A STUDY OF ASSESSMENT OF MINIMUM FLOW IN DOWNSTREAM OF A DAM FROM ECOLOGICAL CONSIDERATIONS

A DISSERTATION

submitted in partial fulfillment of the
requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
WATER RESOURCES DEVELOPMENT

By

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CANDIDATE'S DECLARATION

I, hereby declare that the work which is presented in this Dissertation entitled, **"A STUDY OF ASSESSMENT OF MINIMUM FLOW IN DOWN STREAM OF A DAM FROM ECOLOGICAL CONSIDERATION"** in partial fulfillment of the requirements for the award of the Degree of Master of Technology in Water Resources Development submitted in Water Resources Development Training Centre, Indian Institute of Technology, Roorkee, is an authentic record of my own original work carried out during the period from July 16th, 2001 to January, 2002 under the supervision and guidance of **Prof. G.C.Mishra,** ***Professor, WRDTC, Indian Institute of Technology***, Roorkee & **Dr. N.C.Ghosh,** *Scientist "E", National Institute of Hydrology*, Roorkee,

I have not submitted the matter embodied in this Dissertation for the award of any other Degree or Diploma.

Place: Roorkee
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This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

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CONTENTS

ABSTRACT

River plays an important role in the social and economic development of the human resource sustaining in its basin providing the basic resource water for irrigation, drinking, and industrial use, waste assimilation, and recreation, etc. It is also the source of drinking water for wild and domestic animals and birds, as well as, the shelter place for aquatic lives. Any untoward deterioration of river water quality, which may cause due to the disposal of effluents from urban, industrial, and agricultural areas, would pose a threat to all those beneficial activities.

Disposal of effluents into the rivers is a traditional concept. Rivers have a limiting cleansing capacity of effluents- a known fact but seldom do we realize this important aspect. Pollution more than the self-cleaning capacity of the river water would deteriorate the water quality of the rivers. The health of a river would deteriorate more when the normal flow of the river gets restricted due to construction of a dam. The situation of the Brahmani River in Orissa particularly at the downstream of the Rengali dam is a witness of such problem. Due to the deteriorated water quality in the river the bio-diversity of the region is in danger.

Down below the Rengali dam wastewaters generated from the industrial, mining and urban areas located on and around the river banks are discharged into the river Brahmani through three of its tributaries viz., Tikara, Nandira and Bangaru, which join the river at 25Km, 75 Km, and 95 Km respectively. During non-monsoon months, which occurs from November to May, these tributaries are fed mainly by the wastewaters but the main river course of the Brahmani is perennial. The normal lean period flows in the river are inadequate to maintain the requisite standards of water quality prescribed for different uses. BOD and DO are usually referred as the primary criteria of water quality index.

The present study is aimed at: (I) simulation of the BOD and the DO of the river for a stretch of 310 Km for all low flow months, (ii) estimation of the self purification capacity of the river for different flow conditions, and (iii) assessment of the minimum flow requirement to achieve the water quality standards of category "B".

QUAL2E, Enhanced stream water quality model developed by US-EPA based on the conceptual representation of pollutants transport in a river governed by the advection-dispersion, growth and decay, and sources and sinks, has been used as a tool for simulation of the BOD and the DO profiles of the River Brahmani, and for estimation of the minimum flow requirement.

The input data, such as; river flow at the inlet and at the outlet and river water quality at different locations, point pollution flow rates and concentration of constituents, and ambient temperature etc. required for simulation of the BOD and DO were available from different Organizations. The other input data; coefficients and exponents of discharge for estimation of the flow velocity and the depth of flow and the longitudinal dispersion coefficients are computed utilizing the time series data of river observed at different locations.

Using the observed BOD and DO data, the reaction rate coefficients are estimated by trial and error method treating an inverse problem. The estimated model coefficients are: (i) de-oxygenation rate coefficient, K_1 = 0.23 day^{-1}, (ii) re-aeration rate coefficient, K_2, the expression given by Owens et.al. (iii) Sediment Oxygen demand (SOD), K_3 = 0.3 day^{-1}, and Settling rate coefficient, K_4 = 3.0 gm/sq./day. These calibrated values of reaction coefficients can be used for computation of BOD and DO profiles of the Brahmani river below the Rengali dam for any stress conditions. It is observed that during February through May, in a stretch measuring approximately 100 Km downstream of the Tikara river, i.e., first point load, the DO values reduce below the permissible limit of 5 mg/L. The critical month of DO deficit is May, which is also the minimum low flow month.

The critical point of DO (=2.3 mg/l) is found to be about 115 Km below the Rengali Dam and it is near to the third point load, i.e., Bangaru river.

Three alternatives; (I) augmentation of flow, (ii) control of pollution by treatment of effluents, and (iii) partial flow augmentation and partial treatment of effluents have been considered for analysis of minimum flow requirement in the river. For flow augmentation, it is assumed that quantity of flow required as augmented flow would be available from the upstream reach. Augmented flows show improvement in the DO concentration along the critical DO deficit zone, and follow a quadratic relationship with the DO concentration at a particular. This implies that the increase of DO at the initial stages of the augmented flow is more, and tends to a steady state of DO values as one increases the augmentation of flow after a certain value. Thus, flow augmentation alone is found not an effective method to recover the DO deficit.

In the second alternative, different percentages of treatment to the effluents' BOD are considered to ascertain the assimilative capacity of the river water prevailing in different critical months. It is found that in different months the river requires different degree of treatment of effluents to achieve the target level of DO concentration. In the month of May, about 63% treatment of effluents' BOD over the existing pollution loads would be required to achieve the target DO value of 5 mg/L at the critical point.

In the third alternative, i.e., partial treatment of effluents and partial flow augmentation, it is found that about 50% treatment to the effluents' BOD and minimum flow of about 300 cumecs maintain DO concentration of 5 mg/L along the river reach during all critical months. From ecological point of view, partial treatment and partial flow augmentation appears to be the best alternative.

LIST OF SYMBLES

A = Cross Sectional Area

A_1 = Constant

BOD = Bio Chemical Oxygen Demand

BOD_5 = 5 -day Bio Chemical Oxygen Demand

C = concentration of Constituents

C_b = Concentration of Pollutants in the river before mixing of waste water

C_i = Concentration of indivisual Constituents

C_o = Initial Concentration of an affluent

C_s = Concentration of Pollutants in Waste Water

^0C = Degree Centigrade

D = Depth of Water

D_{crit} = Critical Oxygen Deficit

DO = Dissolved Oxygen

DO_b = Dissolve Oxygen Concentration of River Wter before mixing of waste water

DO_{crit} = Critical Dissolve Oxygen Concentration

DOD = Dissolve Oxygen Deficit

D_L = Longitudinal Dispersion

DO_o = Initial Dissolve Oxygen

DO_s = Dissolve Oxygen concentration of Waste Water

DO_{sat} = Saturated Dissolved Oxygen Concentration

F_r = Froude's Number of Flow

H = Depth of Flow

^0K = Degree Kelvin

K_1 = Deoxygenation Rate Coefficient

K_2 = Reaeration rate coefficient

K_3 = Sediment Oxygen Demand

K_4 = Settling Rate Coefficient

$K_1(T)$ = Value of K_1 at Temperature T^0C

L	=	Bio Chemical Oxygen Demand
L_0	=	Initial Bio Chemical Oxygen Demand
M	=	Mass
n	=	Manning's Rugosity Coefficient
pH	=	Hardness
Q_b	=	Flow Rate of River Before Mixing of Waste Water
q_s	=	Flow Rate of Waste Water
Q	=	Discharge of River Reach
R	=	Hydraulic Mean Radius
R_1	=	Correlation Coefficient
S	=	Slope
s	=	Source
T	=	Temperature
T_K	=	Temperature in ^0K
T_{crit}	=	Time of Dissolved Oxygen
U	=	Mean Speed
U^*	=	Friction Velocity
V	=	Velocity of Stream
V_1	=	Velocity of Stream
X_{crit}	=	Distance at which Dissolved Oxygen Critical Occurs.

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CHAPTER – 1

INTRODUCTION

Rivers are an integral part of eco-system and maintain natural, environmental and nearly all aspects of human culture. Since history of our civilization, almost all human activities have grown on the river sides because of the facts that rivers provide fish as food; and clean water for drinking, bathing, recreation; and irrigation water for development of civilization. The other important aspect of development of human activities on the bank of the rivers is due to ease in disposal of wastewaters originate from the various human activities into the rivers at almost no economic cost. For ages the river has been playing an important role as a basic source for water used in irrigation, domestic purposes, industrial activities and navigation and also for purifying the refusal being discharged into it.

Continuous and unabated disposal of wastewater into the river, in many cases, has caused undesirable changes to the aquatic flora and fauna. These changes are caused mainly due to the presence of organic matter, which has demand of oxygen, resulting in the lowering of the concentration of dissolved oxygen (DO) in the receiving water. Pollution of rivers is also caused by the discharge of toxic substances and inorganic nutrients.

Wastewaters primarily emanate from (i) municipal sources, (ii) industrial sources, (iii) agricultural runoffs, and (iv) storm water and urban runoffs. Effluents originate from municipal and industrial sources are called point sources of pollution, and refusal from agricultural runoffs, storm water and urban runoffs, are called non-point sources of pollution or diffused sources of pollution.

Discharge of wastewaters originated from municipal and industrial sources into a river is a traditional concept with an assumption that river will clean the biodegradable or organic matters present in the wastewaters. River has a limiting self-purification or assimilating capacity, which depends upon geometry of the river, flow condition, ambient temperature and the dissolved oxygen present in the river water. Pollution more than the self-cleaning capacity of the river would deteriorate the water quality of the river including health of the aquatic biota. Aggravation in deterioration of water quality of a river for continuos pollution load would be more when the flow in the river is less that occurs during lean flow period. The health of a river deteriorates when constructing dam restricts the normal flow in a river, so is the situation of Brahmani River in Orissa particularly in the downstream of the Rengali dam.

In between the river stretches of 310 Km downstream of the Rangali Dam, three point sources of industrial wastewaters join the Brahamani river respectively at 25 Km, 75Km, and 95 Km downstream of the dam through the Tikara river, the Nandira river and the Bangura river. The industrial effluents mainly feed these rivers. The flow rates of industrial effluents and the pollution loads are different in different rivers. The Tikara river has the effluent flow rate between 12-13.5 m^3/sec, the Nandira river between 11.5 – 12.0 m^3/sec, and the Bangaru river has 10.5-11.0 m^3/sec and the pollution load in terms of Bio-chemical Oxygen Demand (BOD) varies between 225 mg/L to 245 mg/L. During monsoon months besides the industrial effluents monsoon runoffs increase the flow rate about 25-45% over the normal effluents rate.

Because of the discharge of the industrial effluents into the Brahmuni river, water quality of the river mainly the DO and the BOD besides other water quality parameters is under threat of pollution when compared with the prescribed limit designated for different uses. It mainly occurs during lean period of flow occurring between January to May every year. As a result, the socio-economic and socio-cultural aspects of the people living along the river stretches including the river eco-system are continuously degrading (OSPCB, 2000).

The management of water quality, or the protection of the aquatic ecosystem in broader sense, means the control of pollution. The control of pollution, the protection of aquatic systems, is thus the control of human activities that result in pollution. As control of water quality of a river, the usual options are (i) limiting the amount of wastewaters discharged into the river; (ii) augmentation of flow; (iii) treatment of effluents before being discharged into the river; and (iv) combinations of flow augmentation and effluent treatment.

A crucial element in the series of complex activities of planning and implementing water pollution control actions is the quantitative determination of the relationship between human activities and the response of the system. These activities together can be termed the modelling of aquatic systems. An appropriate method of management of water quality could be addressed when the prevailing conditions of the river health are known or assessed for different pollution loads.

BOD and DO are important and commonly used indicators of water quality, there are, of course, other quality parameters , for example, various forms of nitrogen and phosphorous, numerous organic and inorganic chemicals and toxic industrial waste materials, pathogenic bacteria and virus. DO concentration is a function of numerous parameters that describe the natural bio-chemical and physical processes which take place in rivers. Therefore, BOD and DO are considered for analysis and modeling in the present study.

Enhanced stream water quality model, ' QUAL2E', developed by USEPA (Brown and Barnwell,1987) , which is based on one-dimensional advection-dispersion, growth, and decay, and source and sinks of pollution, has been used for simulation of water quality parameters of the river. The model has been used as a tool to analyze the different options of water quality management of the river.

1.1 Objectives of the Study

The present study is aimed at:

(i) Evaluation of the river health in terms of DO and BOD at the downstream of the Rengali dam.

(ii) Simulation of water quality parameters for different flow conditions and pollution loads.

(iii) Estimation of minimum flow requirement to maintain the prescribed limit of water quality for different uses.

CHAPTER – 2

LITERATURE REVIEW

2.1 INTRODUCTION

2.1.1 ECOLOGICAL ASPECT OF STREAMS

Four major resources land, water, air and living organisms (plants and animals) together constitute an Eco System. Land, air and water together form one group called physical Eco System, where as living organisms form biological Eco System.

The natural environment in the biosphere maintains a perfect balance and equilibrium condition between the various organisms and ecologically a balance system. In Equilibrium State, the relative number of different organisms in a particular environment remains constant. Any untoward action to the natural Eco System changes its physical factors, such as; temperature, rainfall, evaporation, chemical constituents of water etc., which consequently changes the relative number of different organisms in the biosphere.

Characteristics of river serve as integrator of broader environmental conditions as they reflect the condition of the land scope. The biological integrity of a river supports and maintains a balance between the natural processes and living organisms present in the river water. The protection of quality of water is therefore a pre-condition for maintaining the Eco-system of a river.

The developments of civilization and rapid industrialization have caused a great damage to the Eco system. The effects of pollution towards the Eco system of a river could quantitatively be determined and assessed with the help of modeling of aquatic systems. Water quality modeling is one such approach, which is aimed at calculating the impact of natural and anthropogenic processes on the state of water system.

2.2 RIVER WATER QUALITY MODELING

The impact of human activities on the health of a river is an important phenomenon and is a subject of ongoing research. The aquatic plant and animal life present in water bodies require oxygen for survival. When some organic substances originating from point or non-point sources of pollution are discharged into a river, they act as sources of food for many of the living organisms. In order to utilize these wastes, the aquatic organisms require oxygen, which is obtained from the water that is available in dissolved form. Thus the decomposition of organic biodegradable wastes by aquatic organisms tends to reduce the dissolved oxygen concentration of the water that contains wastes. The oxygen required for the decomposition or assimilation of any particular quantity of waste is expressed as its *biochemical oxygen demand* (BOD), the difference between the saturation concentration of dissolved oxygen and the existing dissolved oxygen concentration is called *dissolved oxygen deficit* (DOD). The rate of reduction of BOD and the rate of depletion of DO over space and time in a river due to the decomposition of organic wastes are of interest in water quality modeling. The literature on water quality and water quality modeling of rivers is very voluminous, however, in the present case literature, which are of direct relevance to present investigation have been considered.

2.3 BASIC THEORY OF RIVER WATER QUALITY MODELING

The basic principle of river water quality modeling is conservation of mass, which states that in any given interval of time, the mass transported into the water body minus the mass transported out of the body plus the mass produced within the body equals the change in mass within that body during that time interval. Using the analogy of Fick's law of diffusion, the one-dimensional form of the equation describing the advection-dispersion, sources and sinks terms for steady and uniform flow condition, is expressed as (Muller and Thoman, 1987):

$$\frac{\partial M}{\partial t} = \frac{\partial \left(AD_L \frac{\partial c}{\partial x} \right)}{\partial x} dx - \frac{\partial (AUc)}{\partial x} dx + Adx \frac{dc}{dt} + s \qquad (2.1)$$

where

M = mass of constituent (M) in the control volume A.dx,

x = coordinate (L),

t = time coordinate (T),

c = concentration of constituent (ML^{-3})

D_L = longitudinal dispersion coefficients (L^2T^{-1}),

U = mean velocity LT^{-1}, and

s = external source/ sink MT^{-1}

Since, mass M = V.c, hence,

$$\frac{\partial M}{\partial t} = \frac{\partial (VC)}{\partial t} = V \frac{\partial c}{\partial t} + c \frac{\partial V}{\partial t} \qquad (2.2)$$

For steady flow, $\frac{\partial V}{\partial t} = 0$

Hence,

$$\frac{\partial M}{\partial t} = V \frac{\partial c}{\partial t},$$

Since V = A dx (2.3)

$$\frac{\partial}{\partial x}\left[D_L \frac{\partial c}{\partial x}\right] - U\frac{\partial c}{\partial x} + \frac{dc}{dt}_i + \frac{s}{v} = \frac{\partial c}{\partial t} \qquad (2.4)$$

The first term represents transport due to mechanical dispersion. The second term represent transport due to advection. The third term takes into account of the changes in constituent concentration due to changes from growth ; decay and interfacial transfer. The fourth term is the forcing function i.e. external sources or sink (source is positive and sink is negative).

Steady State Condition:

Under steady state condition

$$\frac{\partial c}{\partial t} = 0$$

Changes that occur to individual constituents or particles independent of advection, dispersion, and waste inputs are defined by the term $\frac{dc}{dt}$.

These changes include the physical, chemical, and biological reactions and interactions that occur in the stream. Examples of these changes are re-aeration, algal respiration and photosynthesis, and coliform die-off.

To apply Eq.(2.4) for estimation of BOD concentrations under steady state condition of input into a river, it is assumed that the rate of change in BOD concentration (ML^{-3}) with distance is proportional to the BOD present and the rate of BOD addition due to runoff and scour. Denoting the proportionality constant as a function of two parameters K_1 and K_3 , the de-oxygenation and BOD sedimentation rate constants (T^{-1}), respectively, the BOD equation is derived as:

$$D_L \frac{d^2 BOD(x)}{dx^2} - \frac{Q}{A}\frac{dBOD(x)}{dx} - (K_1 + K_3)BOD(x) + \frac{S}{V} = 0 \qquad (2.5)$$

The value of the deoxygenation and sedimentation rate constants K_1 and K_3 depend on the composition of the BOD of wastewaters.

To determine the dissolved oxygen, it is assumed that the rate of change in the dissolved oxygen concentration is proportional to the BOD present. Mathematically, the expression of dissolved oxygen concentration is derived as:

$$D_L \frac{d^2 DOC(x)}{dx^2} - \frac{Q}{A}\frac{dDOC(x)}{dx} + K_2\, DOD(x) - K_1\, BOD(x) + \frac{S}{V} = 0 \qquad (2.6)$$

where K_2 is re-aeration rate constant (T^{-1}), DOC is dissolved oxygen concentration (ML^{-3}) and DOD is dissolved oxygen deficit (ML^{-3}).

Neglecting the term accounting for dispersion leads to the simple BOD and DO models, which are used as crude approximation of BOD and DO computations and holds good for a linear system, in which, it is assumed that for a river and a sewage discharge of steady conditions, initial concentration C_0 of an effluent can be described by the general dilution equation of the following form :

$$C_0 = \frac{C_s\, q_s + C_b\, Q_b}{q_s + Q_b} \qquad (2.7)$$

where C_s concentration of the pollutant in the wastewater, (ML^{-3}); C_b is the concentration of the pollutants in the river before mixing of the wastewaters, (ML^{-3}) , q_s the effluent discharge ($L^3\ L^{-1}$); Q_b flow rate of the river before mixing of the wastewaters, ($L^3\ T^{-1}$).

2.4 SIMPLE BOD AND DO MODELS

Most of the water quality models, which are in use today as simple models for computation BOD and DO of river waters, are extensions of two fairly simple equations proposed by Streeter and Phelps (1925). After Streeter and Phelps, several concepts were introduced (Camp, 1963; Gundelach and Castillo, 1976; Bharagava, 1983; Bobba et.al, 1983; Barnwell 1985; Thomman and Muller, 1987; Choudhary et.al, 1990; Jokankai, 1997; Guymer, 1998; Sharma et.al 2000). All these approaches assumed that the substances present in the water, decay according to a first order reaction, that is the rate of loss of the substance is proportional to its concentration at any time. Streeter and Phelps (1925) has first established the relationship between the decay of an organic waste measured by the BOD and the DO sag model.

2.4.1 Bod Decay Model

If L is the BOD (mgl^{-1}) at time t and K_1 is the first order reaction kinetics, Streeter and Phelps has expressed the BOD decay model as:

$$\frac{dL}{dt} = -K_1 L \qquad (2.8)$$

where K_1 is the BOD rate constant in T^{-1} and t is the travel time.

Integrating Eq. 2.8

$$\ln(L) = -K_1 t + A_l \quad (2.9)$$

where A_l is a constant of integration

'A' is obtained using the initial condition, at $t = 0$, $L = L_0$ as

$$A_l = \ln(L_0) \quad (2.10)$$

Substituting 'A_l' in Eq.(2.9), we get

$$L = L_0 e^{-k_1 t} \quad (2.11)$$

2.4.2 Dissolved Oxygen Model

The dissolved oxygen model describes the "sag" of the dissolved oxygen in the river as influenced by the decay of biodegradable organic matter and the re-aeration process. The dissolved oxygen deficit equation is expressed as:

$$\frac{dD}{dt} = K_1 L - K_2 D \quad (2.12)$$

Where D is the DO deficit in mgL^{-1} , which is the difference between the saturated dissolved oxygen and the dissolved oxygen present in water, and K_2 represents re-aeration rate coefficient (T^{-1}).

Multiplying both sides of Eq. 2.11 by $e^{k_2 t}$ one gets;

$$\frac{dDe^{k_2 t}}{dt} + K_2 De^{k_2 t} = K_1 Le^{k_2 t} \quad (2.12(a))$$

Substituting $L = L_0 e^{-k_1 t}$ in Eq. 2.12 (a) and simplifying

$$\frac{d\left(De^{k_2 t}\right)}{dt} = K_1 L_0 e^{(K_2 - K_1)t} \quad (2.13)$$

Integrating Eq. 2.13

$$De^{k_2 t} = \frac{K_1 L_0 e^{(K_2 - K_1)t}}{(K_2 - K_1)} + A_1 \quad (2.14)$$

The constant 'A_1' is obtained using the initial condition, at t = 0 , D = D_0 .

$$A_1 = D_0 - \frac{K_1 L_0}{(K_2 - K_1)} \quad (2.15)$$

Substituting 'A_1' in Eq (2.14), we get:

$$D = D_0 e^{-K_2 t} + \frac{K_1 L_0}{(K_2 - K_1)}(e^{-K_1 t} - e^{-K_2 t}) \quad (2.16)$$

The time, $t = \frac{x}{v}$.

Eqs.(2.11) and (2.16) are the models suggested by the Streeter and Phelps for computation of BOD and DOD in a river. Equation 2.16 is known as "Oxygen-Sag Equation". The critical value of time of occurrence of DO deficit is obtained by differentiating Eq.(2.16) with respect to time 't' and equating to zero. The time to critical DO deficit is given by :

$$t_{crit} = \frac{1}{K_2 - K_1} \ln \frac{K_2}{K_1}\left(1 - \frac{D_0(K_2 - K_1)}{L_o K_1}\right) \quad (2.17)$$

The DO deficit corresponding to the critical time is given by:

$$D_{crit} = \frac{K_1}{K_2} L_0 e^{-K_1 . t_{crit}} \quad (2.18)$$

The location of the critical point is:

$$X_{crit} = V. t_{crit} \quad (2.19)$$

The dissolved oxygen at the critical point is

$$DO_{crit} = DO_{sat} - D_{crit} \quad (2.20)$$

2.4.3 Dilution Equations for BOD and DO

The dilution equations, which provide the initial concentration of BOD and DO in the river downstream of a point source sewage discharge, with the assumption of instantaneous mixing, are given by :

$$L_0 = \frac{L_s\, q_s + L_b\, Q_b}{q_s + Q_b} \tag{2.21}$$

$$DO_0 = \frac{DO_s\, q_s + DO_b\, Q_b}{q_s + Q_b} \tag{2.22}$$

The initial DOD is calculated by subtracting the initial oxygen concentration DO_0 from the saturated oxygen concentration, DO_{sat}, which is temperature dependent. The expression for calculating the DO_{sat} from a given temperature as derived by (APHA, 1985) is given by :

$$l_n DO_{sat} = -139.34411 + \frac{1.575701 \times 10^5}{T_K} - \frac{6.642308 \times 10^7}{T_K^2} + \frac{1.243800 \times 10^{10}}{T_K^3} - \frac{8.621949 \times 10^{11}}{T_K^4} \tag{2.23}$$

where T_K = temperature in ^{0}K (= ^{0}C+273.15)

De-oxygenation rate coefficient (K_1), and re-aeration rate coefficient (K_2) are the two important parameters in stream water quality modeling. There are other reaction coefficients as well that can be derived according to the modeling requirement and the availability of data.

2.5 DE-OXYGENATION RATE COEFFICIENT (K_1)

The de-oxygenation rate coefficient (K_1) is the rate at which the biochemical decomposition of organic matter takes place in a water column. It is estimated either from the laboratory analyses of wastewaters (usually termed as bottle rate coefficient measured at a 20^0C) or from the plot of in-stream BOD data (estimated at 20^0C) versus travel time. The value of K_1 varies with quality of effluents, flow condition and with water temperature. The equation used for the correction of the value of K_1 as a function of water temperature is given as:

$$K_{1(T)} = K_{1(20^0 C)} 1.047^{(T-20)} \qquad (2.24)$$

where

$K_{1(T)}$ is the value of rate coefficient K_1 at water temperature $T_0^{\,O}C$.

$K_1(20^0C)$ is the value of rate coefficient K_1 at water temperature $T = 20^0$ C

T is water temperature (T^0C).

The value of K_1 has been reported to vary between 0.1 to 1.7 day^{-1}.

2.6 RE-AERATION RATE COEFFICIENT (K_2)

Re-aeration rate coefficient, K_2, is one of the important parameters for stream water quality modeling. It is the rate at which oxygen in dissolved form is introduced in the water column and expressed as T^{-1} . The value of the re-aeration coefficient, K_2, depends on the hydraulic parameters of the stream and it is temperature dependent. Over the past few decades, many researchers have derived several empirical formulae for re-aeration coefficient relating the river geometry and flow characteristics. However, more often, K_2 is expressed as a function of stream depth and velocity.

The re-aeration coefficient developed by various investigators and which are more often used in stream water quality modeling are tabulated in Table. 2.1

Table: 2.1 REAERATION COEFFICIENT (K_2) proposed by different investigator

Sl. No	Investigators	Re-aeration equation
1.	O'Connor and Dobbins (1958)	$K_2 = 3.90V_t^{0.5} H^{-1.5}$
2.	Churchill et.al (1962)	$K_2 = 5.010V_t^{0.969} H^{-1.673}$
3.	Krenkel and Orlob (1962)	$K_2 = 173(SV_t)^{0.404} H^{-0.66}$
4.	Owens et.al (1964)	$K_2 = 5.35V_t^{0.67} H^{-1.85}$
5.	Langbein and Durum (1967)	$K_2 = 5.14V_tH^{-1.33}$
6.	Cadwallader and Mc.Donnell (1969)	$K_2 = 186(SV_t)^{0.75} H^{-1}$
7.	Thackston and Krenkel (1969)	$K_2 = 24.9\ (1+F_r^{0.5})\ V_* H^{-1}$
8.	Parkhurst and Pomeroy (1972)	$K_2 = 23(1+0.17F_r^2)(SV_t)^{0.375}H^{-1}$
9.	Tsivoglou and Wallace (1972)	$K_2 = 31200SV_t$ for $Q < 0.28m^3/sec$ $K_2 = 15200SV_t$ for $Q > 0.28m^3/sec$
10.	Smoot (1988)	$K_2 = 543S^{0.6236} V_t^{0.5325} H^{-0.7258-}$
11.	Moog and Jirka (1998)	$K_2 = 1740V_t^{0.46}S^{0.79} H^{0.74}$ for $S>0.0$ $K_2 = 5.59S^{0.16} H^{0.73}$ for $S<0.0$

Here, V_t = velocity of stream water in m/s, H = flow depth in m, S= slope, v_* = friction velocity in m/s, and F_r = Froude number

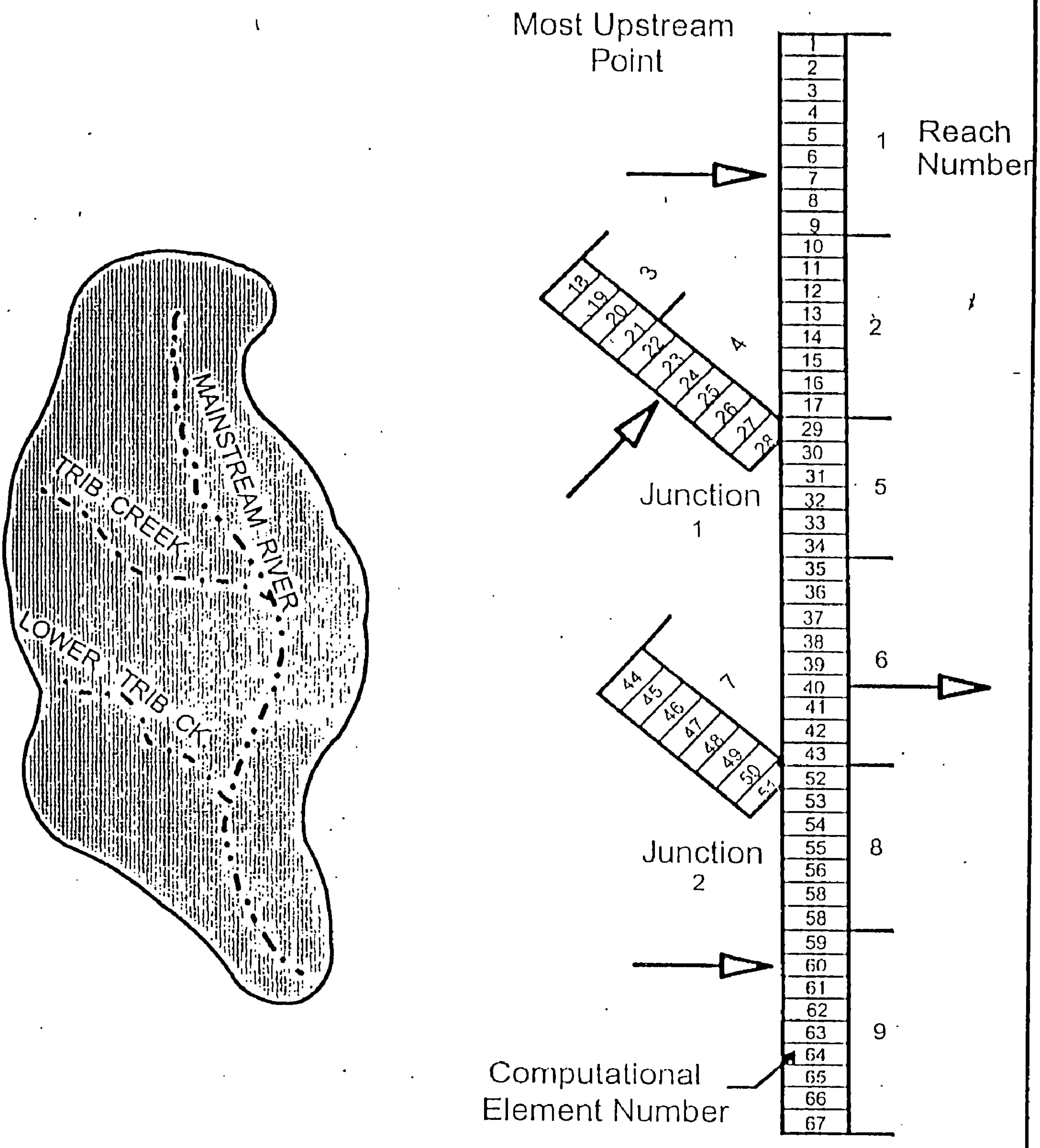
From the table.2.1, it could be seen that different investigators have derived different expressions for K_2 and it varies from river to river .

