A PRACTICAL METHODOLOGY FOR RIVER QUALITY SIMULATION THROUGH THE STAGE-WISE GENERATION OF TRANSITION FUNCTION

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ABSTRACT

It is often necessary to study the effects of urban return flows on the quality of downstream water of a river basin serving a metropolitan area. The quality at the downstream control point is dependent on the quality and quantity of different headwaters, waste treatment discharges, irrigation return flows and urban runoff. These parameters are probabilistic in nature. Thus, the downstream control point quality will also exhibit probabilistic characteristics.

The Texas Water Development Board has developed a powerful model (QUAL-I) for stream water quality routing. This system is especially useful for the prediction of the temporal and spatial distribution of temperature, biochemical oxygen demand, dissolved oxygen, and conservative minerals within segments of streams and canals. However, for a fairly large system containing several tributaries and waste discharges, the development of the probability density function for the control point quality by the direct use of this model will require too much computer time.

In this paper the development and use of quality transition function is proposed. The quality transition function describes the relationship between the water quality of two points in a stream. The two points may be along one stream or may be before and after mixing with a tributary stream or waste discharge.

The entire river basin is broken into segments for which the QUAL-I Model is applied to develop quality transition function. By successive development of the transition functions, the control point quality is obtained as a function of the upstream parameters. This final transition function is used to simulate the downstream quality and develop its probability density function. The application of transition function can result a significant saving on computation requirements.

INTRODUCTION

The reduction of liability of pollution to our water resources has been among the goals of environmental management. The effective preservation and utilization of good quality water has also been recognized as an absolute necessity for the survival of mankind.

Water-quality considerations are extremely broad and varied in streams, rivers, and reservoirs. The problems associated with the effects of municipal, industrial, and agricultural waste discharges are of major importance. Perhaps the most critical aspect of waste disposal in rivers and streams is the disposition of treated effluent from a wastewater treatment plant. Eventually, many waste discharges enter some stream, river, or reservoir and may contribute to altering the environment. In a receiving water, it is highly desirable to make use of the waste-assimilative capacity of the water, but yet maintain the water quality at a level suitable for its intended use. Thus, the capability of routing a given water-quality parameter through a stream or canal system and estimating with reasonable accuracy the waste-assimilative capacity of the system is essential to any comprehensive water resources development plan.

Texas Water Development Board has developed a set of interrelated water-quality models (QUAL-I) capable of routing several water-quality parameters. The system is useful for the prediction of the temporal and spatial distribution of temperature, biochemical oxygen demand, dissolved oxygen, and conservative minerals within segments of streams and canals. Given values of quantity and quality parameters at upstream points, the model is capable to be utilized to compute the values of the parameters at downstream points. However, for a large system of rivers and canals having multiple discharge points of wastes, the computation of the downstream point quality requires too much computer time. The time factor becomes very critical if we need to derive a density function of the control point quality which would require many computations.

A practical approach is to break the entire river system into convenient segments and apply the QUAL-I Model finite number of times within the possible range of the desired parameter values. Then apply regression on the QUAL-I output to develop quality transition functions. By successive development of transition functions from all upstream points to a common downstream control point, we can obtain a composite final transition function of the control point quality in terms of the upstream quantities and qualities. This final transition function can be used to simulate the quality at the downstream point at considerable savings of computer time. The methodology is demonstrated in this paper for the San Antonio River Basin in Texas.

ESSENTIAL FEATURES OF QUAL-I MODEL

The primary objective of the model is the temporal and spatial routing of the following water-quality parameters: temperature, biochemical oxygen demand, dissolved oxygen and conservative minerals. The complete model is structured as separate models for each quality parameter and then they are coupled into an integrated system. Separately, one model is capable of representing the thermal behavior of a turbulent, fully-mixed stream. A second model describes the waste-assimilation characteristics in stream, and a third provides for the routing of conservative minerals. Linked together, the models provide the capability for simulation of the behavior of a given quality parameter within a branching stream or canal system as well as the capability for simulating the interrelationships between the various quality parameters. Theoretical bases and computational techniques used in the QUAL-I Model are not reported here. Interested readers may refer to the original report and user's manual of the QUAL-I Model (4,5).

SAN ANTONIO WASTEWATER TREATMENT SYSTEM

The site selected for the study was the regional wastewater treatment system in the San Antonio Metropolitan Area. There are four rivers and three major waste treatment facilities in the region, with total design capacity of 112.3 million gallons per day (MGD). The river streams are: San Antonio River, Salado Creek, Medina River, and Leon Plant. Elmendorf, a downstream location, was chosen as the control point for the regional water quality management. Figure 1 schematically presents the regional river system under study. Biochemical oxygen demand has been used as the characterizing parameter.

