CS-17

DISSOLVED OXYGEN MODELLING IN RIVERS

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concentration in the stream system against a prespecified target level dissolved oxygen concentration. If the minimum D.O. level is found to be below the target D.O. level, the program has the capability to compute the required amount of flow augmentation to bring the D.O. level to required level in the system. The computer program has been based on DOSAG-1 model of Texas Deptt. of Water Resources, U.S.A. The computer program has been tested with actual data of a river stretch.

The DOSAG-I model was fed into the VAX-11/780 computer of the Institute and the computer program was implemented and tested with test data. The model was successfully run on Hindon river (U.P.) data. The dissolved oxygen profile was compared with actual data and the hand calculated data, the results are quite good. The report gives all the details of the model, computer listing, input and output. The report will be very useful for taking up any river stretch and running DOSAG model. The basic theory, usage of the model etc. are also given.

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1.0 INTRODUCTION

Rivers are one of our most important natural resources. Rivers provide the water necessary to support the processes of life and, in addition provide water necessary for industry, a means of transportation, a source of food, and numerous other benefits, the value of which cannot be readily measured. Because of the significance of water the habitat prefer to be close to water sources. As a consequence to that it becomes natural that the water taken from streams and rivers be returned to the original source , since this is the most economical and feasible way to dispose of waste water.

Streams will continue to be carriers of waste water. Those who deal in water management will have to make critical decisions concerning the treatment necessary before discharge into streams or whether the discharge can be made at all. The management of water quality in a stream is usually based on the maintenance of adequate dissolved oxygen (DO) levels along its length. The concentration of DO along the length of a stream is dependent on a number of environmental factors, the most important being organic waste types and quantity, stream flow, oxygen deficit, stream temperature, dilution due to groundwater and tributary inflow, and the photosynthetic production of oxygen and respiration of aquatic plant life and algae.

Polluted streams are usually characterised by a decline followed by a recovery in the dissolved oxygen level along the length of the stream. The initial decrease in level occurs due to greater rate of oxygen removal by biological oxidation than that which can be supplied by reaeration. The rate of biological oxidation is directly proportional to the quantity of organic material present and consequently decreases with time. The minimum deficit will be that point at which the rate of supply of oxygen by reaeration equals the rate of consumption by biological oxidation. Thereafter the reaeration process dominates and the dissolved oxygen defict is gradually reduced (Bhatia, 1984).

A prime consideration in stream assimilative capacity is dissolved oxygen. A positive dissolved oxygen content must be maintained to prevent putrefaction, however if streams are to support fish, DO must be maintained at not less than 4 to 5mg/l or higher. The Indian Standards specify a DO level of 6.0 mg/l for drinking water (CBPCWP, 1980). In the process of assimilation, oxygen is consumed by the respiration of plants and plankton. Oxygen is provided to the stream by diffusion from the atmosphere and photosynthesis. These elements of oxygen production and oxygen consumption are inter-related. Delicate balances are maintained. Mathematical relationships are maintained.

1.1 Physical System

The dissolved oxygen balance between oxygen supply and deoxygenation in a stream is often expressed in the form of a plot of dissolved oxygen level as a function of streamflow time or distance downstream from the source of pollution. This curve commonly termed as 'Oxygen Sag Curve' may be derived either from field measurements or from a mathematical model and represents the dissolved oxygen distribution along the length of stream for a given set of environmental conditions (Streeter and Phelps, 1925).

Generally the most important factor causing oxygen depletion is that associated with the oxidation of carbonaceous material. However, in some streams the circumstances may be such that nitrification of wastes or the respiration of benthal or aquatic plants may be highly significant. The carbonaceous oxidation process is a manifestation of the respiratory functioning of the micro-organisms. To maintain life and growth micro-organisms consume organic material and dissolved oxygen and respire carbon dioxide in the process. The oxidation of the organic material proceeds in an overlapping stepwise function, the end products of one reaction providing the fresh material for the next reaction.

Nitrification represents a series of associated reactions in which ammonia and simple animal compounds are oxidised to nitrate and to nitrite. Unlike the carbonaceous reaction which is dominated by rather persistent group of heterotrophic organisms, oxidation of the nitrogeneous material is carried out by specialised groups of organisms which are much more sensitive to environmental considerations (Tuck, 1980).

In addition to the removal of orgoanic wastes by biological oxidation some solid wastes may be removed from a stream by sedimentation. Bottom deposits form in three general ways (Velz, 1958) i.e. by deposition of heavy solids, deposition resulting from flocculation and coagulations and thirdly by growth attached to bottoms. The respiration of aquatic plantsand algae can represent a critical factor in establishing the minimum dissolved oxygen deficit of a stream.

The oxygen is supplied to the system by absorption from the atmosphere at the stream surface and when plants are present by photosynthetic activity. If for any reason the oxygen content of a stream falls below saturation more oxygen will be absorbed at the surface than is further oxygen depletion is absent (O'Connor, 1967). The oxygen balance of a natural stream may be influenced by the metabolic activities of chlorophyll bearing algae, phytoplankton and aquatic plants. These use energy provided by solar radiation to synthesize carbohydrates to carbon dioxide, water nutrients and trace material and release oxygen as a byproduct to the surrounding water.

1.2 Scope of Present Study

In the present study, the DOSAG-I model given by Texas Department of Water Resources (earlier known as Texas Water Development Board), USA was used to study the dissolved oxygen variations in a river (Hindon) in Uttar Pradesh. The river is being heavily polluted by the various industrial units around it. The river was choosen because the data for two months of sampling and DO analysis by hand calculations were already available (Patel, 1985). The DOSAG-I, a fairly large computer program of around 1500 statements was fed to the VAX-II / 780 computing system of N I H and was implemented. The test runs were taken and Do sag curves for two situations were computed. The curves have been compared with observed and hand calculated curve (Patel, 1985) and conclusions have been drawn. The study would be highly useful for future works in DO sag curve computations as the computer program (Appendix-II) has been tested, used and is readily available.

2.0 REVIEW

For understanding the nature of river and stream system dissolved oxygen responses to organic waste loads, important relationships are discussed here. An appreciation of the nature and significance of the factors discussed would help to develop a recognition of the significance of certain aspects of the analysis and assist in understanding and evaluating the technical output of a mathematical model analysis.

2.1 Transport

When a waste load is discharged into a flowing stream or river, it is subjected to three characteristic factors that tend to modify the concentrations resulting from the initial dilution. The factors that determine the concentration at any particular time or location are:

Advection - This represents the downstream transport of a discrete element of the waste load by the stream flow.

Reaction - The biodegradable materials in the waste (BOD) undergo decay under the action of naturally occurring bacteria in the stream. In the presence of dissolved oxygen, bacteria convert the BOD to oxidized end products (e.g., CO_2, NO_3, and H_2O), the result being that the mass of organic matter (BOD) in a discrete element of the waste load gradually diminishes.

Dispersion - Under the influence of turbulence, eddy currents, and similar mixing forces, a discrete element of the waste load tends not to remain intact, but to mix with adjacent upstream and down-stream elements. Dispersion is a predominant factor in tidal waters. In rivers and streams its influence is usually relatively small compared with advection and reaction, however, it can be important in some circumstances. For example, when a slug load results from a spill or accidential dump, dispersion effects can have an important influence on resulting peak concentrations, particularly at longer distances from the point of discharge. Intermittent discharges, such as storm runoff, are also influenced by dispersion. However, for continuous discharges (e.g. from waste-water treatment plants) and steady-state conditions, dispersion effects are usually insignificant, for reasons discussed later in the section.

These factors are shown schematically in Figure 1 to illustrate the behaviour of a waste load discharged into a stream. A discrete element of the waste load is shown as it transported downstream. The picture presented is what would be observed if a single slug of waste load were injected and could be followed downstream over a period of time. Conservative constituents in the waste (those not subject to reaction and decay, such as chloride) would track as shown in the sketch for advection only, or advection and dispersion. Reactive constituents, such as BOD, would behave as shown in the sketches that include reaction.

While the Figure 1 represent the behavior of a discrete pulse of waste load, they can be extended to provide a representation of steady-state conditions. Waste load allocations are often performed to examine impacts under a steady-state condition.

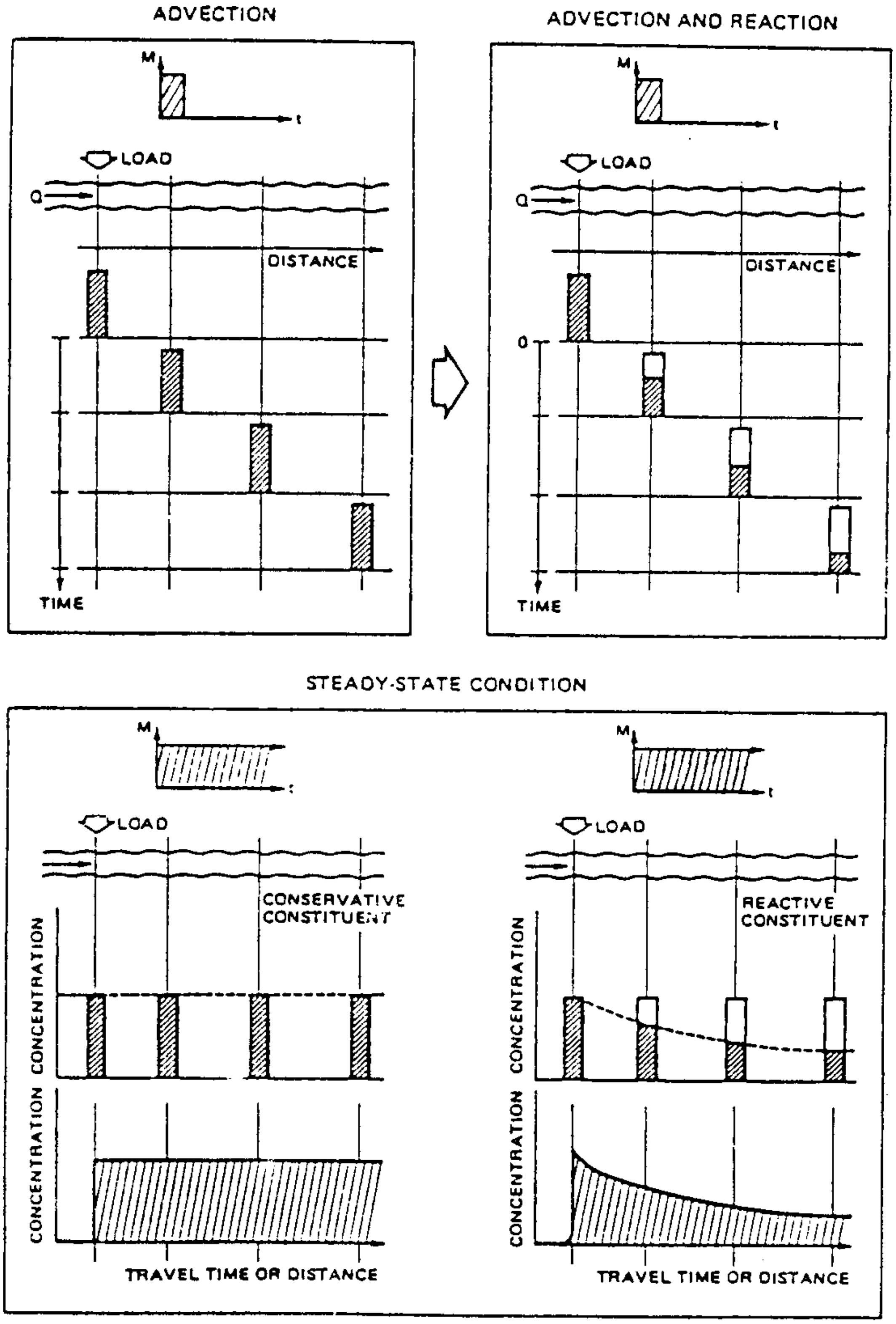

Figure 1 Steady-state responses.

An extended period of some critical low flow and associated maximum temperature is often selected to represent the design condition. Such conditions normally provide a close enough appropriate. For this illustration under steady-state conditions, stream flow and environmental factors affecting reaction rate are constant, and the waste load discharges continuously at a constant loading rate. The load pulses shown in Figure 1 as different conditions of a single pulse in space and time can also be considered to represent the condition of separate elements of the continuous load being discharged. Under a true steady-state condition, each pulse will behave exactly the same as preceding and following ones. Thus they can be taken (as shown in Figure 2) to represent individual points on a continuous profile. Typical concentration profiles are shown for a conservative substance and for a reactive substance such as BOD.

Dispersion has been ignored in these plots. To illustrate why under steady-state conditions, and for conservative constituents it is valid to ignore it in single calculations or why it will not affect results when a computer model which includes dispersion is used, consider Figure 3. This presents a set of calculated profiles for a conservative substance (Reaction = 0) under an assumed set of conditions (loading, advection and dispersion). As described earlier, they can represent the concentration profile in the hypothetical stream selected, at successive intervals of 0.1, 0.2, 0.3.... days after a load was introduced as a single pulse.