2.7 QUAL2E

Enhanced Stream water quality model, QUAL2E, developed by the US-EPA (1987) has a long history in systems analysis in water quality management. The foundation, on which the series is built, was laid by the Texas Water

Development (TWDB) in the late 1960s. The computer program of QUAL2E (Brown and Barnwell,1987) permits simulation of several water quality constituents in a branching stream governed by the one-dimensional advective – dispersive mass transport and reaction equation. The conceptual representation of a stream used in the QUAL2E formulation is a stream reach that has been divided into a number of sub-reaches or computational elements equivalent to finite difference (Fig.2.1). For each computational element, a hydrologic balance in terms of flow (Q), heat balance in terms of temperature (T), and a materials balance in terms of concentration (C) has been conceptualized in the formulation. Both advective and dispersive transports are considered in the materials balance. Mass can be gained or lost from an element by transport processes, external sources and sinks (e.g. waste discharge or withdrawals) or by internal sources and sinks (e.g., benthic sources or biological transformations); these terms have been included in the mathematical formulation. Implicit backward difference scheme has been used to solve the partial differential equation of the form given by Eq.(2.1) under the steady state of flow and pollutants load, in which, it is assumed that output of the element (i-1) flows into the element (i) and output of the element (i) flows into element (i+1).The specific equations and solution technique are described in detail in the QUAL2E computer program documentation. **Fig. No.2.2**

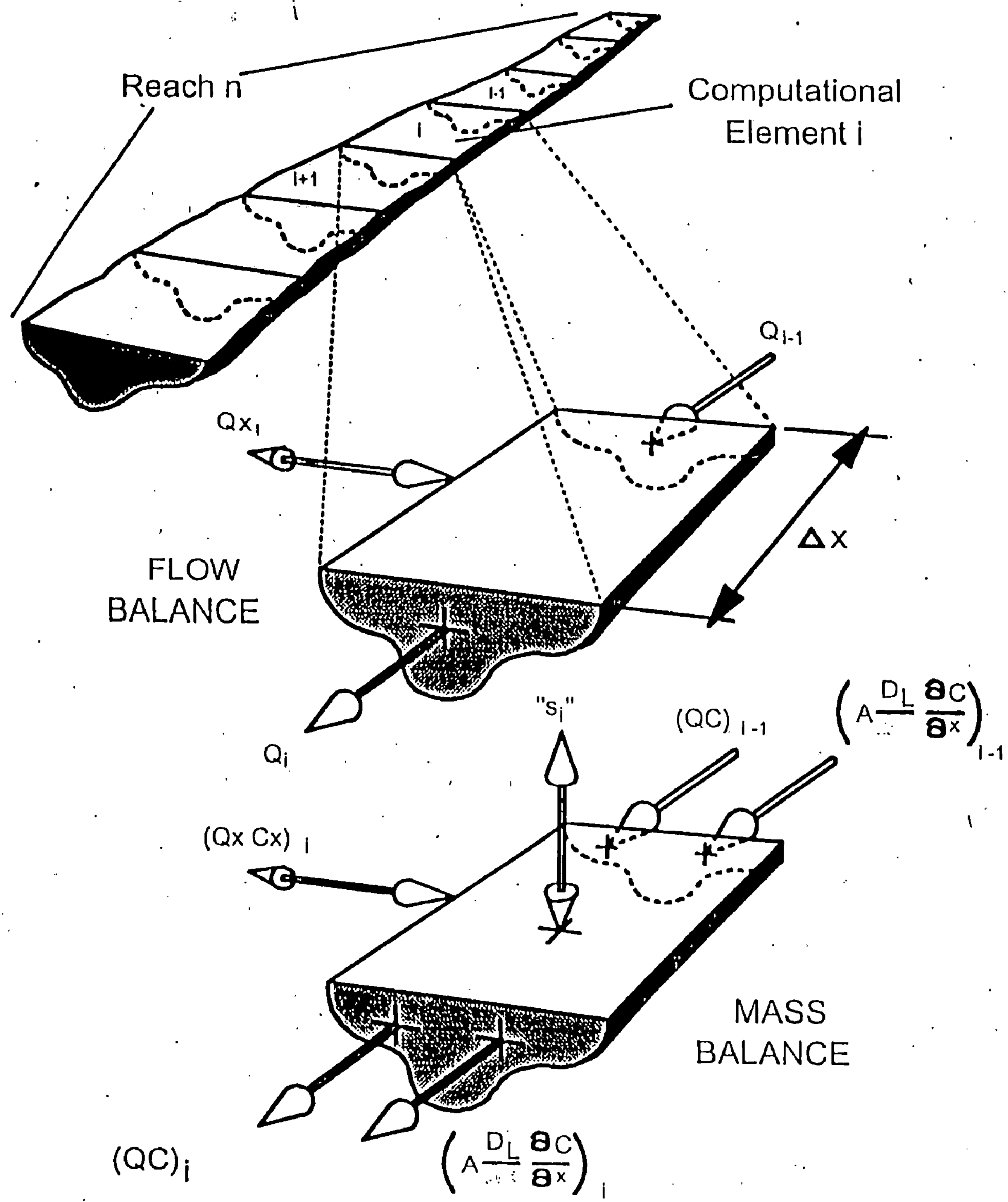
Prototype representation conceptualized in QUAL2E consists of stream network divided as "Headwater", "Reaches", and "Junctions". The "Headwater" is the beginning point of every tributary as well as the main river system and a



CONCEPTUAL REPRESENTATION

STREAM NETWORK OF COMPUTATIONAL ELEMENTS AND REACHES

Fig. No.2.1



CONCEPTUAL REPRESENTATION
Discretized Stream System

Fig. No.22

"Junction" is the joining of tributary and the main river system. The "Reaches" are the segregated form of the stream network, which are stretches of stream that have uniform hydraulic characteristics. The reach is further sub-divided into computational elements, which indicate the finite difference size used in the numerical solution of the differential equations. The fundamental reason for subdividing sections of a stream into "Reaches" is that QUAL2E assumes the physical, chemical and biological properties (model-input parameters or coefficients) are constant along a "Reach". **Fig. No.2.3**

The computation of water temperature is performed from the heat balance equation that considers the net energy flux through the air water interface from the net short wave solar radiation, net long wave atmospheric and back radiation, convective inputs and losses, and evaporative losses. Solar radiation may either be input or estimated from latitude, time of year, and climatologic factors.

One of the most important considerations in determining the assimilative capacity of a stream is its ability to maintain an adequate dissolved oxygen concentration. The QUAL2E computer program includes the major interactions of the nutrient cycles, algal production, benthic and carbonaceous oxygen demand, atmospheric re-aeration, and their effect on the dissolved oxygen balance. These interactions are illustrated in Fig. (2.4). In addition, the computer program includes a heat balance for the computation of temperature and mass balances for conservative minerals, and coliform bacteria. Chlorophyll "a" is modeled as the indicator of planktonic algae biomass in QUAL2E. The model also permits computation of nitrogen cycle composed of four compartments: Organic nitrogen,

EXAMPLE STREAM NETWORK OF COMPUTATIONAL ELEMENTS AND REACHES

Type 1: Headwater
Elements 1, 18, 44

Type 3: Upstream From Junction
Elements 17, 43

Type 4: Junction
Elements 29, 52

Type 5: End of Network
Element 67

Type 6: Point Sources
Elements 7, 24, 60

Type 7: Point Withdrawal
Element 40

Type 2: Standard
All other Elements

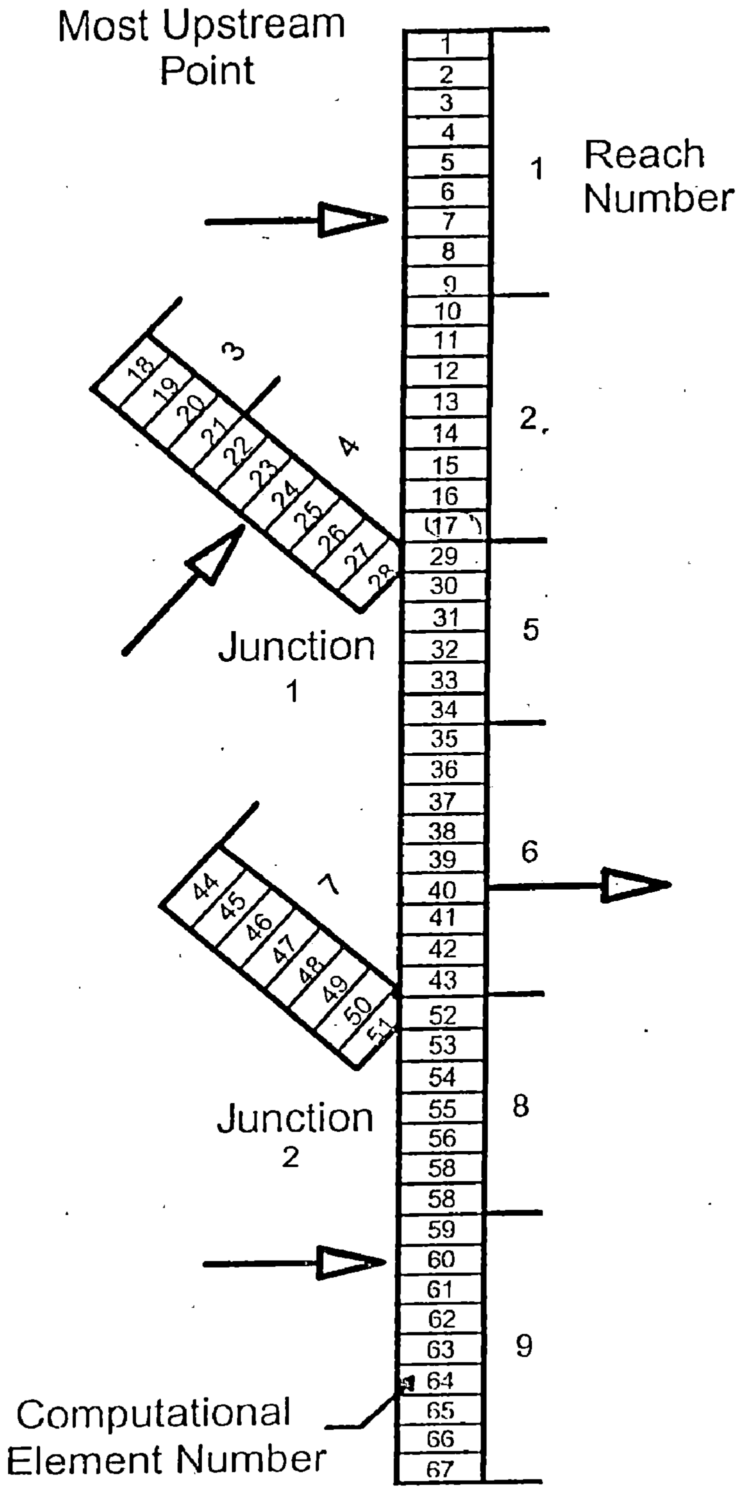


Fig. No.2.3

QUAL2E CONSTITUENT SCHEMATIC

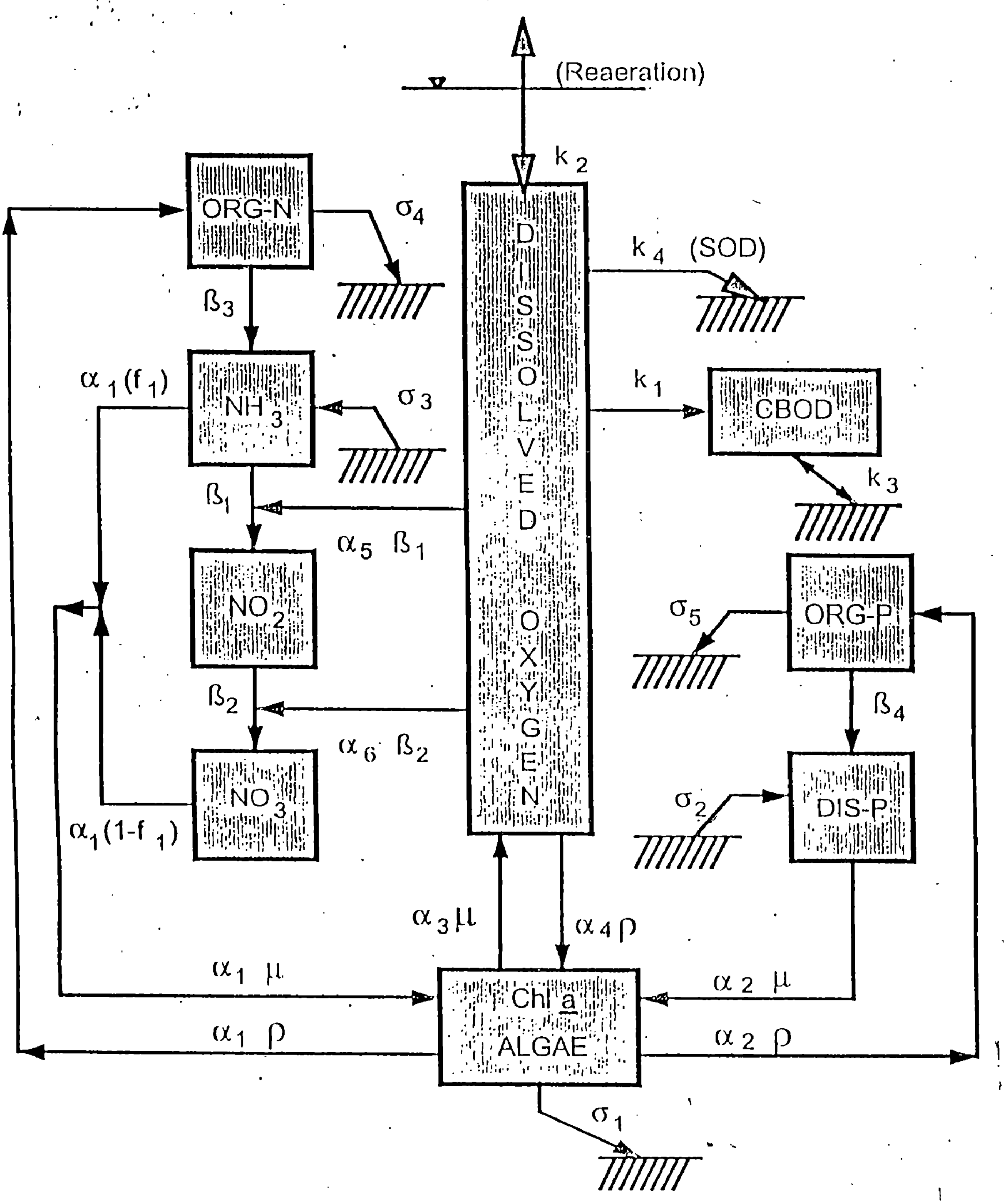


Fig. No.2.4

Ammonia nitrogen, Nitrite nitrogen and Nitrate nitrogen. Modeling of the phosphorous cycle is similar to the nitrogen cycle, having only two compartments, namely; organic phosphorus, and dissolved phosphorus. Ultimate carbonaceous biochemical oxygen demand (BOD) is modeled as first-order degradation process considering the processes of settling without affecting the oxygen balance.

Following are the assumptions in QUAL 2E:

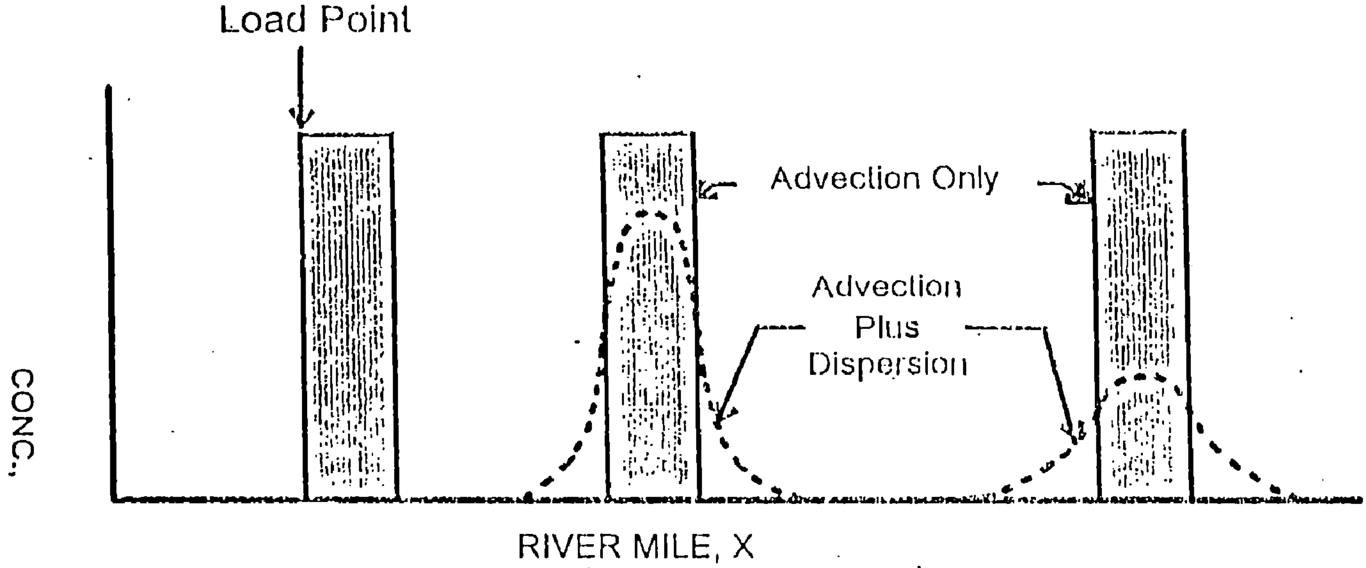
- The flow is one dimensional steady state and completely mixed;
- All concentrations are uniform over the cross section of the river;
- The physical characteristics of the river, e.g. depth and cross sectional area, are uniform over the reach;.
- The variation of river flow between two reaches is considered as incremental flow and distributed uniformly over the reaches (non point flow);
- The temperature and all other climatological factors affect the quality;
- The dispersion is also considered is a major influencing factor; (Fig. 2.5).

The main differences of simple BOD and DO model derived by many investigators based on the concept of Streeter and Phelps (1925) with that of the formulation conceptualized in QUAL2E are:

In simple BOD and DO model, the organic substances are assumed to be completely mixed at each computation length and traveled at the mean velocity

LONGITUDINAL DISPERSION

- SCHEMATIC REPRESENTATION



- D_L COMPUTED FROM FISCHER'S GENERALIZATION OF ELDER'S EQUATION

$$D_L = K d u^* \qquad S_e = \left[\frac{un}{1.49 R^{2/3}}\right]^2$$

$$u^* = \sqrt{g d S_e} \qquad D_L = 3.82 K n u d^{0.833}$$

where:

D_L = longitudinal dispersion coefficient, ft^2/sec.

n = Manning's roughness coefficient

u = mean velocity, ft/sec.

d = mean depth, ft.

K = dispersion constant, typically between 6.0 and 6000. Elder Eq. uses 5.93

Fig. No.2.5

of flow with no dispersion of substances, which holds good for a long linear system, and the decomposition processes follow a first order reaction kinetics. This is a very rough approximation and does not hold good for rivers of large width with variable cross-sectional geometry. In QUAL2E formulation, it is assumed that besides the decomposition of organic substances, which follows the first order kinetics, the organic substances dispersed in accordance to the diffusion process and transport of substances are governed by the advection and dispersion process.

CHAPTER – 3

WATER QUALITY MODELING OF THE BRAHMANI RIVER USING QUAL2E

3.1 INTRODUCTION

The river Brahmani is one of the major interstate rivers in peninsular India. The river originates from the Chotnagpur plateau of Bihar, and travels through Madhya-Pradesh and Orissa States and finally meets the Bay of Bengal. The river plays an important role in socio-economic, agricultural and industrial development of Orissa.

Nearly two decades back, the Brahmani Basin was a virgin natural Environment with almost non existence of human interference and environment pollution. Mineral deposits in the basin, availability of water, and infrastructure facilities have favoured industrial activities and urban development in the river basin, which resulted in change in the naturally maintained Eco system. Today, a number of industries located on and around the riverbanks are discharging their effluents to different tributaries of the Brahmani River without even primary treatment. Consequences of that ,a number of stretches of the river have been reported to be under the grim of pollution, i.e., exceeding the limiting level of BOD and DO prescribed for different beneficial uses and for aquatic biota. The National Water Commission has categorized the river Brahmani as one of the polluted rivers of the country (N.W.C.Report,2000). The most polluted stretch of the river is the stretch below the Rengali dam measuring a linear distance 310

Km. Wastewaters from different industries like: Aluminium, steel and fertilizer factories, and thermal power station from mining and urban activities; are discharged into the River Brahmani through its three tributaries; Tikara, Nandira and Bangaru rivers which join the river Bbrahmani at 25Km, 75 Km, and 95 Km respectively below the Rengali dam. During non-monsoon months these tributaries are mainly fed by the wastewaters. Since the flow in the Brahmani river is controlled by the Rengali dam, the river flow has a limiting assimilation capacity of wastewaters, which is found to be inadequate to maintain the requisite BOD and DO level in the river, particularly during lean flow period. The level of BOD_5 and DO along the river stretch have been reported to be varying respectively between 25 mg/L to 41 mg/L and 1.9 mg/L to 4.3 mg/L. Comparison of BOD_5 and DO measured at different locations with that of the prescribed limits of BOD, DO and other water quality constituents of a river for different beneficial uses, as per Indian standards (given in Table 3.1), shows that the river waters do not meet the requirement of designated uses. The values BOD and DO measured at a specific location are indicative of concentration of that location and do not show the spatial variation of pollution characteristics along the river stretch. In this chapter, it is intended to simulate the BOD and DO profiles of the river Brahmani below the Rengali dam for different flow conditions and pollution loads using QUAL2E.

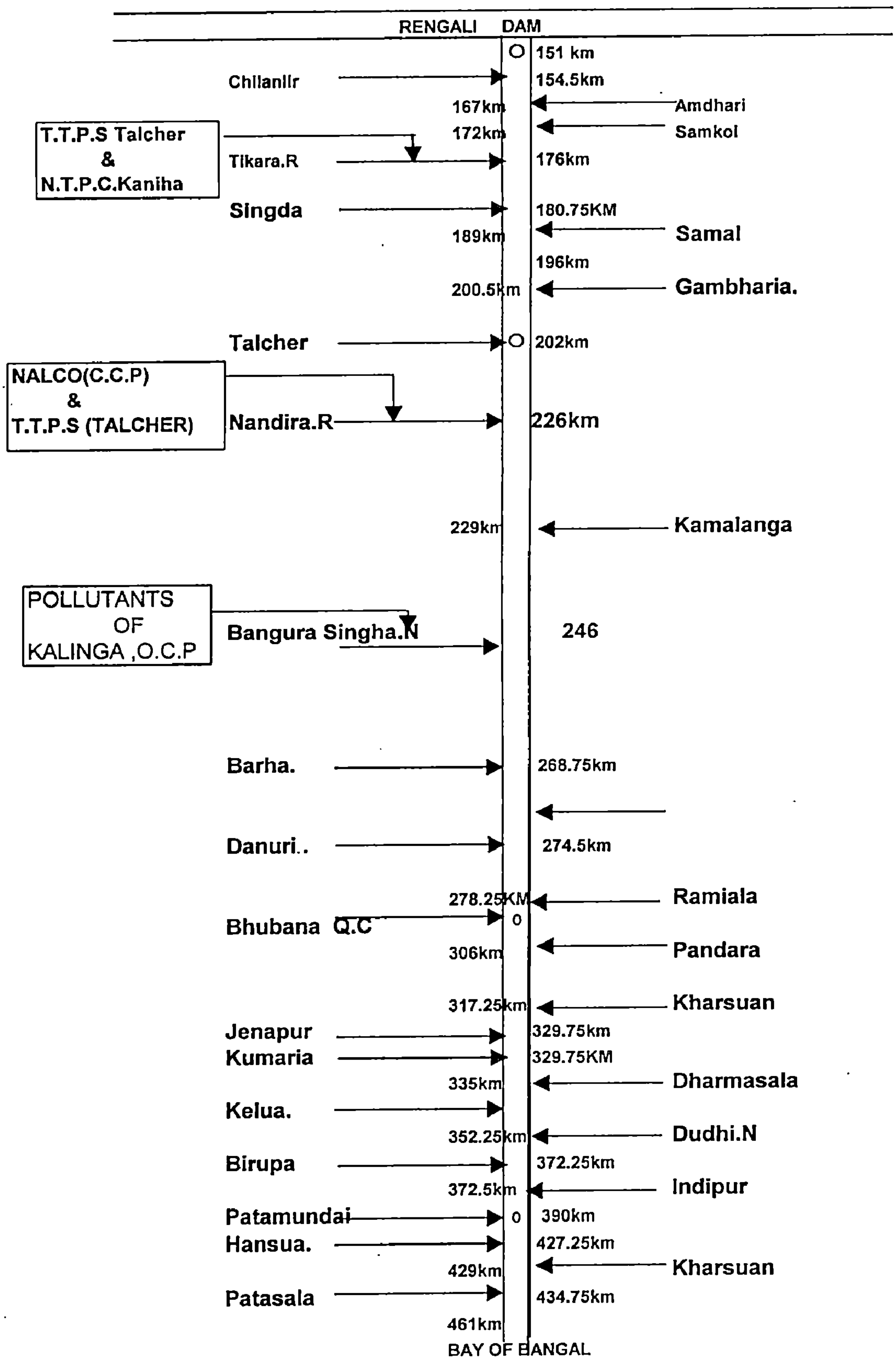
Table 3.1 Water Quality Standards for Surface Water Sources as per CPCB

Class of Water	Designated Best use	Parameters affecting	Quality Criteria
(1)	(2)	(3)	(4)
A	drinking Water Source, without conventional treatment but after disinfection	1. Total Coliform MPN 2. BOD (20^0C5 days) 3. DO 4. pH	< 50 / 100 ml < 2 mg/l > 6mg/l 6.5 – 8.5
B	Bathing, Swimming and Recreation (outdoor)	1. Total Coliform MPN 2. BOD (20^0C5 days) 3. DO 4. pH	< 500 / 100 ml < 4 mg/l > 6mg/l 6.5 – 8.5
C	Drinking Water Source after conventional treatment and disinfection	1. Total Coliform MPN 2. BOD (20^0C5 days) 3. DO 4. pH	< 5000 / 100 ml < 3 mg/l > 4mg/l 6.5 – 9.0
D	Propagation of wild Life Fisheries	Free Amonia (N) DO pH	< 1.2 mg/l > 4 mg/l 6.8-8.5
E	Irrigation Industrial Cooling and Controlled waste disposal	1. pH 2. Electrical Conductivity 3. Sodium Absorption Ratio 4. Boron	6-8.5 <2250 micromhos/cm <26 <2mg/l

3.2 DESCRIPTION OF THE STUDY AREA

The study reach is a part of the Brahmani river system, located below the Rengali dam in Orissa and covers a distance of 310 Km up to its confluence with Bay of Bengal (Fig.3.1) Location wise, the study reach measures between the longitude 21^0 30" to 20^0 35'N and the latitude 85^0 01' to 86^0 37' E. An index map of the study area is shown in Fig.3.2. The river Brahmani is a perennial river. Down below the Rengali dam, wastewaters originating from the nearby industries (Fig.3.3(a-e)), mining, and urban activities are discharged to the Brahmani river through its tributaries Tikara, Nandira and Bangaru rivers, which join the main Brahmani at 25 Km, 75 Km and 95 Km respectively (Fig.3.4). There is no withdrawal of water from the river downstream of the dam. The catchment area of the river at upstream, and below the Rengali dam receives considerable amount of rainfall, which varies between 890 mm/year to 2850 mm/year with an average annual rainfall in the order of 1570 mm. The hydro-meteorological characteristics of the study area are given in Table-3.2.

Fig. 3.1 Schematic Diagram of River Brahmani Below Rengali Dam



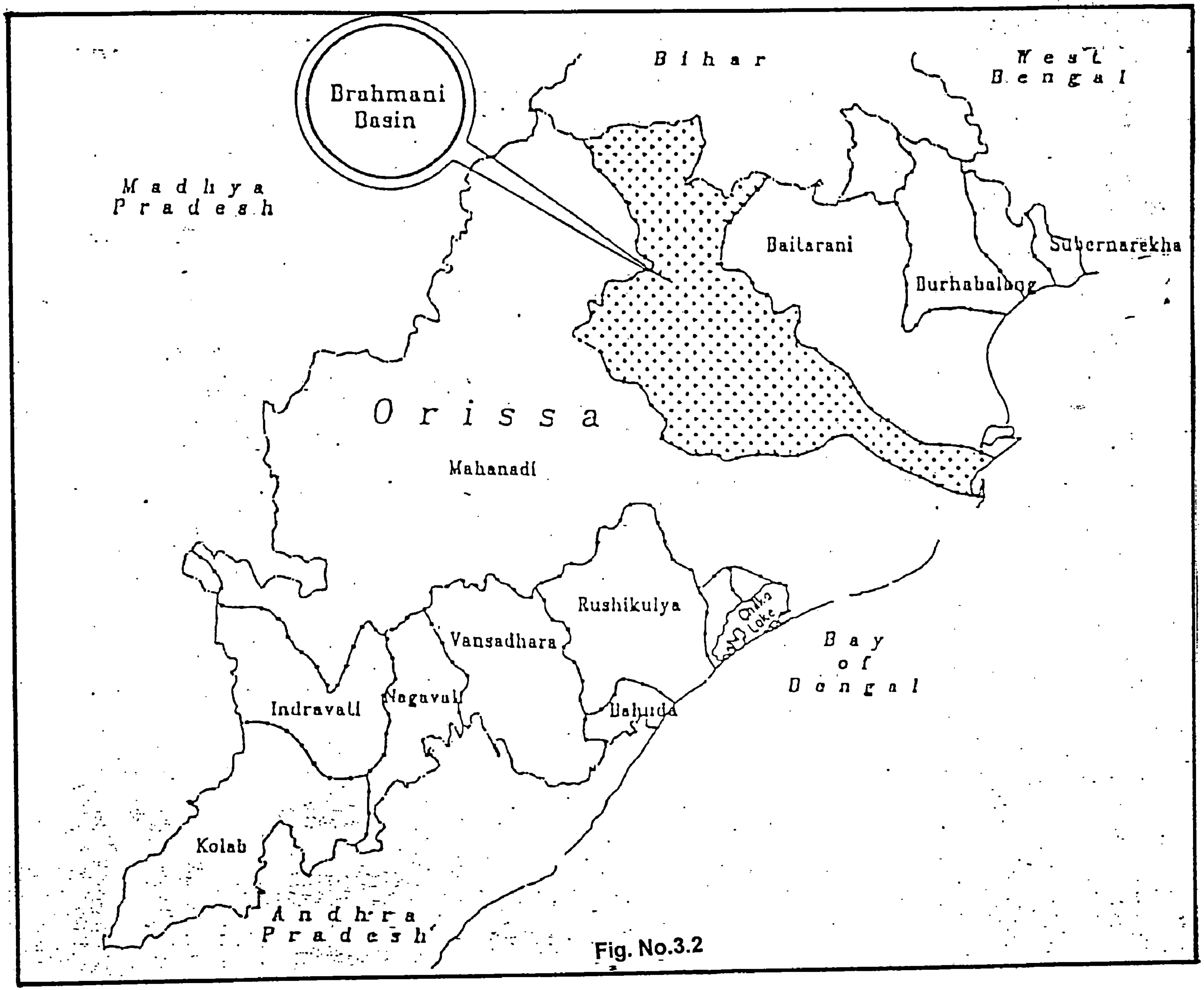

Brahmani Basin
Bihar
West Bengal
Madhya Pradesh
Orissa
Bailarani
Subernarekha
Durhabalbog
Mahanadi
Rushikulya
Chilka Lake
Vansadhara
Nagavul
Bahuda
Indravali
Kolab
Andhra Pradesh
Bay of Bengal