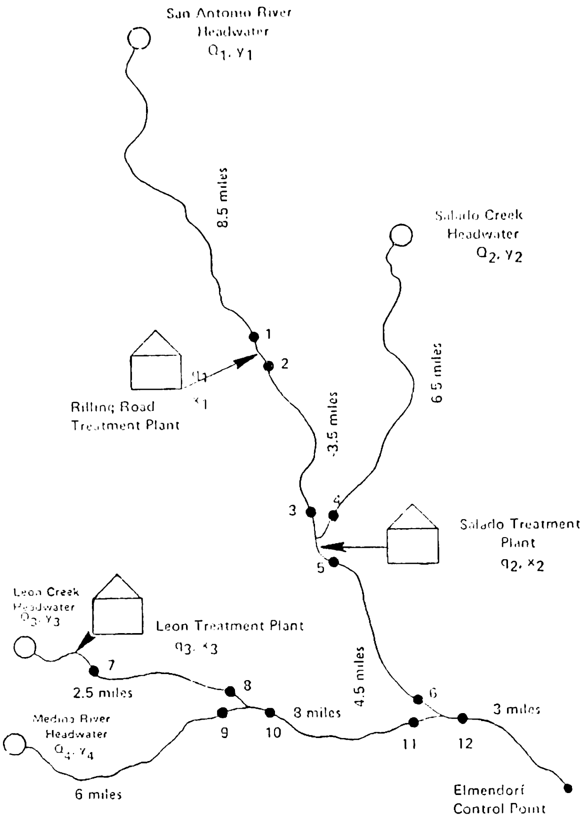


Figure 1.
Identification of various points of
Regional River System

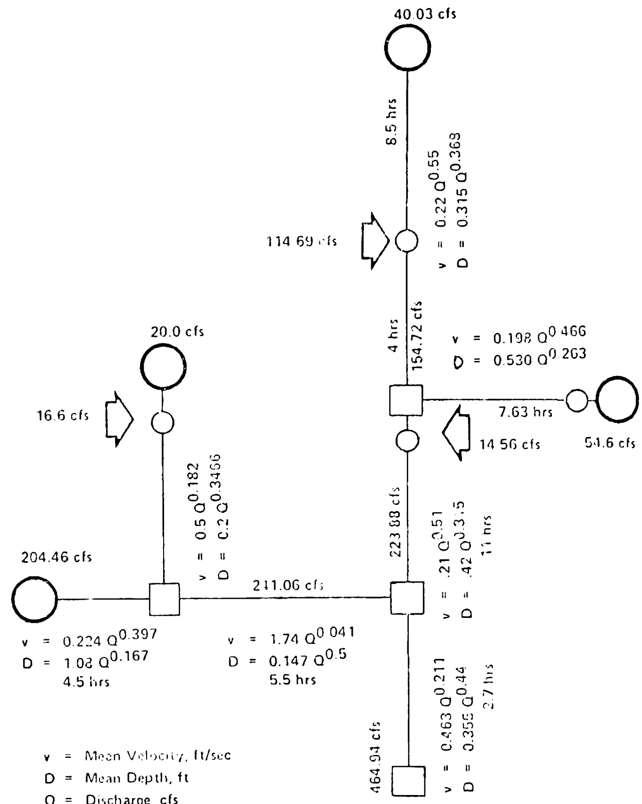


Figure 2.
Manning Roughness Coefficient n = 0.035 for all points
Hydraulic Coefficients for Determining Velocity and Depth

STREAM QUALITY TRANSITION FUNCTIONS

Quality transition functions are the relationships between the water quality of two points in a stream. The two points may be along one stream or may be before and after mixing with a tributary stream or waste discharge.

The Texas Water Development Board has developed a powerful model for stream water quality routing (QUAL-I) (4,5). This system is especially useful for the prediction of the temporal and spatial distribution of temperature, biochemical oxygen demand, dissolved oxygen, and conservative minerals within a segment of streams and canals. Thus, the QUAL-I Model is applied to derive the water quality (BOD) transition functions for this paper.

The application of transition function can result a significant saving on computation requirements, as the direct utilization of QUAL-I in quality simulation runs. However, with finite number of runs within the practical ranges of stream quality, the transition between interested points on a stream system can easily be formulated.

Input Data For QUAL-I Model

For the purpose of quality transition function derivation, the various points and variables in the San Antonio River Basin are identified in Figure 1. The input data used for the QUAL-I Model runs are summarized in Figure 2. The functional relationships in Figure 2 were obtained from graphs of mean velocity vs. discharge and mean depth vs. discharge.

Development of Quality Transition Functions

By successive use of the QUAL-I Model for the routing of Biochemical Oxygen Demand (BOD) and by applying the material balance formula for mixing as the streams meet tributaries and waste discharges from treatment plants, quality transition functions for various points of interests in San Antonio River Basin are developed.