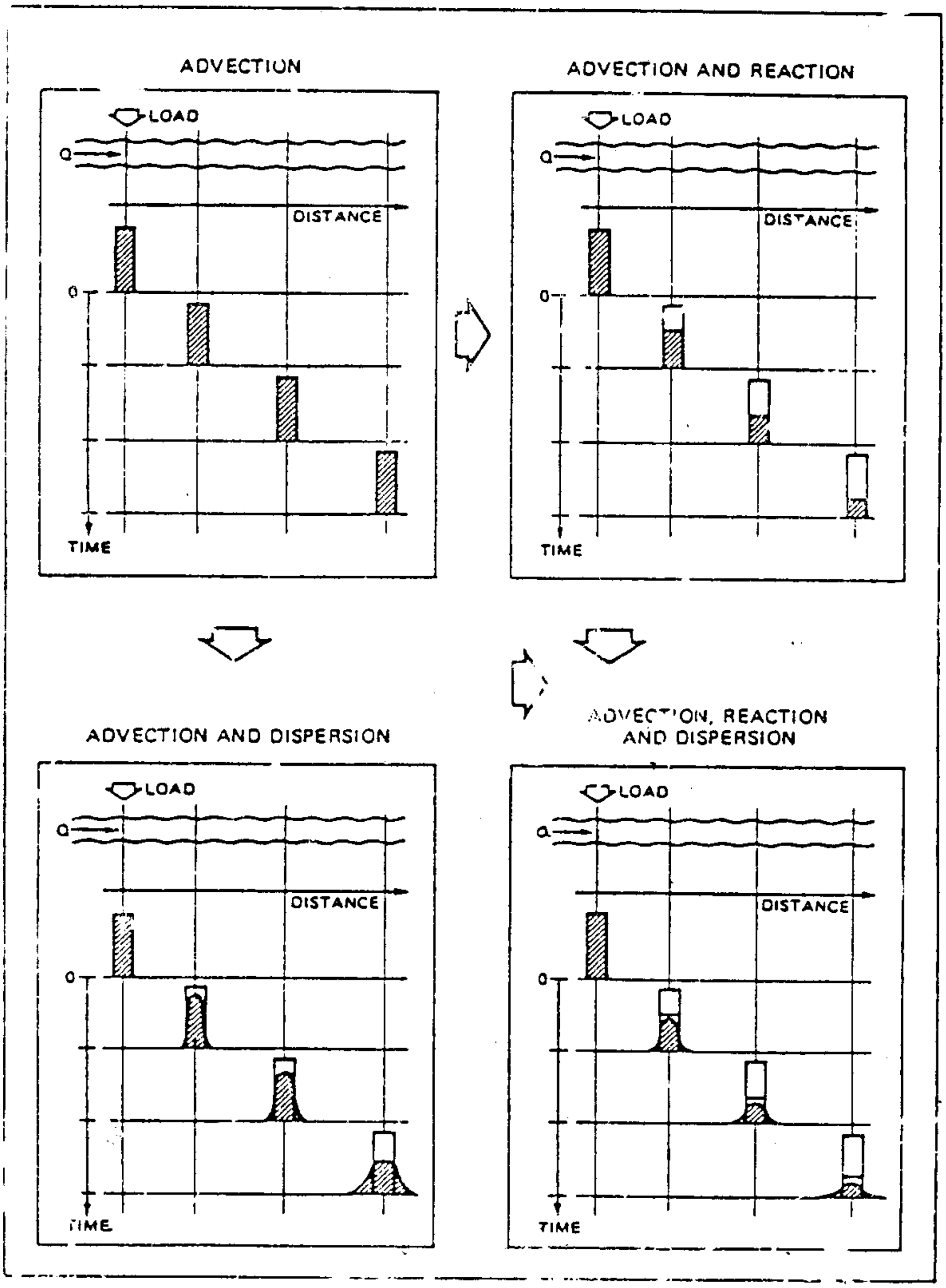

Figure 2 : Transport mechanisms for waste loads.

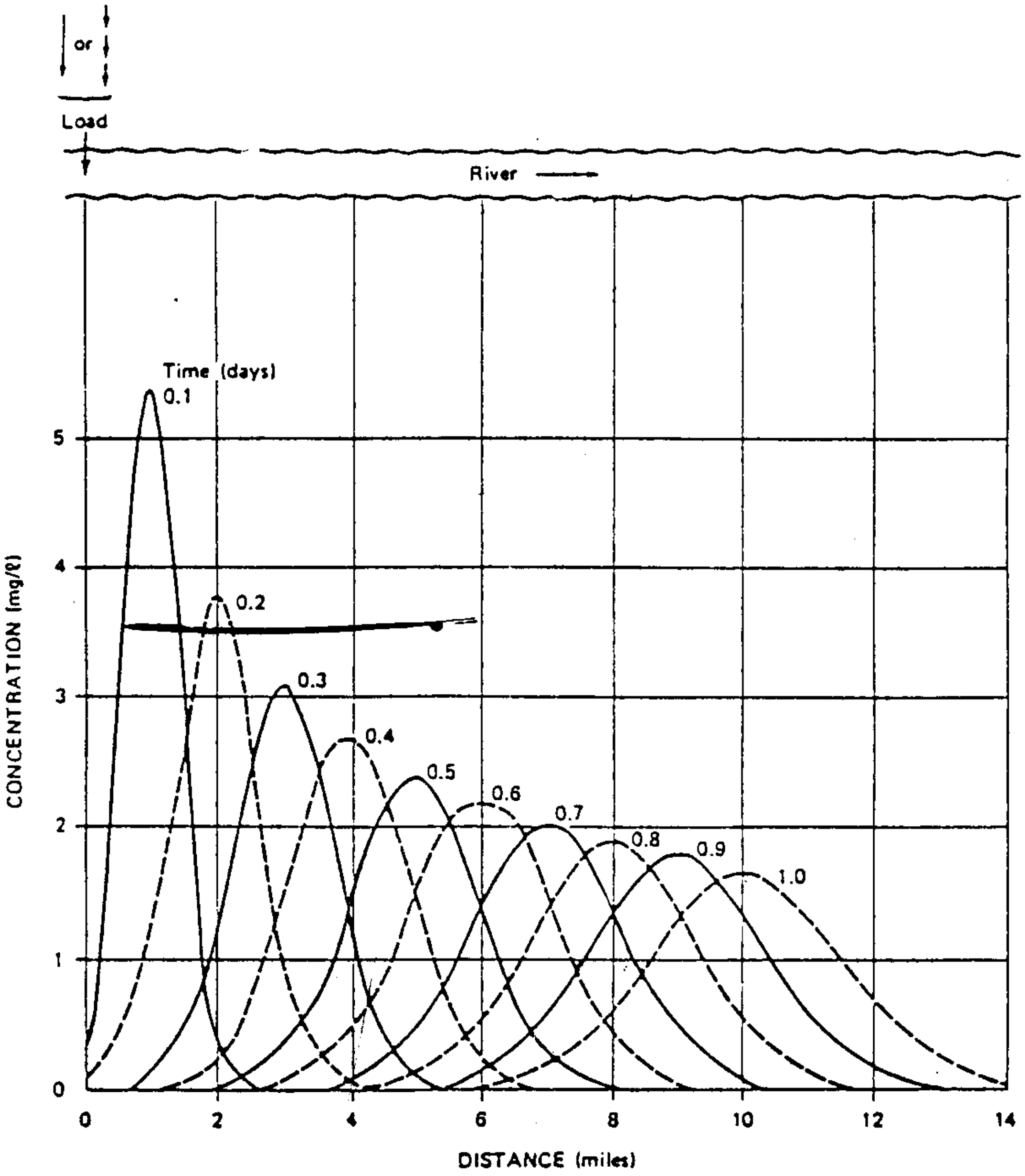

Figure 3 – Stream dispersion effects.

It also represents the group of concentration profiles that would exist in the stream reach shown at any time if the load were introduced in a sequence of pulses spaced 0.1 day apart. At any point along the stream length, the total concentration at that point is made up of components of a number of pulses. By graphically adding up the appropriate individual pulse component it will be seen that total concentration will be approximately the same at each point in the stream. As pulses are spaced closer together approaching a continuous discharge, the approximation of total concentration at all points will approach the single value represented by W/Q (i.e. mass discharge rate/stream flow rate), shown as steady state profile for a conservative constituent in Fig. 2.

2.2 BOD Reactions

BOD (biochemical oxygen demand) is a measure of biodegradable material in terms of the oxygen utilized in stabilizing it. Both carbonaceous organic compounds (CBOD) and nitrogenous forms (NBOD), principally ammonia and organic nitrogen, are subject to bio-oxidation. For convenience, the oxygen equivalent of biodegradation over a 5-day period usually measured (BOD_5) rather than the full oxygen equivalency (Ultimate BOD, ULT, BOD, DOB_u), which commonly requires in excess of twenty or thirty days for completion. In some cases, such as with pulp and paper mill effluents, the BOD_u test can require over one hundred days. The rate at which biodegradable material (CBOD or NBOD) is removed in a stream may be determined from an analysis of river BOD_5 or BOD_u, since both are suitable indicators of biodegradable material present. The analysis of BOD (whether ultimate or 5-day) referred to in this manual utilized a nitrification-inhibdited test, unless stated otherwise, thus ratios of ultimate oxygen demand to 5-day oxygen demand are for carbonaceous demands only. Table 3-20 gives a range of values appropriate for the $CBOD_u/CBOD_5$ ratio .

The actual shape of the BOD profile would be a result of the rate of removal in a particular stream system, although this removal rate may actually represent a composite of several effluent decay rates. BOD exertion, like many biological reactions, is considered to follow "First-order" kinetics that is, the rate of removal at any specific time is proportional to the amount remaining.

$$\text{fraction remaining} = e^{-kt}$$

The time (t) is generally expressed in days, the reaction rate coefficient (k) in terms of 'per day'.

A stream's ability to exhibit self-purification is related to the ability of naturally occuring bacteria to decompose the organic waste materials, utilizing the oxygen resources of the

the stream, coupled with ability of stream to replenish these resources by natural reaeration processes. Transfer of atmospheric oxygen to the water column occurs through diffusion and turbulence of critical importance to the protection of water quality, one aspect which is usually defined in terms of a minimum acceptable concentration for dissolved oxygen is the rate at which reaeration takes place and the magnitude of this rate in relation to the rate of oxygen consumption.

Most analytical methods are based on the concept of oxygen deficit (D), defined as the difference in concentration between the saturation value (C_S) and the actual DO concentration (C).

Like BOD, reaeration is considered to follow 'first-order' kinetics, such that the rate of reaeration at any time is proportionl to the dissolved oxygen deficit at that time. An equation of fraction of the initial deficit remaining versus time would have the same form as that presented previously for BOD decay, except that the reaction rate coefficient would be the reaeration rate.

2.3 Dissolved Oxygen Profile

In natural waters, the oxygen consumed by becteria in oxidizing the biodegradable organic matter in a wastewater discharge (BOD) is taken from the dissolved oxygen originally present in the water and from the additional amounts transfered into the water by atmospheric reaeration. This is illustrated graphically in Figure 4. A general DO profile is shown in Figure 5.