Fig. No.3.2

DUST SUPPRESSION MEASURE AT COAL TRANSFER POINT, TTPS, TALCHER

ASH POND OVERFLOW
TTPS, TALCHER

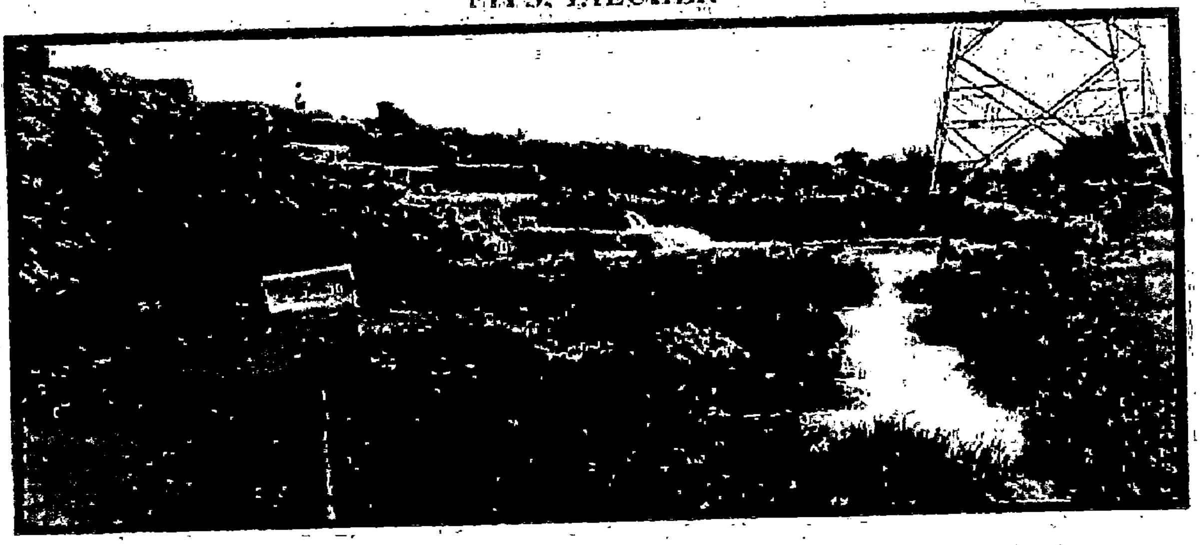
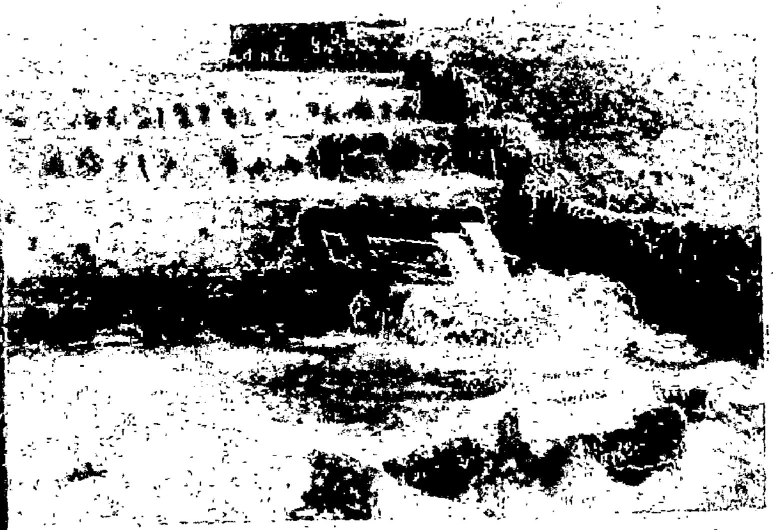


Fig. No.3.3(a)



DISCHARGE FROM ASH POND OF TALCHER THERMAL POWER STATION (NTPC)

(DISCHARGE FROM ASH POND OF TALCHER SUPPER THERMAL POWER PLANT, KANHIA)

EXISTING FLOURIDE TREATMENT SYSTEM (SMELTER PLANT, NALCO) BY MANNUAL METHOD

Fig. 3.3(b)

SEDEMENTATION TANKS FOR TREATMENT OF MINE DRAINAGE WATER, LINGARAJ OCP ☞

FIRE IN COAL STACK YARD KALINGA OCP ☞

GENERATION OF FUGITIVE DUST IN MINE QUARRY, NORTH QUARRY, BHARATPUR OCP ☞

Fig. 3.3(c)

RIVER BRAHMANI AFTER POLLUTION

RIVER BRAHMANI BEFORE POLLUTION

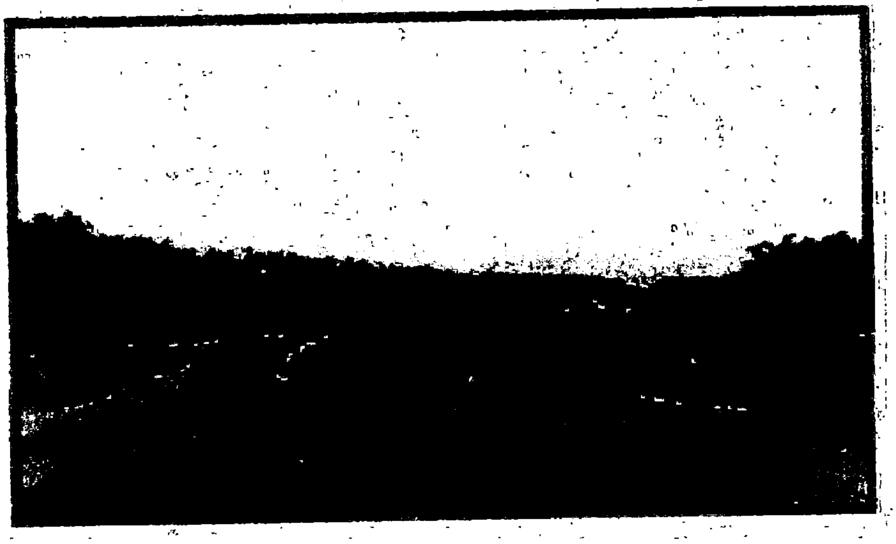


Fig. 3.3(d)

(GURHADI NALLA CARRYING EFFLUENT FROM ROURKELA STEEL PLANT)

(FINAL DISCHARGE POINT OF EFFLUENT FROM ROURKELA STEEL PLANT)

Fig. 3.3(e)

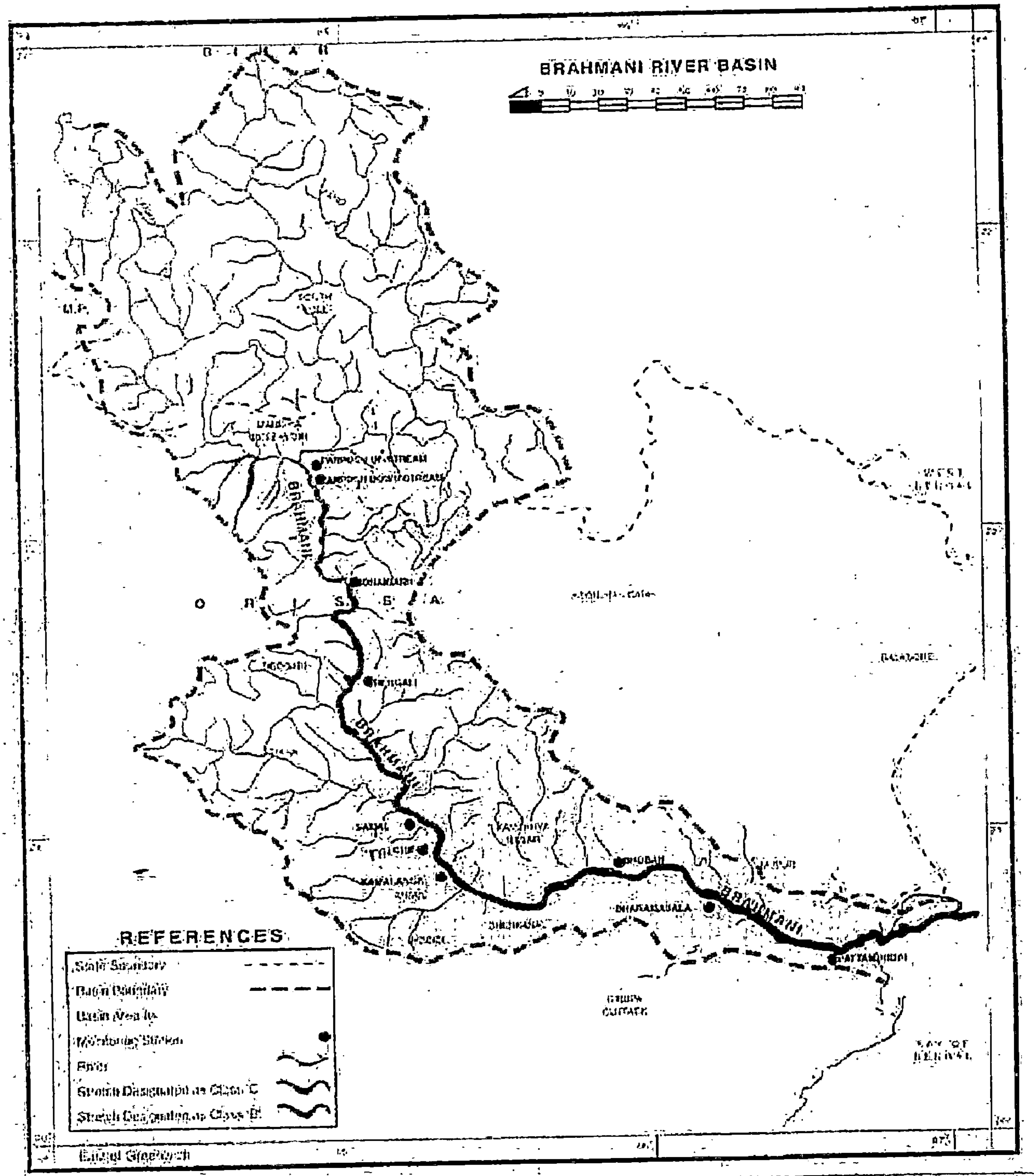

BRAHMANI RIVER BASIN
REFERENCES
BRAHMANI
O R I S S A
BAY OF BENGAL

Fig. No.3.4

Table: 3.2 Hydro-meteorological characteristics of the Brahmani Basin.

No.of Days with	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Thunder storm	1.0	3.4	5.0	9.5	10.8	14.2	10.5	12.2	13.4	5.6	0.4	0.0
Foggy	3.0	2.4	0.9	0.2	0.0	0.0	0.0	0.0	0.0	2.0	1.2	1.7
Hail Storm0.1	0.0	0.2	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Dust Storm	0.0	0.0	0.1	0.2	1.3	0,5	0.0	0.0	0.0	0.0	0.0	0.0
Squall	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Cloud Cover in Morning												
All Clouds	2.2	2.4	2.1	2.3	3.5	6	7	6.7	6.1	4.5	2.8	1.8
Low Clouds	0.5	0.8	0.7	0.7	1.1	2.4	3.8	3.5	3.1	2.3	0.8	0.2
Cloud Cover Afternoon												
All Clouds	2.1	2.1	2.5	4.1	5.1	6.4	7.3	7.1	6.7	4.9	3.3	2.1
Low Clouds	0.7	0.7	1.0	1.8	2.4	3.3	4.8	4.3	4.0	2.6	0.9	0.4
Average Wind Speed (m/sec)												
Wind Speed	3.2	3.4	4.2	5.2	6.0	5.7	5.0	4.4	3.9	3.6	4.2	3.4
Rainfall in mm												
Rainfall	-	-	-	1.3	92.6	134.0	463.8	536.7	283.5	222.0	0.7	
Temperature in ^{0}C												
Temp. (Max)	29.1	38.8	42	44	50.9	40.6	36.8	37.3	36.7	35.9	33.5	32.0
Temp. (Min.)	10.9	18.5	16.6	21.0	22.5	22.9	21.4	23.1	22.4	21.1	12.7	11.1
Average Relative Humidity												
Maximum	85	81	79	83	87	89	96	98	96	95	96	95
Minimum	28	27	22	34	49	50	71	67	63	57	55	37

3.3 DATA REQUIREMENT

Data requirement varies according to the objective of the study. For BOD and DO modeling of the river using QUAL2E, following are the data requirement:

(i) **Flow data**	:Discharge of the river at the upstream and downstream of the reach, and river hydraulic data particularly velocity and depth.
(ii) **Water Quality data**	:Quality of the river water at the upstream of the entry of the pollution, and along the river stretch.
(iii) **Pollution data**	:Point sources – Flow rate and concentration of the constituents, and location of the point loads. **Non**-point source – Flow rate and concentration of constituents.
(iv) **Climatic data**	: Ambient temperature.
(v) **Reaction coefficients**	:Different rate coefficients such as; de-oxygenation rate coefficient, re-aeration rate coefficient, settling rate coefficient, benthic demands etc.

Most of the data requirement were collected from the State Pollution Control Board; Central Water Commission, Bhubaneswar; Central Ground Water Board, Bhubaneswar; Office of the Engineer-in-Chief , Water Resources

Department , Govt. of Orissa, Bhubaneswar; National Water Development Agency, Bhubaneswar; Metrological Centre, Bhubaneswar.

3.3.1 Flow data

Plots of the daily discharge data of the Brahmuni River (Fig.3.5 and 3.6) observed at downstream of the Rengali Dam (Talcher) and at a lower stretch of the river (Janapur) show that during monsoon months, which occur between June to October, the flow in the river varies between 500 cumecs to 2500 cumecs both at the upstream and downstream sides. During non-monsoon months, which occur through November to May, the flow in the river reduces considerably and varies between 125 cumecs to 280 cumecs at the upstream site and 173 cumecs to 368 cumecs at the downstream site with minimum flow occurring in the month of May. From these figsures, it could be seen that during non-monsoon months, flow varies marginally at each location except some eventualities. Non-monsoon months, November through May, could therefore be considered as the low flow months. The longitudinal section of the river, given in Fig. 3.7, shows that river has a bed slope of 1 in 5600.

The depths versus discharge plots of the river at the two stations (Down Stream ,Rengali, Janapur) are shown in Figs. 3.8 and 3.9 .

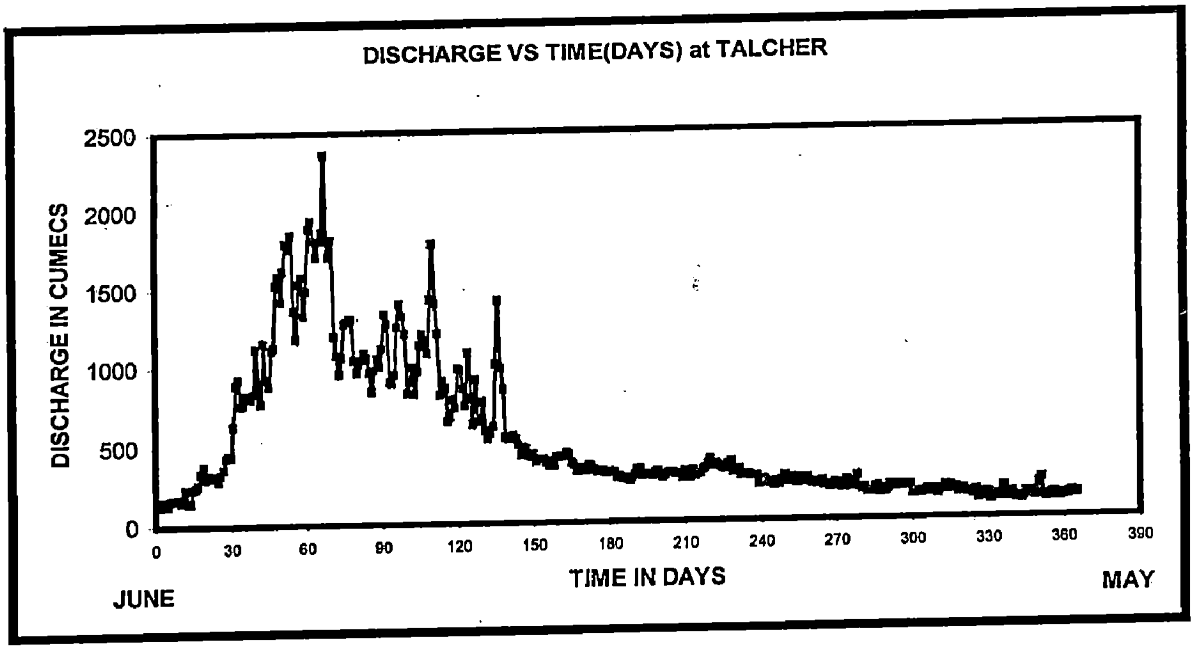


Fig. No. 3.5

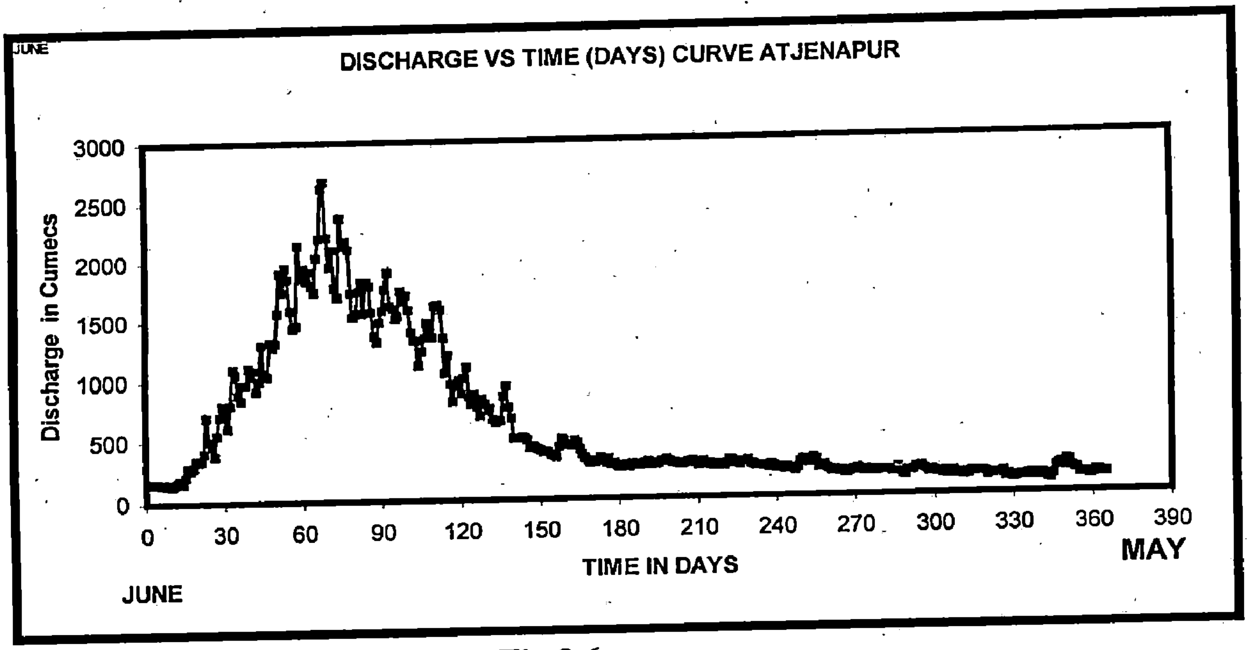

JUNE
DISCHARGE VS TIME (DAYS) CURVE ATJENAPUR
Discharge in Cumecs
3000
2500
2000
1500
1000
500
0
0
30
60
90
120
150
180
210
240
270
300
330
360
390
MAY
TIME IN DAYS
JUNE

Fig.3.6

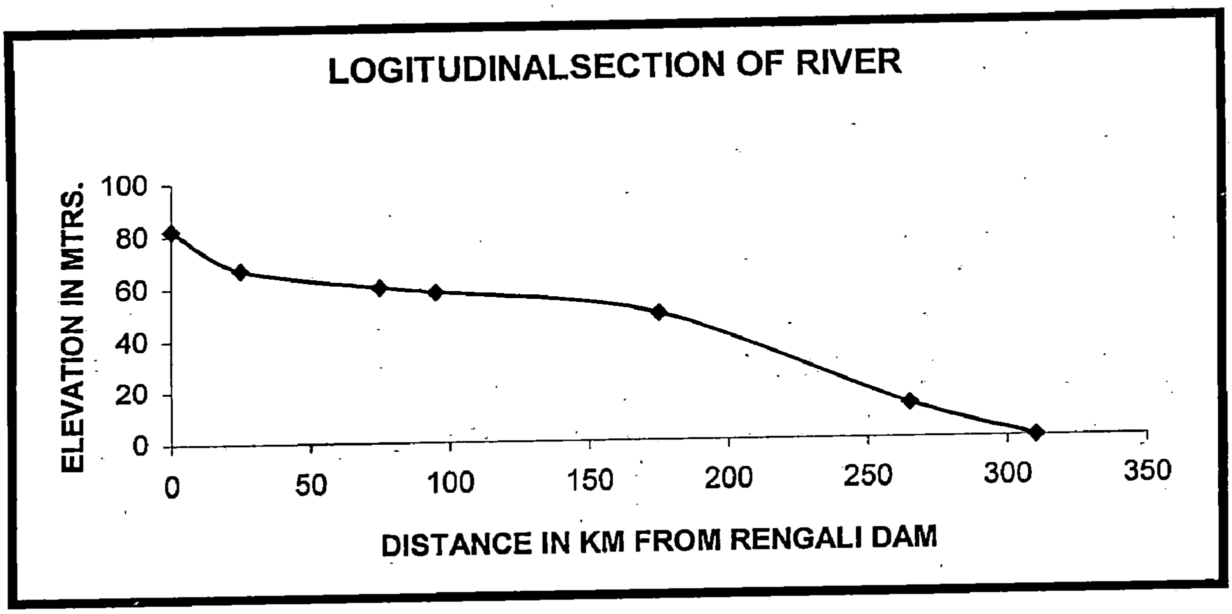

LOGITUDINALSECTION OF RIVER
ELEVATION IN MTRS.
100
80
60
40
20
0
0
50
100
150
200
250
300
350
DISTANCE IN KM FROM RENGALI DAM

Fig.3.7

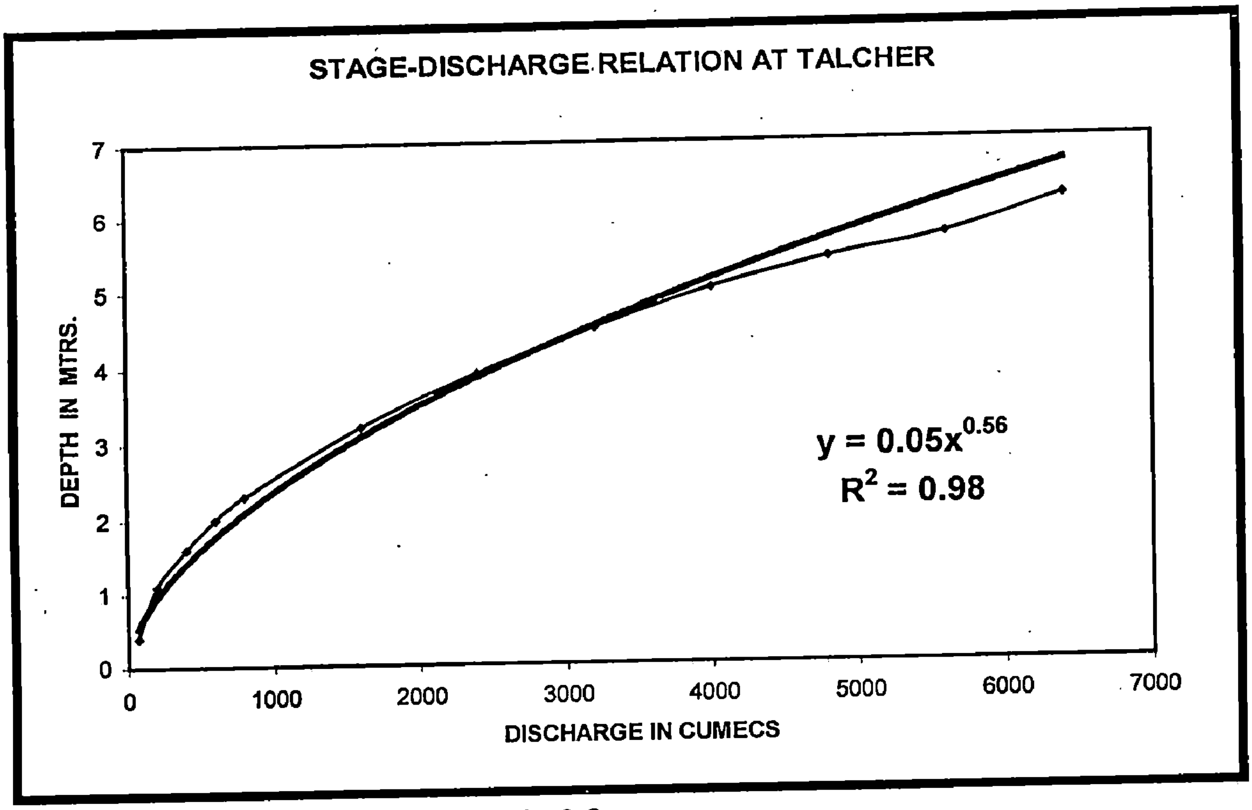

STAGE-DISCHARGE RELATION AT TALCHER
DEPTH IN MTRS.
DISCHARGE IN CUMECS
0
1
2
3
4
5
6
7
0
1000
2000
3000
4000
5000
6000
7000
y = 0.05x^0.56
R^2 = 0.98

Fig.3.8

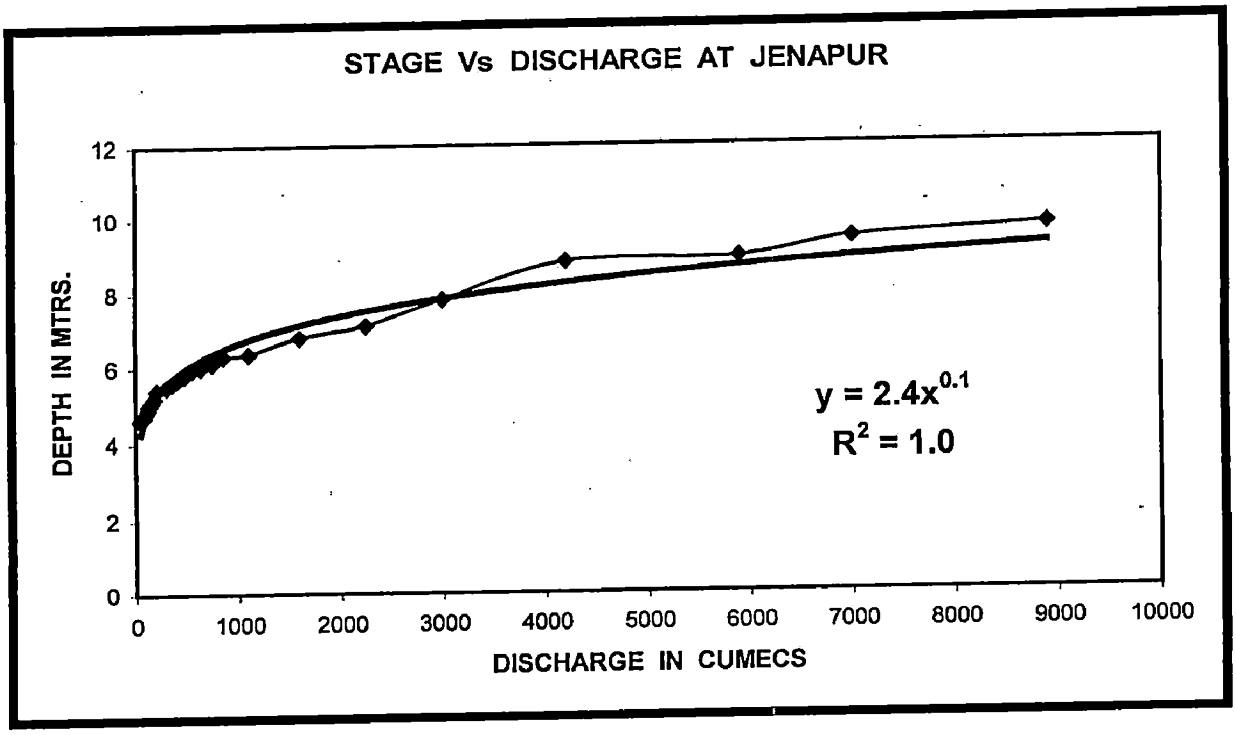

STAGE Vs DISCHARGE AT JENAPUR
DEPTH IN MTRS.
DISCHARGE IN CUMECS
0
2
4
6
8
10
12
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
y = 2.4x^0.1
R^2 = 1.0

Fig.3.9

3.3.2 Water Quality Data

The physical characteristics, such as; pH, temperature, turbidity, hardness and the bio-chemical characteristics i.e BOD and DO of the river water observed at different sampling locations are given in (Table.3.3 to 3.6). The plot of daily DO measured downstream of the point loads near Talcher (Fig.3.10) shows that during low flow period , November through May, the DO of the river water reduces from 4.3 mg/L to a minimum value of 1.9 mg/L .

Table. 3.3 Chemical Contents of Tikira River Water

Units: Discharge = cumecs, T.C.F.C. = MPN per 100 ml

BOD, DO,COD,TSS, SO_4, Na, Ca, = mg per Liter

MONTH	DISCHARGE	D.O	BOD	COD	TSS	TC	FC	Cl	SO_4	Na	Ca
Nov.	18.1	3.4	21.6.8	2.7.7	165.6	1449	1362.5	59.6	33.9	50.5	24.9
Dec.	15.4	3.3	218.9	221.0	196.4	1728.7	1625.5	55.1	40.4	60.2	29.8
Jan	13.7	2.9	221.6	219.6	183.4	1604.3	1508.5	74.4	37.5	55.9	27.6
Feb.	13.5	1.5	223.5	226.4	246.9	2168.2	2038.7	92.8	50.7	75.5	37.3
Mar.	13.2	1.5	225.6	233.0	308.7	2704.1	2542.6	103	63.2	94.2	46.5
Apr.	12.50	1.2	228.6	236.8	343.5	3001.5	2822.3	113.7	70.2	104.5	51.7
May	13.30	0.9	229.5	242.3	394.8	3313.4	3115.6	127.5	77.5	115.4	66.5

Table. 3.4 Chemical Contents of Nandira River Water

Units: Discharge = cumecs, T.C.F.C. = MPN per 100 ml

BOD, DO,COD,TSS, SO_4, Na, Ca, = mg per Liter

MONTH	DISCHARGE	D.O	BOD	COD	TSS	TC	FC	Cl	SO_4	Na	Ca
Nov.	14.60	4.6	215.4	237.2	181.4	7028.8	1927.7	67.8	36.1	41.8	27.1
Dec.	13.60	3.9	219.8	244.4	216.4	8385.6	2299.8	80.8	43.2	49.9	32.3
Jan	11.01	2.3	221.3	244.3	220.5	7782.2	2134.3	75.1	39.9	46.3	29.9
Feb.	11.99	2.2	223.0	255.7	271.4	10517.2	2884.4	101.4	53.9	62.6	40.5
Mar.	11.82	1.8	228.7	269.4	338.6	13116.7	3597.3	126.5	67.3	78.0	50.5
Apr.	11.42	1.6	236.5	236.8	343.5	3001.5	3993.1	113.7	70.2	104.5	51.7
May	11.87	1.7	241.2	242.3	394.8	3313.4	4408.2	127.5	77.5	115.4	66.5

Table. 3.5 Chemical Contents of Bangaru River Water

Units: Discharge = cumecs, T.C.F.C. = MPN per 100 ml

BOD, DO,COD,TSS, SO_4, Na, Ca, = mg per Liter

MONTH	DISCHARGE	D.O	BOD	COD	TSS	TC	FC	Cl	SO_4	Na	Ca
Nov.	12.22	4.7	218.6	238.9	219.1	3265.3	1457.6	64.4	26.1	47.1	34.4
Dec.	11.48	4.0	222.1	245.3	260.3	3879.1	1731.6	76.5	31.2	55.9	40.9
Jan	11.01	3.2	223.6	248.2	278.2	4167.7	1851.1	81.8	33.2	59.7	43.7
Feb.	10.96	2.9	229.8	260.9	351.4	5237.7	2338.1	103.4	41.9	75.5	55.2
Mar.	10.88	1.9	233.6	268.7	396.7	5912.9	2639.5	116.7	47.3	85.1	62.3
Apr.	10.69	1.6	239.8	277.7	448.5	6684.9	2985.1	131.9	53.3	96.3	70.4
May	10.91	1.3	241.6	282.6	485.9	5345.7	3262.6	105.5	65.5	117.8	86.2

Table. 3.6 Water Quality of Brahamani River Water at Different Locations

Units: Discharge = cumecs, T.C.F.C. = MPN per 100 ml

BOD, DO,COD,TSS, SO_4, Na, Ca, = mg per Liter

Monitoring station	D.O	B.O.D	Temp.	Turb.	T . C	F.C	pH	Cl.	SO_4	Na.	Ca.	T. Hard
RENGALI	7.7	13.6	27.6	72	627	712	7.9	16	4	21	13.8	56
SAMALA	7.3	12.6	27.7	94	638	734	7.8	15	6	22	14.3	32
TALCHER U/S	4.4	22.6	28.6	120	712	766	7.8	20	18	38	14.7	54
KAMALANGA D/S	3.6	24.3	27.6	94	736	812	7.8	21	14	29	17.5	56
BHUBANA	3.8	12.9	27.3	188	786	786	8.0	16	10	29	13	57
DHARAMASALA	4.6	14.3	27.5	126	806	745	7.9	20	9	27	16.7	67
PATTAMUNDAI	4.3	14.9	27.9	88	866	702	8.0	10	5	31	19.6	73

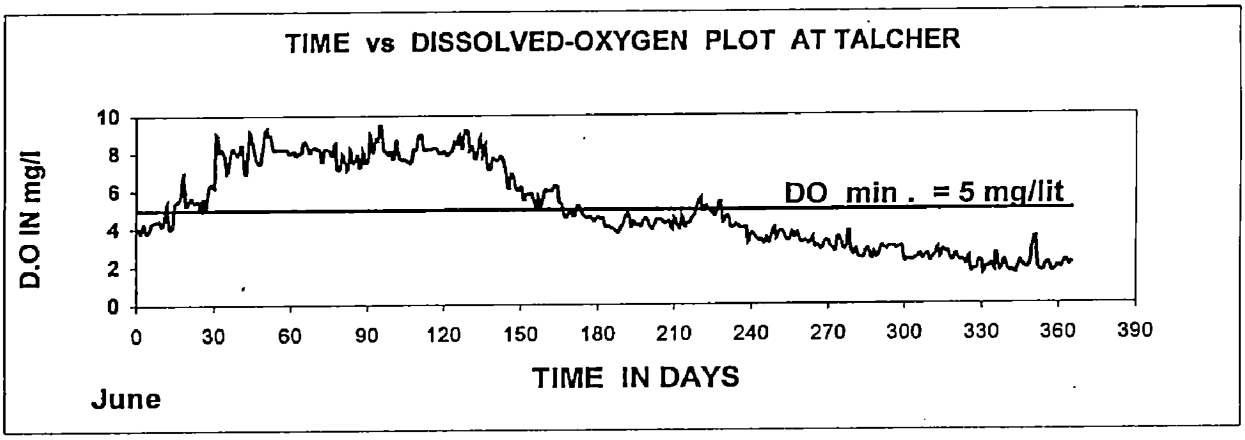


Fig. 3.10

3.3.3 Pollution data

Three point loads of pollution, which constitute the wastewaters generated from steel and fertilizer factories, thermal power stations, mining and urban activities, join the river Brahmani through its tributaries Tikira river, Nandira river, and Bangaru river respectively at 25 Km, 75 Km, and 95 Km downstream of Rengali dam . According to the CPCB estimation, about 29,80,000 m^3/day of wastewaters are generated from the Industrial activities, 60,000 m^3/day of wastewaters are generated from Mining activities and 15,00,000 m^3/day of wastewaters are generated from the Urban activities, which constitute the pollution loads of the following order:

Industrial pollutants : 65.7 %

Urban pollutants : 33%

Mines pollutants : 1.3%

The rate of discharge of wastewaters and the chemical characteristics of the three point loads for the months from November to May are given in Tables. 3.3 to 3.5. From the tables, it could be seen that except in November and December months, the rate of discharge of wastewaters is nearly equal and steady. The concentrations of BOD of the constituents of three point loads are also similar, which indicate that the composition of the wastewaters is more or less similar.