The following notations are used for the different variables of the system (Figure 1):

Q_1, Y_1	Quantity and BOD of San Antonio River headwater
Q_2, Y_2	Quantity and BOD of Salado Creek headwater
Q_3, Y_3	Quantity and BOD of Leon Creek headwater
Q_4, Y_4	Quantity and BOD of Medina River headwater
q_1, x_1	Quantity and BOD of Rilling Road Treatment Plant
q_2, x_2	Quantity and BOD of Salado Treatment Plant
q_3, x_3	Quantity and BOD of Leon Treatment Plant
ℓ_i	Stream quality at point i
$\ell_{control}$	Stream quality at Elmendorf Control Point.

Transition Between San Antonio River Headwater And Point 1

The BOD on the stream will be oxidized as it travels downstream. The transition function between the San Antonio River Headwater and point 1 is developed by successive use of QUAL-I Program with different upstream quality. The computed values are as shown in Table 1.

TABLE 1
TRANSITION BETWEEN SAN ANTONIO RIVER HEADWATER AND POINT 1

Headwater BOD, y_1	Point 1 BOD, ℓ_1
5.0	4.3
10.0	8.6
15.0	12.9

By plotting ℓ_1 vs. y_1 we can obtain the relationship

$$\ell_1 = 0.1 + 0.8571\, y_1 \qquad [1]$$

Transition Between Point 1 And Point 2

The point 1 and 2 are separated by a negligible distance. However, effluent from the Rilling Road Waste Treatment Plant meets the stream in between these two points. By assuming complete mixing, the transition equation may be written as:

$$\ell_2 = \frac{Q_1\ell_1 + q_1x_1}{Q_1 + q_1} \qquad [2]$$

By substituting [1] into [2], we can obtain

$$\ell_2 = \frac{Q_1(a_1 + b_1y_1) + q_1x_1}{Q_1 + q_1} \qquad [3]$$

Applying similar techniques the expressions for qualities as functions of upstream parameters for all other specified points in the system can be written as follows:

$$\ell_3 = a_2 + b_2\left[\frac{Q_1(a_1 + b_1y_1) + q_1x_1}{Q_1 + q_1}\right] \qquad [4]$$

$$\ell_5 = \frac{(Q_1+q_1)\left[a_2+b_2\left(\frac{Q_1(a_1+b_1y_1)+q_1x_1}{Q_1+q_1}\right)\right]+Q_2(a_3+b_3y_2)+q_2x_2}{Q_1+q_1+Q_2+q_2} \qquad [5]$$

$$\ell_6 = a_4+b_4\left\{\frac{(Q_1+q_1)\left[a_2+b_2\left(\frac{Q_1(a_1+b_1y_1)+q_1x_1}{Q_1+q_1}\right)\right]+Q_2(a_3+b_3y_2)+q_2x_2}{Q_1+q_1+Q_2+q_2}\right\} \qquad [6]$$

$$\ell_8 = a_5+b_5\left[\frac{Q_3y_3+q_3x_3}{Q_3+q_3}\right] \qquad [7]$$

$$\ell_{10} = \frac{(Q_3+q_3)\left[a_5+b_5\left(\frac{Q_3y_3+q_3x_3}{Q_3+q_3}\right)\right]+Q_4(a_6+b_6y_4)}{Q_3+q_3+q_4} \qquad [8]$$

$$\ell_{11} = a_7+b_7\left\{\frac{(Q_3+q_3)\left[a_5+b_5\left(\frac{Q_3y_3+q_3x_3}{Q_3+q_3}\right)\right]+Q_4(a_6+b_6y_4)}{Q_3+q_3+Q_4}\right\} \qquad [9]$$

$$\ell_{12} = \frac{(Q_1+q_1+Q_2+q_2)\ell_6+(Q_3+q_3+Q_4)\ell_{11}}{Q_1+q_1+Q_2+q_2+Q_3+q_3+Q_4} \qquad [10]$$

$$\ell_{\text{control}} = a_8+b_8\left\{\frac{(Q_1+q_1+Q_2+q_2)\ell_6+(Q_3+q_3+Q_4)\ell_{11}}{Q_1+q_1+Q_2+q_2+Q_3+q_3+Q_4}\right\} \qquad [11]$$

$$= F(Q_1,Q_2,Q_3,Q_4,y_1,y_2,y_3,y_4,q_1,q_2,q_3,x_1,x_2,x_3)$$

For the system under consideration, the values of the constants in the above equations were as follows:

$a_1 = 0.1$, $b_1 = 0.8571$, $a_2 = 0.1$, $b_2 = 0.9756$
$a_3 = 0.05$, $b_3 = 0.8491$, $a_4 = 0.15$, $b_4 = 0.959$
$a_5 = 0.1$, $b_5 = 0.9333$, $a_6 = -0.05$, $b_6 = 0.9167$
$a_7 = 0.0$, $b_7 = 0.90$, $a_8 = 0.05$, $b_8 = 0.94$.