The top figure is a calculated BOD profile in a river with a BOD removal rate of 0.5 per day. At time t = 0, there is in this example, a concentration of 10 mg/l present, and after about 10 days all of the biochemical oxygen demand (BOD) has been exerted. Since the BOD test measures the amount of organic matter present directly in terms of the amount of oxygen required for its stabili-

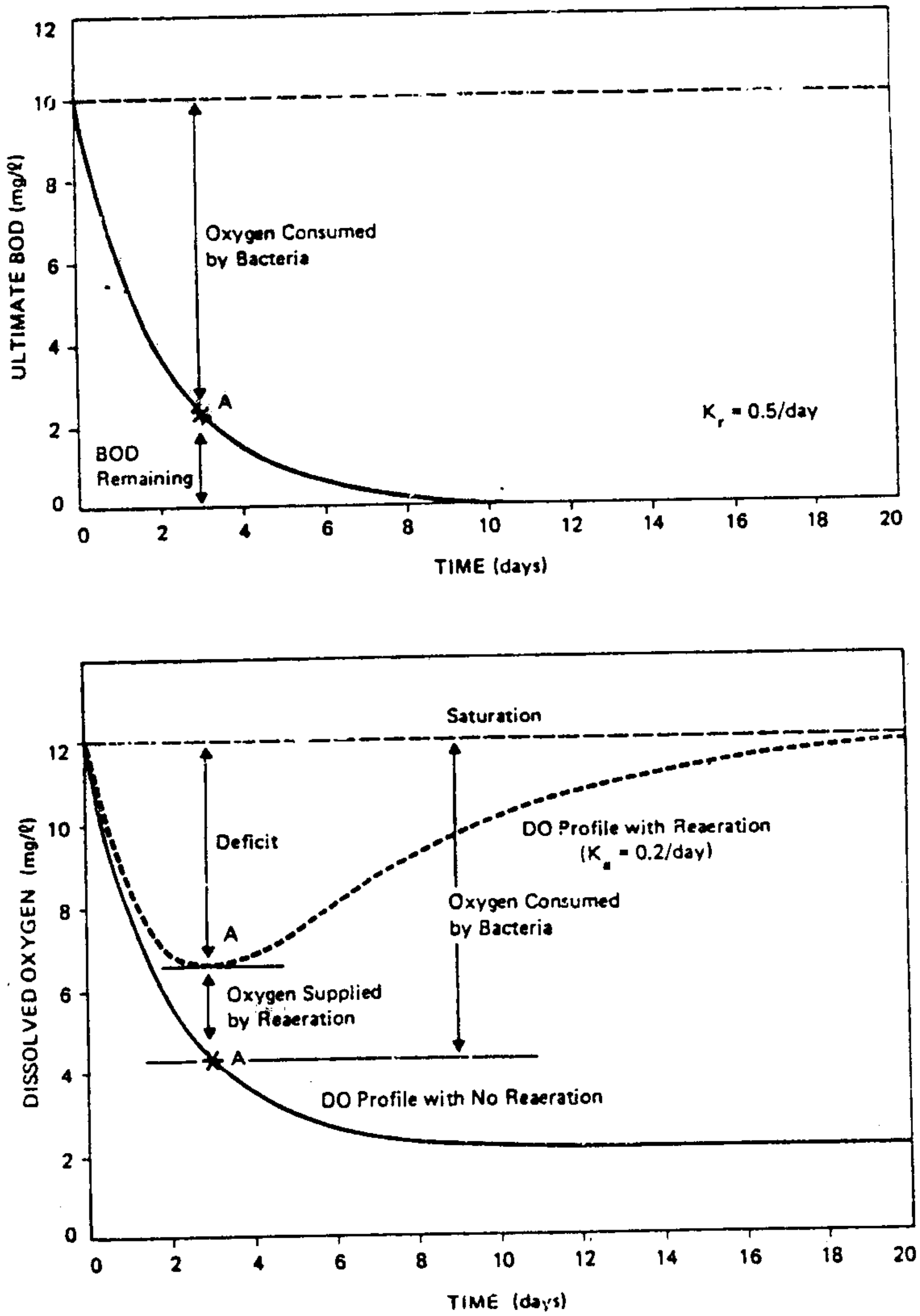

Figure 4 — Stream reaeration relationships.

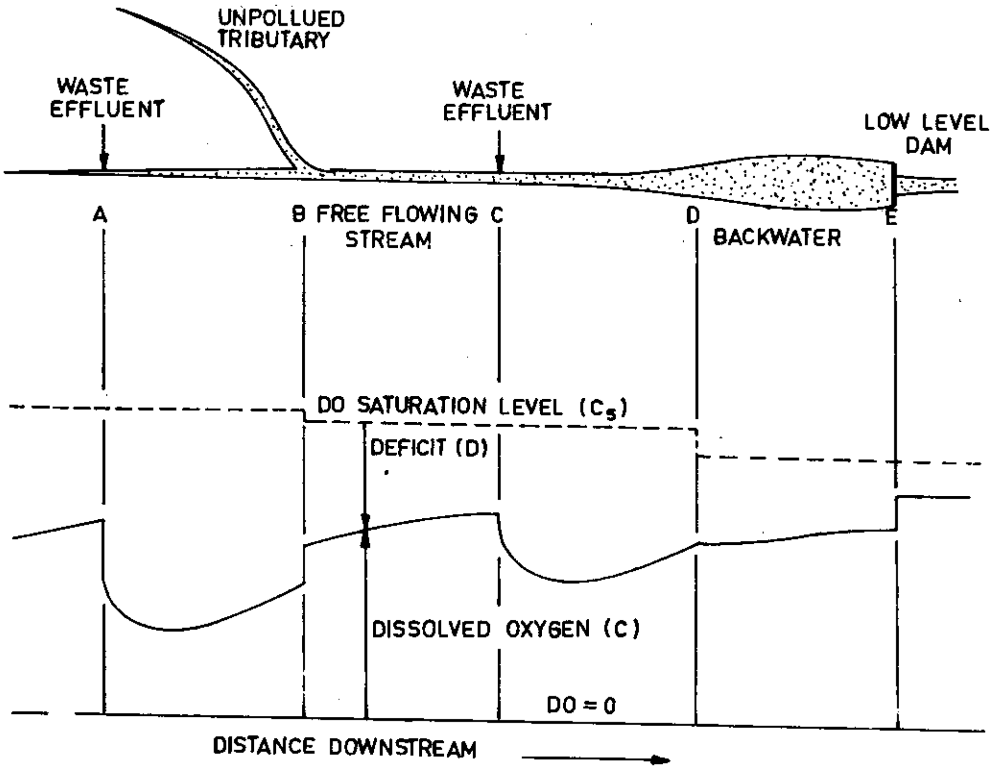

FIGURE 5 : DO PROFILE FOR A SIMPLE STREAM

zation by biological action, the reduction in BOD concentration is equivalent to dissolved oxygen consumption.

The bottom figure shows two calculated dissolved oxygen profiles associated with the BOD removal profile in the upper plot. The profile indicated by the solid line represents conditions that would occur in a river if oxygen were not replenished by reaeration. In this case, the assumed initial dissolved oxygen concentration of 12 mg/l is ultimately reduced to 2 mg/l to satisfy the ultimate BOD of 10 mg/l. The dotted profile illustrates the net effect of reaeration providing an additional source of oxygen.

The characteristic shape of the stream dissolved oxygen profile (the DO sag curve) is the result of the interplay of the oxidation and reaeration reaction rates. Each is represented by first-order kinetics: the rate of oxygen consumed is proportional to the concentration of BOD remaining at any time, and the rate of oxygen supplied is proportional to the magnitude of the deficit at any time.

In the early stages, oxidation greatly exceeds reaeration because BOD concentrations are high and river dissolved oxygen concentrations are close to saturation (i.e., deficits are small). Oxygen is used faster than it is replaced, and stream dissolved oxygen concentrations decrease. As time progresses, the consumption of oxygen decreases as the amount of BOD remaining is reduced, and the supply of oxygen increases as stream concentrations drop and deficits become greater. At some point the decreasing utilization and the increasing supply are equal since oxygen is supplied at the same rate it is utilized. This situation defines the 'critical' point when the lowest concentration of dissolved oxygen will be reached in the stream. Although the rate of supply gradually diminishes after this, it always exceeds the utilization rate, which continues to drop. River dissolved oxygen concentrations increase thereafter, through at a decreasing rate as concentrations approach saturation. Figure 6. presents a set of computations performed to illustrate the nature of stream system responses under the influence of a range of reaction rate.

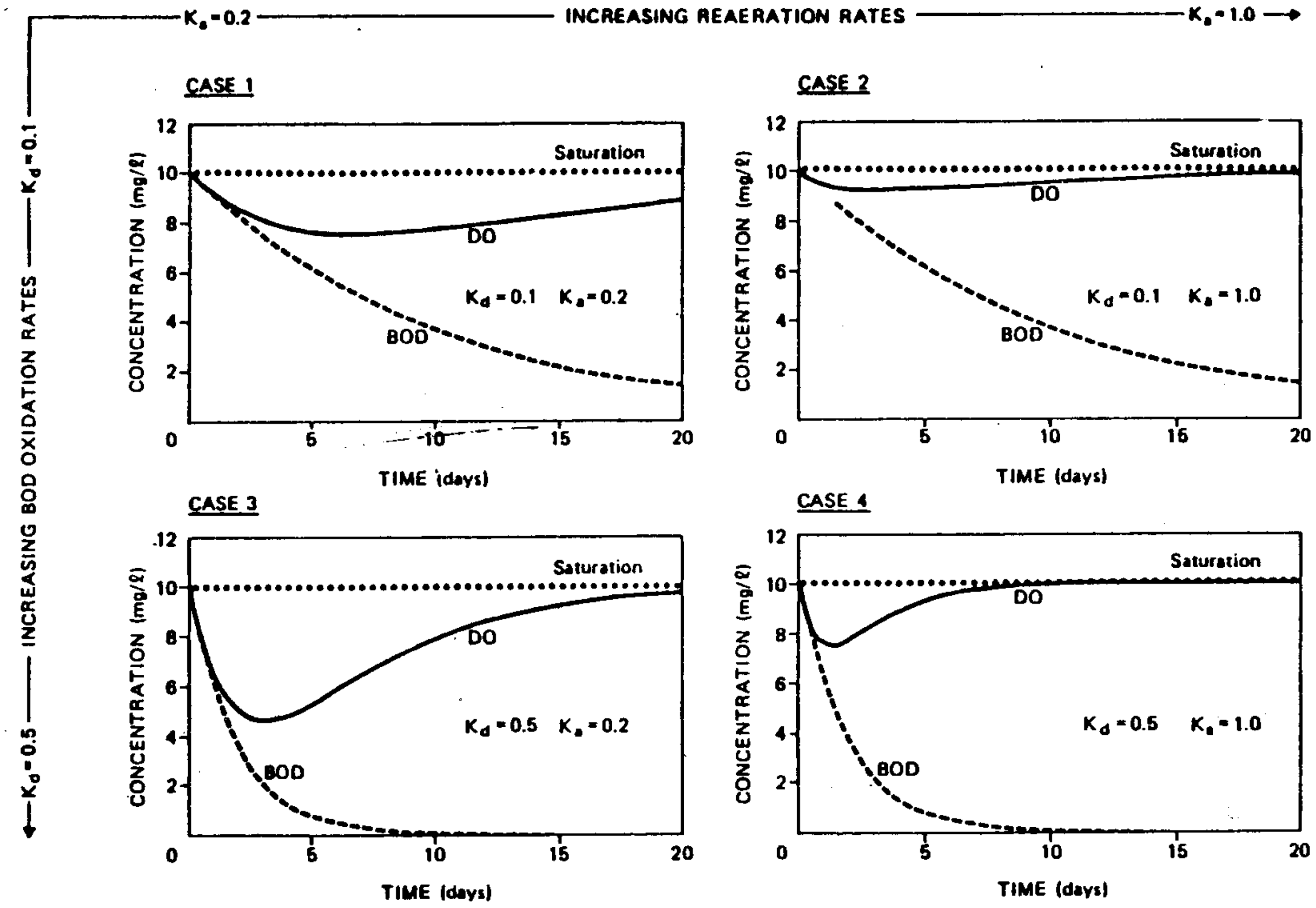

FIG. 6: Effect of rates on stream DO impacts.

3.0 STUDY AREA

The study area was chosen as detailed hydrochemical studies were earlier conducted by Patel (1985) and the data required to run DOSAG-I was partly available.

3.1 Location

The area under study is a part of the Indogangetic Plain and lies in the Upper Hindon basin, bounded between latitude 29°52' and 30°0' N and longitudes 77°32'30'' and 77°37'15'' E (Figure 7). The area is located within Saharanpur district of Uttar Pradesh (India) and is included in the Survey of India topographic sheet No. $53\frac{G}{9}$ on the scale of 1:50, 000. The study was confined to a nearly 17 km. stretch of Hindon river system starting from near the village of Mohammadpur in the north to Sadauli Haria in south.

The area under study is well connected by roads and railway. Saharanpur is the important town in the north-western part of the area. Some of its parts, are, however, connected be cart-tracks or seasonal roads only.