3.3.4 Climatic data

During non-monsoon months, November to May, the ambient temperature varies between 33^0 C to 45^{0}C (Table –3.7(a) & 3.7(b)).

Table.3.7 (a): Climatological Data

Month	Ave.Temp.	Wind speed	Sun shines	Evaporation	Relativity humidity	
	^{0}C	M/sec.	Hours	Mm/d	Max	min
Nov.	21.5	4.2	11.2	94.7	96	55
Dec	21.7	3.4	10.9	82.4	95	37
Jan	22.6	3.5	11.1	90.5	85	28
Feb.	28.7	3.8	11.5	110.8	81	27
March	30.5	4.2	12.1	162.8	79	22
April	32.7	5.2	12.6	187.7	83	34
May	36.7	6.1	13.4	216.2	87	49

Table.3.7 (b): Climatological Data

Reach No.	Name of the reach	Latitude Degree	Longitude Degree	Elevation Metres	Dust automation
R1	Brahmani	21.5	85.02	82.00	0.13
R2	Tikara	21.05	85.20	67.00	0.13
R3	Brahmani	21.05	85.20	67.00	0.13
R4.	Nandira	20.86	85.45	58.00	0.13
R5	Brahmani	20.86	85.59	85.00	0.13
R6	Bangaru	20.88	85.67	49.00	0.13
R7	Brahmani	20.88	85.67	13.00	0.13
R8	Brahmani	20.90	86.00	7.00	0.13
R9	Brahmani	20.50	86.62	0.00	0.13

3.3.5 Reaction Co-efficients

De-oxygenation rate coefficient (K_1), and re-aeration rate co-efficient (K_2), and settling rate co-efficient data of the river are not available, which are to be estimated from the simulation of the BOD and DO profiles.

3.4 Discretization of River Reach

The river reach between Rengali Dam up to the Bay of Bengal of length 310 Km forms the main reach. Three tributaries; Tikara of length 15 Km, Nandira of length 10 Km, and Bangaru of length 10 km, form the branching channels. Considering the length of each element to be 5 km, we get a total of 69 elements of equal size, in which, the main reach constitutes 62 elements. These 69 elements along with 3 point sources at 25, 75, and 95 km respectively divide the network of main reach and branching channel into 9 segments. The details of the river network showing the arrangement of each computational element and their category are shown in Fig.3.11. The segment wise category of computational elements is given in Table.3.8.

STREAM NETWORK OF COMPUTATIONAL ELEMENTS AND REACHES

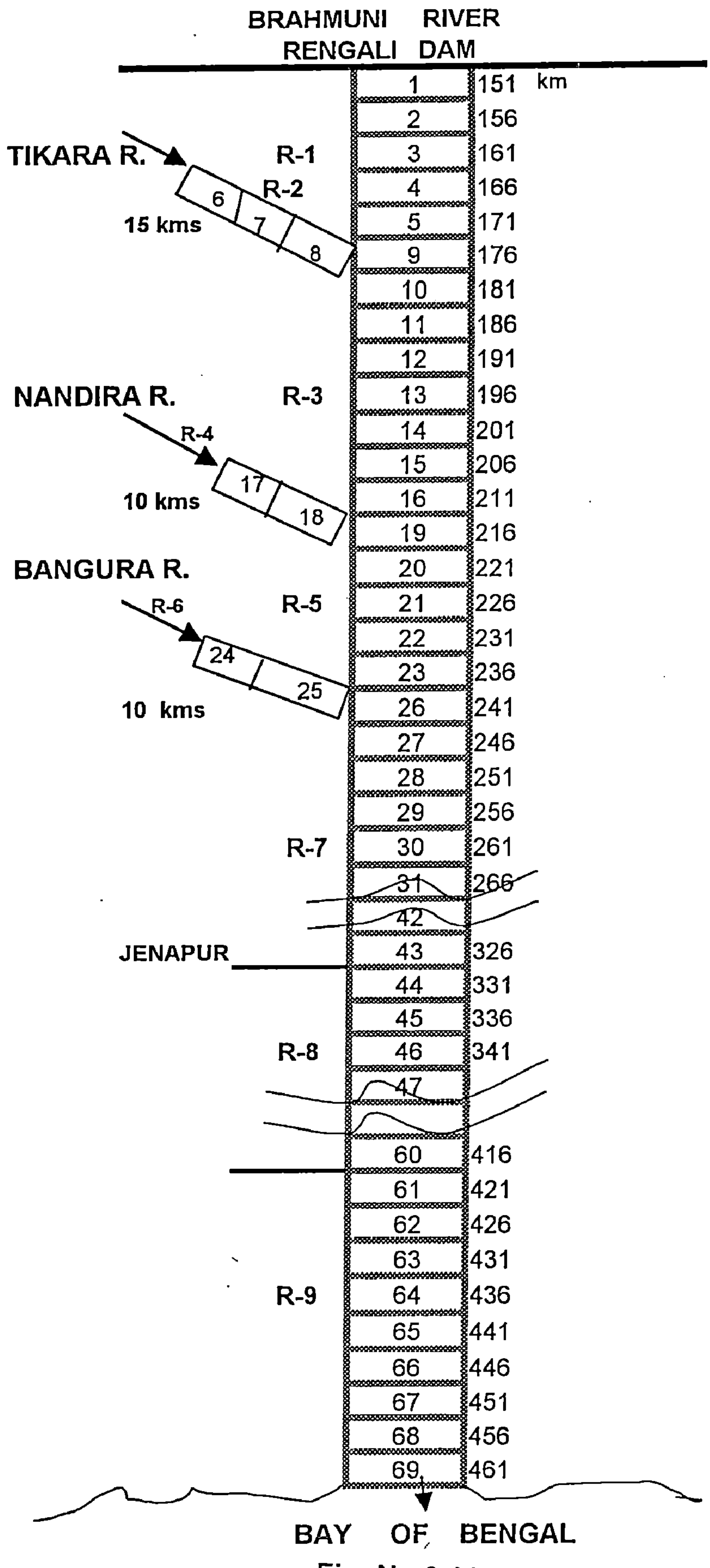


Fig. No.3.11

Table.3.8 : River Reach And Category Of Elements

Reach No.	Length in Km	Number of Computational elements	Remarks
1	20	4	Head reach
2	15	3	Head reach and Point source
3	40	8	Standard elements
4	10	2	Head and Point source
5	25	5	Standard elements
6	10	2	Head and point source
7	90	18	Standard elements
8	90	18	Standard elements
9	45	9	End reach

3.5 Water Balance in the Reach

For water quality modeling, flow balance is pre-requisite. For steady flow, the quantity of flow in should be equal to the quantity of flow out for each reach. The segment wise water balance is carried out considering the inflow to the reach and outflow from the reach. In case of difference in outflow and inflow, the differential quantity is considered as incremental flow to the river, when it is positive or uniform withdrawal of flow from the river when it is negative. The differential flow is considered to be uniformly distributed over the reach. This increase and decrease in flow could be due to the stream-aquifer interaction. Increment in flow for different reaches is estimated for different low flow months and is given in Tables.3.9 to 3.11. Distribution of incremental flow along the river reach for different low flow months are shown in Figs. 3.12 to 3.18 .

Table. 3.9 Monthly Discharge in cumecs in different reaches (Non Monsoon)

MONTH	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8	R-9
NOV	280.79	18.10	330.83	14.60	334.72	12.22	341.95	349.18	368.04
DEC	252.00	15.40	278.74	13.60	285.03	11.48	282.68	280.33	295.46
JAN	239.00	13.70	258.93	11.01	272.09	11.01	279.92	285.26	290.47
FEB	190.93	13.50	224.96	11.99	226.31	10.96	227.16	228.75	239.96
MAR	168.88	13.20	192.71	11.82	194.24	10.88	195.78	198.98	203.11
APR	133.66	12.50	157.48	11.42	160.76	10.69	164.03	165.98	166.82
MAY	124.06	12.30	146.17	11.87	148.24	10.91	156.19	164.15	173.01

Table:3.10 COMPUTATION OF INCREMENT IN FLOW IN DIFFERENT REACHES

UNIT= cumecs

	R-1	R-3	R-5	R-7	R-8	R-9
LENGTH--	25	50	20	85	85	45
MONTH						
NOV	8.55	31.94	-10.71	-4.99	7.23	18.86
DEC	25.40	11.34	-7.31	-13.83	-2.35	15.14
JAN	2.42	6.23	-2.15	-3.18	5.34	5.21
FEB	8.61	20.53	-10.64	-10.11	1.59	11.21
MAR	7.65	10.63	-10.29	-9.34	3.20	4.13
APR	7.43	11.32	-8.14	-7.42	1.95	0.84
MAY	7.71	9.81	-9.80	-2.96	7.95	8.86

Table: 3.11 COMPUTATION OF INCREMENTAL FLOW IN DIFFERENT REACHES

UNIT= cumecs / km

MONTH	R-1	R-3	R-5	R-7	R-8	R-9
NOV	0.3419	0.6388	-0.5355	-0.0587	0.0851	0.4190
DEC	1.0160	0.2268	-0.3654	-0.1628	-0.0277	0.3364
JAN	0.0968	0.1246	-0.1075	-0.0374	0.0628	0.1158
FEB	0.3445	0.4106	-0.5320	-0.1189	0.0187	0.2491
MAR	0.3062	0.2125	-0.5145	-0.1099	0.0376	0.0919
APR	0.2972	0.2264	-0.4070	-0.0873	0.0229	0.0187
MAY	0.3083	0.1962	-0.4899	-0.0348	0.0936	0.1970

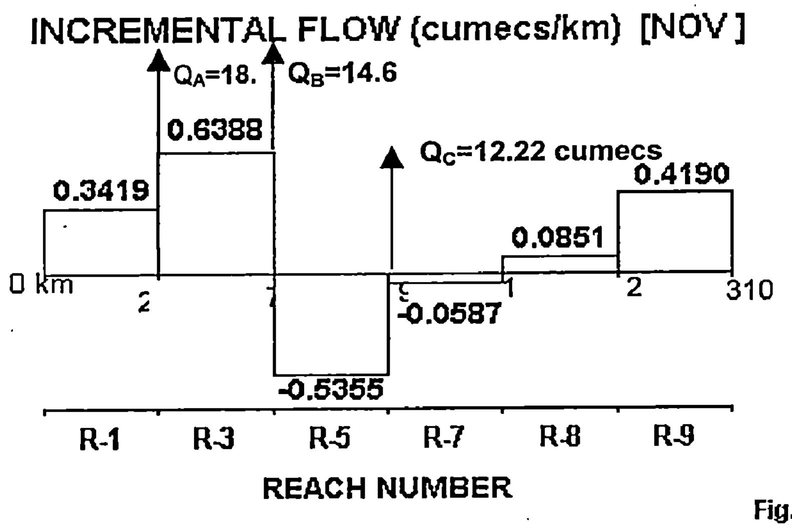


Fig. 3.12

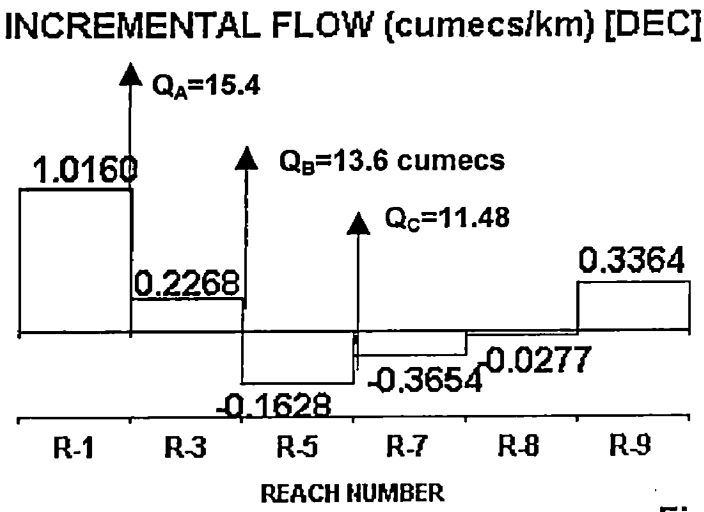


Fig. No.3.13

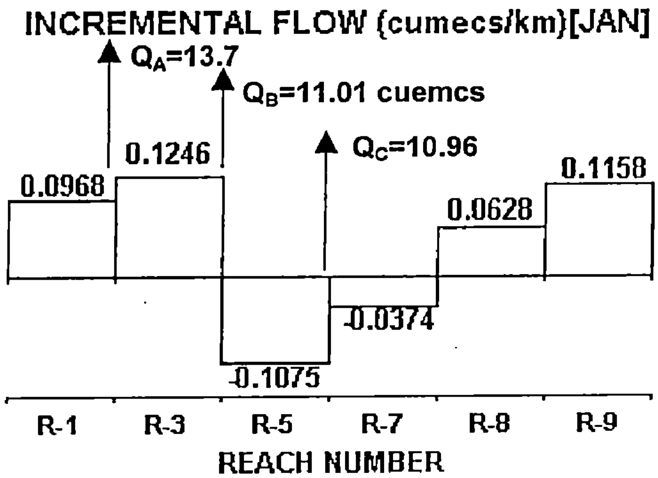


Fig. 3.14

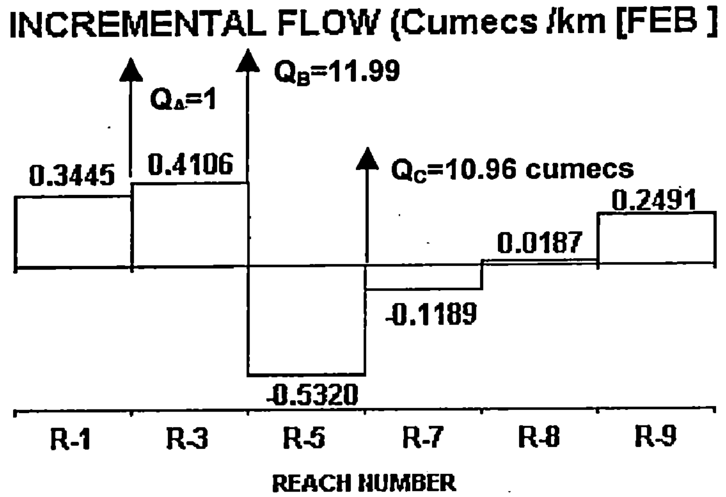


Fig. 3.15

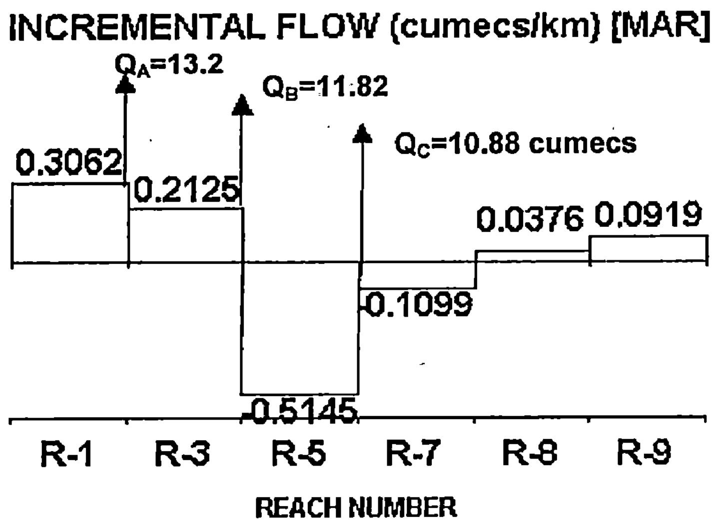


Fig. 3.16

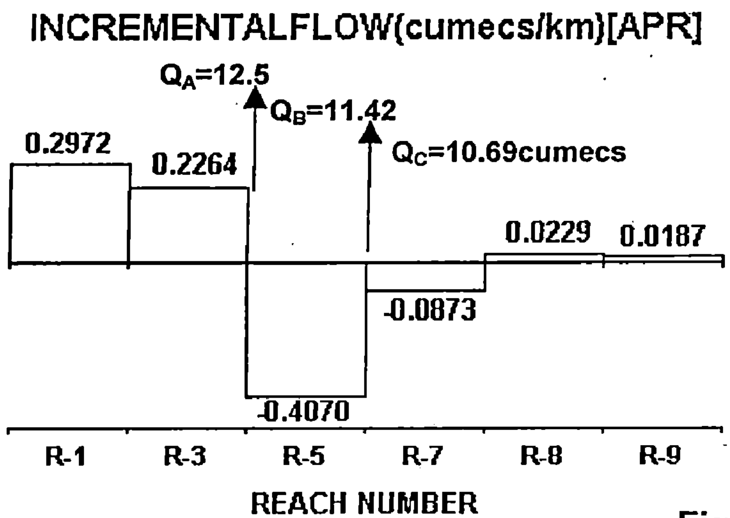


Fig. No.3.17

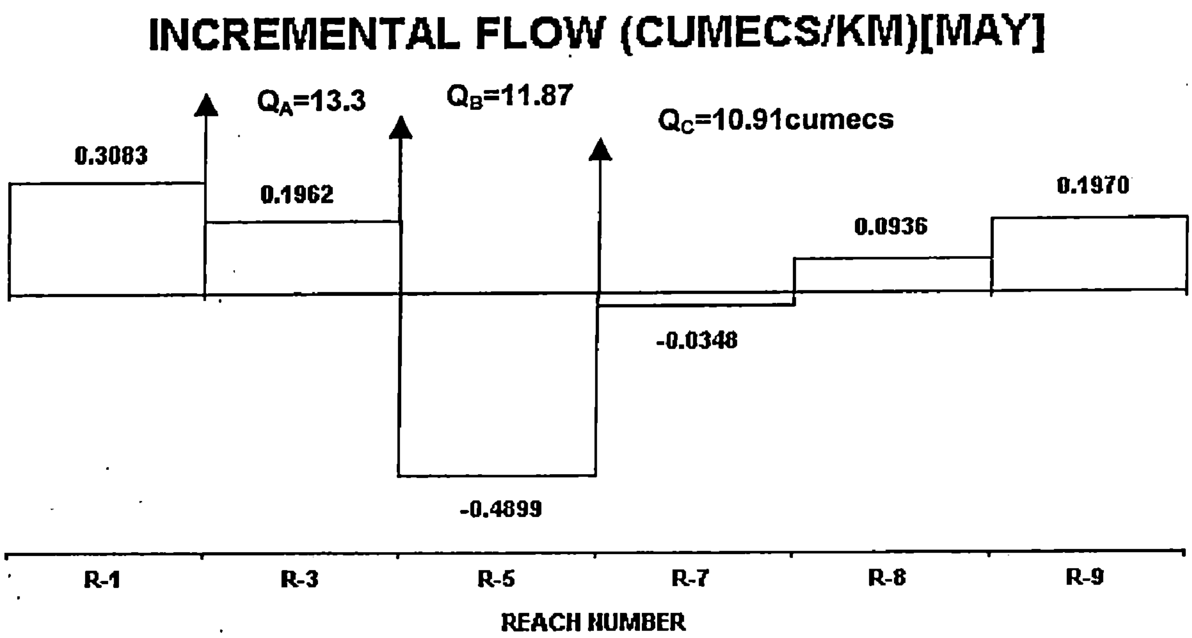

INCREMENTAL FLOW (CUMECS/KM)[MAY]
QA=13.3
QB=11.87
QC=10.91cumecs
0.3083
0.1962
0.1970
0.0936
-0.0348
-0.4899
R-1
R-3
R-5
R-7
R-8
R-9
REACH NUMBER

Fig. 3.18

3.6 HYDRAULIC CHARACTERISTICS

The flow velocity and depth corresponding to a flow are required by the model at each computational element to estimate the dispersion coefficient and the re-aëration rate coefficient. QUAL2E accepts the coefficients and exponents of discharge of the following form to compute the flow velocity and depth of flow at each section.

$V = a\,Q^{b}$; $D = cQ^{d}$;

Where

V = average velocity (LT^{-1}), D= Depth of flow (L) ,

a,b,c,d, are the exponents and empirical coefficients.

Q = Discharge in the river ($L^{3}T^{-1}$).

These coefficients and exponents for all the segments of the river were calculated utilizing the average discharge data of 1988 to 1998 assuming Mannings' roughness coefficient, n = 0.035 and these values are given in Table.3.12.

Table. 3.12 Channel Properties
(expressing velocity and depth in terms of discharge)

Reach No.	Slope	Manning-n	Velocity (V)	DEPTH (D)
1	$5x10^{-4}$	0.035	$V_1=0.1Q^{0.68}$	$D=0.06Q^{0.56}$
2	$31\ x10^{-4}$	0.035	$V_2=2.87Q^{0.32}$	$D=0.19Q^{0.48}$
3	$2\ x10^{-4}$	0.035	$V_3=0.054Q^{0.7}$	$D=0.05Q^{0.59}$
4	$28\ x10^{-4}$	0.035	$V_4=2.72Q^{0.32}$	$D=0.21Q^{0.48}$
5	$4\ .5x10^{-4}$	0.035	$V_5=0.08Q^{0.75}$	$D=0.05Q^{0.65}$
6	$32\ x10^{-4}$	0.035	$V_6=2.91Q^{0.36}$	$D=0.18Q^{0.54}$
7	$4.5\ x10^{-4}$	0.035	$V_7=1.09Q^{0.29}$	$D=0.43Q^{0.24}$
8	$0.7\ x10^{-4}$	0.035	$V_8=0.42Q^{0.1}$	$D=0.65*Q^{0.15}$
9	$1.6\ x10^{-4}$	0.035	$V_9=0.64Q^{0.1}$	$D=0.53*Q^{0.15}$

3.7 LONGITUDINAL DISPERSION COEFFICIENT

QUAL2E accepts reach wise variable dispersion coefficient, D_L, as an external input or one can use the option of computing the dispersion coefficient from the mathematical expression included in the formulation of QUAL2E. The expression for computation of dispersion coefficient considered in QUAL2E is:

$$D_L = 3.82K\,n\,U\,D$$

where

K is the dispersion constant, n Mannings' roughness coefficient, U is the mean velocity of flow, and d is the depth of flow.

The value of K is usually considered as 5.93. The expression of D_L indicates that dispersion coefficient is a function of velocity and depth., and hence varies from reach to reach as the flow velocity and depth changes. Dispersion coefficients are estimated for each reach and are given in Table. No. 3.13

Table.3.13 . Dispersion coefficient

Unit: D_L = Sq.m/sec.

MONTH	REACH								
	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8	R-9
NOV	47.01	22.71	31.75	15.56	99.26	9.32	70.65	7.96	13.63
DEC	38.41	16.97	25.73	11.63	78.76	6.72	64.68	7.65	13.00
JAN	41.79	12.88	28.13	8.83	86.32	4.93	66.91	7.77	12.76
FEB	29.60	12.45	19.65	8.53	58.65	4.74	57.81	7.26	11.95
MAR	23.02	11.73	15.10	8.04	44.16	4.43	51.92	6.91	11.58
APR	20.41	9.73	13.33	6.67	38.52	3.59	49.29	6.75	11.19
MAY	18.25	11.91	11.85	8.16	34.07	4.51	47.08	6.61	11.90

3.8 MODEL CALIBRATION

The task we have as calibration of the model is estimation of de-oxygenation rate coefficient (K_1), the re-aeration rate co-efficient (K_2), settling rate coefficient (K_3), and Sediment oxygen demand (SOD) using observed BOD and DO data along the river reach. There are other reaction kinetics those we have not considered in this study. Estimation of rate coefficients from the observed value of a constituent is a trial and error method.

3.8.1 Procedure of calibration

The calibration of the model coefficients is carried out by numerical experiment. For a given flow conditions and input pollution loads and other factors as described above, a value of K_1, and an expression of K_2,, a value of K_3, and K_4 are assumed and the model is run. The output of the model, such as; DO, is compared with the observed value of DO. If response of the model for the assumed values of model coefficients do not show an agreement with the observed value, another set of model coefficients are chosen. The model coefficients are adjusted performing the sensitivity analysis of the computed results. The procedure is repeated till a reasonable match between the observed DO and computed DO is obtained. The model coefficients corresponding to the match between the observed and computed DO are considered as calibrated value.

The calibrated model coefficients are applied to other set of flow data and pollution data to investigate the reliability of the calibration. When the responses of calibrated model coefficients are found to the expected agreement, the model can be considered validated. Comparison of the computed profile of DO corresponding to the validated model coefficients and the observed DO values for the month of May is shown in Fig. 3.19.

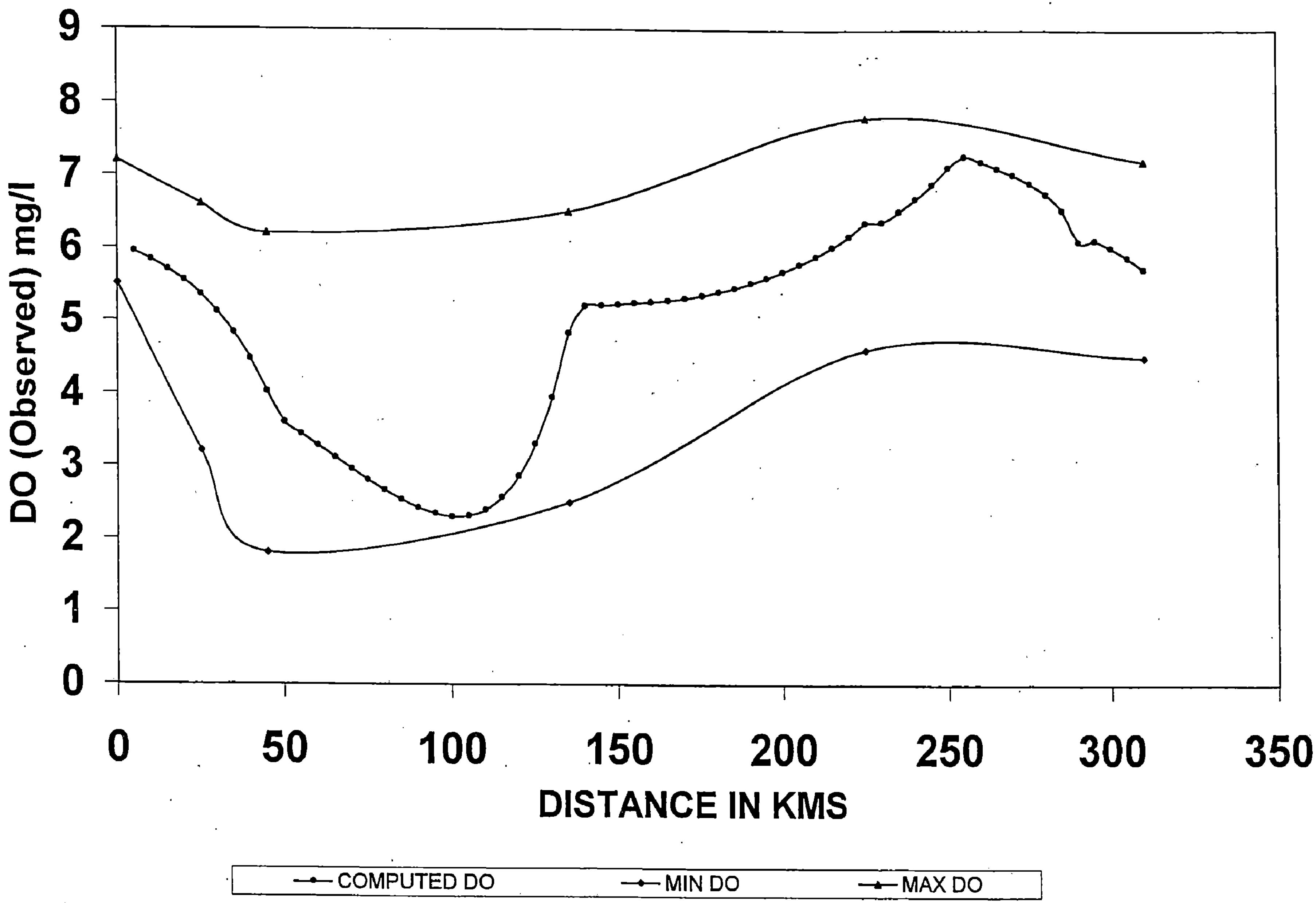
Performing the numerical experiments, the model coefficients are estimated as : (I) de-oxygenation rate coefficient, $K_1 = 0.23\ day^{-1}$, (ii) re-aeration rate coefficient, K_2 , the expression given by Owens et.al. , (iii) Sediment Oxygen demand (SOD), $K_3 = 0.3\ day^{-1}$, and Settling rate coefficient, K_4 = 3.0 gm/sq.m/day. The estimated values of the model coefficients could be used for simulation of BOD and DO profiles of the Brahmuni river for any stress conditions **APPENDIX-1**

3.9 RESULTS AND DISCUSSION

The flow pattern in the river at different locations and the flow patterns of the tributaries through which wastewaters are discharged into the river are given in Fig.3.20. From the Fig.3.21. It could be seen that during the non-monsoon months, i.e., November to May, the tributaries through which wastewaters are discharged to the river have almost steady flows, whereas during monsoon months, flows in these tributaries increase considerably, which is due to the catchment runoff of each tributary.