Equation [11] is the final formula computing the quality of water at the downstream control point. When the expressions for ℓ_6 and ℓ_{11} are substituted into this equation, it becomes a function of the following variables: (1) all headwater flows Q_1, Q_2, Q_3, Q_4 and their respective qualities y_1, y_2, y_3, y_4; and (2) waste discharge flow rates from waste treatment plants q_1, q_2, q_3, and their respective qualities x_1, x_2, x_3. The values of constants a_1, a_2, ... a_8 and b_1, b_2, ... b_8 were determined by graphical method.

It should be pointed out that the above equation [11] developed through the use of QUAL-I for the San Antonio River System happens to be linear. However, this does not restrict the equation for final water quality at the control point to be always linear. Nonlinear form of the equation may result for other systems.

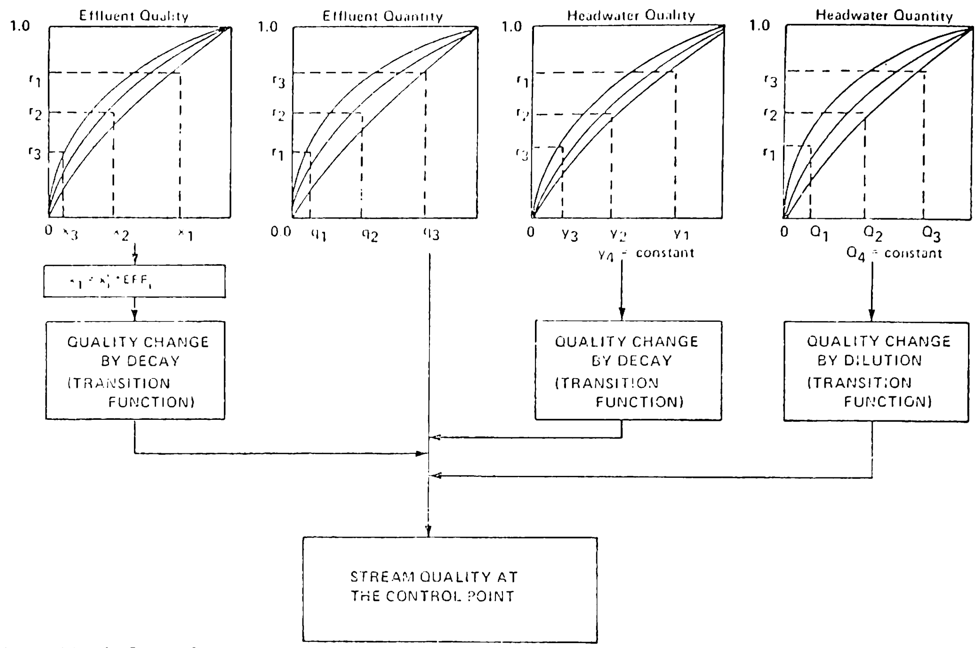
SYNTHESIS OF WATER QUALITY AT THE CONTROL POINT

Equation [11] of the previous section provides the expression for control point quality. This is a function of headwater quantities and qualities, and wastewater treatment plant effluent quantities and qualities. Since all these are random variables, the downstream control point quality will be probabilistic in nature. A simulation model was designed to produce a composite probability distribution of the control point quality which considered the unique combination of effluent discharges and qualities, and headwater flows and qualities. In the case of effluent quality, the empirical distribution of waste effluent quality from each plant is first normalized by dividing the quality (at class mark value) by the mean. Thus, the standardized distribution has a mean of 1.0. After random observations were generated and compared to the cumulative values, corresponding observations of the standardized values were selected. These observations were then multiplied by pre-specified effluent quality level to obtain the quality value to be used in computation of control point quality. Figure 3 schematically presents the simulation model.

CONCLUSION

It is observed that QUAL-I is a powerful model for the prediction of water-quality parameter values at downstream points in a river system. However, for complex river systems with many tributaries and waste discharges, the direct use of the QUAL-I Model requires too much computer time.

The proposed methodology for the development of transition functions require the use of QUAL-I only finite number of times. The final transition function is then utilized for simulation of the control point quality. The method takes the advantage of the powerful QUAL-I Model and at the same time minimizes computational time considerably.



x_i' = Normalized variables for Effluent Quality, i = 1, 2, 3

EFF_i = Pre-specified Effluent Quality, i = 1, 2, 3

Figure 3. Schematic Representation of Computation Methodology for Control Point Quality

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