3.2 Climate and Rainfall

The climate around the Hindon basin studied is of moderate to subtropical monsoon type. Thus, there exists a well marked seasonal variation in precipitation, temperature, pressure, wind, relative humidity etc. In general, the average normal monsoon

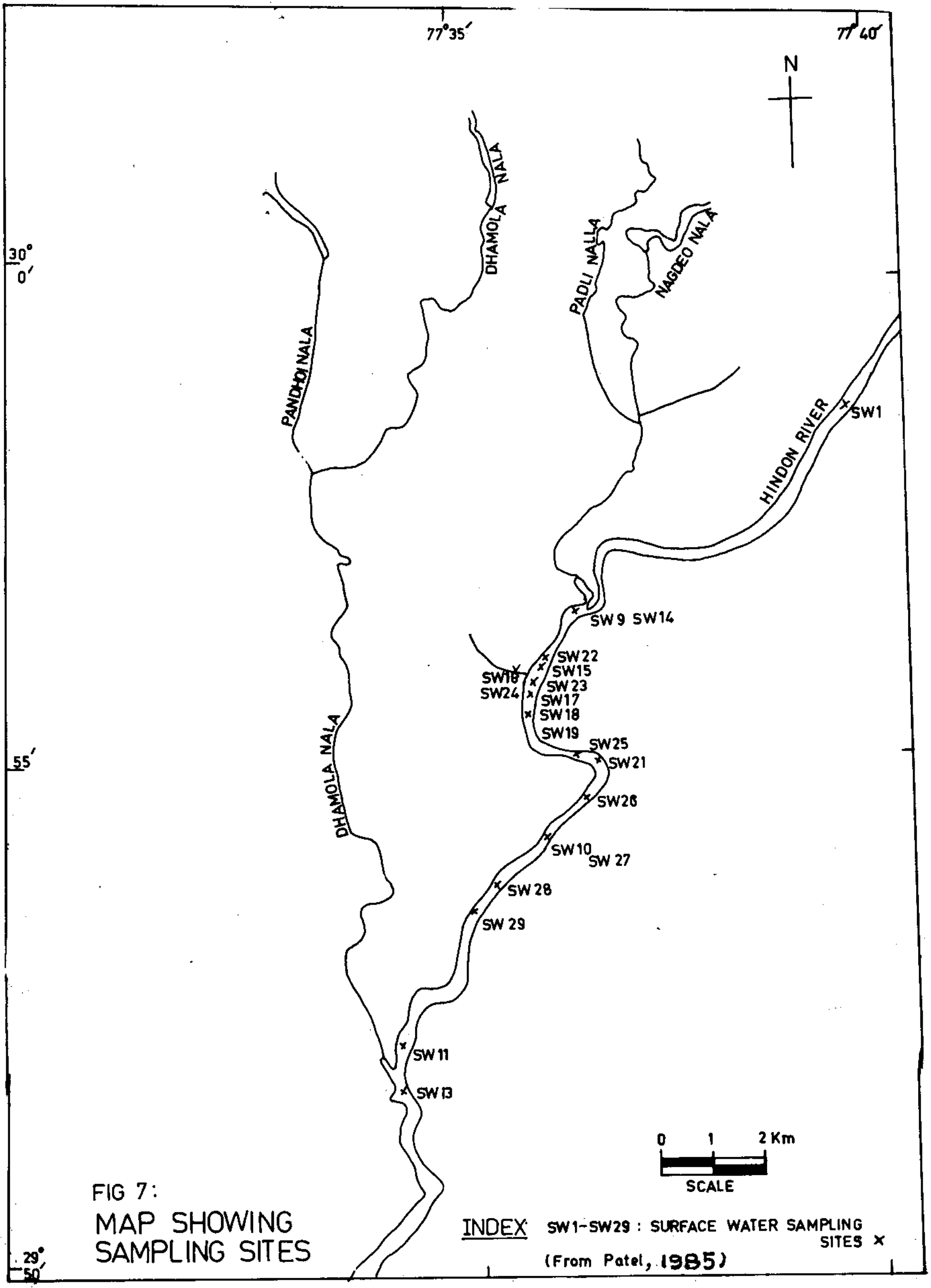

FIG 7:
MAP SHOWING
SAMPLING SITES

INDEX SW1-SW29 : SURFACE WATER SAMPLING SITES ×

(From Patel, 1985)

rainfall in the Saharanpur town is 486 mm. and the daily temperature ranges from 8°C in winter to 40°C in summer.

The average annual rainfall and the average monsoon rainfall for 3 years (1980-82) recorded for the three rain-gauge stations located in Saharanpur, Nakur and Deoband Tehsil in Saharanpur district covering the area of study is 874.19 mm.and 650.29 mm respectively. Thus the monsoon rainfall accounts for about 75 percent of the total annual rainfall.

3.3 Physiography and Drainage

Physiographically, the Hindon basin which has river Hindon as the main stream is characterised by about 18 m. variation in altitude, ranging between 280 m. above M.S.L. in the north to 262 m. in the south.

The drainage of the area comprises of the Hindon river which is an ephemeral river and has its flow generally towards south. This river finally meets the Yamuna river system near Ghaziabad town. In the area of study, the Hindon river has two perennial tributaries viz. Nagdeo nalla and Dhamola nalla joining it near Ghogreki and Sadauli Haria villages respectively.

3.4 Inhabitants and Industries

The area under study is densely populated because of the rapid industrialisation and agricultural growth that have taken place during last few decades especially around Saharanpur town having a population of over 1 million.

In the vicinity of Saharanpur town, a variety of industries have come up such as those relating to paper, sugar, food-proceesing, dairy products, lime and brick kilns, engineering and cottage products. In particular, the Star Paper Mill and Indana Ghee Factory are significant industries in the area. The effluents generated from these industries are mostly discharged to nallas without any significant pretreatment which ultimately join the river Hindon or its tributaries. The description of the study area has been given in detail by Patel (1985).

4.0 DATA USED

The data used in the case study are taken from a thesis done at University of Roorkee, Roorkee (Patel, 1985). The data were collected for hydrochemical studies of Hindon basin in U.P. The parameters were computed by using field and experimental data between Dudhli Bukhara village (SW_{22}) and Mabarikpur village (SW_{29}).

In developing Dissolved oxygen curve using DOSAG, in two phased data have been used. In first phase (Phase-I) of observations, the data for April 1985 have been used for SW_{14} to SW_{21} only. For computing discharge the data of depth, width and velocity were used. In second phase (Phase-II) of observations, the data for May 1985 have been used for SW_{22} to SW_{29}.

The discharge values have been obtained by regression coefficient values method. The BOD_5 values, as given by Patel (1985) have been used. The values of reoxygenation any reoxygennation coefficients as given by Patel (1985) have been used. The data are given in Table 1 to Table 5 (Patel,1985).

TABLE 1

DATA FOR VARIOUS POINTS IN THE RIVER

(AS PER FIGURE 7, FROM PATEL, 1985)

Sampling Site	June, 1984		Sept., 1984		Nov., 1984	
	Water Temp. (°C)	DO (mg/l)	Water Temp. (°C)	DO (mg/l)	Water Temp. (°C)	DO (mg/l)
SW_1	30.0	11.3	29.0	6.3	15.0	3.4
SW_2	35.5	6.3	-	-	20.0	0.6
SW_3	35.0	6.3	-	-	19.0	8.3
SW_4	35.0	6.9	-	-	21.0	1.4
SW_5	32.5	5.6	29.0	4.0	20.0	3.8
SW_6	31.0	2.0	-	-	21.0	0.9
SW_7	32.0	3.2	-	-	23.0	2.9
SW_8	32.0	6.0	30.0	0.7	24.0	0.06
SW_9	31.0	5.1	-	-	24.0	11.7
SW_{10}	,	3.0	32.0	0.3	26.0	0.4
SW_{11}	-	-	-	-	24.0	0.3
SW_{12}	-	-	-	-	24.0	3.3
SW_{13}	-	-	-	-	21.0	2.9

TABLE 2

DATA FOR VARIOUS POINTS USED IN MODEL

(As per Figure -7, From Patel, 1985)

Sampling Site	April, 1985 (Phase-I)		
	Temp. (°C)	DO (mg/l)	BOD (mg /l)
SW_{14}	29.5	0.9	200
SW_{15}	32.0	5.4	63
SW_{16}	31.0	1.2	220
SW_{17}	34.0	1.5	324
SW_{18}	32.0	1.4	160
SW_{19}	31.5	1.8	198
SW_{20}	33.5	1.2	224
SW_{21}	34.5	1.0	140

TABLE 3

DATA FOR VARIOUS POINTS, USED IN MODEL

(As per Figure -7 , From Patel, 1985)

Sampling Site	May, 1985 (Phase-II)		
	Temp. (^{o}C)	DO (mg/l)	BOD_5 (mg/l)
SW_{22}	29.0	5.9	260
SW_{23}	31.0	1.3	180
SW_{24}	33.0	0.9	60
SW_{25}	35.0	1.1	40
SW_{26}	35.0	2.2	56
SW_{27}	35.0	2.5	40
SW_{28}	35.0	2.3	40
SW_{29}	33.0	3.2	82

TABLE 4

DATA OF RIVER GEOMETRY AND VELOCITY AT DIFFERENT POINTS

April, 1985					May, 1985				
Sampling Location	Distance (km)	Depth (m)	Width (m)	Velocity (m/s)	Sampling Location	Distance (km)	Depth (m)	Width (m)	Velocity (m/s)
SW_{14}	0.0	0.30	10.0	0.16	SW_{22}	-	0.22	8.5	0.14
SW_{15}	1.7	0.22	13.5	0.22	SW_{23}	0.0	0.18	7.2	0.10
SW_{16}	-	-	-	-	SW_{24}	-	-	-	-
SW_{17}	0.3	0.25	4.1	0.25	SW_{25}	1.1	0.42	3.8	0.15
SW_{18}	0.45	0.18	4.3	0.37	SW_{26}	1.6	0.50	6.3	0.11
SW_{19}	0.45	0.29	4.2	0.40	SW_{27}	1.0	0.35	13.7	0.18
SW_{20}	0.60	0.36	3.65	0.27	SW_{28}	1.3	0.20	11.2	0.22
SW_{21}	0.0	0.20	4.15	0.43	SW_{29}	0.8	0.20	6.6	0.25

TABLE 5

BOD VALUES OF DIFFERENT SAMPLES

April, 1985 (Phase-I)		May, 1985 (Phase-II)	
Sample Site	BOD_5	Sample Site	BOD_5
SW_{14}	200	SW_{22}	260
SW_{15}	63	SW_{23} (Sample of confluence)	180
SW_{16} (Paper Mill Effluent)	220	SW_{24} (Paper Mill Effluent)	60
SW_{17} (Confluence Point)	324	SW_{25}	40
SW_{18}	160	SW_{26}	56
SW_{19}	198	SW_{27}	40
SW_{20}	244	SW_{28}	40
SW_{21}	140	SW_{29}	82

5.0 METHODOLOGY

The DOSAG water quality simulation model computes the carbonaceous and nitrogenous biochemical oxygen demand and dissolved oxygen profiles in a stream system using explicit solutions for the differential equation of these constituents at steady-state. The differential equations, explicit solutions, and solution techniques used in the simulation model are described below (Adopted from CRWR -145).

5.1 Basic Equations

The concentration of a water quality constituent such as biochemical oxygen demand (BOD) in a stream may be affected by its transport downstream, the introduction of more BOD in a waste discharge or from benthic deposits and the loss of BOD by water withdrawal or decay. The general equation that describes these processes is :

$$\frac{\partial L}{\partial t} = -\frac{1}{A} \frac{\partial (QL)}{\partial X} - KL + \frac{L'}{A} + \frac{\partial Q}{\partial X} + L_d \qquad \ldots (1)$$

where,

L = BOD concentration in river

L' = BOD concentration in distributed flow

L_d = BOD from distributed source without flow

A = river cross-section area

K = decay coefficient

Q = river flow

X = distance downstream

t = time

Given the system to be simulated and the inputs and losses to be considered, this equation may be reduced to a simpler form. Steady-state conditions may be assumed and the equation is then in a form simple enough to be integrated using elementary techniques. The equations used in DOSAG-I originally were derived in this fashion.

5.2 Biochemical Oxygen Demand

Carbonaceous and nitrogenous BOD is assumed to be removed from water according to a first order decay relationship as shown in Equations 2 and 3.

$$\frac{dL}{dt} = - K_r L \qquad \ldots (2)$$

$$\frac{dL^N}{dt} = -K_n L^N \qquad \ldots (3)$$

where,

t = time of travel (days) = x/u, $u = Q/A$

L = carbonaceous BOD concentration, mg/l

L^N = nitrogenous BOD concentration, mg/l

K_r, K_n = carbonaceous and nitrogenous BOD removal rates respectively, $\frac{\text{mg CBOD or NBOD removed/time}}{\text{mg CBOD or NBOD present}}$ or t^{-1}

The exponential relationship as defined by the above equations assumes that the rate of removal of a compound (the rate of degradation) is proportional to the concentration of that compound remaining in solution.

These equations have been found to approximate the rate of disappearance of the BOD within most stream systems. The removal rates for carbonaceous BOD (K_n) are considered to be constant for each user-specified stream reach being simulated. The user may specify a different K_r and K_n value for each stream reach in the basin, however, it has been shown in practice that K_r and K_n are proportional to the distance and time of travel from the point of discharge. This decrease is due to the settling of some BOD while oxidation accounts for the rest. The occurrence of several waste dischargs along a given stream reach vastly complicates the problem of developing the removal rate constants.

The most appropriate method for determining K_r and K_n is to measure these values in the field with a complete dissolved oxygen biochemical oxygen demand field survey. If this type of survey is not possible, it is necessary to estimate values for the removal rates. In this situation, the most appropriate means for estimating these constants is to review the literature to find removal rates for wastes with characteristics similar to those wastes entering the stream system to be modeled. The model user must be aware that using literature values lowers the confidence of the model results considerably. There is no substitute for field data in the calibration of this model to a river basin.