Using the calibrated values of model coefficients, K_1, K_2, K_3, and K_4, which are temperature dependent, DO sag curve along the river reach are computed utilizing the corresponding flow conditions and pollution loads of each low flow months. The computed profiles of BOD and DO for different months, November through May, are shown in Figs. 3.22 to Fig. 3.28. It could be seen from the Figs. that during all low flow months BOD profiles at the downstream of the point

CALIBRATION OF DO WITH OBSERVED DATA Fig.3.19



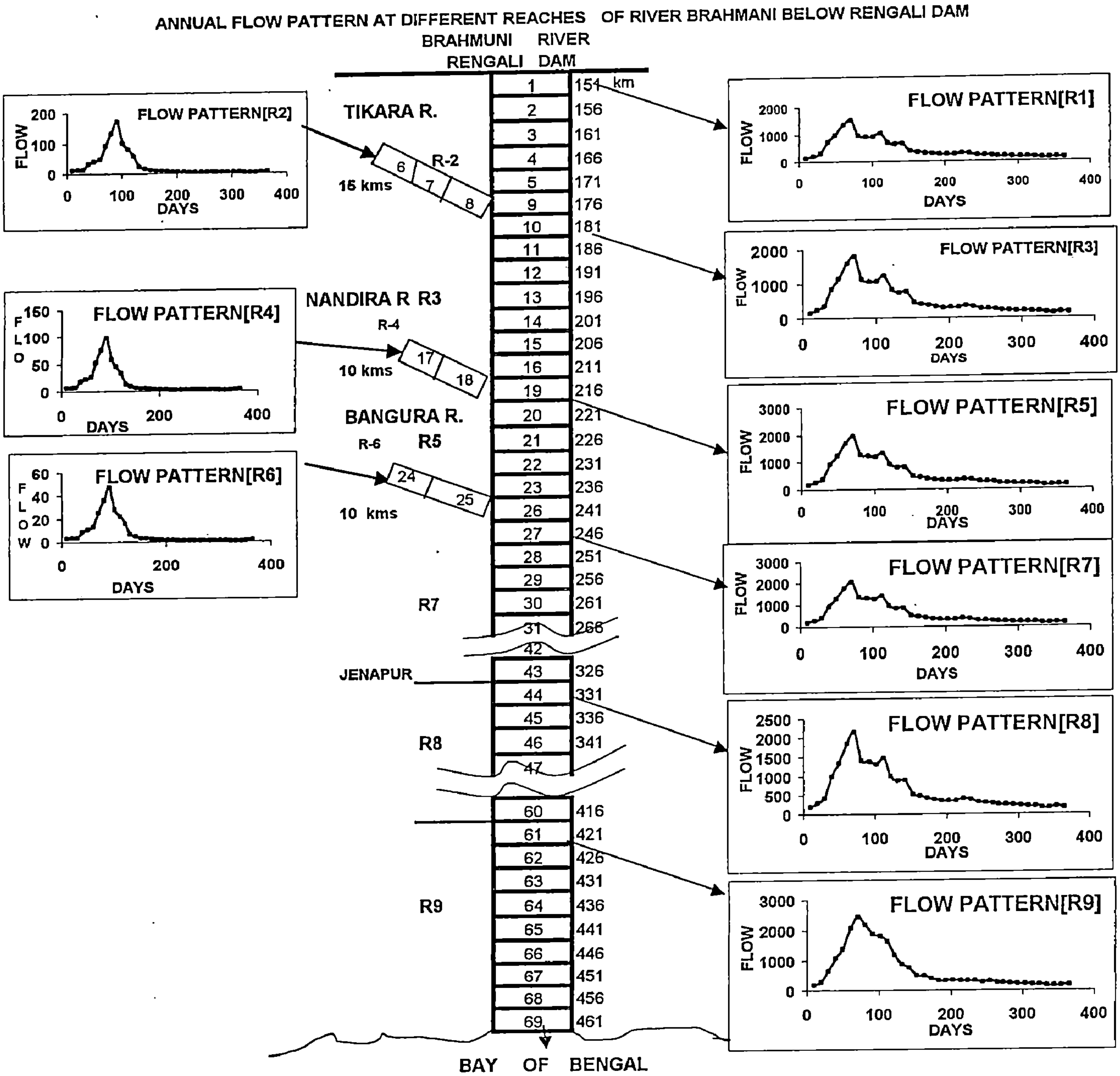

ANNUAL FLOW PATTERN AT DIFFERENT REACHES OF RIVER BRAHMANI BELOW RENGALI DAM
BRAHMUNI RIVER
RENGALI DAM
TIKARA R.
R-2
15 kms
NANDIRA R R3
R-4
10 kms
BANGURA R.
R-6 R5
10 kms
R7
JENAPUR
R8
R9
BAY OF BENGAL
FLOW PATTERN[R1]
FLOW PATTERN[R2]
FLOW PATTERN[R3]
FLOW PATTERN[R4]
FLOW PATTERN[R5]
FLOW PATTERN[R6]
FLOW PATTERN[R7]
FLOW PATTERN[R8]
FLOW PATTERN[R9]
FLOW
DAYS

Fig 3.20

FLOW PATTERN AT DIFFERENT REACHES OF RIVER BELOW RENGALI DAM IN BRAHMANI RIVER (NON MONSOON PERIOD)

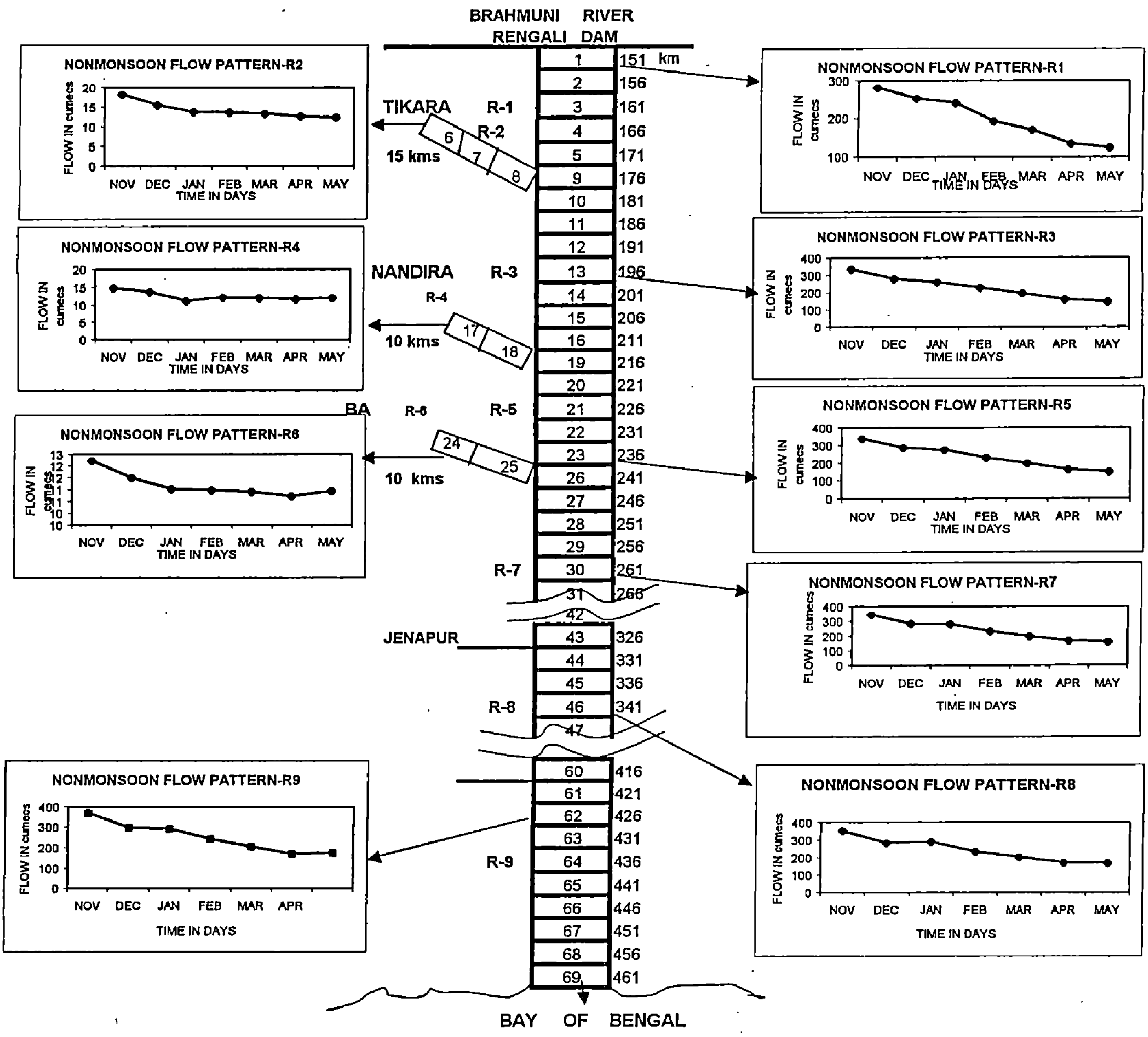


Fig. No.3.21

pollution , particularly beyond the reach length of 25 Km, exceed the permissible prescribed limit of 4 mg/L. In case of DO (Figs.3.23 to 3.29), in all low flow months, except the months November to January, the DO values get reduced than the prescribed permissible limit of 5 mg/L in the stretch measuring approximately 100 Km down below the Tikara river, i.e., first point load. The critical point of DO is found to be same for low flow months, which is found at a distance about 115 Km below the Rengali Dam and it is near to the third point load, i.e., Bangaru river. After the critical stretch, the DO in the river along its length increases. The magnitude of DO values in the critical stretch of 100 Km get reduced as the flow in the river decreases, as expected. The flow is minimum in the month of May so is the DO in the river. The computed values of BOD and DO at the critical point, i.e., 115Km downstream of Rengali dam, for different low flow months are tabulated in Table. 3.14

DO SAG CURVE [NOVEMBER] Fig. 3.22

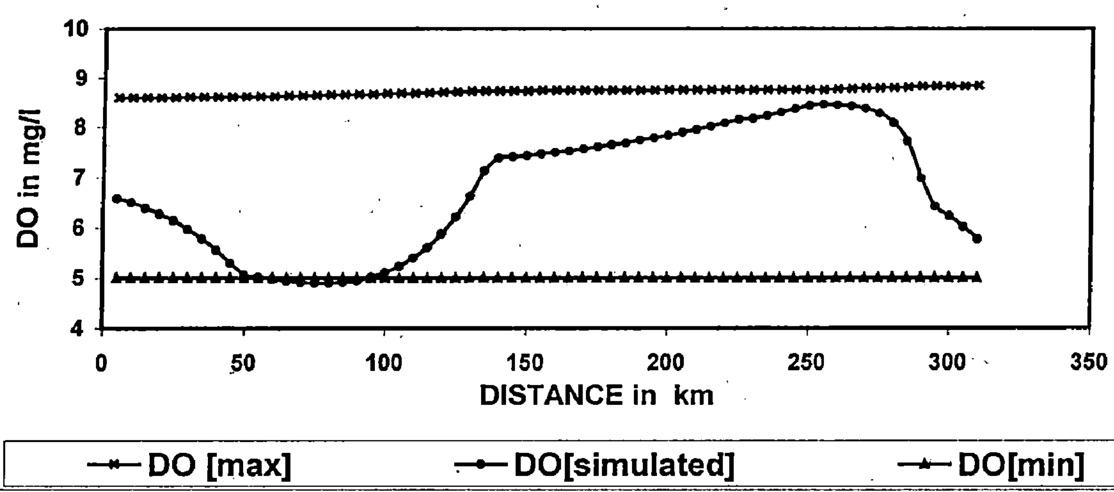
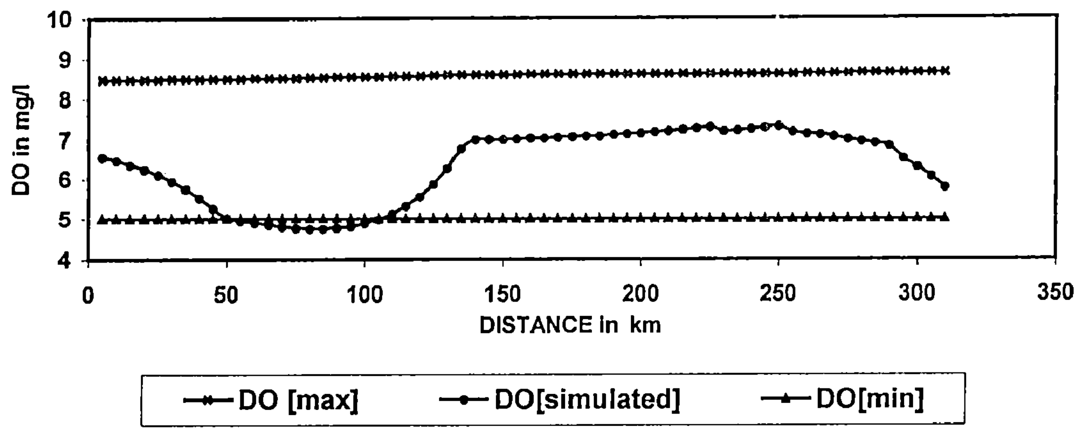


Fig. 3.23

DO SAG CURVE [DECEMBER]



DO SAG CURVE[JANUARY]

Fig.3.24

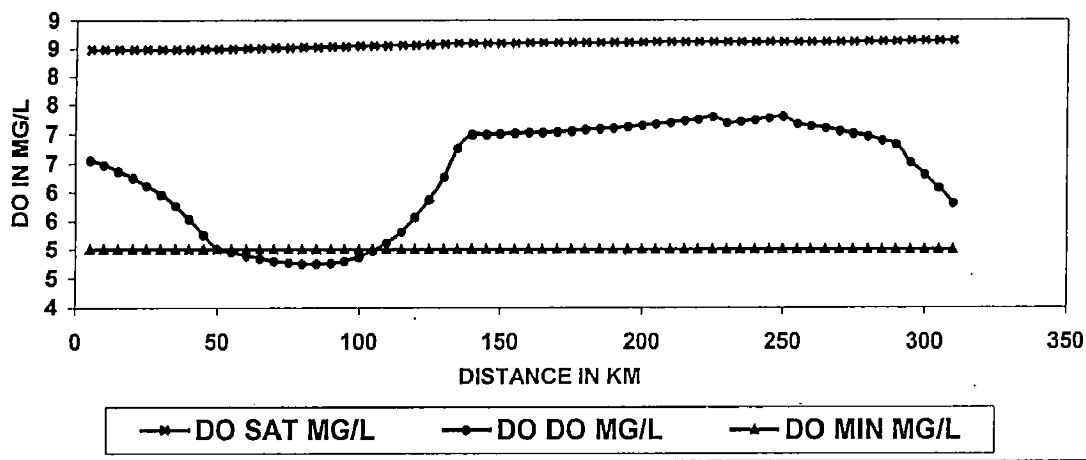
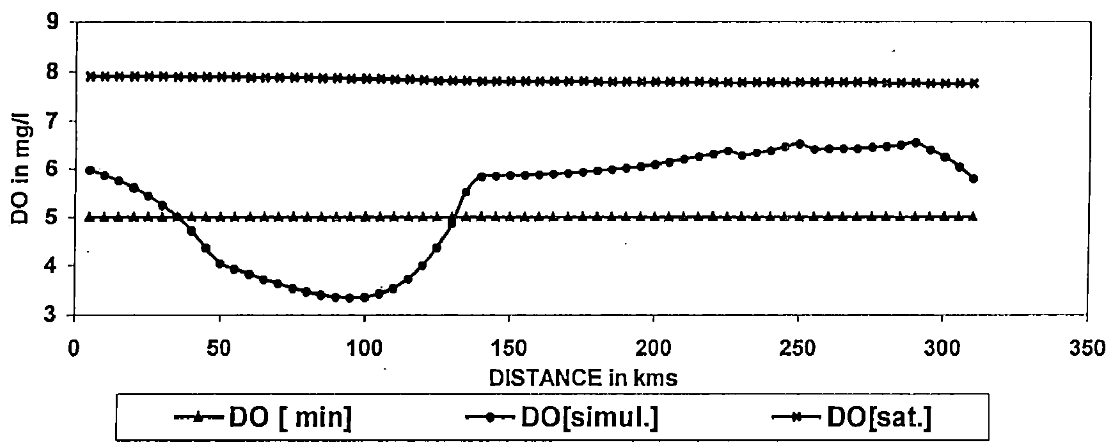
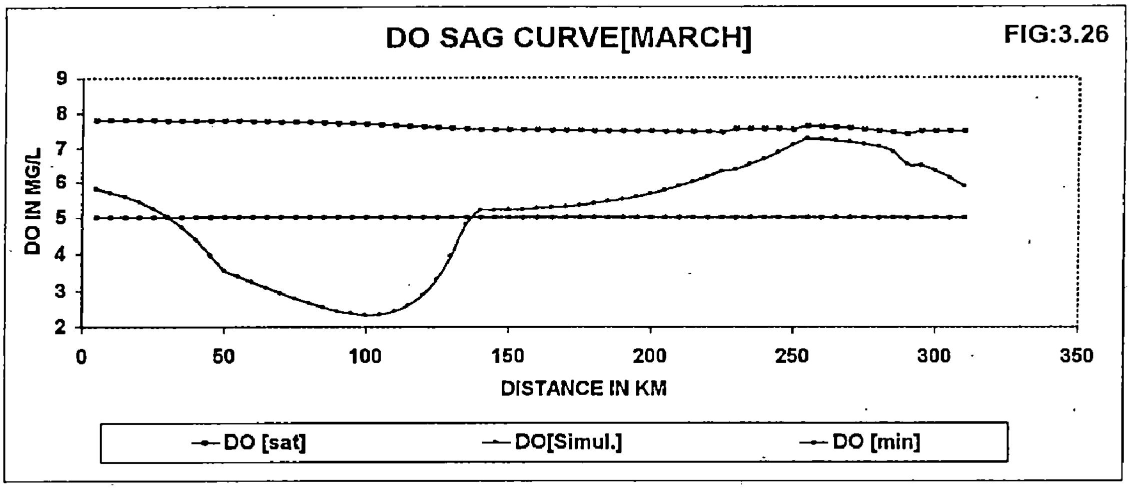
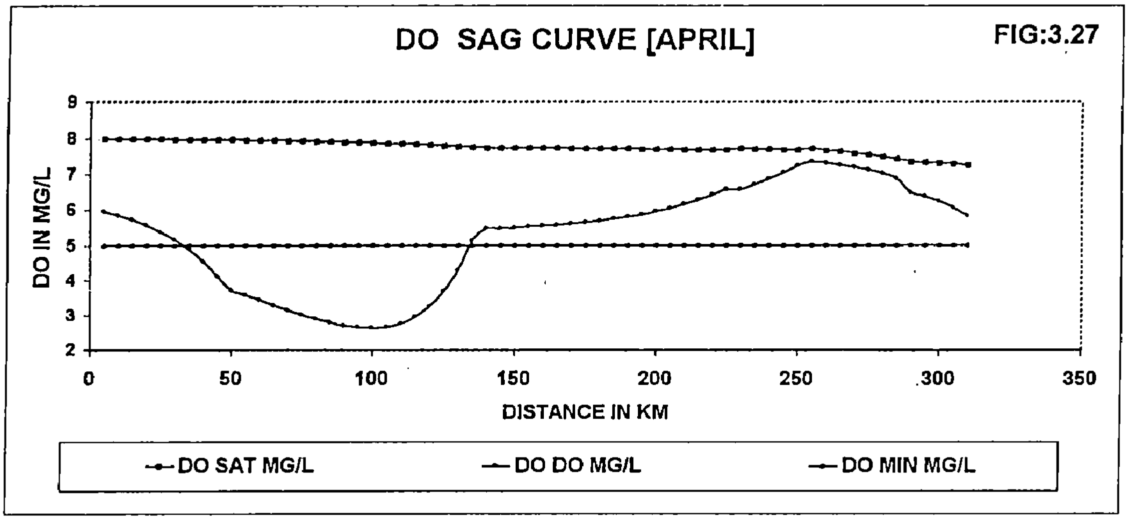


Fig. 3.25

DO SAG CURVE [FEBRUARY]




DO SAG CURVE[MARCH]
FIG:3.26
DO IN MG/L
DISTANCE IN KM
DO [sat]
DO[Simul.]
DO [min]


DO SAG CURVE [APRIL]
FIG:3.27
DO IN MG/L
DISTANCE IN KM
DO SAT MG/L
DO DO MG/L
DO MIN MG/L

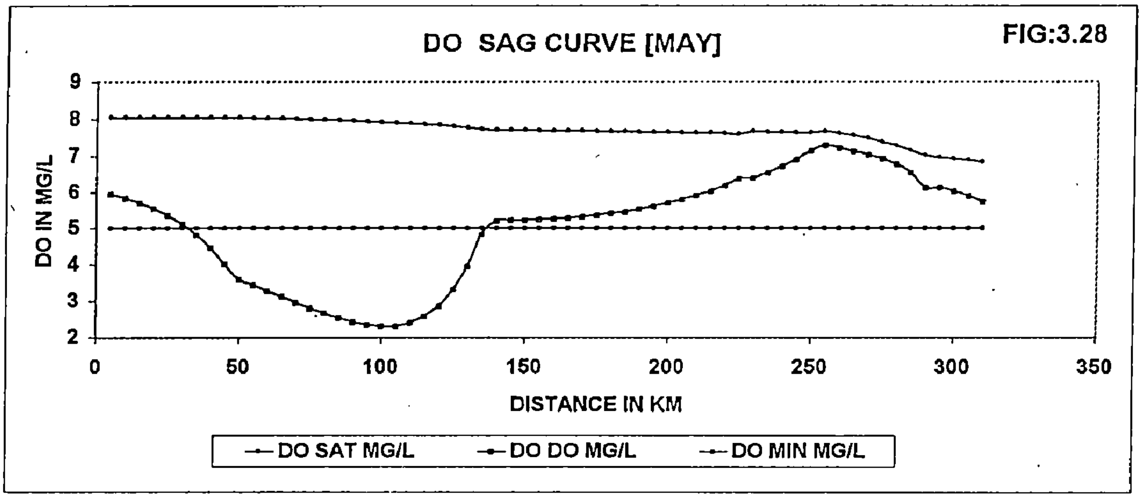

DO SAG CURVE [MAY]
FIG:3.28
DO IN MG/L
DISTANCE IN KM
DO SAT MG/L
DO DO MG/L
DO MIN MG/L

Table. 3.14 Computed BOD and DO values at critical point.

BOD	BOD at critical point	DO at critical point
Nov.	25.33	4.91
Dec	26.50	4.59
Jan	24.99	4.76
Feb.	29.24	3.34
March.	37.10	2.94
April	37.21	2.62
May	41.0	2.30

3.10 CONCLUSIONS

Using the QUAL2E and utilizing the observed BOD and DO values, de-oxygenation rate coefficient (K_1), re-aeration rate coefficient (K_2), settling rate coefficient (K_3), and sediment oxygen demand (K_4) of the river Brahmani have been estimated and these values are found nearly: K_1= 0.23 day^{-1} , K_3 = 0.3 day^{-1} , K_4 = 3 $gm/m^2/day$. It is found that K_2 is to be calculated from OWENS et.al. equation for all reaches. The computed concentration profiles of BOD and DO for different flow conditions and pollution loads corresponding to the estimated values of reaction coefficients are found within the range of observed values.

The critical stretch, which exceeds the prescribed permissible limit of DO of 5mg/L is found between 25 Km to 125 Km. The critical point of DO deficit is found at 115 Km. below the Rengali dam. The critical months of DO deficits are February to May, in which May is the critical month. The pH value of the river water is with-in the permissible limit of 6.5 to 8.0.

CHAPTER – 4

ANALYSIS OF MINIMUM FLOW REQUIREMENT

4.1 INTRODUCTION

The term "Minimum flow" means, the quantity of flow requirement in a river to maintain the prescribed limits of water quality constituents designated for different beneficial uses for a given pollution load. A river has its own characteristics towards assimilation of wastewaters, which mainly depends upon composition of the wastewater, reaction coefficients, dissolved oxygen present in the water, river geometry, temperature, and discharge etc. For a given pollution load into a river, if the health of the river is deteriorated below the limits prescribed for different beneficial uses of the river water, then what criterion/criteria of management and control are to be followed to uphold the water quality of the river, is a matter of research. The minimum flow requirement in a river could therefore be; (i) to find the additional flow requirement to dilute the constituents concentration along the river reach considering pollution loads to be uninterrupted, or (ii) to find the pollution loads in accordance to the assimilative capacity of the river considering flow in the river to be uninterrupted. A river with steep slope can purify more pollution loads than a river with mild slope because of more aeration of water due to high velocity. Again, constituents having more demand of oxygen even with less inflow of pollutants may cause pollution hazards in a river having large flow. The demand of oxygen of an organic constituent is more at the beginning as it follows an exponential decay curve. Therefore, towards control and management of water quality of a river, one requires an appropriate analysis and strategy to choose the best alternatives. Usual methods for control and management of water quality in a river, which depends on purposes and resources available, are:

(i) augmentation of flow from the different upstream sources, i.e., dilution of the river water,

(ii) controlling of wastewaters ,

(iii) artificial aeration through different devices,

(iv) treatment of wastewaters before they are discharged into the river water,

(v) combinations of (I) and (iv).

The "purpose" means why the restoration of river water quality is necessary whether to restore the ecological degradation of the river or the river waters are going to be used for different beneficial purposes. The "resource" means availability of water at the upstream for flow augmentation and economic aspects for treatment of wastewaters. The objective of the above methods has a single point that is control of DO. In the present case, the study is limited to the investigation of flow augmentation, treatment of wastewaters before their discharge into the river, and combination of flow augmentation and partial treatment.

4.2 STATEMENT OF THE PROBLEM

In chapter 3, the BOD and DO profiles of the Brahmani river for different low flow months have been simulated. From the simulation of BOD and DO profiles, a reach length of about 100 Km, measuring between 25 Km to 125 Km below the Rengali dam, has been found to be the critical stretch of DO deficit for all low flow months, February to May, in which May is most critical month. Within the reach length of 100 Km, BOD and DO of the river water is found exceeding the permissible prescribed limit of category 'B' (limit prescribed for bathing, swimming, and recreation etc.) i.e., BOD $\leq$ 3 mg/L, and DO $\geq$ 5 mg/L. The critical point of DO deficit occurs at 115 Km below the Rengali dam. The computed values of BOD and DO at the critical point for different low flow months are given Table 3.12. It is intended to investigate the best management alternatives to restore the limit of BOD and DO at category "B".

4.3 METHODS OF ANALYSIS

In order to meet the above requirements, quantitative analysis is carried out for all low flow months considering the following approaches:

- Flow augmentation,
- Control of effluents by treatment,
- Partial treatment and partial augmentation

4.3.1 Flow Augmentation

Flow augmentation in another term means 'dilution of wastewater', which can be achieved by an additional flow to the river from an external source. The external sources could be from a upstream storage or from an aquifer. The additional flow decreases the critical flow conditions of the river by increasing the flow in the river and the reaction rates, by reducing temperature etc. and thereby reduces the treatment costs. Flow augmentation has three primary effects on water quality (Biswas, 1976). First, augmenting flow increases the volume of water in a water body. The increased flow increases the minimum dissolved oxygen concentration. Second, flow augmentation increases the velocity of water, which in turn usually increases the re-aeration rate and lengthen the distance over which a pollutant causes an oxygen deficit. Third, if the aquifer waters are augmented, which may have low temperature, the de-oxygenation rate decreases and the saturated concentration of dissolved oxygen increases. Conversely, if higher temperature waters are used for augmentation, de-oxygenation rates increase and saturation dissolved oxygen decrease. Finally, increased river flows may increase the BOD in the river. All these factors may well result in flow augmentation being beneficial to some cases and may be detrimental to others.

Keeping the above points in mind, the flow augmentation is carried out assuming that the required flow would be available only from the upstream storage, i.e., Rengali dam, during the critical months, i.e., the months when the DO concentration in a stream drops below the target level.

4.3.1.1 Procedure of flow augmentation

QUAL2E has an option to compute the flow augmentation. There is no exact functional relationship to calculate the amount of flow necessary to bring the DO concentrations up to required limit. The functional form that has been considered in formulation of flow augmentation in QUAL2E is an approximate relationship of the following quadratic form:

$$DO_R = DO_T - DO_{min}$$

and

$$Q_R = Q_c\left[\frac{DO_R}{DO_T} + 0.15\left(\frac{DO_R}{DO_T}\right)^2\right]$$

Where,

DO_R = extra dissolved oxygen concentration required to meet target conditions, mg/L

DO_T = required target level of DO, mg/L

DO_{min} = minimum DO concentration (critical level) in the oxygen sag curve, mg/L

Q_R = amount of flow augmentation required, ft^3/sec

Q_C = flow at the critical point in the oxygen sag curve, ft^3/sec

Using the flow augmentation option of the QUAL2E and adopting different flow conditions at the upstream and keeping the pollution loads unchanged and so the reaction coefficients, the BOD and DO profiles corresponding to these augmented flow are computed for all low flow months.

4.3.2 Control of Effluents by Treatment

The control of effluents by treatment means the removal of some fraction of the total waste load prior to discharging the remainder into the river. The process removes a percentage of BOD prior to make an entry to the receiving water body. This method in other words means determination of assimilative capacity of the river towards pollution load.

QUAL2E has the option to input the percentage treatment to be given to a pollution load before being discharged to the receiving water body. Adopting different percentage of treatment on BOD and keeping all other conditions same, the BOD and DO along the river reach are computed for all critical periods.

4.3.3 Combination of flow augmentation and effluents treatment

Flow augmentation may require a large quantity of flow to uphold the required water quality standards, which may not be available from the upstream. Treatment to the effluents can bring the water quality up to the desired standards. However, it may not be cost effective. The combination of flow augmentation and partial treatment to the effluents in such case could be a useful alternative. It means, treatment to the pollutants to a certain percentage before releasing to the river and further dilution of the river water by releasing certain quantity of water from the upstream storage. In this case, the concentration of input pollution and the upstream flow changes, while all other conditions remain unchanged.

4.4 RESULTS AND DISCUSSION

February to May have been identified as the critical months of dissolved oxygen deficit along the river reach of 100 Km. These months are considered for analysis of augmentation of flow and for control of pollution by treatment. The critical point of DO deficit is considered as the reference point to investigate the improvement of water quality, and DO is considered as the decision variable with a target value of 5 mg/L

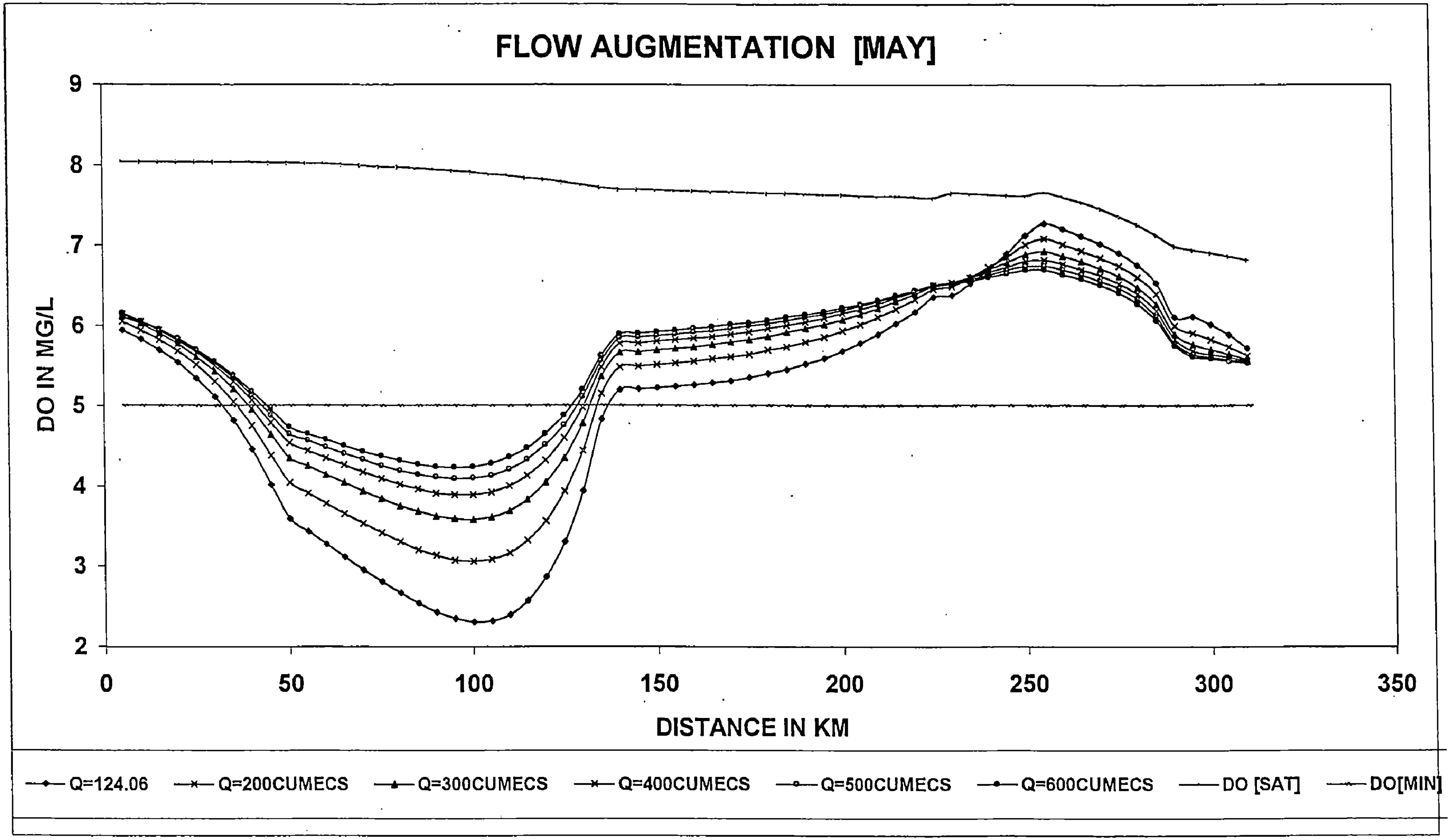
For flow augmentation, It is assumed that quantity of water required for augmentation would be available from the headreach, i.e., from the storage of Rengali dam. Using the pollution loads of each critical month for all point sources and adopting different values of augmented flow, which has same water quality constituents as that of headreach, the BOD and DO profiles are computed using the QUAL2E. The DO value at the critical point, which occurs at 115 km, without flow augmentation is 2.3 mg/L. The computed values of DO corresponding to the different augmented flows for the most critical month i.e., May are given in Table. 4.1 and the computed DO profiles are shown in Fig.4.1. In this figure the DO saturation profile along the river is also plotted for comparison. It could be seen from the Fig. that increase in the augmented flow increases the DO along the critical DO deficit zone and the improvement in the DO concentration at a particular location follows a quadratic relationship with the augmented flow as expected (Fig.4.2) From Fig. 4.2, it could be seen that about 5 times increase in the augmented flow (600 cumecs) over the initial flow of 124 cumecs increases the DO value by about 1.8 times (4.23 mg/L) over the critical DO value of 2.3 mg/L., and the ratio of improvement of DO and the augmented flow decreases as we increase the rate of flow augmentation. From the Fig.4.2, which shows plot of the DO versus augmented flow, it could be seen that the increase of DO at the initial stages of augmented flow is more and tends to a steady state of DO value as we increase the augmentation of flow and after certain limit of flow augmentation there is no improvement of DO value. Thus, flow augmentation alone does not sound to be an appropriate method for recovering the DO deficit, in this case.

