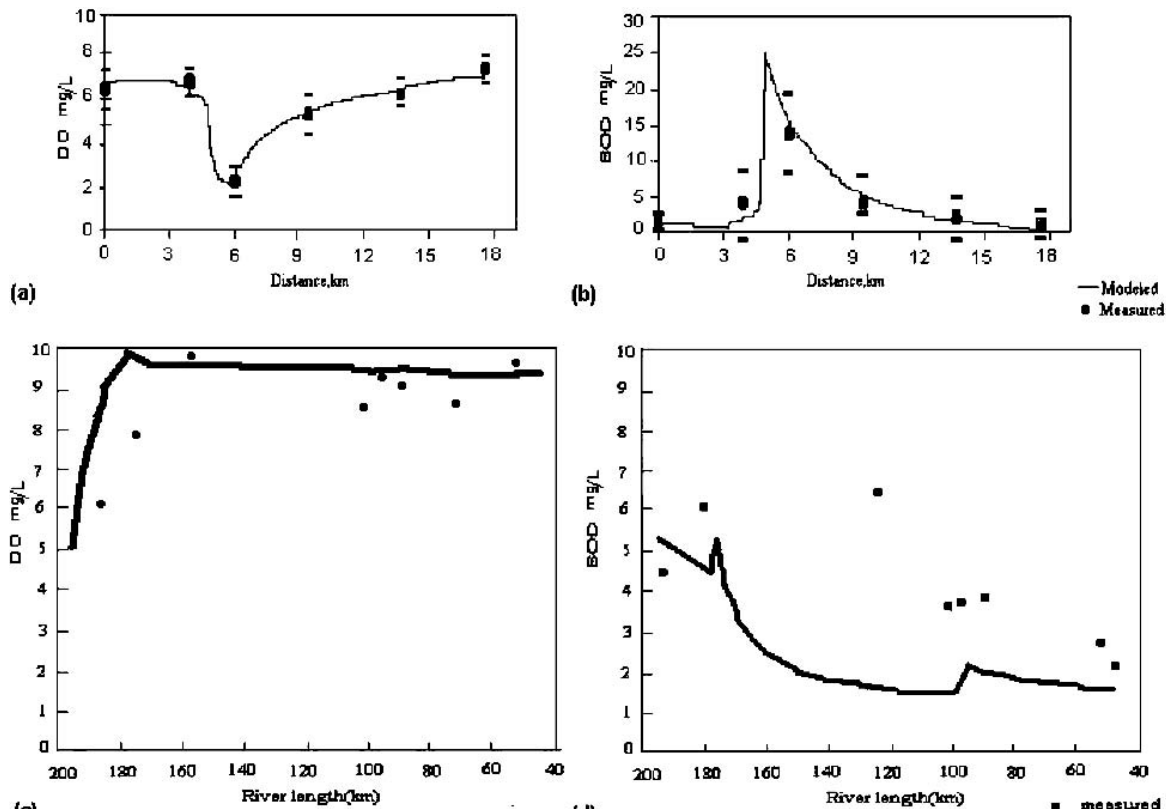


Figure 8—(a) Dissolved oxygen and (b) BOD results obtained with Qual2E for the Balatuin River, and (c) dissolved oxygen and (d) BOD results obtained with Qual2E for the Orhaneli River.

6d). These results support the dissolved oxygen results and explain the decrease in dissolved oxygen concentrations to critical levels at this region. However, higher dissolved oxygen concentrations are reached at downstream points of the main stream.

Observed deviations between actual and model simulation results might be the result of the use of modeling assumptions that did not accurately reflect the conditions of the Büyüksu Stream. A major change in assumptions is to consider substantial mixing of the stream water (independent of time), both vertically and laterally. However, Büyüksu is a small stream with highly changing flowrates. Therefore, it is difficult to achieve complete mixing; there would be some dead regions in the stream resulting from seasonal changes. Another contributor to the observed deviations could be the rate constants and coefficients used. Because they are estimates, they are accurate and precise only within certain confidence limits. Another contibuting factor could be the survey hydrological data, which may need to be adjusted before being used in the model. Also, omission of SOD assumptions in the model might have been a contributor. Büyüksu is a small stream, and it is highly probable that the sediments from waste discharges would have been settled on the bottom of the stream. Moreover, the appearance of greater pollution from the wood- and food-processing plants when compared with the city wastewater discharge might be the result of assuming Mudurnu Creek to be the main stream in the model.

The Qual2E simulation results of the Balatuin River (McAvoy et al., 2003) and Büyüksu Stream (Figures 5a and 5b) were used for comparison, because, in both studies, a short distance of the main stream was modeled by Qual2E. Biokinetic rate and hydrological constants were determined by experimental methods in the Balatuin River study (Dyer et al., 2003); however, in our study, these model input values were assumed. The values used in the model simulation were all within the range of typical reported values reported in the QUAL2E User's Manual for a stream of this size (Brown and Barnwell, 1987). An 18-km stretch of Balatuin River simulated with Qual2E and the predicted concentrations for dissolved oxygen and BOD were in good agreement with observed values (Figures 8a and 8b). Likewise, the model simulation results obtained for a 24-km stretch of the Büyüksu Stream were also in good agreement with the observed dissolved oxygen and BOD values, as shown in Figures 5a and 5b. The Qual2E simulation results for both studies contain similarities, in terms of changing dissolved oxygen and BOD concentrations along the stream. This agreement between predicted and observed values provides evidence that the Qual2E model can be used as an excellent tool for simulating the processes that affect dissolved oxygen concentrations. Compared with another modeling study with Qual2E by Ergen (1992) for the Orhaneli River (Figures 8c and 8d), it is seen that no sharp changes could be observed in the river system (approximately 150 km) because of the high flow levels at all seasons and high longitudinal dispersion in the river. There was no significant change in BOD concentrations, as a result of the high turbidity and high reaeration capacity of the river in this study. Simulated dissolved oxygen concentrations (Figure 8c) were also in good agreement with the measured dissolved oxygen concentrations in the field.

Conclusions

A water quality modeling study was performed on the Büyüksu Stream by applying the Qual2E model. The hydrological variables and coefficients were estimated and used in the model with primary water quality parameters, such as dissolved oxygen and BOD. Because the time lag between carbonaceous and nitrogenous BOD is typically 8 to12 days, the effects of nitrifying bacteria were not considered. Also, other physicochemical parameters, such as pH, alkalinity, hardness, nitrate, and nitrite, were measured but not conditioned in the model. These parameters were used in a pH/alkalinity model to calculate equilibrium pH concentrations of the stream water.

Computed dissolved oxygen and BOD concentrations with Qual2E were found to be close to the measured dissolved oxygen and BOD concentrations in the field (Figures 5a and 5b), but some differences are present between computed and measured concentrations along the main stream. Nevertheless, the conditioned model is a useful tool to show the effects of untreated wastewater entering the Büyüksu Stream and to determine improvements in water quality that might be realized by reducing the contribution of pollutant sources. Because this kind of study has been carried out for the first time on the Büyüksu Stream, it is important to show the principal pollution sources affecting the stream and also the feasibility of applying such a powerful mathematical model to Büyüksu.

If conducted in the near future, the study would need to be expanded to encompass all of the Büyüksu Stream system, to the point where it discharges to the Black Sea. Also, the number of sampling points should be increased to minimize deviations between modeled and actual stream conditions.

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