5.3 Dissolved Oxygen

The equation used by the model to compute the dissolved oxygen concentration in the stream as given in Equation 4.

$$\frac{dC}{dt} = K_2 \ (C_s - C) - k_{dn} L^N \qquad \ldots (4)$$

where,

C = in stream dissolved oxygen concentration, mg/l

C_s = dissolved oxygen saturation concentration, mg/l

K_2 = reaeration coefficient, $\frac{\text{mg DO added/time}}{\text{mg present}}$ or t^{-1}

k_{dn} = carbonaceous BOD deoxygenation coefficient, $\frac{\text{mg } O_2 \text{ removed/time}}{\text{mg NBOD}}$ or t^{-1}

t = time of travel

The reaeration portion of this equation is based on the Fickian law of diffusion and states that the rate of diffusion of dissolved oxygen into the stream is proportional to the difference between the oxygen, concentration within the stream and the concentration the stream would have if it were completely saturated with oxygen at the existing temperature and elevation. The value of C_s is estimated by Equation 5.

$$C_s = (14.62 - 0.3898T + 0.006969T^2 - 0.00005897T^3) \times (1.0 - 0.00002287675\ E)^{5.167} \qquad \ldots (5)$$

where,

T = water temperature, ^oC

E = river basin mean elevation, meters.

The benthic oxygen demand, is the amount of oxygen consumed by bacteria in the sediments over some period of time. It is measured in situ if possible as described in Standard Methods, or estimated from literature data and specified as grams DO consumed/m^2/day.

The terms L and L^N are the concentrations of carbonaceous and nitrogenous BOD as calculated in Equations 2 and 3.

5.4 Other Sources and Sinks

Other sources and sinks of dissolved oxygen may be important in various stream system, but these are not included in DOSAG. For example, an important source of dissolved oxygen is the photosynthetic activity of aquatic plants, both macroscopic and microscopic. The photosynthetic activity increases the dissolved oxygen concentration within the stream during the day, whereas during the hours of darkness the increased respiration of the photosynthetic organisms may cause the dissolved oxygen concentration to be depressed. These effects may be extermely significant in some streams. Although some work has been done in fitting harmonic functions to various models to account for these photosynthetic effects, the coefficients used in these harmonic equations to date are limited in their transferability.

In using DOSAG, the user should be aware of the fact that not all of the known sinks and sources of oxygen within the stream system are simulated. However, the model, as constructed, should provide the engineer with a good description of the stream system, and from this he can use his judgment of the possible effects of the other important factors on the oxygen resources predicted by the model.

5.5 Solution Techniques

A La Grangian solution technique is used to solve the dissolved oxygen equation in the DOSAG quality routing model. This solution technique involves using a coordinate system which moves with a particle of water in its path down the stream. The La Grangian coordinate system allows a relatively simple computational technique to be used and reduces the computer time required to solve a given problem.

At each change in reach and at every junction a simple mass balance is performed to arrive at the biochemical oxygen demand and dissolved oxygen concentrations in the next reach downstream. In this way, the stream system is modeled from its upper to its lower end recording its response to all of the pollutional loads imposed on it. Equations 2, 3 and 4 are combined and integrated to obtain the relationship between dissolved oxygen reaeration and oxygen consumption within a stream system. The integrated forms of the BOD and dissolved oxygen equation as used in this model are shown in Equation 6, 7 and 8.

$$L(t) = L_o e^{-K_r t} = L_o e^{-(K_r/U)x} \qquad \ldots (6)$$

$$L^N(t) = L_o^N e^{-(K_n/U)x} \qquad \ldots (7)$$

$$C(t) = C_s - \frac{K_d L_o}{K_2 - K_r} \left(e^{-K_r t} - e^{-K_2 t}\right)$$

$$- \frac{K_{dn} L_o^N}{K_2 - K_n} \left(e^{-K_n t}\right) - (C_s - C_o)\, e^{-K_2 t}$$

$$= C_s - \frac{K_d L_o^N}{K_2 - K_r} \left(e^{-(K_r/U)x} - e^{-(K_2/U)x}\right)$$

$$- \frac{K_{dn} L_o}{K_2 - K_n} \left(e^{-(K_n/U)x} - e^{-(K_2/U)x}\right) - (C_s - C_o)\, e^{-(K_2/U)x} \quad \ldots (8)$$

where,

L_o = initial (ultimate) carbonaceous BOD in the river (mg/l)

L_o^N = initial (ultimate) nitrogenous BOD in the river (mg/l) where nitrogenous BOD = 4.57x(Org-N+NH_3-N), in mg/l

C_o = initial dissolved oxygen concentration (mg/l)

H = average depth in segment (meters)

x = distance downstream (km)

t = time of travel (days)

6.0 DETAILS OF DOSAG - I MODEL

1. Name :- DOSAG - I

2. Time Variability :- Steady state

3. Spatial Dimension :- One Dimensional

4. Reciving Water Type:- Stream

5. Reach :- Network

6. Waste load type :- Point and Multiple

7. Loading rate :- Constant

8. Dissolved Oxygen - sinks :- CBOD, NBOD

   -source :- Reaeration

9. Special Features :-
   - i) Can specify treatment levels
   - ii) Can calculate augmentation in flow which is required to maintain a DO.

10. Can Model :-
    - i) DO
    - ii) NBOD
    - iii) CBOD

11. One has to specify :- Temperature

12. Physical processes accounted :
    - i) Advection
    - ii) Dilution
    - iii) Reacration
    - iv) Ist order decay of CBOD and NBOD

13. Options :
    - i) Input directly
    - ii) Calculate as a function of velocity and depth
    - iii) Calculate as a function of flow

14. Assumptions:- 1) Quantity:
    - a) Steady state
    - b) Geometry and velocity are uniform throughout a reach
    - c) No lateral or vertical variation in velocity

- d) Completely mixed
- e) Velocity depth can be expressed as power function of flow.

ii) Quality

- a) Ist order decay of NBOD and CBOD
- b) Constant waste load
- c) Neglects benthic demand and photosynthesis
- d) Reaction rates are constant in a reach
- e) No longitudinal dispersion
- f) Well mixed flow

15. Data Requirement

i) Geometric

- a) Stream lengths
- b) Uniform reaches
- c) Connection scheme
- d) Coefficients for depth-flow regression

ii) Hydrologic

- a) Head water inflows
- b) Tributary inflows
- c) Withdrawals

iii) Hydraulic

- a) Coefficients for velocity-flow regressions

iv) Water Quality

- a) Inflow concentrations
- b) Stream temperatures

v) Effluent

- a) Flow rates
- b) Concentrations

vi) Decay rates

- a) Reaeration and reaction rate coefficients
- b) Temperature correction factors

vii) Others

a) Treatment factor

b) Target minimum DO concentration

16. Output form : COMPUTER PRINTOUT

17. Output Content

i) Listing of input data

ii) DO, CBOD, NBOD concentrations at start and end of each reach and magnitude and location of minimum DO concentration in each reach.

18. Memory Required:

i) 27000 Words storage

ii) FORTRAN - IV compiler

iii) No tape or disk needed.

7.0 MODEL USAGE

This part has been generously taken from DOSAG-I (1970). In order to use the DOSAG-I Quality Routing Model, the user must take the stream system which he proposes to simulate and break it down into the elements which are used as input to the program. Figure 8 shows a schematic diagram of a typical river system which has been decomposed into the elements required to model it using DOSAG-I. There are essentially four major elements into which a system must be decomposd so that it can be modeled using this program. These elements are

(1) junctions - the confluence between two streams within the river basin being modeled,

(2) stretches - the length of a river between junctions,

(3) headwater stretches - the length of a river from its headwater to its first junction with another stream, and

(4) reaches - the subunits which comprise a stretch (headwater or normal).

A new reach is designated at any point in the stretch where there is a significant change in the hydraulic, biologic, or physical characteristics of the channel, including the addition of a waste load, or the withdrawal of water from the stream.

After a stream has been represented schematically, it is necessary to specify the hydraulic and physical characteristics of each reach in the stream system. This step involves reading into the program various coefficients to describe all of the factors

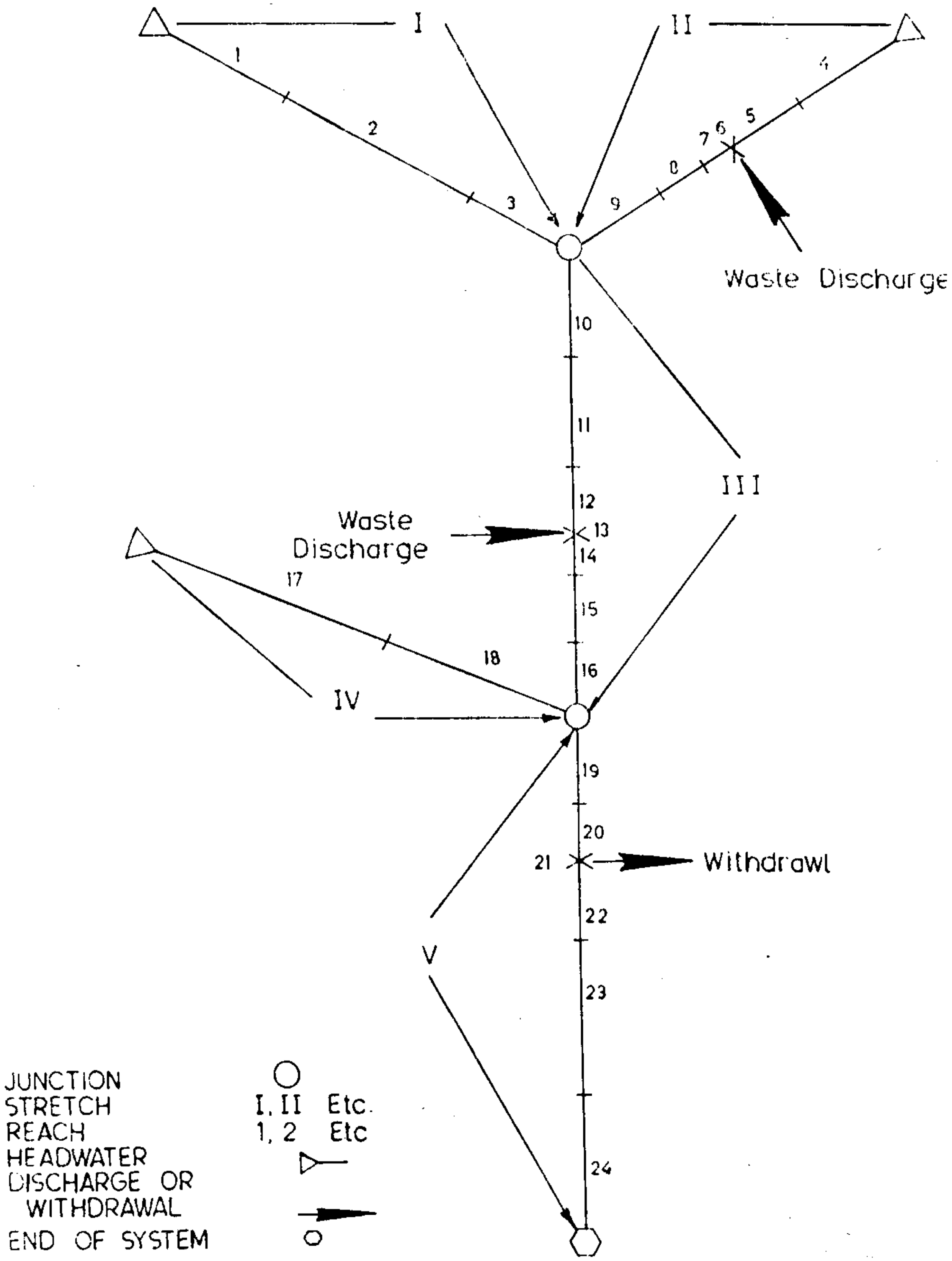

FIG 8 : TYPICAL RIVER SYSTEM

which are involved in the decay of biochemical oxygen demand, and the replenishment and depletion of dissolved oxygen within the stream system. It should be noted that this is some of the most important information required for the simulation process. The results obtained from the simulation of the dissolved oxygen resources within a riversystem, using DOSAG-I as a modeling medium, are only as accurate as the input data provided for the modeling process. It thus behooves the user to take great care in specifying the coefficients to be used in the program for simulating the stream system.

Two equations are used to describe the hydraulic characteristics of each reach in the river system. The first equation represents the relationship between discharge and velocity, and the second between discharge and depth. It is assumed that both of the these relationships can be represented by exponential equations as shown below:

$$V = A_1 Q^{B_1} \qquad \ldots (9)$$

$$D = A_2 Q^{B_2} \qquad \ldots (10)$$

where,

V = mean velocity in a reach (fps)

Q = mean discharge in a reach (cfs)

D = mean depth (feet)

A_1, A_2, B_1, B_2 = coefficients

The above regression coefficients are used as input data into the program. These coefficients must be developed from data obtained from the actual stream system. The most readily available data of this type are those collected by the U.S. Geological Survey at each of its streamflow gaging station sites. Data from other sources, but of the same type, in a given river basin, can also be very useful to the modeling process. If the type of data necessary to develop these relationships are not available for a given stream, it will be necessary to estimate these coefficients based on the known topography and physical characteristics of the stream. However, this method is subject to serious error and is not recommended unless absolutely necessary.