In the second alternative i.e., control of effluents by treatment, different percentage of treatment to the effluents' BOD before discharging to the river are chosen to ascertain the assimilative capacity of the river water prevailing in different critical months. It is observed that percentage reduction of effluents'

Table. No.4.1 COMPUTATION OF FLOW AUGMENTATION[MAY]

UNIT OF Q=CUMECS

DIST IN KM	Q=124.06 DO MG/L	Q=200 DO MG/L	Q=300 DO MG/L	Q=400 DO MG/L	Q=500 DO MG/L	Q=600 DO MG/L	DO SAT MG/L	DO MIN MG/L
310	5.71	5.62	5.57	5.55	5.54	5.53	6.81	5.00
305	5.88	5.73	5.64	5.6	5.57	5.55	6.86	5.00
300	6.01	5.82	5.7	5.64	5.6	5.58	6.90	5.00
295	6.11	5.9	5.76	5.68	5.64	5.61	6.94	5.00
290	6.10	5.99	5.89	5.83	5.78	5.75	6.99	5.00
285	6.53	6.39	6.26	6.18	6.11	6.06	7.13	5.00
280	6.75	6.6	6.47	6.39	6.32	6.26	7.26	5.00
275	6.90	6.74	6.61	6.52	6.46	6.4	7.36	5.00
270	7.02	6.84	6.71	6.62	6.55	6.5	7.46	5.00
265	7.11	6.93	6.79	6.69	6.63	6.57	7.54	5.00
260	7.20	7.01	6.86	6.76	6.69	6.63	7.60	5.00
255	7.27	7.08	6.92	6.81	6.74	6.69	7.66	5.00
250	7.12	7	6.88	6.8	6.73	6.68	7.61	5.00
245	6.89	6.85	6.78	6.72	6.68	6.64	7.62	5.00
240	6.69	6.72	6.69	6.66	6.62	6.6	7.63	5.00
235	6.52	6.59	6.6	6.59	6.57	6.55	7.64	5.00
230	6.37	6.48	6.52	6.53	6.52	6.51	7.65	5.00
225	6.35	6.45	6.49	6.5	6.5	6.49	7.59	5.00
220	6.17	6.32	6.39	6.42	6.43	6.43	7.60	5.00
215	6.02	6.2	6.3	6.34	6.36	6.37	7.61	5.00
210	5.89	6.1	6.21	6.27	6.3	6.31	7.61	5.00
205	5.78	6.01	6.14	6.2	6.24	6.26	7.62	5.00
200	5.68	5.93	6.07	6.15	6.19	6.22	7.63	5.00
195	5.59	5.85	6.01	6.09	6.14	6.17	7.63	5.00
190	5.52	5.79	5.96	6.04	6.1	6.13	7.64	5.00
185	5.45	5.73	5.91	6.	6.06	6.1	7.65	5.00
180	5.40	5.69	5.86	5.96	6.02	6.06	7.65	5.00
175	5.35	5.64	5.82	5.92	5.99	6.03	7.66	5.00
170	5.31	5.61	5.79	5.89	5.96	6.01	7.67	5.00
165	5.28	5.58	5.76	5.86	5.93	5.98	7.67	5.00
160	5.26	5.55	5.73	5.84	5.91	5.96	7.68	5.00
155	5.24	5.53	5.71	5.82	5.89	5.94	7.68	5.00
150	5.22	5.51	5.69	5.8	5.87	5.92	7.69	5.00
145	5.21	5.49	5.67	5.78	5.85	5.9	7.70	5.00
140	5.20	5.48	5.66	5.77	5.84	5.89	7.70	5.00
135	4.83	5.15	5.36	5.48	5.56	5.62	7.72	5.00
130	3.94	4.44	4.78	4.98	5.11	5.2	7.76	5.00
125	3.30	3.93	4.35	4.6	4.76	4.88	7.79	5.00
120	2.86	3.56	4.04	4.32	4.51	4.65	7.82	5.00
115	2.57	3.32	3.83	4.13	4.33	4.47	7.84	5.00
110	2.39	3.16	3.69	4	4.21	4.36	7.87	5.00
105	2.31	3.08	3.61	3.92	4.13	4.28	7.89	5.00
100	2.30	3.06	3.58	3.89	4.1	4.24	7.91	5.00
95	2.34	3.07	3.59	3.89	4.09	4.23	7.93	5.00
90	2.42	3.13	3.62	3.91	4.11	4.24	7.94	5.00
85	2.53	3.2	3.68	3.96	4.14	4.27	7.96	5.00
80	2.66	3.3	3.75	4.02	4.19	4.32	7.97	5.00
75	2.80	3.41	3.84	4.09	4.25	4.37	7.98	5.00
70	2.95	3.53	3.93	4.17	4.33	4.43	8.00	5.00
65	3.11	3.65	4.04	4.26	4.4	4.5	8.01	5.00
60	3.27	3.78	4.14	4.35	4.48	4.58	8.02	5.00
55	3.43	3.91	4.25	4.44	4.57	4.65	8.02	5.00
50	3.59	4.04	4.35	4.54	4.65	4.73	8.03	5.00
45	4.01	4.38	4.64	4.79	4.88	4.95	8.03	5.00
40	4.46	4.75	4.95	5.07	5.13	5.18	8.04	5.00
35	4.82	5.05	5.21	5.3	5.35	5.38	8.04	5.00
30	5.11	5.3	5.43	5.5	5.53	5.55	8.04	5.00
25	5.34	5.51	5.61	5.67	5.69	5.7	8.04	5.00
20	5.54	5.68	5.77	5.81	5.83	5.84	8.04	5.00
15	5.69	5.82	5.9	5.94	5.95	5.95	8.04	5.00
10	5.83	5.94	6.02	6.04	6.05	6.05	8.04	5.00
5	5.94	6.05	6.11	6.14	6.15	6.14	8.04	5.00



FLOW AUGMENTATION [MAY]
DO IN MG/L
9
8
7
6
5
4
3
2
0
50
100
150
200
250
300
350
DISTANCE IN KM
Q=124.06
Q=200CUMECS
Q=300CUMECS
Q=400CUMECS
Q=500CUMECS
Q=600CUMECS
DO [SAT]
DO[MIN]

FIG.4.1

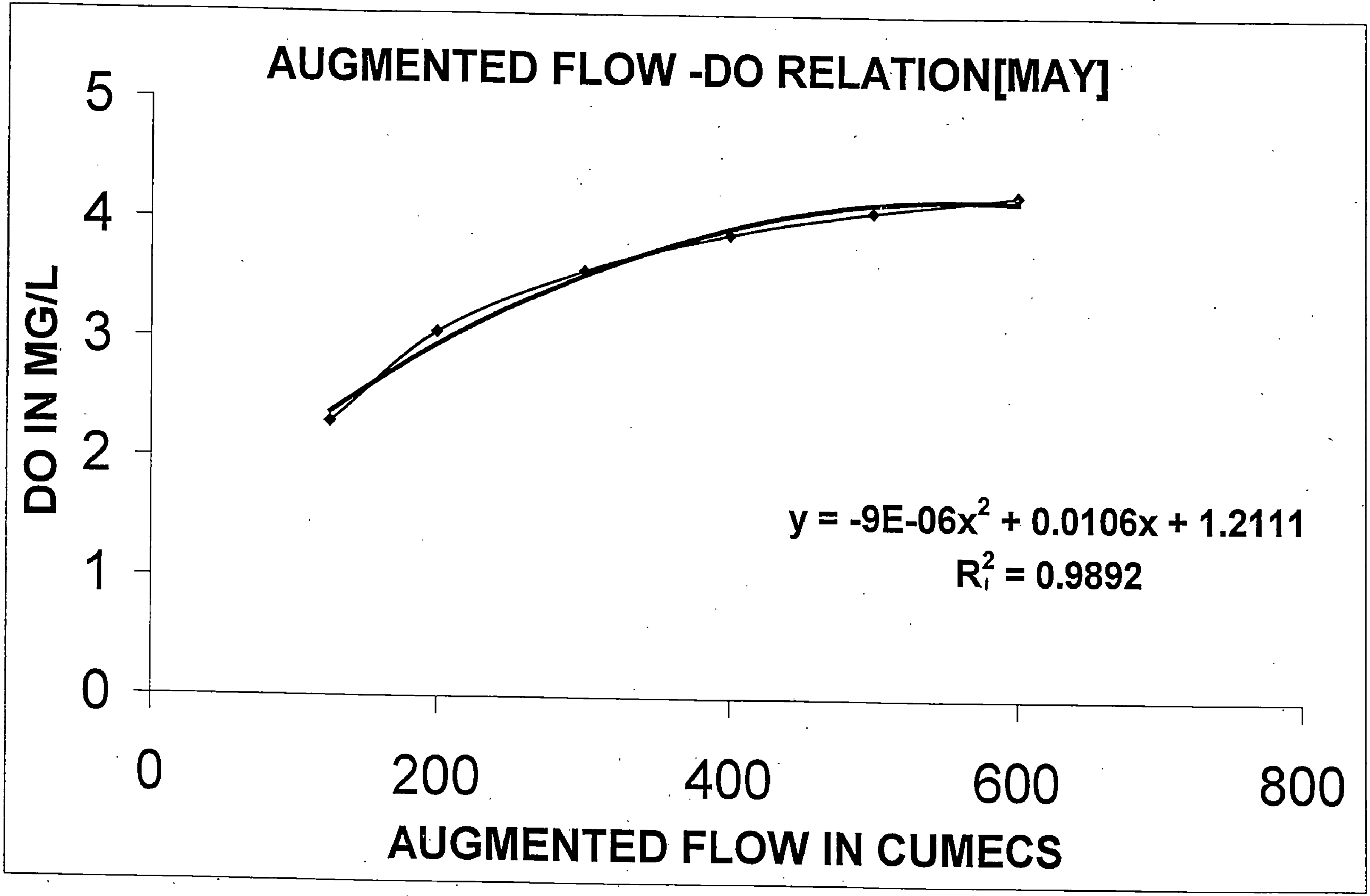
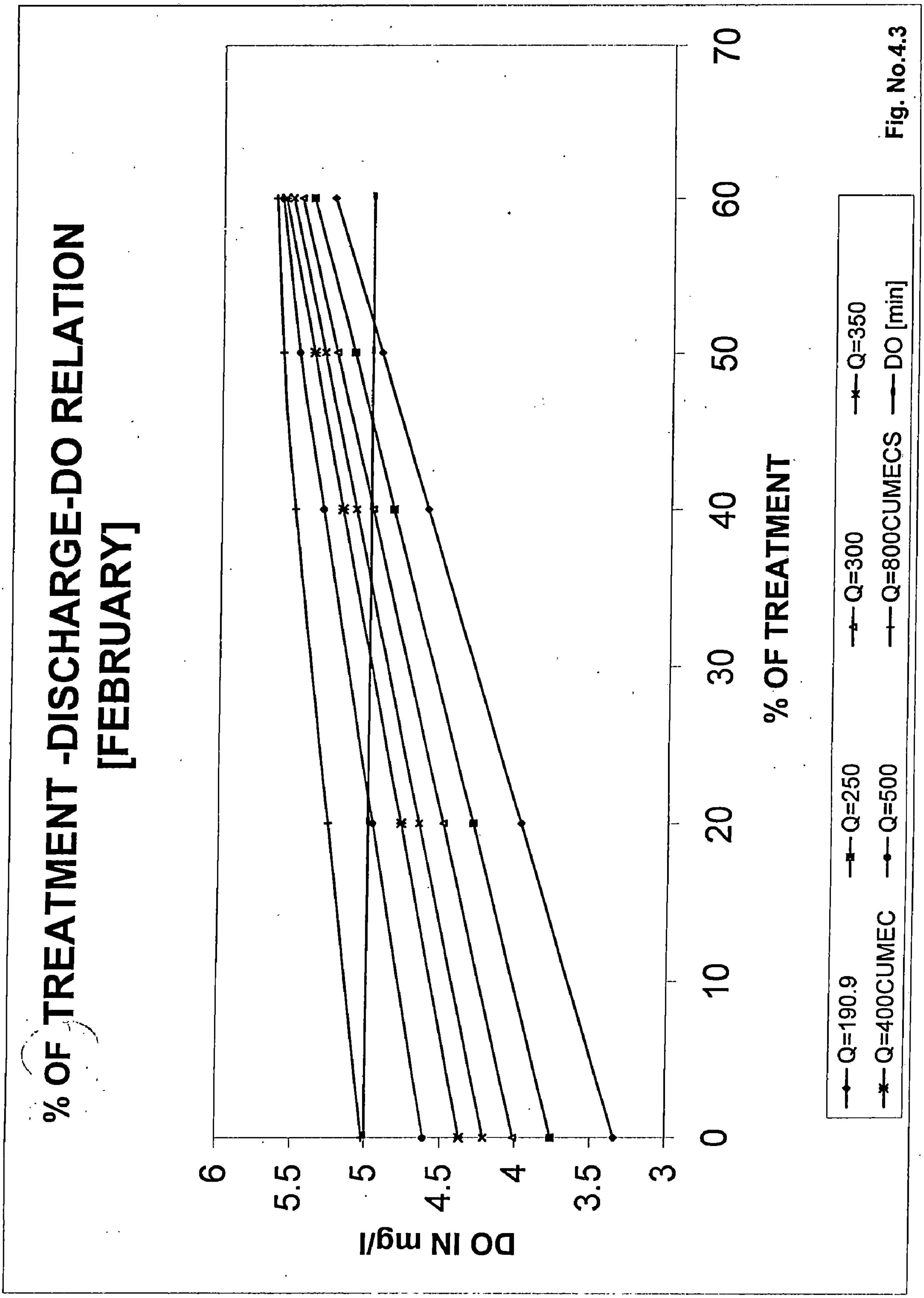

AUGMENTED FLOW -DO RELATION[MAY]
DO IN MG/L
5
4
3
2
1
0
0
200
400
600
800
AUGMENTED FLOW IN CUMECS
y = -9E-06x2 + 0.0106x + 1.2111
R2 = 0.9892

Fig. No.4.2

BOD and the DO value at a specific location in the critical DO deficit zone follows a linear relationship. The plots of percentage treatment of effluents' BOD and the corresponding DO concentration at the critical point of DO deficit for different months are shown in Figs. 4.3 to 4.6. It could be seen from the figures that different critical months require different degree of treatment to achieve the DO level of 5 mg/L. It is obvious, because natural flows in the river in each critical month are different (Table. 4.2 to 4.5). The percentage treatment requirement to the effluents BOD to achieve the DO level of 5 mg/L along the river reach in different low flow months is given in Table. 4.6. From the Table.4.6 , it could be seen that about 53% to 63% treatment to the effluents' BOD satisfies the target level of DO concentration in all critical low flow months. Percentage treatment of the effluents to the order of 63% may involve a huge cost.

In the third alternative i.e., partial treatment of effluents and partial flow augmentation, different percentage of treatment to the effluents' BOD and different quantity of flow augmentation are considered to investigate the response of DO concentration at the critical point. The plots of percentage treatment to the effluents BOD' versus DO concentration at the critical point for different augmented flows of different critical months are shown in Figs. 4.3 to 4.6. It could be seen from the figures that for a fixed percentage of treatment different months require different quantity of augmented flow to attain the DO level of 5 mg/L , Alternately, for a specific quantity of augmented flow, the degree of treatment to the effluents' BOD varies from month to month. About 50% treatment to the effluents' BOD and minimum flow of 300 cumecs in the


% OF TREATMENT -DISCHARGE-DO RELATION
[FEBRUARY]
DO IN mg/l
6
5.5
5
4.5
4
3.5
3
0
10
20
30
40
50
60
70
% OF TREATMENT
Q=190.9
Q=250
Q=300
Q=350
Q=400CUMEC
Q=500
Q=800CUMECS
DO [min]
Fig. No.4.3

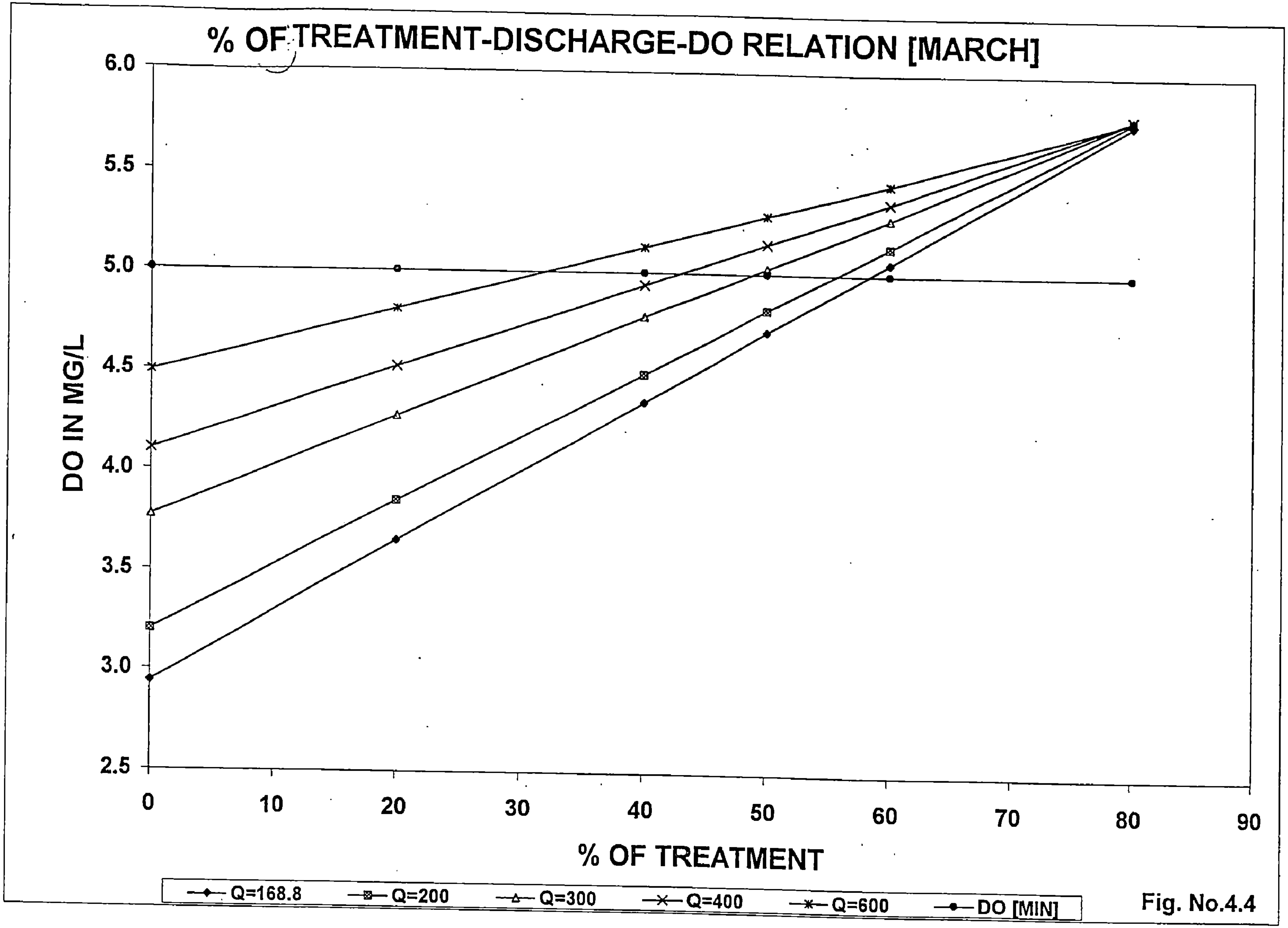

% OF TREATMENT-DISCHARGE-DO RELATION [MARCH]
DO IN MG/L
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
0
10
20
30
40
50
60
70
80
90
% OF TREATMENT
Q=168.8
Q=200
Q=300
Q=400
Q=600
DO [MIN]

Fig. No.4.4

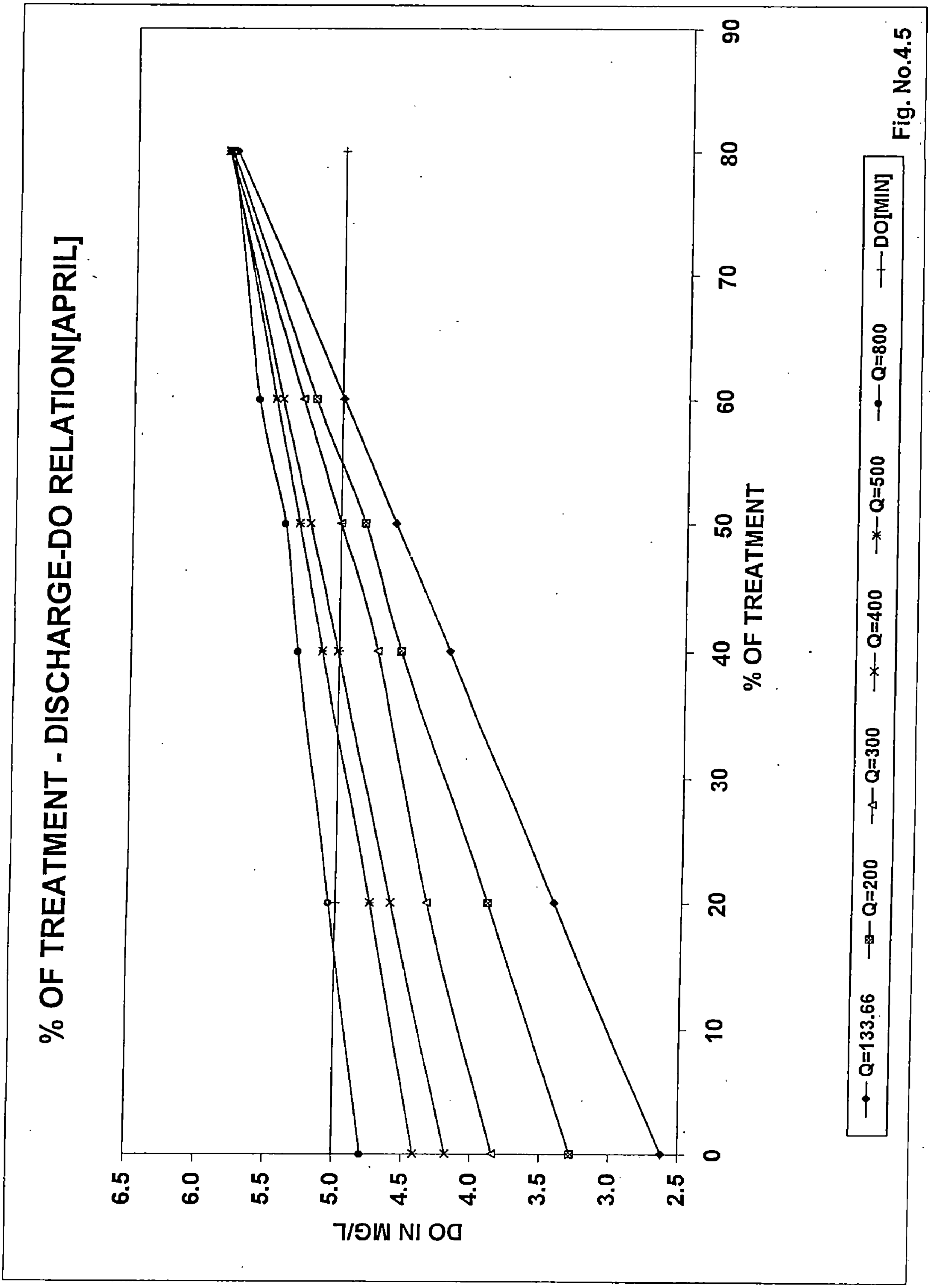

% OF TREATMENT - DISCHARGE-DO RELATION[APRIL]
DO IN MG/L
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
0
10
20
30
40
50
60
70
80
90
% OF TREATMENT
Q=133.66
Q=200
Q=300
Q=400
Q=500
Q=800
DO[MIN]

Fig. No.4.5

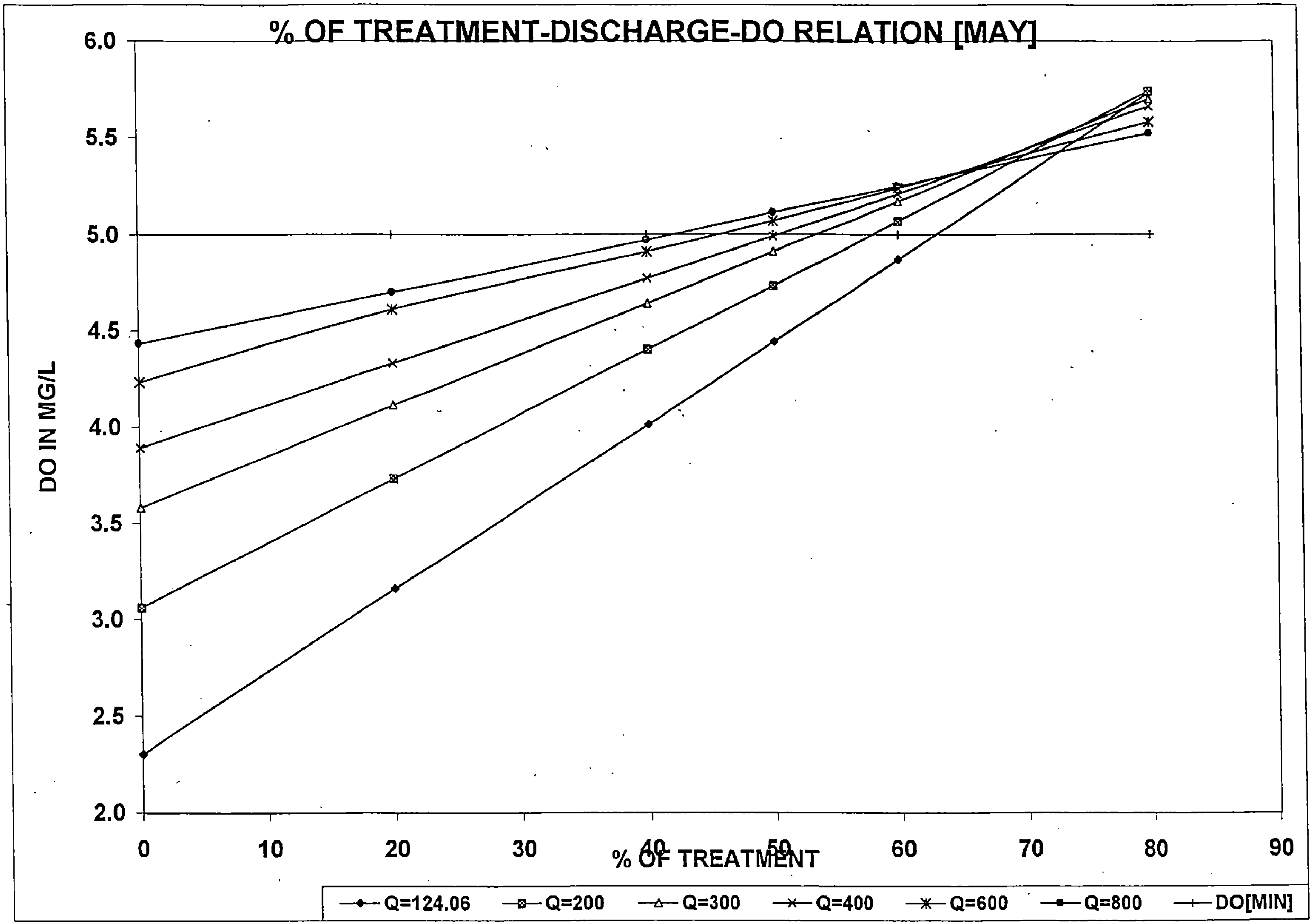

% OF TREATMENT-DISCHARGE-DO RELATION [MAY]
DO IN MG/L
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
0
10
20
30
40
50
60
70
80
90
% OF TREATMENT
Q=124.06
Q=200
Q=300
Q=400
Q=600
Q=800
DO[MIN]

Fig. No.4.6

Table. 4.2

%Treatment---Discharge----dissolvedOxygen relation

For the month of-FEBRUARY

%Treatmen	Discharge(cumecs)							DO
	190.9	250	300	350	400	500	800	
0	3.34	3.76	4.01	4.21	4.37	4.61	5.02	5.00
20	3.98	4.3	4.5	4.66	4.78	4.97	5.27	5.00
40	4.62	4.85	4.99	5.1	5.19	5.32	5.51	5.00
50	4.94	5.12	5.24	5.32	5.39	5.49	5.6	5.00
60	5.26	5.4	5.48	5.54	5.59	5.61	5.65	5.00

Table. No.4.3

%Treatment---Discharge----dissolvedOxygen relation

For the month of-MARCH

%Treatment	Discharge(cumecs)					DO
	168.88	200	300	400	600	
0	2.94	3.2	3.77	4.1	4.49	5.00
20	3.65	3.85	4.27	4.52	4.81	5.00
40	4.35	4.49	4.78	4.94	5.13	5.00
50	4.71	4.82	5.03	5.15	5.29	5.00
60	5.06	5.14	5.28	5.36	5.45	5.00
80	5.76	5.78	5.79	5.79	5.78	5.00

Table.No.4.4

%Treatment---Discharge-----dissolvedOxygen relation

For the month of-APRIL

%Treatmen	Discharge(cumecs)						DO
	133.66	200	300	400	500	800	Required
0	2.62	3.28	3.84	4.18	4.41	4.79	5.00
20	3.42	3.9	4.34	4.6	4.75	5.05	5.00
40	4.2	4.55	4.72	5.01	5.12	5.3	5.00
50	4.6	4.82	5	5.22	5.3	5.4	5.00
60	4.99	5.19	5.28	5.43	5.48	5.6	5.00
80	5.78	5.82	5.84	5.84	5.83	5.81	5.00

Table. No.4.5

%Treatment----Discharge-----dissolvedOxygen relation

For the month of-MAY

Treatment	Discharge(cumecs)						DO
%	124.06	200	300	400	600	800	Required
0	2.3	3.06	3.58	3.89	4.23	4.43	5
20	3.16	3.73	4.11	4.33	4.61	4.7	5
40	4.01	4.4	4.64	4.77	4.91	4.97	5
50	4.44	4.73	4.91	4.99	5.07	5.11	5
60	4.87	5.07	5.17	5.21	5.24	5.25	5
80	5.73	5.74	5.7	5.66	5.58	5.52	5

river satisfies the condition of DO of 5mg/L. Table.4.6 shows the percentage of treatment and augmented flow required in different months to maintain the DO as per specification of CPCB for category 'B'.

Table. 4.6 Percentage of Treatment required to Maintain DO as per specification of CPCB for Category "B".

FEBUARY		MARCH		APRIL		MAY	
Flow M^3/sec	percentage of Treatment	Flow M^3/sec	Percentage of Treatment	Flow M^3/sec	Percentage of Treatment	Flow M^3/sec	percentage of Treatment
190.9	53	168.8	59	133.66	60	124	63
250	47	200	55	200	56	200	57
300	40	300	50	300	50	300	50
350	35	400	43	400	41	400	48
400	30	600	33	500	37	600	45
600	23	800	24	800	18	800	42

4.5 Conclusions

Three water quality management alternatives, augmentation of flow, Control of effluents by treatment, and partial treatment and partial augmentation have been analyzed to ascertain the minimum flow requirement and to assess the assimilative capacity of the river.

The flow augmentation analysis shows that improvement of DO and augmentation of flow rate follows a quadratic relationship. The increase of DO at the initial stages of augmented flow is more and tends to a steady state after certain limit of augmented flow. Thus, flow augmentation alone is not adequate for recovering the DO deficit, when the deficit is more.

Treatment to the effluents up to the desired degree satisfying the assimilative capacity of the river water before it is discharged into the water bodies is the best alternative, when there is no scope of flow augmentation.

Partial treatment to the effluents and partial flow augmentation could be an alternative, where scope exists for augmenting the flow. The methods of complete treatment, and partial treatment with partial flow augmentation would require an economic analysis to choose the appropriate alternative. However, from ecological point of view, partial treatment of effluents and partial augmentation of flow would be a desirable solution.

CHAPTER- 5

SUMMARY AND CONCLUSIONS

Downstream of the Rengali dam across Brahmani river in Orissa, the river reach of 310 Km. has been studied to ascertain the health of the river in terms of BOD and DO. Within this reach, three point sources of pollution containing refusal of industries, mining and urban areas are discharged to the main stream of Brahmani through its tributaries; Tikara, Nandira, and Bangaru rivers at 25, 75 and 95 km respectively at the down stream of the Rengali dam. During non-monsoon months, which occurs between November through May every year, these tributaries are fed by the wastewater only. In these months, the Brahmani river experiences ecological imbalance due to the threat of pollution.

The BOD and DO are usually referred as the primary index of water quality in a river. Using QUAL2E, an enhanced stream water quality model, the BOD and DO of the river Brahmani for the linear stretch of 310 Km have been modeled for all non-monsoon months. The reaction kinetics such as; deoxygenating rate coefficient, re-aeration rate coefficients, setting rate constant, and sediment oxygen demand coefficient have been assessed. These rate coefficients can be used to simulate BOD and DO profiles of any given stress conditions in the river. Out of the 7 non-monsoon months, February through May have been found to be the critical months, in which, May is the most critical one, exceeding the DO level below the prescribed limit of category "B". A stretch of 100 Km measuring between 25 Km to 125 Km below the Rengali dam has been identified as the critical zone of DO deficit and the critical point of DO deficit occurs at 115 Km below the Rengali dam.

Three alternatives; flow augmentation, control of effluents by treatment, and partial treatment and partial augmentation, for controlling the deficit of DO in the river have been analyzed for all critical low flow months. Control of effluents by only treatment, and partial treatments with partial flow augmentation provide the solution towards upholding the DO in the river above the prescribed limit. However, from ecological point of view, partial treatment and partial flow augmentation appears to be the best alternative.

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APPENDIX -1

APPENDIX

QUAL-2E STREAM QUALITY ROUTING MODEL

WATER QUALITY OF BRAHMUNI RIVER (MAY)