An extremely important factor in the dissolved oxygen modeling of a stream system is the reaeration coefficient, K_2, which is used in the calculation of the rate of diffusion of dissolved oxygen into the stream. There are four options available in this program for specifying the reaeration rate coefficient. One option is to read it in for each of the reaches in the stream system. The read-in values of K_2 should be to the Naperian logarithmic base. Read-in values might be used if, for example, field surveys of the stream to be modeled have been made and values of the reaeration coefficient have been computed from the results of these. However, the reaeration coefficients determined from surveys of this type are only useful for the discharges measured during the survey period. A change in discharge in the stream would probably result in greatly different values for this coefficient. The program user may also choose to estimate K_2 values for each reach, based on the known physical and hydraulic characteristics of the stream being modeled. Obviously, this method is very subjective and may involve large errors.

Several investigators have found that the reaeration coefficient, K_2, can be represented by a relationship as shown in equation 11.

$$K_2 = \frac{A_3 V^{B_3}}{D^{C_3}} \qquad \ldots (1')$$

Where,

A_3, B_3, C_3 = coefficients

This relationship postulates that the reaeration rate coefficient is directly proportional to the mean stream velocity and inversely proportional to the mean depth. It is based on two observed phenomena.:

> increasing velocity and turbulence increases the surface renewal rate of dissolved oxygen and promotes mixing and dispersion of the oxygen throughout the depth of the stream, and
>
> increased depth decreases the rate of dispersion of dissolved oxygen throughout the water mass, thus resulting in lower quantities of oxygen being transferred from the atmosphere.

Several investigators have presented the necessary coefficients for use in equation 11 to calculate the reaeration coefficient for any stream in which the mean velocity and mean depth are known. Table 6 presents these coefficients as determined by four investigators in both field and laboratory tests. The coefficients developed by Churchill in 1962 and by Langbein and Durum in 1967 are probably the best known for the computation of the reaeration rate coefficient for general model use.

TABLE 6

COEFFICIENTS FOR COMPUTATION OF THE REAERATION COEFFICIENT

Investigator	A_3	B_3	C_3
Churchill, et al. (1962)	5.026	0.969	1.673
Langbein and Durum (1967)	3.3	0.50	1.33
O'Connor and Dobbins (1958)	5.6	0.50	1.50
Owens and Gibbs (1969)	9.4	0.67	1.85

If equation 11 is desired to be used for the calculation of the reaeration rate coefficient, the appropriate coefficients in this equation are read into the program for every reach in which it is desired to calculate K_2 in this manner. A note of caution should be observed when using an equation of this form. Mean stream depths of less than one foot cause the reaeration coefficients predicted by the equation to be higher than are normally observed under actual field conditions. If the stream being modeled has significant areas in which the mean depth of flow is less than one foot, the user is advised to employ alternative methods for computing the reaeration coefficient in these areas.

Another technique for computing the reaeration coefficient, also available to the user of this program, is a direct proportionality between the reaeration coefficient and the stream discharge. This relationship is shown in equation 12 :

$$K_2 = A_4 Q^{B_4} \qquad \ldots (12)$$

A relationship of this type may be developed from data obtain from a field survey of a stream in which mean velocity and depth were not determined but discharge was known. The coefficients used in the discharge-reaeration coefficient equation must be computed from measured field data. Equation 8 is not generally applicable to most river systems, because many of the factors which effect the reaeration coefficient are not adequately described by a simple discharge-reaeration coefficient relationship.

The fourth technique available for computing the reaeration coefficient for each reach is based on the investigation by Thackston and Krenkle. This technique was developed experimentally by determining the reaeration coefficient in laboratory channels, using as parameters the mean velocity, channel slope, and mean depth. Equation 13 shows the solution for the reaeration coefficient as developed by Thackston and Krenkle, and as is used in this program.

$$K_2 = 0.00125 \left(1 + \left[\frac{V}{(9D)^{1/2}} \right]^{1/2}\right) \quad (S_e)^{1/2} \left(\frac{9}{D}\right) \qquad \ldots (13)$$

where,

S_e = mean channel slope (feet/feet)

Use of this option requires that the program user specify a mean channel slope for each reach in the river system being modeled. Equation 13 indicates that the reaeration coefficient is proportional to the shear velocity developed within the stream. Thackston and Krenkle applied this equation to their laboratory data and showed that it gave a reasonably good description of the reaeration rate in the channel. However, only limited data were available to verify the predictive capability of this equation in an actual stream system. Studies at the Texas Water Development Board have indicated that equation 13 may tend to give higher values for reaeration coefficients than are actually measured during the field evaluation of Texas streams.

The program user may specify any of the four methods described above for the prediction of the reaeration rate coefficient for a given reach. The use of equation 11 and 12 for reaeration coefficient computation requires the user to specify the appropriate coefficients for the equations. Equation 13 requires the program user to specify the mean channel slope in feet per foot for each reach for which this equation is to be used. The user may elect to use the same technique for calculating the reaeration coefficient for all reaches in the stream system or he may use a different method for each of the reaches in the system, depending upon the degree of knowledge obtained of the physical and hydraulic characteristics of each reach.

Waste discharges are entered into the system by specifying a new reach at each location at which a discharge takes place. The reach specified should be of zero length and should be located at the nearest river mile to the site of the actual waste discharge in the prototype system. The user specifies the waste discharge volume in cubic feet per second, and the carbonaceous and nitrogenous biochemical oxygen demand concentrations in milligrams per liter. A provision is available in this program to reduce the effluent loadings from a waste discharge by the application of a treatment factor which is read into the program for both the carbonaceous and nitrogenous B.O.D.s in percent. If the treatment factor is to be used, it is assumed that the biochemical oxygen demand concentrations of the waste, as read into the program, are actually the concentrations present in the raw wastewater prior to waste treatment. If the user desires to suppress this option, he inserts treatment factors of 0.01 for both the nitrogenous and carbonaceous B.O.D.s for each waste treatment plant. In effect this means that the B.O.D., values specified for each waste treatment plant will be used in the program as effluent B.O.D. values and will not be changed in any manner by the model.

The model has provisions for withdrawing water at any location within the stream system. The water is withdrawn from the stream at the quality existing at the location of the withdrawal as determined by the model. The withdrawal is specified in the same manner as a waste input to the stream system. A separate reach of zero length is set up for each withdrawal in the system. A negative flow is specified on the waste and withdrawal input cards to indicate that water is being withdrawal from the system. The B.O.D. and treatment factor values for withdrawal are not taken into consideration by the model.

The DOSAG-I quality routing model allows the user to specify up to twelve different water temperatures for modeling the stream system. The biochemical oxygen demand and dissolved oxygen concentrations are computed by the model for each of the temperatures specified. The model modifies the bio-degradation coefficients, K_1 and K_3, and the reaeration coefficient, K_2, for each of the temperatures used in the routing computations. Equations 14 and 15 show the relationships used to modify these rate constants for the temperature changes :

$$K_d(T) = K_d(20^\circ C)\ 1.047^{(T-20)} \qquad \ldots (14)$$

$$K_2(T) = K_2(20^\circ)\ 1.0159^{(T-20)} \qquad \ldots (15)$$

where,

$K_d = K_1$ or K_3

T = Temperature in °C

The 20 degree centigrade values for these rate coefficients are the values which have been specified by the user for the particular run being made. The coefficients used to modify the K_1 and K_2 rate terms have been established from field data by a number of investigators and represent the best information available for this modification. The variation in K_3 with temperature is not well established so the K_1 modification is used pending the development of a better relationship.

The user of the DOSAG-I Quality Routing Model has several options available which will enable him to simulate several different stream conditions in one computer run, without reading in additional data. The user of the program may read in up to four carbonaceous and nitrogenous biological waste treatment factors. The program will calculate a new dissolved oxygen profile based on the organic load released from each plant after the treatment factor has been applied. This process is repeated for each of the treatment factors entered in the program. The user may also specify up to four dissolved oxygen target levels, which are the minimum permissible dissolved oxygen concentrations in the stream system. By specifying a dissolved oxygen target level, the user also indicates that he wishes the program to calculate the flow augmentation requirements, if any, needed to meet this target level. The other option available to the user is that up to twelve different temperatures and corresponding headwater flows may be specified, and the program will completely model the stream for each value. The above three options enable the program user, in a single run, to perform a large number of simulations of the stream system to determine the effects of various waste loadings, temperatures, and dissolved oxygen target levels on the dissolved oxygen concentration within the system.

The procedure used by the DOSAG-I Quality Routing Model to determine augmentation requirements should be briefly mentioned. The model begins routing organic wastes and dissolved oxygen from the uppermost point in the stream system and proceeds downstream. As the simulation progresses downstream, reach by reach, the calculated dissolved oxygen concentration is checked against the target dissolved oxygen level specified by the user. When the model discovers a dissolved oxygen concentration below the target it stops at this reach. The model then searches all of the upstream headwaters to see which headwaters have water available for flow augmentation purposes. The model then estimates, using a parabolic relationship between dissolved oxygen deficit and the target dissolved oxygen level, the quantity of water required for flow augmentation to increase the minimum dissolved oxygen concentration to the target level. The volume of water required is then divided equally among all of the headwaters from which water is available for augmentation. These new flows are then re-routed through the stream system. If the amount of augmentation was insufficient to raise the minimum dissolved oxygen concentration above the target level at the reach being investigated, the process is repeated until the target dissolved oxygen concentration is attained. After the target dissolved oxygen concentration has been satisfied, the program proceeds downstream until it comes to another dissolved oxygen concentration level below the target and then the process is repeated as before. The program is designed so that it can only augment from a headwater stretch, and the augmentation requirement are divided equally among all the headwater stretches which have augmentation availability. The flow augmentation option is suppressed by specifying a negative value for the target dissolved oxygen concentration.

8.0 RESULTS AND DISCUSSION

The main objective of the present study was to understand DOSAG-I model, implement and test it on the main frame VAX-11/780 computer system and to run it with Indian data. The computer programme which is a fairly large one (about 1500 statements) was not available on tape and hence it was fed and implemented on the computer.

In order to asses the applicability, accuracy and sensitivity of stream simulation capability of DOSAG-I, it was used to model the downstream portion of the Hindon river in U.P. Data were available (Patel, 1985) on the physical, hydrological and biological characteristics of this basin. The data on the physical and hydraulic characteristics of the Hindon basin were collected under a Department of Environment sponsored research project being undertaken by Deptt. of Earth Sciences, University of Roorkee. This data was used to arrive at DOSAG-output.

The modelling was performed with the available data and wherever data were not available regression analysis and assumptions were made. The modelling was done for two periods

i. April, 1985

ii. May, 1985

These periods were chosen as extensive data were available as well as hand calculations for DO sag curve were already available (Patel, 1985). The results of these studies are plotted in Fig. 9 and Fig. 10.

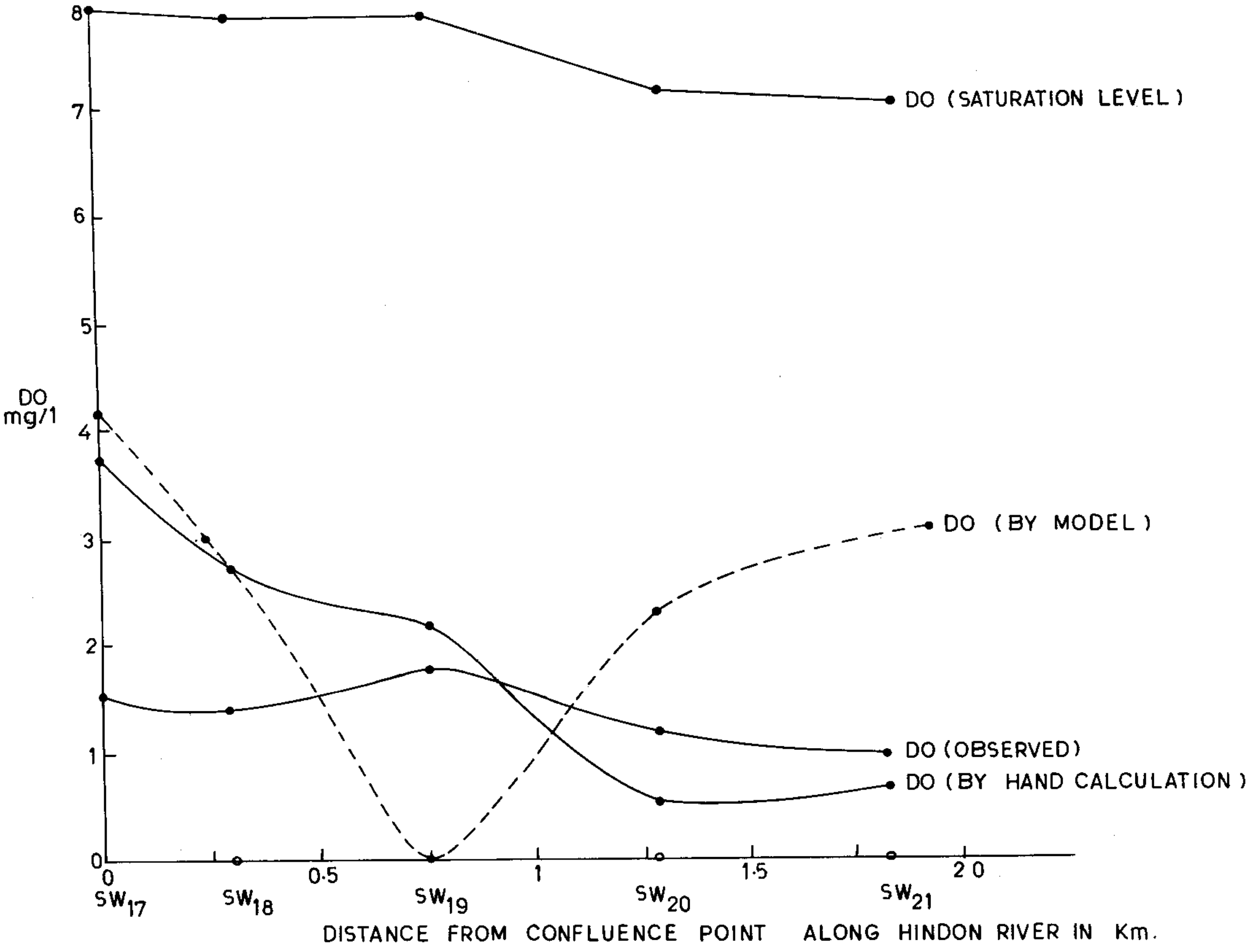

FIG. 9-DISSOLVED OXYGEN SAG CURVE (APRIL, 1985; PHASE I)