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TITLE02
TITLE03  YES     CONSERVATIVE MINERAL I       TDS IN MG/L
TITLE04  NO      CONSERVATIVE MINERAL II
TITLE05  NO      CONSERVATIVE MINERAL III
TITLE06  YES     TEMPERATURE
TITLE07  YES     5-DAY BIOCHEMICAL OXYGEN DEMAND
TITLE08  NO      ALGAE AS CHL-A IN UG/L
TITLE09  NO      PHOSPHORUS CYCLE AS P IN MG/L
TITLE10            (ORGANIC-P; DISSOLVED-P)
TITLE11  NO      NITROGEN CYCLE AS N IN MG/L
TITLE12            (ORGANIC-N; AMMONIA-N; NITRITE-N;' NITRATE-N)
TITLE13  YES     DISSOLVED OXYGEN IN MG/L
TITLE14  YES     FECAL COLIFORM IN NO./100 ML
TITLE15  NO      ARBITRARY NON-CONSERVATIVE
ENDTITLE
```

(CONTROL DATA)

CARD TYPE		CARD TYPE	
LIST DATA INPUT	0.00000		0.00000
WRITE OPTIONAL SUMMARY	0.00000		0.00000
NO FLOW AUGMENTATION	0.00000		0.00000
STEADY STATE	0.00000		0.00000
NO TRAP CHANNELS	0.00000		0.00000
PRINT LCD/SOLAR DATA	0.00000		0.00000
PLOT DO AND BOD DATA	0.00000		0.00000
FIXED DNSTM CONC (YES=1) =	0.00000	5D-ULT BOD CONV K COEF =	0.23000
INPUT METRIC =	1.00000	OUTPUT METRIC =	1.00000
NUMBER OF REACHES =	9.00000	NUMBER OF JUNCTIONS =	3.00000
NUM OF HEADWATERS =	4.00000	NUMBER OF POINT LOADS =	3.00000
TIME STEP (HOURS) =	1.00000	LNTH. COMP. ELEMENT (DX) =	5.00000
MAXIMUM ROUTE TIME (HRS) =	10.00000	TIME INC. FOR RPT2 (HRS) =	6.00000
LATITUDE OF BASIN (DEG) =	21.00000	LONGITUDE OF BASIN (DEG) =	85.27000
STANDARD MARIDIAN (DEG) =	75.00000	DAY OF YEAR START TIME =	1.00000
EVAP. COEF.,(AE) =	0.00001	EVAP. COEF.,(BE) =	0.00001
ELEV. OF BASIN (ELEV) =	82.00000	DUST ATTENUATION COEF. =	0.13000
ENDATA1	0.00000		0.00000

THETA VALUE

THETA(1)	BOD DECA	1.047	DFLT
THETA(2)	BOD SETT	1.024	DFLT
THETA(3)	OXY TRAN	1.024	DFLT
THETA(4)	SOD RATE	1.060	DFLT
THETA(5)	ORGN DEC	1.047	DFLT
THETA(6)	ORGN SET	1.024	DFLT
THETA(7)	NH3 DECA	1.083	DFLT
THETA(8)	NH3 SRCE	1.074	DFLT
THETA(9)	NO2 DECA	1.047	DFLT
THETA(10)	PORG DEC	1.047	DFLT
THETA(11)	PORG SET	1.024	DFLT
THETA(12)	DISP SRC	1.074	DFLT
THETA(13)	ALG GROW	1.047	DFLT
THETA(14)	ALG RESP	1.047	DFLT
THETA(15)	ALG SETT	1.024	DFLT
THETA(16)	COLI DEC	1.047	DFLT
THETA(17)	ANC DECA	1.000	DFLT
THETA(18)	ANC SETT	1.024	DFLT
THETA(19)	ANC SRCE	1.000	DFLT
ENDATA1B			

(REACH IDENTIFICATION)

CARD TYPE	REACH ORDER AND IDENT				R. MI/KM		R. MI/KM
STREAM REACH	1.0	RCH=	BR-1	FROM	310.0	TO	290.0
STREAM REACH	2.0	RCH=	TIKARA	FROM	15.0	TO	0.0
STREAM REACH	3.0	RCH=	BR-2	FROM	290.0	TO	250.0
STREAM REACH	4.0	RCH=	NANDIRA	FROM	10.0	TO	0.0
STREAM REACH	5.0	RCH=	BR-3	FROM	250.0	TO	225.0
STREAM REACH	6.0	RCH=	BANGARU	FROM	10.0	TO	0.0
STREAM REACH	7.0	RCH=	BR-4	FROM	225.0	TO	135.0
STREAM REACH	8.0	RCH=	BR-5	FROM	135.0	TO	45.0
STREAM REACH	9.0	RCH=	BR-6	FROM	45.0	TO	0.0
ENDATA2	0.0				0.0		0.0

(COMPUTATIONAL REACH FLAG FIELD)

CARD TYPE	REACH	ELEMENTS/REACH	COMPUTATIONAL FLAGS
FLAG FIELD	1.	4.	1.2.2.3.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD	2.	3.	1.2.6.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD	3.	8.	4.2.2.2.2.2.2.3.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD	4.	2.	1.6.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD	5.	5.	4.2.2.2.3.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD	6.	2.	1.6.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD	7.	18.	4.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.0.0.
FLAG FIELD	8.	18.	2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.2.0.0.
FLAG FIELD	9.	9.	2.2.2.2.2.2.2.2.5.0.0.0.0.0.0.0.0.0.0.0.
ENDATA4	0.	0.	0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0

(HYDRAULIC DATA FOR DETERMINING VELOCITY AND DEPTH)

CARD TYPE	REACH	COEF-DSPN	COEFQV	EXPOQV	COEFQH	EXPOQH	CMANN
HYDRAULICS	1.	18.25	0.100	0.680	0.060	0.560	0.035
HYDRAULICS	2.	11.91	2.870	0.320	0.190	0.480	0.035
HYDRAULICS	3.	11.85	0.054	0.700	0.050	0.390	0.035
HYDRAULICS	4.	8.16	2.720	0.320	0.210	0.480	0.035
HYDRAULICS	5.	34.07	0.080	0.750	0.050	0.650	0.035
HYDRAULICS	6.	6.41	2.910	0.360	0.180	0.540	0.035
HYDRAULICS	7.	47.08	1.090	0.290	0.430	0.240	0.035
HYDRAULICS	8.	6.61	0.420	0.100	0.650	0.150	0.035
HYDRAULICS	9.	11.90	0.640	0.100	0.530	0.150	0.035
ENDATA5	0.	0.00	0.000	0.000	0.000	0.000	0.000

(STEADY STATE TEMPERATURE AND CLIMATOLOGY DATA)

CARD TYPE	REACH	ELEVATION	DUST COEF	CLOUD COVER	DRY BULB TEMP	WET BULB TEMP	ATM PRESSURE	WIND	SOLAR RAD ATTENUATION
TEMP/LCD	1.	82.00	0.13	0.30	36.70	22.50	1000.00	6.10	1.00
TEMP/LCD	2.	82.00	0.13	0.30	36.70	22.50	1000.00	6.10	1.00
TEMP/LCD	3.	82.00	0.13	0.30	36.70	22.50	1000.00	6.10	1.00
TEMP/LCD	4.	82.00	0.13	0.30	36.70	22.50	1000.00	6.10	1.00
TEMP/LCD	5.	82.00	0.13	0.30	36.70	22.50	1000.00	6.10	1.00
TEMP/LCD	6.	82.00	0.13	0.30	36.70	22.50	1000.00	6.10	1.00
TEMP/LCD	7.	82.00	0.13	0.30	36.70	22.50	1000.00	6.10	1.00
TEMP/LCD	8.	82.00	0.13	0.30	36.70	22.50	1000.00	6.10	1.00
TEMP/LCD	9.	82.00	0.13	0.30	36.70	22.50	1000.00	6.10	1.00
ENDATA5A	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(REACTION COEFFICIENTS FOR DEOXYGENATION AND REAERATION)

CARD TYPE	REACH	K1	K3	SOD RATE	K2OPT	K2	COEQK2 OR TSIV COEF FOR OPT 8	EXPQK2 OR SLOPE FOR OPT 8
REACT COEF	1.	0.23	0.30	3.000	4.	0.00	0.000	0.00000
REACT COEF	2.	0.23	0.30	3.000	4.	0.00	0.000	0.00000
REACT COEF	3.	0.23	0.30	3.000	4.	0.00	0.000	0.00000
REACT COEF	4.	0.23	0.30	3.000	4.	0.00	0.000	0.00000
REACT COEF	5.	0.23	0.30	3.000	4.	0.00	0.000	0.00000
REACT COEF	6.	0.23	0.30	3.000	4.	0.00	0.000	0.00000
REACT COEF	7.	0.23	0.30	3.000	4.	0.00	0.000	0.00000
REACT COEF	8.	0.23	0.30	3.000	4.	0.00	0.000	0.00000
REACT COEF	9.	0.23	0.30	3.000	4.	0.00	0.000	0.00000
ENDATA6	0.	0.00	0.00	0.000	0.	0.00	0.000	0.00000

CARD TYPE	REACH	ALPHAO	ALGSET	EXCOEF	CK5 CKCOLI	CKANC	SETANC	SRCANC
ALG/OTHER COEF	1.	50.00	0.15	0.38	1.50	0.60	0.10	8.00
ALG/OTHER COEF	2.	50.00	0.15	0.38	1.50	0.60	0.10	8.00
ALG/OTHER COEF	3.	50.00	0.15	0.38	1.50	0.60	0.10	8.00
ALG/OTHER COEF	4.	50.00	0.15	3.80	1.50	0.60	0.10	8.00
ALG/OTHER COEF	5.	50.00	0.15	3.80	1.50	0.60	0.10	8.00
ALG/OTHER COEF	6.	50.00	0.15	0.01	1.50	0.00	0.00	0.00
ALG/OTHER COEF	7.	50.00	0.15	0.01	1.50	0.00	0.00	0.00
ALG/OTHER COEF	8.	50.00	0.15	0.01	1.50	0.00	0.00	0.00
ALG/OTHER COEF	9.	50.00	0.15	0.01	1.50	0.00	0.00	0.00
ENDATA6B	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(INITIAL CONDITIONS)

CARD TYPE	REACH	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI
INITIAL COND-1	1.	36.70	5.50	2.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	2.	36.70	5.50	2.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	3.	36.70	5.50	2.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	4.	36.70	5.50	2.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	5.	36.70	5.50	2.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	6.	36.70	5.50	2.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	7.	36.70	5.50	2.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	8.	36.70	5.50	2.00	0.00	0.00	0.00	0.00	0.00
INITIAL COND-1	9.	36.70	5.50	2.00	0.00	0.00	0.00	0.00	0.00
ENDATA7	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(INCREMENTAL INFLOW CONDITIONS)

CARD TYPE	REACH	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3	ANC	COLI
INCR INFLOW-1	1.	7.710	36.70	5.50	2.00	55.00	0.00	0.00	0.00	100.00
INCR INFLOW-1	2.	0.000	36.70	5.50	2.00	55.00	0.00	0.00	0.00	100.00
INCR INFLOW-1	3.	9.830	36.70	5.50	2.00	55.00	0.00	0.00	0.00	100.00
INCR INFLOW-1	4.	0.000	36.70	5.50	2.00	55.00	0.00	0.00	0.00	100.00
INCR INFLOW-1	5.	-9.800	36.70	5.50	2.00	55.00	0.00	0.00	0.00	100.00
INCR INFLOW-1	6.	0.000	36.70	5.50	2.00	0.00	0.00	0.00	0.00	100.00
INCR INFLOW-1	7.	-2.960	36.70	5.50	2.00	0.00	0.00	0.00	0.00	100.00
INCR INFLOW-1	8.	7.950	36.70	5.50	2.00	0.00	0.00	0.00	0.00	100.00
INCR INFLOW-1	9.	8.860	36.70	5.50	2.00	0.00	0.00	0.00	0.00	100.00
ENDATA8	0.	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(STREAM JUNCTIONS)

CARD TYPE	JUNCTION ORDER AND IDENT			UPSTRM	JUNCTION	TRIB
STREAM JUNCTION	1.	JNC=	1	4.	8.	7.
STREAM JUNCTION	2.	JNC=	2	15.	18.	17.
STREAM JUNCTION	3.	JNC=	3	22.	25.	24.
ENDATA9	0.			0.	0.	0

(HEADWATER SOURCES)

CARD TYPE	HDWTR ORDER	NAME	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3
HEADWTR-1	1.	BR-1	124.06	36.70	5.50	2.00	83.00	0.00	0.00
HEADWTR-1	2.	TIKARA	0.01	36.70	5.50	2.00	98.00	0.00	0.00
HEADWTR-1	3.	NANDIRA	0.01	36.70	5.50	2.00	98.00	0.00	0.00
HEADWTR-1	4.	BANGARU	0.01	36.70	5.50	2.00	0.00	0.00	0.00
ENDATA10	0.		0.00	0.00	0.00	0.00	0.00	0.00	0.00

(POINT SOURCE / POINT SOURCE CHARACTERISTICS)

CARD TYPE	POINT LOAD ORDER	NAME	EFF	FLOW	TEMP	D.O.	BOD	CM-1	CM-2	CM-3
POINTLD-1	1.	TIKARA	0.00	13.30	36.70	0.90	229.50	120.00	0.00	0.00
POINTLD-1	2.	NANDIRA	0.00	11.87	36.70	1.70	241.20	120.00	0.00	0.00
POINTLD-1	3.	BANGARU	0.00	10.91	36.70	1.30	247.60	143.00	0.00	0.00
ENDATA11	0.		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

STEADY STATE TEMPERATURE SIMULATION; CONVERGENCE SUMMARY

ITERATION	NUMBER OF NONCONVERGENT ELEMENTS
1	62
2	28
3	0

SUMMARY OF VALUES FOR STEADY STATE TEMPERATURE CALCULATIONS (SUBROUTINE HEATER)

DAILY NET SOLAR RADIATION = 1538.089 BTU/FT-2 (417.392 LANGLEYS)
NUMBER OF DAYLIGHT HOURS = 10.7
HOURLY VALUES OF SOLAR RADIATION (BTU/FT-2)

1	0.00	9	65.76	17	95.77
2	0.00	10	129.57	18	27.70
3	0.00	11	181.68	19	0.00
4	0.00	12	217.28	20	0.00
5	0.00	13	232.87	21	0.00
6	0.00	14	226.95	22	0.00
7	0.00	15	200.09	23	0.00
8	5.52	16	154.90	24	0.00

TEMPERATURE

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	36.23	35.80	35.40	35.04																
2	27.09	25.82	36.43																	
3	34.68	33.44	32.40	31.53	30.80	30.18	29.65	29.20												
4	27.15	36.42																		
5	29.62	29.54	29.47	29.40	29.33															
6	26.59	36.44																		
7	29.74	29.69	29.63	29.58	29.53	29.48	29.43	29.38	29.33	29.28	29.24	29.19	29.14	29.10	29.05	29.01	28.96	28.92		
8	28.77	28.52	28.29	28.09	27.90	27.73	27.57	27.43	27.30	27.18	27.07	26.98	26.89	26.81	26.74	26.67	26.61	26.55		
9	26.54	26.53	26.52	26.52	26.51	26.51	26.50	26.49	26.49											

DISSOLVED OXYGEN IN MG/L

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	5.71	5.88	6.01	6.11																
2	7.91	8.10	6.42																	
3	6.10	6.53	6.75	6.90	7.02	7.11	7.20	7.27												
4	7.90	6.41																		
5	7.12	6.89	6.69	6.52	6.37															
6	7.99	6.56																		
7	6.35	6.17	6.02	5.89	5.78	5.68	5.59	5.52	5.45	5.40	5.35	5.31	5.28	5.26	5.24	5.22	5.21	5.20		
8	4.83	3.94	3.30	2.86	2.57	2.39	2.31	2.30	2.34	2.42	2.53	2.66	2.80	2.95	3.11	3.27	3.43	3.59		
9	4.01	4.46	4.82	5.11	5.34	5.54	5.69	5.83	5.94											

5-DAY BIOCHEMICAL OXYGEN DEMAND

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1.96	1.92	1.89	1.86																
2	1.89	1.79228.36																		
3	22.20	21.45	20.74	20.08	19.46	18.87	18.31	17.78												
4	1.88239.90																			
5	33.27	32.90	32.52	32.14	31.78															
6	1.87246.39																			
7	45.44	45.04	44.65	44.26	43.87	43.49	43.11	42.74	42.37	42.00	41.63	41.27	40.92	40.56	40.21	39.87	39.53	39.19		
8	37.81	35.64	33.60	31.69	29.91	28.23	26.66	25.18	23.79	22.48	21.25	20.09	18.99	17.96	16.99	16.08	15.21	14.39		
9	13.71	13.17	12.66	12.17	11.70	11.25	10.81	10.40	10.00											

FECAL COLIFORM IN NO./100 ML

RCH/CL	1	2	3	4	5	6	7	8	9	10
1	1.43E+00	2.74E+00	3.93E+00	5.12E+00						
RCH/CL	1	2	3	4	5	6	7	8	9	10
2	2.54E-07	2.89E-02	3.26E+03							
RCH/CL	1	2	3	4	5	6	7	8	9	10
3	2.89E+02	2.63E+02	2.41E+02	2.22E+02	2.05E+02	1.90E+02	1.76E+02	1.64E+02		
RCH/CL	1	2	3	4	5	6	7	8	9	10
4	1.02E-01	1.58E+04								
RCH/CL	1	2	3	4	5	6	7	8	9	10
5	1.24E+03	1.19E+03	1.15E+03	1.11E+03	1.07E+03					
RCH/CL	1	2	3	4	5	6	7	8	9	10
6	1.85E-02	5.27E+03								
RCH/CL	1	2	3	4	5	6	7	8	9	10
7	1.32E+03	1.28E+03	1.24E+03	1.21E+03	1.18E+03	1.15E+03	1.11E+03	1.08E+03	1.06E+03	1.03E+03
CL	11	12	13	14 15	16	17	18	19	20	
	9.99E+02	9.73E+02	9.46E+02	9.21E+02	8.97E+02	8.73E+02	8.49E+02	8.27E+02		
RCH/CL	1	2	3	4	5	6	7	8	9	10
8	7.46E+02	6.29E+02	5.31E+02	4.49E+02	3.81E+02	3.23E+02	2.74E+02	2.33E+02	1.99E+02	1.69E+02
CL	11	12	13	14 15	16	17	18	19	20	
	1.44E+02	1.23E+02	1.05E+02	9.01E+01	7.72E+01	6.61E+01	5.67E+01	4.87E+01		
RCH/CL	1	2	3	4	5	6	7	8	9	10
9	4.31E+01	3.91E+01	3.56E+01	3.24E+01	2.96E+01	2.70E+01	2.48E+01	2.27E+01	2.09E+01	

HYDRAULICS SUMMARY

ELE ORD	RCH NUM	ELE NUM	BEGIN LOC KILO	END LOC KILO	FLOW CMS	POINT SRCE CMS	INCR FLOW CMS	VEL MPS	TRVL TIME DAY	DEPTH M	WIDTH M	VOLUME K-CU-M	BOTTOM AREA K-SQ-M	X-SECT AREA SQ-M	DSPRSN COEF SQ-M/S
1	1	1	310.00	305.00	125.99	0.00	1.93	2.681	0.022	0.900	52.212	235.06	270.12	47.00	4.91
2	1	2	305.00	300.00	127.92	0.00	1.93	2.708	0.021	0.908	52.022	236.20	269.25	47.23	5.00
3	1	3	300.00	295.00	129.84	0.00	1.93	2.736	0.021	0.916	51.836	237.33	268.39	47.46	5.09
4	1	4	295.00	290.00	131.77	0.00	1.93	2.764	0.021	0.923	51.653	238.46	267.56	47.68	5.17
5	2	1	15.00	10.00	0.01	0.00	0.00	0.657	0.088	0.021	0.730	0.08	3.86	0.02	0.03
6	2	2	10.00	5.00	0.01	0.00	0.00	0.657	0.088	0.021	0.730	0.08	3.86	0.02	0.03
7	2	3	5.00	0.00	13.31	13.30	0.00	6.571	0.009	0.658	3.078	10.13	21.97	2.03	6.06
8	3	1	290.00	285.00	146.31	0.00	1.23	1.770	0.033	0.349	236.462	413.29	1186.08	82.64	0.96
9	3	2	285.00	280.00	147.54	0.00	1.23	1.781	0.033	0.351	236.284	414.33	1185.20	82.85	0.97
10	3	3	280.00	275.00	148.77	0.00	1.23	1.791	0.032	0.352	236.108	415.36	1184.33	83.05	0.97
11	3	4	275.00	270.00	149.99	0.00	1.23	1.802	0.032	0.353	235.933	416.39	1183.47	83.26	0.98
12	3	5	270.00	265.00	151.22	0.00	1.23	1.812	0.032	0.354	235.760	417.41	1182.61	83.46	0.99
13	3	6	265.00	260.00	152.45	0.00	1.23	1.822	0.032	0.355	235.588	418.42	1181.76	83.67	1.00
14	3	7	260.00	255.00	153.68	0.00	1.23	1.832	0.032	0.356	235.418	419.43	1180.92	83.87	1.01
15	3	8	255.00	250.00	154.91	0.00	1.23	1.843	0.031	0.357	235.249	420.43	1180.09	84.07	1.02
16	4	1	10.00	5.00	0.01	0.00	0.00	0.623	0.093	0.023	0.697	0.08	3.72	0.02	0.02
17	4	2	5.00	0.00	11.88	11.87	0.00	6.005	0.010	0.689	2.872	9.89	21.25	1.98	3.94
18	5	1	250.00	245.00	164.83	0.00	-1.96	3.680	0.016	1.381	32.443	223.99	176.06	44.79	17.98
19	5	2	245.00	240.00	162.87	0.00	-1.96	3.647	0.016	1.370	32.599	223.33	176.73	44.66	17.71
20	5	3	240.00	235.00	160.91	0.00	-1.96	3.614	0.016	1.359	32.757	222.65	177.42	44.52	17.43
21	5	4	235.00	230.00	158.95	0.00	-1.96	3.581	0.016	1.348	32.918	221.97	178.11	44.38	17.16
22	5	5	230.00	225.00	156.99	0.00	-1.96	3.548	0.016	1.337	33.082	221.28	178.83	44.25	16.89
23	6	1	10.00	5.00	0.01	0.00	0.00	0.554	0.104	0.015	1.205	0.09	6.17	0.02	0.01
24	6	2	5.00	0.00	10.92	10.91	0.00	6.881	0.008	0.655	2.425	7.94	18.67	1.59	3.40
25	7	1	225.00	220.00	167.75	0.00	-0.16	4.815	0.012	1.470	23.697	174.24	133.22	34.84	34.26
26	7	2	220.00	215.00	167.58	0.00	-0.16	4.813	0.012	1.470	23.686	174.12	133.16	34.82	34.25
27	7	3	215.00	210.00	167.42	0.00	-0.16	4.812	0.012	1.470	23.675	174.00	133.10	34.79	34.23
28	7	4	210.00	205.00	167.25	0.00	-0.16	4.811	0.012	1.469	23.664	173.87	133.04	34.77	34.21
29	7	5	205.00	200.00	167.09	0.00	-0.16	4.809	0.012	1.469	23.653	173.75	132.98	34.74	34.20
30	7	6	200.00	195.00	166.92	0.00	-0.16	4.808	0.012	1.468	23.642	173.63	132.93	34.72	34.18
31	7	7	195.00	190.00	166.76	0.00	-0.16	4.807	0.012	1.468	23.631	173.51	132.87	34.69	34.16
32	7	8	190.00	185.00	166.59	0.00	-0.16	4.805	0.012	1.468	23.620	173.39	132.81	34.67	34.15
33	7	9	185.00	180.00	166.43	0.00	-0.16	4.804	0.012	1.467	23.609	173.27	132.75	34.65	34.13
34	7	10	180.00	175.00	166.27	0.00	-0.16	4.802	0.012	1.467	23.598	173.15	132.69	34.62	34.11
35	7	11	175.00	170.00	166.10	0.00	-0.16	4.801	0.012	1.467	23.587	173.02	132.63	34.60	34.10
36	7	12	170.00	165.00	165.94	0.00	-0.16	4.800	0.012	1.466	23.576	172.90	132.58	34.57	34.08
37	7	13	165.00	160.00	165.77	0.00	-0.16	4.798	0.012	1.466	23.565	172.78	132.52	34.55	34.06
38	7	14	160.00	155.00	165.61	0.00	-0.16	4.797	0.012	1.466	23.554	172.66	132.46	34.52	34.05
39	7	15	155.00	150.00	165.44	0.00	-0.16	4.796	0.012	1.465	23.543	172.54	132.40	34.50	34.03
40	7	16	150.00	145.00	165.28	0.00	-0.16	4.794	0.012	1.465	23.532	172.42	132.34	34.48	34.01
41	7	17	145.00	140.00	165.11	0.00	-0.16	4.793	0.012	1.465	23.521	172.29	132.28	34.45	34.00
42	7	18	140.00	135.00	164.95	0.00	-0.16	4.791	0.012	1.464	23.510	172.17	132.23	34.43	33.98
43	8	1	135.00	130.00	165.39	0.00	0.44	0.700	0.083	1.399	168.936	1181.63	858.86	236.27	0.67
44	8	2	130.00	125.00	165.83	0.00	0.44	0.700	0.083	1.399	169.274	1184.47	860.56	236.84	0.67
45	8	3	125.00	120.00	166.27	0.00	0.44	0.700	0.083	1.400	169.612	1187.31	862.26	237.41	0.67
46	8	4	120.00	115.00	166.72	0.00	0.44	0.701	0.083	1.400	169.950	1190.15	863.95	237.98	0.67
47	8	5	115.00	110.00	167.16	0.00	0.44	0.701	0.083	1.401	170.287	1192.98	865.64	238.54	0.67
48	8	6	110.00	105.00	167.60	0.00	0.44	0.701	0.083	1.401	170.625	1195.82	867.34	239.11	0.67
49	8	7	105.00	100.00	168.04	0.00	0.44	0.701	0.083	1.402	170.962	1198.65	869.03	239.68	0.67
50	8	8	100.00	95.00	168.48	0.00	0.44	0.701	0.083	1.402	171.299	1201.49	870.72	240.24	0.67
51	8	9	95.00	90.00	168.92	0.00	0.44	0.701	0.083	1.403	171.635	1204.32	872.41	240.81	0.67
52	8	10	90.00	85.00	169.37	0.00	0.44	0.702	0.082	1.404	171.972	1207.16	874.10	241.38	0.67
53	8	11	85.00	80.00	169.81	0.00	0.44	0.702	0.082	1.404	172.308	1209.99	875.78	241.94	0.67
54	8	12	80.00	75.00	170.25	0.00	0.44	0.702	0.082	1.405	172.644	1212.82	877.47	242.51	0.68
55	8	13	75.00	70.00	170.69	0.00	0.44	0.702	0.082	1.405	172.980	1215.65	879.15	243.08	0.68
56	8	14	70.00	65.00	171.13	0.00	0.44	0.702	0.082	1.406	173.315	1218.48	880.84	243.64	0.68
57	8	15	65.00	60.00	171.57	0.00	0.44	0.703	0.082	1.406	173.651	1221.31	882.52	244.21	0.68
58	8	16	60.00	55.00	172.02	0.00	0.44	0.703	0.082	1.407	173.986	1224.14	884.20	244.77	0.68
59	8	17	55.00	50.00	172.46	0.00	0.44	0.703	0.082	1.407	174.321	1226.97	885.88	245.34	0.68
60	8	18	50.00	45.00	172.90	0.00	0.44	0.703	0.082	1.408	174.656	1229.80	887.56	245.90	0.68
61	9	1	45.00	40.00	173.88	0.00	0.98	1.072	0.054	1.149	141.169	811.19	717.50	162.20	1.57
62	9	2	40.00	35.00	174.87	0.00	0.98	1.073	0.054	1.150	141.768	815.32	720.50	163.03	1.57
63	9	3	35.00	30.00	175.85	0.00	0.98	1.073	0.054	1.151	142.366	819.45	723.51	163.85	1.57
64	9	4	30.00	25.00	176.84	0.00	0.98	1.074	0.054	1.152	142.963	823.58	726.50	164.68	1.58
65	9	5	25.00	20.00	177.82	0.00	0.98	1.074	0.054	1.153	143.560	827.70	729.50	165.50	1.58
66	9	6	20.00	15.00	178.81	0.00	0.98	1.075	0.054	1.154	144.155	831.83	732.48	166.33	1.58
67	9	7	15.00	10.00	179.79	0.00	0.98	1.076	0.054	1.155	144.750	835.95	735.47	167.15	1.58
68	9	8	10.00	5.00	180.78	0.00	0.98	1.076	0.054	1.156	145.344	840.07	738.45	167.98	1.58
69	9	9	5.00	0.00	181.76	0.00	0.98	1.077	0.054	1.157	145.938	844.18	741.42	168.80	1.59

STEADY STATE SIMULATION
REACTION COEFFICIENT SUMMARY

RCH NUM	ELE NUM	DO SAT MG/L	K2 OPT	OXYGN REAIR 1/DAY	BOD DECAY 1/DAY	BOD SETT 1/DAY	SOD RATE G/M2D	ORGN DECAY 1/DAY	ORGN SETT 1/DAY	NH3 DECAY 1/DAY	NH3 SRCE MG/M2D	NO2 DECAY 1/DAY	ORGP DECAY 1/DAY	ORGP SETT 1/DAY	DISP SRCE MG/M2D	COLI DECAY 1/DAY	ANC DECAY 1/DAY	ANC SETT 1/DAY	ANC SRCE MG/M2D
1	1	6.81	4	18.41	0.48	0.44	7.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.16	0.00	0.00	0.00
1	2	6.86	4	18.14	0.48	0.44	7.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.10	0.00	0.00	0.00
1	3	6.90	4	17.82	0.47	0.43	7.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.04	0.00	0.00	0.00
1	4	6.94	4	17.51	0.46	0.43	7.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.99	0.00	0.00	0.00
2	1	7.95		46135.05	0.32	0.36	4.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.08	0.00	0.00	0.00
2	2	8.14		45951.76	0.30	0.34	4.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.96	0.00	0.00	0.00
2	3	6.79		43858.56	0.49	0.44	7.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.19	0.00	0.00	0.00
3	1	6.99	4	57.45	0.45	0.43	7.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.95	0.00	0.00	0.00
3	2	7.13	4	75.04	0.43	0.41	6.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.78	0.00	0.00	0.00
3	3	7.26	4	73.07	0.41	0.40	6.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.65	0.00	0.00	0.00
3	4	7.36	4	71.43	0.39	0.39	5.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.55	0.00	0.00	0.00
3	5	7.46	4	70.05	0.38	0.39	5.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.46	0.00	0.00	0.00
3	6	7.54	4	68.88	0.37	0.38	5.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.39	0.00	0.00	0.00
3	7	7.60	4	67.89	0.36	0.38	5.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.34	0.00	0.00	0.00
3	8	7.66	4	67.04	0.35	0.37	5.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.29	0.00	0.00	0.00
4	1	7.95		44924.65	0.32	0.36	4.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.08	0.00	0.00	0.00
4	2	6.79		43094.18	0.49	0.44	7.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.19	0.00	0.00	0.00
5	1	7.61	4	32.40	0.36	0.38	5.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.33	0.00	0.00	0.00
5	2	7.62	4	8.84	0.36	0.38	5.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.33	0.00	0.00	0.00
5	3	7.63	4	8.90	0.36	0.38	5.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.32	0.00	0.00	0.00
5	4	7.64	4	8.96	0.35	0.37	5.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.31	0.00	0.00	0.00
5	5	7.65	4	9.03	0.35	0.37	5.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.30	0.00	0.00	0.00
6	1	8.03		49964.45	0.31	0.35	4.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.03	0.00	0.00	0.00
6	2	6.79		46325.74	0.49	0.44	7.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.19	0.00	0.00	0.00
7	1	7.59	4	20.39	0.36	0.38	5.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.35	0.00	0.00	0.00
7	2	7.60	4	9.42	0.36	0.38	5.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.34	0.00	0.00	0.00
7	3	7.61	4	9.41	0.36	0.38	5.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.34	0.00	0.00	0.00
7	4	7.61	4	9.40	0.36	0.38	5.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.33	0.00	0.00	0.00
7	5	7.62	4	9.39	0.36	0.38	5.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.32	0.00	0.00	0.00
7	6	7.63	4	9.38	0.36	0.38	5.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.32	0.00	0.00	0.00
7	7	7.63	4	9.37	0.35	0.38	5.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.31	0.00	0.00	0.00
7	8	7.64	4	9.36	0.35	0.37	5.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.31	0.00	0.00	0.00
7	9	7.65	4	9.36	0.35	0.37	5.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.30	0.00	0.00	0.00
7	10	7.65	4	9.35	0.35	0.37	5.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.30	0.00	0.00	0.00
7	11	7.66	4	9.34	0.35	0.37	5.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.29	0.00	0.00	0.00
7	12	7.67	4	9.33	0.35	0.37	5.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.29	0.00	0.00	0.00
7	13	7.67	4	9.32	0.35	0.37	5.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.28	0.00	0.00	0.00
7	14	7.68	4	9.31	0.35	0.37	5.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.28	0.00	0.00	0.00
7	15	7.68	4	9.31	0.35	0.37	5.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.27	0.00	0.00	0.00
7	16	7.69	4	9.30	0.35	0.37	5.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.27	0.00	0.00	0.00
7	17	7.70	4	9.29	0.35	0.37	5.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.26	0.00	0.00	0.00
7	18	7.70	4	9.28	0.35	0.37	5.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.26	0.00	0.00	0.00
8	1	7.72	4	6.02	0.34	0.37	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.25	0.00	0.00	0.00
8	2	7.76	4	2.76	0.34	0.37	4.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.22	0.00	0.00	0.00
8	3	7.79	4	2.74	0.34	0.37	4.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.20	0.00	0.00	0.00
8	4	7.82	4	2.73	0.33	0.36	4.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.18	0.00	0.00	0.00
8	5	7.84	4	2.71	0.33	0.36	4.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.16	0.00	0.00	0.00
8	6	7.87	4	2.70	0.33	0.36	4.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.14	0.00	0.00	0.00
8	7	7.89	4	2.69	0.33	0.36	4.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.12	0.00	0.00	0.00
8	8	7.91	4	2.68	0.32	0.36	4.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.11	0.00	0.00	0.00
8	9	7.93	4	2.67	0.32	0.36	4.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.10	0.00	0.00	0.00
8	10	7.94	4	2.66	0.32	0.36	4.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.09	0.00	0.00	0.00
8	11	7.96	4	2.65	0.32	0.35	4.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.08	0.00	0.00	0.00
8	12	7.97	4	2.65	0.32	0.35	4.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.07	0.00	0.00	0.00
8	13	7.98	4	2.64	0.32	0.35	4.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.06	0.00	0.00	0.00
8	14	8.00	4	2.63	0.31	0.35	4.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.05	0.00	0.00	0.00
8	15	8.01	4	2.63	0.31	0.35	4.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.04	0.00	0.00	0.00
8	16	8.02	4	2.62	0.31	0.35	4.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.04	0.00	0.00	0.00
8	17	8.02	4	2.62	0.31	0.35	4.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.03	0.00	0.00	0.00
8	18	8.03	4	2.61	0.31	0.35	4.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.03	0.00	0.00	0.00
9	1	8.03	4	3.82	0.31	0.35	4.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.03	0.00	0.00	0.00
9	2	8.04	4	5.04	0.31	0.35	4.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.03	0.00	0.00	0.00
9	3	8.04	4	5.03	0.31	0.35	4.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.02	0.00	0.00	0.00
9	4	8.04	4	5.02	0.31	0.35	4.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.02	0.00	0.00	0.00
9	5	8.04	4	5.02	0.31	0.35	4.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.02	0.00	0.00	0.00
9	6	8.04	4	5.01	0.31	0.35	4.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.02	0.00	0.00	0.00
9	7	8.04	4	5.00	0.31	0.35	4.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.02	0.00	0.00	0.00
9	8	8.04	4	5.00	0.31	0.35	4.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.02	0.00	0.00	0.00
9	9	8.04	4	4.99	0.31	0.35	4.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.02	0.00	0.00	0.00

STEADY STATE SIMULATION
WATER QUALITY VARIABLES

RCH NUM	ELE NUM	TEMP DEG-C	CM-1 TDS MG/L	CM-2	CM-3	DO MG/L	BOD MG/L	ORGN MG/L	NH3N MG/L	NO2N MG/L	NO3N MG/L	SUM-N MG/L	ORGP MG/L	DIS-P MG/L	SUM-P MG/L	COLI #/100ML	ANC	CHLA UG/L
1	1	36.23	82.57	0.00	0.00	5.71	1.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.43	0.00	0.00
1	2	35.80	82.16	0.00	0.00	5.88	1.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.74	0.00	0.00
1	3	35.40	81.75	0.00	0.00	6.01	1.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.93	0.00	0.00
1	4	35.04	81.36	0.00	0.00	6.11	1.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.12	0.00	0.00
2	1	27.09	98.00	0.00	0.00	7.91	1.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	2	25.82	98.00	0.00	0.00	8.10	1.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
2	3	36.43	119.98	0.00	0.00	6.42	228.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3264.39	0.00	0.00
3	1	34.68	84.67	0.00	0.00	6.10	22.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	288.58	0.00	0.00
3	2	33.44	84.42	0.00	0.00	6.53	21.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	263.24	0.00	0.00
3	3	32.40	84.18	0.00	0.00	6.75	20.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	241.24	0.00	0.00
3	4	31.53	83.94	0.00	0.00	6.90	20.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	221.93	0.00	0.00
3	5	30.80	83.70	0.00	0.00	7.02	19.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	204.84	0.00	0.00
3	6	30.18	83.47	0.00	0.00	7.11	18.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	189.59	0.00	0.00
3	7	29.65	83.24	0.00	0.00	7.20	18.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	175.90	0.00	0.00
3	8	29.20	83.02	0.00	0.00	7.27	17.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	163.66	0.00	0.00
4	1	27.15	98.00	0.00	0.00	7.90	1.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00
4	2	36.42	119.98	0.00	0.00	6.41	239.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*******	0.00	0.00
5	1	29.62	85.66	0.00	0.00	7.12	33.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1237.47	0.00	0.00
5	2	29.54	85.66	0.00	0.00	6.89	32.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1193.86	0.00	0.00
5	3	29.47	85.66	0.00	0.00	6.69	32.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1151.56	0.00	0.00
5	4	29.40	85.66	0.00	0.00	6.52	32.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1110.53	0.00	0.00
5	5	29.33	85.66	0.00	0.00	6.37	31.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1070.99	0.00	0.00
6	1	26.59	0.00	0.00	0.00	7.99	1.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
6	2	36.44	142.87	0.00	0.00	6.56	246.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5269.04	0.00	0.00
7	1	29.74	89.39	0.00	0.00	6.35	45.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1315.64	0.00	0.00
7	2	29.69	89.39	0.00	0.00	6.17	45.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1279.64	0.00	0.00
7	3	29.63	89.39	0.00	0.00	6.02	44.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1244.69	0.00	0.00
7	4	29.58	89.39	0.00	0.00	5.89	44.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1210.77	0.00	0.00
7	5	29.53	89.39	0.00	0.00	5.78	43.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1177.83	0.00	0.00
7	6	29.48	89.39	0.00	0.00	5.68	43.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1145.86	0.00	0.00
7	7	29.43	89.39	0.00	0.00	5.59	43.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1114.82	0.00	0.00
7	8	29.38	89.39	0.00	0.00	5.52	42.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1084.67	0.00	0.00
7	9	29.33	89.39	0.00	0.00	5.45	42.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1055.40	0.00	0.00
7	10	29.28	89.39	0.00	0.00	5.40	42.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1026.97	0.00	0.00
7	11	29.24	89.39	0.00	0.00	5.35	41.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	999.36	0.00	0.00
7	12	29.19	89.39	0.00	0.00	5.31	41.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	972.54	0.00	0.00
7	13	29.14	89.39	0.00	0.00	5.28	40.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	946.48	0.00	0.00
7	14	29.10	89.39	0.00	0.00	5.26	40.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	921.17	0.00	0.00
7	15	29.05	89.39	0.00	0.00	5.24	40.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	896.58	0.00	0.00
7	16	29.01	89.39	0.00	0.00	5.22	39.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	872.68	0.00	0.00
7	17	28.96	89.39	0.00	0.00	5.21	39.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	849.46	0.00	0.00
7	18	28.92	89.39	0.00	0.00	5.20	39.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	826.82	0.00	0.00
8	1	28.77	89.15	0.00	0.00	4.83	37.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	745.97	0.00	0.00
8	2	28.52	88.91	0.00	0.00	3.94	35.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	628.99	0.00	0.00
8	3	28.29	88.68	0.00	0.00	3.30	33.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	531.28	0.00	0.00
8	4	28.09	88.44	0.00	0.00	2.86	31.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	449.45	0.00	0.00
8	5	27.90	88.21	0.00	0.00	2.57	29.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	380.78	0.00	0.00
8	6	27.73	87.97	0.00	0.00	2.39	28.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	323.03	0.00	0.00
8	7	27.57	87.74	0.00	0.00	2.31	26.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	274.39	0.00	0.00
8	8	27.43	87.51	0.00	0.00	2.30	25.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	233.33	0.00	0.00
8	9	27.30	87.28	0.00	0.00	2.34	23.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	198.64	0.00	0.00
8	10	27.18	87.06	0.00	0.00	2.42	22.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	169.28	0.00	0.00
8	11	27.07	86.83	0.00	0.00	2.53	21.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	144.40	0.00	0.00
8	12	26.98	86.60	0.00	0.00	2.66	20.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	123.29	0.00	0.00
8	13	26.89	86.38	0.00	0.00	2.80	18.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	105.37	0.00	0.00
8	14	26.81	86.16	0.00	0.00	2.95	17.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	90.14	0.00	0.00
8	15	26.74	85.94	0.00	0.00	3.11	16.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	77.18	0.00	0.00
8	16	26.67	85.72	0.00	0.00	3.27	16.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	66.15	0.00	0.00
8	17	26.61	85.50	0.00	0.00	3.43	15.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	56.75	0.00	0.00
8	18	26.55	85.28	0.00	0.00	3.59	14.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	48.74	0.00	0.00
9	1	26.54	84.79	0.00	0.00	4.01	13.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	43.10	0.00	0.00
9	2	26.53	84.32	0.00	0.00	4.46	13.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	39.15	0.00	0.00
9	3	26.52	83.85	0.00	0.00	4.82	12.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	35.61	0.00	0.00
9	4	26.52	83.38	0.00	0.00	5.11	12.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	32.44	0.00	0.00
9	5	26.51	82.92	0.00	0.00	5.34	11.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	29.60	0.00	0.00
9	6	26.51	82.46	0.00	0.00	5.54	11.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	27.04	0.00	0.00
9	7	26.50	82.01	0.00	0.00	5.69	10.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.76	0.00	0.00
9	8	26.49	81.56	0.00	0.00	5.83	10.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.70	0.00	0.00
9	9	26.49	81.12	0.00	0.00	5.94	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.86	0.00	0.00

STEADY STATE SIMULATION
DISSOLVED OXYGEN DATA (MG/L-DAY)

ELE ORD	RCH NUM	ELE NUM	TEMP DEG-C	DO SAT MG/L	DO MG/L	DO DEF MG/L	DAM INPUT MG/L	NIT INHIB FACT	F-FNCTN INPUT	OXYGN REAIR	C-BOD	SOD	NET P-R	NH3-N	NO2-N
1	1	1	36.23	6.81	5.71	1.10	0.00	0.00	254.70	20.21	-0.95	-8.59	0.00	0.00	0.00
2	1	2	35.80	6.86	5.88	0.98	0.00	0.00	3.88	17.81	-0.91	-8.30	0.00	0.00	0.00
3	1	3	35.40	6.90	6.01	0.90	0.00	0.00	3.86	15.99	-0.88	-8.05	0.00	0.00	0.00
4	1	4	35.04	6.94	6.11	0.84	0.00	0.00	3.84	14.64	-0.86	-7.81	0.00	0.00	0.00
5	2	1	27.09	7.95	7.91	0.04	0.00	0.00	62.47	258.65	-0.60	-217.80	0.00	0.00	0.00
6	2	2	25.82	8.14	8.10	0.04	0.00	0.00	0.00	216.79	-0.54	-202.16	0.00	0.00	0.00
7	2	3	36.43	6.79	6.42	0.37	0.00	0.00	102.09	1439.06	-111.78	-11.88	0.00	0.00	0.00
8	3	1	34.68	6.99	6.10	0.89	0.00	0.00	1.41	50.86	-10.03	-20.21	0.00	0.00	0.00
9	3	2	33.44	7.13	6.53	0.61	0.00	0.00	1.41	45.46	-9.15	-18.73	0.00	0.00	0.00
10	3	3	32.40	7.26	6.75	0.51	0.00	0.00	1.41	37.15	-8.44	-17.58	0.00	0.00	0.00
11	3	4	31.53	7.36	6.90	0.47	0.00	0.00	1.40	33.23	-7.85	-16.65	0.00	0.00	0.00
12	3	5	30.80	7.46	7.02	0.44	0.00	0.00	1.40	30.81	-7.35	-15.91	0.00	0.00	0.00
13	3	6	30.18	7.54	7.11	0.42	0.00	0.00	1.40	29.00	-6.93	-15.29	0.00	0.00	0.00
14	3	7	29.65	7.60	7.20	0.41	0.00	0.00	1.39	27.53	-6.56	-14.78	0.00	0.00	0.00
15	3	8	29.20	7.66	7.27	0.39	0.00	0.00	1.39	26.31	-6.24	-14.36	0.00	0.00	0.00
16	4	1	27.15	7.95	7.90	0.05	0.00	0.00	59.21	237.61	-0.60	-197.71	0.00	0.00	0.00
17	4	2	36.42	6.79	6.41	0.38	0.00	0.00	176.21	1173.57	-117.36	-11.35	0.00	0.00	0.00
18	5	1	29.62	7.61	7.12	0.49	0.00	0.00	-5.38	15.81	-11.91	-3.81	0.00	0.00	0.00
19	5	2	29.54	7.62	6.89	0.73	0.00	0.00	-5.22	6.46	-11.73	-3.82	0.00	0.00	0.00
20	5	3	29.47	7.63	6.69	0.94	0.00	0.00	-5.09	8.38	-11.56	-3.83	0.00	0.00	0.00
21	5	4	29.40	7.64	6.52	1.12	0.00	0.00	-4.97	10.07	-11.39	-3.85	0.00	0.00	0.00
22	5	5	29.33	7.65	6.37	1.28	0.00	0.00	-4.87	11.54	-11.22	-3.86	0.00	0.00	0.00
23	6	1	26.59	8.03	7.99	0.03	0.00	0.00	52.69	326.47	-0.58	-294.23	0.00	0.00	0.00
24	6	2	36.44	6.79	6.56	0.23	0.00	0.00	154.40	1447.96	-120.63	-11.95	0.00	0.00	0.00
25	7	1	29.74	7.59	6.35	1.25	0.00	0.00	-0.52	25.41	-16.36	-3.60	0.00	0.00	0.00
26	7	2	29.69	7.60	6.17	1.43	0.00	0.00	-0.50	13.42	-16.17	-3.59	0.00	0.00	0.00
27	7	3	29.63	7.61	6.02	1.58	0.00	0.00	-0.49	14.89	-15.99	-3.58	0.00	0.00	0.00
28	7	4	29.58	7.61	5.89	1.72	0.00	0.00	-0.48	16.18	-15.81	-3.57	0.00	0.00	0.00
29	7	5	29.53	7.62	5.78	1.84	0.00	0.00	-0.47	17.31	-15.64	-3.56	0.00	0.00	0.00
30	7	6	29.48	7.63	5.68	1.95	0.00	0.00	-0.46	18.30	-15.47	-3.55	0.00	0.00	0.00
31	7	7	29.43	7.63	5.59	2.04	0.00	0.00	-0.46	19.16	-15.30	-3.54	0.00	0.00	0.00
32	7	8	29.38	7.64	5.52	2.13	0.00	0.00	-0.45	19.90	-15.13	-3.53	0.00	0.00	0.00
33	7	9	29.33	7.65	5.45	2.20	0.00	0.00	-0.45	20.54	-14.96	-3.52	0.00	0.00	0.00
34	7	10	29.28	7.65	5.40	2.26	0.00	0.00	-0.44	21.09	-14.80	-3.51	0.00	0.00	0.00
35	7	11	29.24	7.66	5.35	2.31	0.00	0.00	-0.44	21.56	-14.64	-3.51	0.00	0.00	0.00
36	7	12	29.19	7.67	5.31	2.35	0.00	0.00	-0.44	21.96	-14.48	-3.50	0.00	0.00	0.00
37	7	13	29.14	7.67	5.28	2.39	0.00	0.00	-0.43	22.28	-14.33	-3.49	0.00	0.00	0.00
38	7	14	29.10	7.68	5.26	2.42	0.00	0.00	-0.43	22.56	-14.17	-3.48	0.00	0.00	0.00
39	7	15	29.05	7.68	5.24	2.45	0.00	0.00	-0.43	22.78	-14.02	-3.47	0.00	0.00	0.00
40	7	16	29.01	7.69	5.22	2.47	0.00	0.00	-0.43	22.96	-13.87	-3.46	0.00	0.00	0.00
41	7	17	28.96	7.70	5.21	2.49	0.00	0.00	-0.43	23.10	-13.73	-3.45	0.00	0.00	0.00
42	7	18	28.92	7.70	5.20	2.50	0.00	0.00	-0.43	23.20	-13.58	-3.45	0.00	0.00	0.00
43	8	1	28.77	7.72	4.83	2.89	0.00	0.00	0.18	17.41	-13.02	-3.58	0.00	0.00	0.00
44	8	2	28.52	7.76	3.94	3.82	0.00	0.00	0.18	10.54	-12.13	-3.52	0.00	0.00	0.00
45	8	3	28.29	7.79	3.30	4.49	0.00	0.00	0.18	12.31	-11.32	-3.48	0.00	0.00	0.00
46	8	4	28.09	7.82	2.86	4.96	0.00	0.00	0.18	13.53	-10.57	-3.43	0.00	0.00	0.00
47	8	5	27.90	7.84	2.57	5.28	0.00	0.00	0.18	14.32	-9.89	-3.39	0.00	0.00	0.00
48	8	6	27.73	7.87	2.39	5.47	0.00	0.00	0.18	14.79	-9.26	-3.36	0.00	0.00	0.00
49	8	7	27.57	7.89	2.31	5.58	0.00	0.00	0.18	15.00	-8.68	-3.33	0.00	0.00	0.00
50	8	8	27.43	7.91	2.30	5.61	0.00	0.00	0.17	15.03	-8.15	-3.30	0.00	0.00	0.00
51	8	9	27.30	7.93	2.34	5.59	0.00	0.00	0.17	14.92	-7.65	-3.27	0.00	0.00	0.00
52	8	10	27.18	7.94	2.42	5.52	0.00	0.00	0.17	14.70	-7.19	-3.25	0.00	0.00	0.00
53	8	11	27.07	7.96	2.53	5.43	0.00	0.00	0.17	14.41	-6.76	-3.23	0.00	0.00	0.00
54	8	12	26.98	7.97	2.66	5.31	0.00	0.00	0.17	14.06	-6.37	-3.21	0.00	0.00	0.00
55	8	13	26.89	7.98	2.80	5.18	0.00	0.00	0.17	13.68	-6.00	-3.19	0.00	0.00	0.00
56	8	14	26.81	8.00	2.95	5.04	0.00	0.00	0.17	13.27	-5.65	-3.17	0.00	0.00	0.00
57	8	15	26.74	8.01	3.11	4.90	0.00	0.00	0.17	12.85	-5.33	-3.16	0.00	0.00	0.00
58	8	16	26.67	8.02	3.27	4.74	0.00	0.00	0.17	12.43	-5.02	-3.15	0.00	0.00	0.00
59	8	17	26.61	8.02	3.43	4.59	0.00	0.00	0.17	12.01	-4.74	-3.13	0.00	0.00	0.00
60	8	18	26.55	8.03	3.59	4.44	0.00	0.00	0.17	11.59	-4.47	-3.12	0.00	0.00	0.00
61	9	1	26.54	8.03	4.01	4.02	0.00	0.00	0.58	15.38	-4.26	-3.82	0.00	0.00	0.00
62	9	2	26.53	8.04	4.46	3.58	0.00	0.00	0.57	18.01	-4.09	-3.82	0.00	0.00	0.00
63	9	3	26.52	8.04	4.82	3.22	0.00	0.00	0.57	16.19	-3.93	-3.81	0.00	0.00	0.00
64	9	4	26.52	8.04	5.11	2.93	0.00	0.00	0.57	14.72	-3.78	-3.81	0.00	0.00	0.00
65	9	5	26.51	8.04	5.34	2.70	0.00	0.00	0.57	13.52	-3.63	-3.80	0.00	0.00	0.00
66	9	6	26.51	8.04	5.54	2.50	0.00	0.00	0.56	12.55	-3.49	-3.80	0.00	0.00	0.00
67	9	7	26.50	8.04	5.69	2.35	0.00	0.00	0.56	11.74	-3.35	-3.80	0.00	0.00	0.00
68	9	8	26.49	8.04	5.83	2.21	0.00	0.00	0.56	11.07	-3.22	-3.79	0.00	0.00	0.00
69	9	9	26.49	8.04	5.94	2.10	0.00	0.00	0.55	10.50	-3.10	-3.79	0.00	0.00	0.00

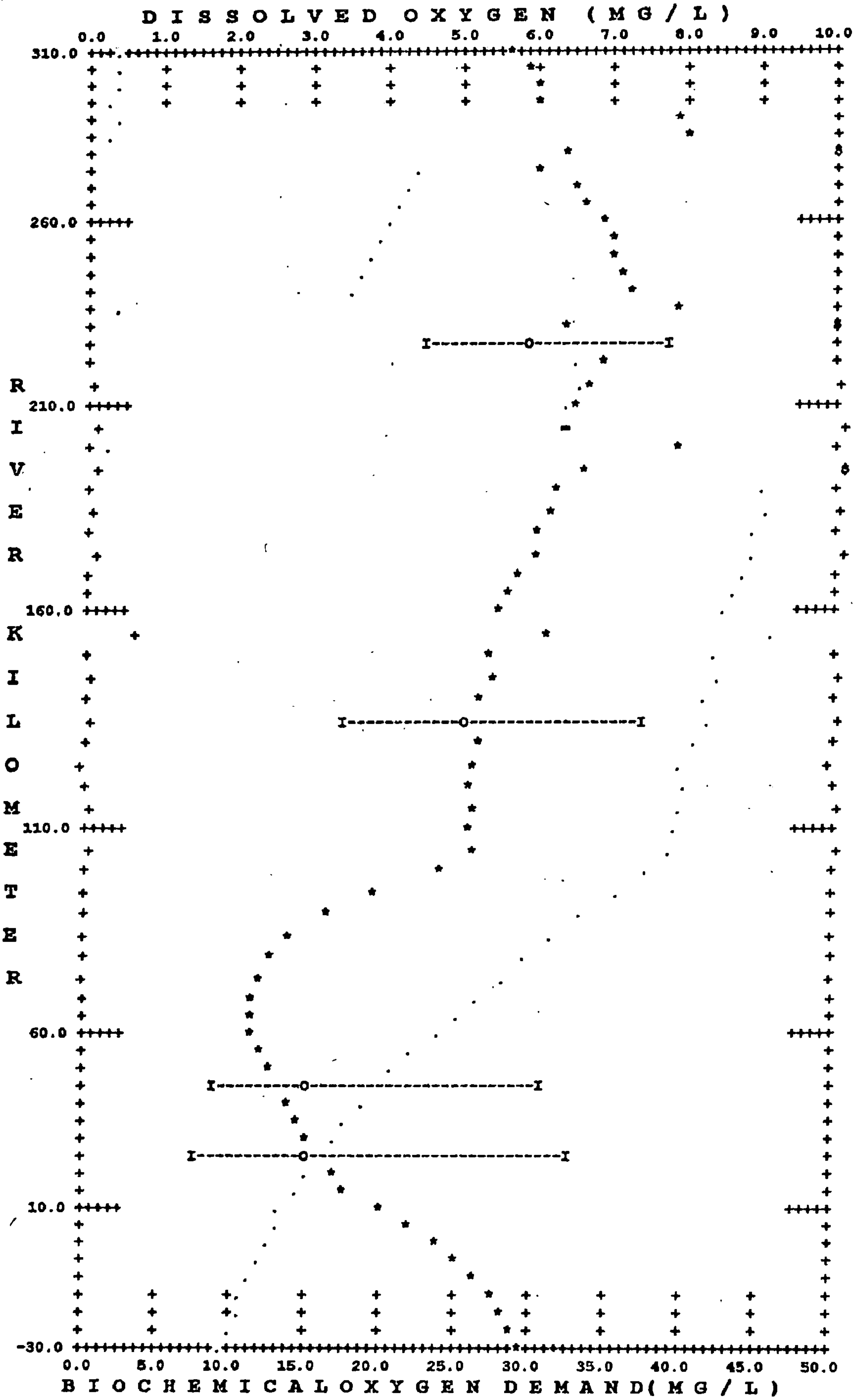
DISSOLVED OXYGEN (MG/L)
0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0
310.0 260.0 210.0 160.0 110.0 60.0 10.0 -30.0
RIVER KILOMETER
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0
BIOCHEMICALOXYGEN DEMAND(MG/L)

Fig. No.A1

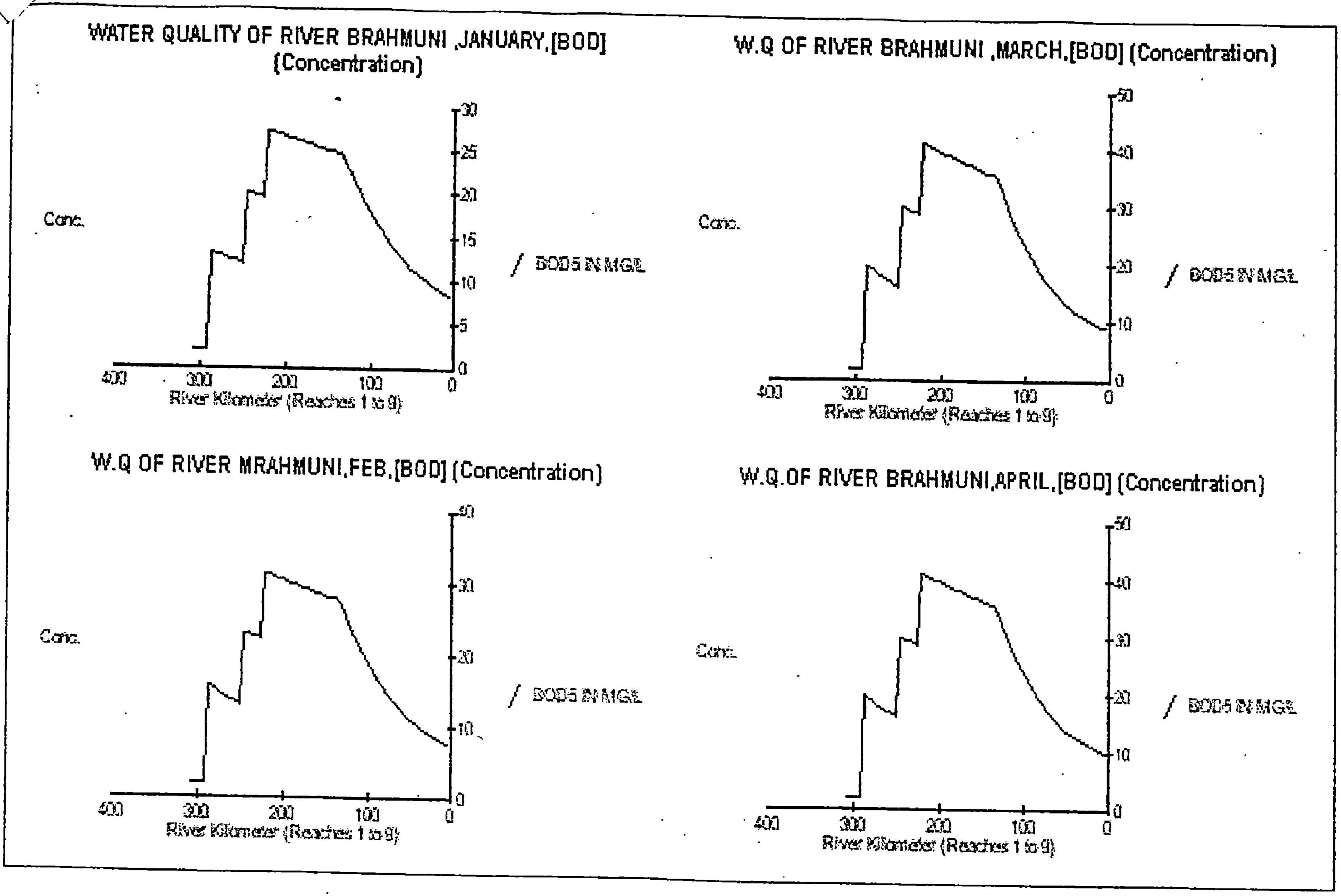
WATER QUALITY OF RIVER BRAHMUNI ,JANUARY,[BOD] (Concentration)
Conc.
BOD5 IN MG/L
River Kilometer (Reaches 1 to 9)
W.Q OF RIVER BRAHMUNI ,MARCH,[BOD] (Concentration)
Conc.
BOD5 IN MG/L
River Kilometer (Reaches 1 to 9)
W.Q OF RIVER MRAHMUNI,FEB,[BOD] (Concentration)
Conc.
BOD5 IN MG/L
River Kilometer (Reaches 1 to 9)
W.Q.OF RIVER BRAHMUNI,APRIL,[BOD] (Concentration)
Conc.
BOD5 IN MG/L
River Kilometer (Reaches 1 to 9)

Fig. No.A2