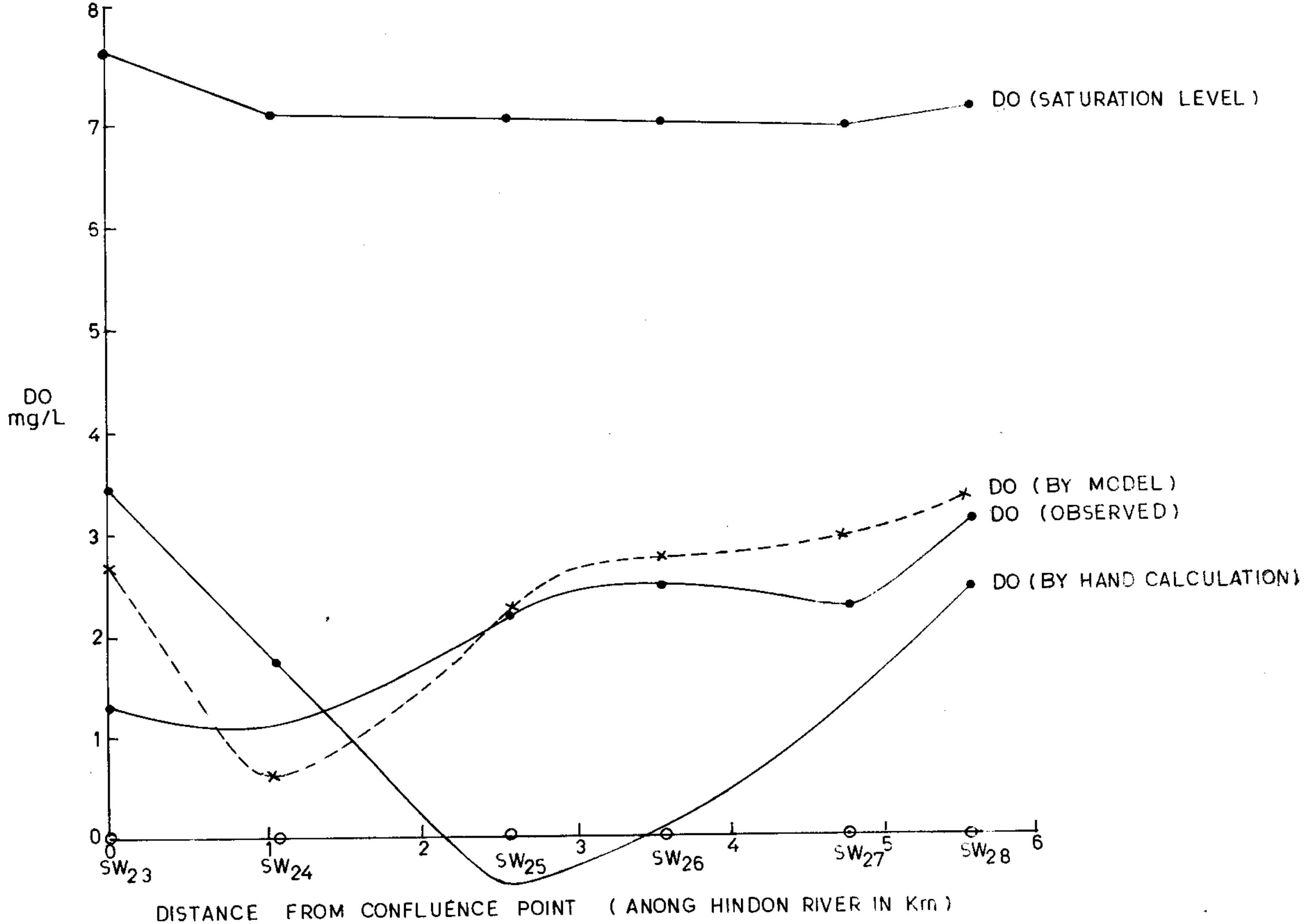

FIG 10-DISSOLVED OXYGEN DO SAG CURVE (MAY, 1985; PHASE II)

It is seen from these figures that DO sag curve is closely matching the actual measurements most of the time. As well, the DOSAG-I gives better results that the hand calculations. It can also be seen that DO curve by model follows a definite trend and does not give inaccurate curve.

From the Figures, it is also clear that the dissolved oxygen limit is always below 6 mg/l, the recommended level by CBPCWP, Delhi. This means that industrial pollution is taking its toll on the river and the minimum DO level is not maintained. The computed and measured DO values also indicate that there is occurrence of severe anaerobic conditions in a part of river. This is supported, in field, by prevalance of foul smells probably emitting due to formation of gases like hydrogen sulphides, methane etc. (Patel et al. 1985). The deviation of computed and observed dissolved oxygen values may be due to :

a) Incomplete lateral mixing

b) Non-prestime conditions of water

c) Occurrence of photosynthetic activity, and

d) Due to benthic sludge.

As a future work it would be worthwhile to take up rivers like Yamuna with all details and to model it using DOSAG.

9.0 CONCLUSIONS

This study is focussed on the use of dissolved oxygen sag model (DOSAG model) for a typical river reach. The model can be used to evaluate the water quality in river reaches under various arrangements of stream flows, temperatures and waste load discharges. The model has the capacity to make steady state evaluations and determinations of concentrations of dissolved oxygen, biochemical oxygen demand and other water quality parameters as may be desired, in all river reaches. Outputs from the model can be used by state agencies for planning purposes and can also be used for input to other models to be developed in connection with technical economic feasibility studies of any basin.

The DOSAG model is a digital computer program which ma be used for analysing the oxygen resources of a complex river system for a variety of stream flows and pollutant loadings. The loadings represent the existing or projected waste discharges to the stream and stream flows are either minimum flows occuring or those which can be achieved by low flow augmentation through the development and/or regulation of multipurpose reservoirs.

A step-by-step description of the calculations performed by the computer program is as follows :

1. Input data-river segment lengths and locations, stream flow and velocity, temperature, waste loadings, reaction coefficients (deoxygenation and reaeration) and other stream flow data-loaded into the computer.

2. Program finds - dissolved oxygen deficit.
3. Based on the minimum allowable dissolved oxygen concentrations specified in the input data - program decides if flow augmentation is required.
4. If additional stream flow is required - computer program searches for additional flow and reruns the data.
5. If additional flow is not required - the program continues on to the next down - stream section.
6. Information for each river segment is listed in bring out and user is provided with a complete description of DO resources of the stream system.

The outputs from the DOSAG program may be useful to water resources managers to evaluate the following :

a) The type of waste treatment required at each point sources, existing or projected, to prevent degradation of water quality below desired levels.

b) The effect on river quality resulting from expanded or new industrial developments in the basin.

c) The optimum location of new industrial units from various water quality, point of view.

d) The effect on water quality resulting from various water withdrawals.

e) Stream flow augmentation required, to maintain a specified DO level.

f) The water quality profiles (DO) which result from implementation of alternative water pollution control systems.

The above information is useful for (Armstrong, 1977, Silva, 1981) :

- Land use planning and Zoning
- Industrial development
- Quality - quantity cost benefit ratio
- Waste treatment requirements
- Stream classifications and water quality standards.

The model has certain limitations like it can not (in its present form) simulate coliforms, benthic demands etc. The following restrictions also apply.

a) Units are in FPS (however in present study conversions have been made in data sets)

b) Maximum number of headwater stretches - 10

c) Maximum number of junctions - 20

d) Maximum number of reaches - 50

e) Maximum number of stretches - 20

f) Maximum of twelve months for temperature and head water flows

g) Minimum of one month

h) Maximum number of DO targets - 4.

The model has to be very widely tested for

a) Very wide rivers

b) Very fast flowing streams.

In the present study, due to paucity of data the model has been used on a small river, it would be interesting to use it on large rivers like Yamuna etc. where extensive field data have been collected and the model can be tested for many options.

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APPENDIX - I

DESCRIPTION OF VARIABLES

	Variable	Description
1.	DUM 1, DUM 2	Dummy Variable
2.	TITLE (I), I=1, 18	Title of basin in 18 characters
3.	NINIT	No. of Headwater reaches in basin
	NJUNC	No. of Junctions in basin
	NREA	No. of Reaches in basin
	NTRIB	No. of Stretches in basin
	ICK	Flag for print option = 1 for final summary = 0 for final summary and int. summary
	ELEV	Basin Mean Elevation
5.	IORD (I,J)	Indentifier for order of reaches in each strech
7.	JUNC (I,J)	Junction identification, identifies U/S and D/S stretches entering junction
9.	IAUG (I)	Headwater stretches where water for augmentation is available
10.	CONDZ (I,J)	J=1 Initial % of Do saturation in Headwater I J=2 Initial carbonaceous BOD conc. in headwater I (mg/l) J=3 Initial nitrogener BOD conc. in headwater I (mg/l) J=4 Initial discharge in headwater I
11 to 17 (part)		DATA (I,J) J=1 Length of reach I in miles J=2 River mile to head of reach J=3 Value of carbonacers reac. coeff. K_1, for reach I (base e). [1 day]

J=4 K_3 nitrogen react. coeff.

J=5 Coeff. of discharge to cal. Vel. for reach I.

J=6 Exponent of disch to cal. Vel. for reach I.

J=7 Discharge of incremental run off for reach I.

J=8 DO conc. of the incremental run off for reach I.

J=9 Carbonace

J=10 Nitrogenous BOD of the incremental runoff for reach I.

J=11 Discharge of sewage and ind. waste or withdrawal in reach I.

J=12 D conc. of the sewage and ind. disch. in reach 2.

J=13 Carb. BOD of the sewage

J=14 Nit. BOD of the sewage

J=15 K_2 reaeration coeff.

J=16 Coeff. of vel.if option 2 is used for finding K_2.

J=17 Exponent of vel. if opt. 2 is used for K_2

J=18 Exponent of depth if opt. 2 is used for K_2

J=19 Coeff. of Disch. if opt. 3 is used to calculate K_2

J=20 Exp. of disch. if opt. 3 is used

J=21 Coeff. of disch. to cal. the average depth

J=22 Exp. of disch. to cal. the Depth

J=23 Slope of channel if opt. 4 is used to find K_2

17.	K20PT (I)	Option for cal. K_2 for reach I.
	RIDENT (I,J)	Reach Identification, alphanumeric.
19.	DOL (I)	Min. permissible DO in basin (I = target level)
	TRFAC (I)	Treatment factor for carb. wastes (maximum of 5)
	TRFACN (I)	Treatment factor for Nit.wastes (Maximum of 5)
21.	TEMMO (I)	Monthly mean st temp.

LISTING OF COMPUTER PROGRAM, INPUT & OUTPUT

```
C       MAIN PROGRAMME
C******************************************************************
C       THIS PROGRAM IS USEFUL FOR ARRIVING AT DISSOLVED OXYGEN LEVELS IN
C       A STREAM WHEN WASTE DISCHARGES ARE ENTERING IN THE STREAM . IT
C       HAS AN OPTION FOR AUGMENTING THE FLOW TO MAINTAIN A CERTAIN
C       SPECIFIED DISSOLVED OXYGEN LEVEL.
C##################################################################
        COMMON CRMIN(50),JNIT(20),F(10),C(11),IONE(20),C(15),TITLE(20),
        1IORD(20,20),JUNC(20,3),INIT(10),IAUG(20),DOL(10),TRFAC(10),
        2CONDZ(20,4),TEMMO(12),DATA(50,25),FINIS(50,16),CONDI(20,4),
        3(DMCH(20,10),CONDE(20,4),RIDENT(50,5),HWFLOW(10,12),
        4TRFACN(10),K2OPT(50),SEASON(12)
        COMMON/C2/ JJ,KK,II,B,RMLOW,MAX,CLOW,NTRIB,NREA,NINIT,NJUNC,ELEV,
        1DOLEV,TF,TEMP,CSAT,M,QUP,FINL,FINC,JA,IA,ICK,FINLN,DELQ,
        2NI,NJ,K2,VEL,NSEAS,NRUN,TFN
        DIMENSION AMONTH(12)
        REAL K2
        DATA AMONTH/3HOCT,3HNOV,3HDEC,3HJAN,3HFEB,3HMAR,3HAPR,3HMAY,
        13HJUN,3HJUL,3HAUG,3HSEP/
        DATA ENDF/4HENDF/
        OPEN(UNIT=2,FILE='DOS.DAT',STATUS='OLD')
        OPEN(UNIT=7,FILE='DOS.OUT',STATUS='NEW')
        NI=2
        NJ=7
        DO 2020 I=1,12
        SEASON(I)=AMONTH(I)
2020    CONTINUE
        DO 3333 I=1,20
        DO 3333 J=1,3
3333    CONDZ(I,J)=0.
        DO 40 I=1,20
40      IAUG(I)=0
        WRITE(7,2055)
2055    FORMAT(1H1)
        WRITE(NJ,901)
901     FORMAT (39X,'* * * FILE A - BASIN TITLE * * *',//)
        WRITE(NJ,601)
601     FORMAT (15X,'CARD                                       NAME
        1 OF ',/,
        2       15X,'TYPE                                      RIVER
        3 BASIN')
41      READ(NI,1)DUM1,DUM2,(TITLE(I),I=1,18)
        WRITE(NJ,737) DUM1,DUM2,(TITLE(I),I=1,18)
1       FORMAT(20A4)
737     FORMAT(15X,20A4)
801     FORMAT(1H0,15X,20A4,//)
        READ(NI,1) DUM1,DUM2
        WRITE(NJ,801) DUM1,DUM2
        IF(DUM1.NE.ENDF) GO TO 777
        WRITE(NJ,902)
```

```
902     FORMAT (35X,'* * * FILE B - PHYSICAL DESCRIPTION * * *',///)
        WRITE(NJ,602)
602     FORMAT(15X,'CARD            NO. OF    NO. OF    NO. ',
        1          'OF     NO. OF    INSERT 1          MEAN ',/,
        2      15X,'TYPE          HEAD WATERS JUNCTIONS REAC',
        3          'HES   STRETCHES FOR FINAL          ELEV.',/,
        4      15X,'               MAX OF 10 MAX OF 10 MAX O',
        5          'F 50  MAX OF 20  SUMMARY            (FT)'/)
        READ(NI,26) DUM1,DUM2,NINIT,NJUNC,NREA,NTRIB,ICK,ELEV
26      FORMAT(2A4,5X,I2,5X,4(4X,I2,4X),14X,F6.0)
        WRITE(NJ,804) DUM1,DUM2,NINIT,NJUNC,NREA,NTRIB,ICK,ELEV
804     FORMAT(15X,2A4,2X,5(5X,I5),14X,F6.1)
        READ(NI,1) DUM1,DUM2
        WRITE(NJ,801) DUM1,DUM2
        IF(DUM1.NE.ENDF) GO TO 777
        WRITE(NJ,904)
904     FORMAT(39X,'* * * FILE C - REACH ORDER * * *'//)
        WRITE(NJ,603)
603     FORMAT(15X,'CARD       NO. OF             ORDER OF
        1 ALL REACHES IN EACH STRETCH',/15X,'TYPE      STRETCH
        1                     (UPSTREAM TO  DOWNSTREAM) '/)
        DO 10 K=1,NTRIB
        READ(NI,3) DUM1,DUM2,I,(IORD(I,J),J=1,20)
3       FORMAT(2A4,3X,I2,7X,20(1X,I2))
        WRITE(NJ,805) DUM1,DUM2,I,(IORD(I,J),J=1,20)
805     FORMAT(15X,2A4,2X,I5,5X,20(1X,I2))
10      CONTINUE
        READ(NI,1) DUM1,DUM2
        WRITE(NJ,801) DUM1,DUM2
        IF(DUM1.NE.ENDF) GO TO 777
        WRITE(NJ,905)
905     FORMAT(40X,'   *  *  * FILE D  - JUNCTIONS  * * *'//)
        WRITE(NJ,604)
604     FORMAT(15X,'CARD                  NO.     NO. OF   ',
        1'   NO. OF     NO. OF'/
        2      15X,'TYPE                  OF      UPSTREAM',3X,
        3   'UPSTREAM  DOWNSTREAM'/
        433X,   '  JUNCTION   STRETCH'
        53X,         ' STRETCH   STRETCH')
        DO 11 K=1,NJUNC
        READ(NI,33) DUM1,DUM2,I,(JUNC(I,J),J=1,3)
33      FORMAT(2A4,13X,I2,2X,3(4X,I2,4X))
        WRITE(NJ,806) DUM1,DUM2,I,(JUNC(I,J),J=1,3)
806     FORMAT(15X,2A4,12X,I5,3(5X,I5))
11      CONTINUE
        READ(NI,1) DUM1,DUM2
        WRITE(NJ,801) DUM1,DUM2
        IF(DUM1.NE.ENDF) GO TO 777
        WRITE(NJ,906)
906     FORMAT(40X,'* * * FILE E - HEAD WATERS * * *'//)
```

```
      WRITE(NJ,605)
605   FORMAT(15X,'CARD',22X,'NO. OF',18X,'INSERT 1',7X,
     1'PERCENT',4X,'CARBON.',3X,'NITROG.'/15X,'TYPE',21
     2X,'HEADWATER',18X,'FOR',12X,'D.O.',7X,'BOD',7X,'
     3BOD'/41X,'STRETCH',14X,'AUGMENTATION',7X,'STAT.',
     45X,'(MG/L)',5X,'(MG/L)')
      DO 12 K=1,NINIT
      READ(NI,27) DUM1,DUM2,I,IAUG(I),(CONDZ(I,J),J=1,3)
      INIT(K)=I
27    FORMAT(2A4,21X,I2,8X,I2,9X,3(2X,F8.0))
      WRITE(NJ,807) DUM1,DUM2,I,IAUG(I),(CONDZ(I,J),J=1,3)
807   FORMAT(15X,2A4,17X,I5,15X,I10,5X,3(2X,F8.1))
12    CONTINUE
      READ(NI,1) DUM1,DUM2
      WRITE(NJ,801) DUM1,DUM2
      IF(DUM1.NE.ENDF) GO TO 777
      WRITE (NJ,907)
907   FORMAT(31X'* * * FILE F(1) - DATA(I,J) THRU DATA(1,6)  * * *'//)
      WRITE(NJ,606)
606   FORMAT(15X,'CARD                 NO. LENGTH OF RIVER M
     1ILE CARBON,    NITROG.   COEF.     EXP.',/
     2      15X,'TYPE                 OF    REACH    TO HEA
     3D   REACTION   REACTION ON Q FOR  ON Q FOR',/
     4      15X,'                    REACH  (MILES)  OF REACH  COEF.
     5      COEF.    VELOCITY   VELOCITY',/)
      DO 100 K=1,NREA
      READ (NI,105) DUM1,DUM2,I,(DATA(I,J),J=1,6)
105   FORMAT(2A4,8X,I2,2X,6(2X,F8.0))
      WRITE(NJ,808) DUM1,DUM2,I,(DATA(I,J),J=1,6)
808   FORMAT(15X,2A4,7X,I5,2(2X,F8.1),4(2X,F8.3))
100   CONTINUE
      READ(NI,1) DUM1,DUM2
      WRITE(NJ,801)DUM1,DUM2
      IF(DUM1.NE.ENDF) GO TO 777
      WRITE(NJ,908)
908   FORMAT(51X,'* * * FILE F(2) - DATA(I,7) THRU DATA(I,14)
     1 * * *',//)
      WRITE(NJ,607)
607   FORMAT(15X,'CARD',13X,'NO.',6X,'INCREMENTAL (RUN OFF)
     1 FLOWS',3X,'SEWAGE AND INDUSTRIAL  FLOWS'/15X,'TYPE'
     2,13X,'OF',6X,'FLOW',3X,'DISS. CARBON. NITROG.',2X,
     3'FLOW',3X,'DISS.',2X,'CARBON.',1X,'NITROG.'/31X,
     4'REACH',4X,'RATE',3X,'OXYGEN',1X,'BOD',4X,'BOD',6X,
     5'RATE',2X,'OXYGEN',4X,'BOD',3X,'BOD')
      DO 150 K=1,NREA
      READ(NI,140) DUM1,DUM2,I,(DATA(I,J),J=7,14)
140   FORMAT(2A4,8X,I2,2X,2(2X,F7.0,2X,F5.0,2X,F5.0,2X,F5.0))
      WRITE(NJ,809) DUM1,DUM2,I,(DATA(I,J),J=7,14)
809   FORMAT(15X,2A4,7X,I5,2(2X,F7.1,2X,F5.1,2X,F5.1,2X,F5.1))
150   CONTINUE
```

```
        READ(NI,1) DUM1,DUM2
        WRITE(NJ,801) DUM1,DUM2
        IF(DUM1.NE.ENDF) GO TO 777
        WRITE(NJ,909)
 909    FORMAT(30X,'* * * FILE F(3) - DATA(I,15) THRU DATA(I,20)',
        1' * * * ,'//)
        WRITE(NJ,608)
 608    FORMAT(15X,'CARD            NO.     VALUE  COEF. O',
        1'N  EXP.  ON  EXP. ON  COEFF.  ON   EXP. ON',/,
        215X,'TYPE           OF   FOR  K2    V FOR K
        32   V FOR K2   D FOR K2  Q FOR K2   Q FOR K2',/,
        415X,'             REACH OPTION-1  OPTION-2  OPTION-2
        5  OPTION 2 OPTION-3 OPTION-3'/)
        DO 160 K=1,NREA
        READ(NI,170) DUM1,DUM2,I,(DATA(I,J),J=15,20)
 170    FORMAT(2A4,8X,I2,2X,6(2X,F8.0))
        WRITE(NJ,810) DUM1,DUM2,I,((DATA(I,J),J=15,20))
 810    FORMAT(15X,2A4,7X,I5,6(2X,F8.3))
 160    CONTINUE
        READ(NI,1) DUM1,DUM2
        WRITE(NJ,801) DUM1,DUM2
        IF(DUM1.NE.ENDF) GO TO 777
        WRITE(NJ,910)
 910    FORMAT(30X,'**** FILE F(4)    DATA(I,21) THROUGH DATA(I,23)')
        WRITE(NJ,609)
 609    FORMAT(15X,'  CARD             NO.  OPTION             NAME
        1            COEF.      EXP.    CHANNEL'/
        215X'TYPE             OF     FOR       OF           ON Q FOR
        3   ON Q FOR    'LOPE'/15X'             REACH    K2      REACH
        4          DEPTH      DEPTH     OPTION-4')
        DO 230 K=1,NREA
        READ(NI,240) DUM1,DUM2,I,K2OPT(I),(RIDENT(I,J),J=1,5),
        1(DATA(I,J),J=21,23)
 240    FORMAT(2A4,8X,I2,6X,I2,4X,5A4,3(2X,F8.0))
        WRITE(NJ,811) DUM1,DUM2,I,K2OPT(I),(RIDENT(I,J),J=1,5),
        1(DATA(I,J),J=21,23)
 811    FORMAT(15X,2A4,7X,I5,4X,I2,4X,5A4,3(2X,F8.3))
 230    CONTINUE
        READ(NI,1)DUM1,DUM2
        WRITE(NJ,801)DUM1,DUM2
        IF(DUM1.NE.ENDF) GO TO 777
        WRITE(NJ,911)
 911    FORMAT (34X,'* * * FILE G - BASIN CHARACTERISTICS * * *',//)
        WRITE (NJ,610)
 610    FORMAT(15X,'CARD          MINIMUM ALLOWABLE
        1       PERCENT TREATMENT  (M+ I FLOWS)     ',/,
        215X,'TYPE          D.O. LEVEL  (MG/L)   ',
        3'CAR  NIT  CAR  NIT  CAR  NIT  CAR  NIT')
        READ(NI,5) DUM1,DUM2,(DOL(I),I=1,4),(TRFAC(I),TRFACN(I),I=1,4
 5      FORMAT(2A4,7X,4F5.0,5X,8F5.0)
```

```
      WRITE(NJ,812) DUM1,DUM2,(DOL(I),I=1,4),(TRFAC(I),TRFACN(I),I=1,4)
812   FORMAT(15X,2A4,7X,4F5.1,5X,8F5.1)
      READ(NI,1) DUM1,DUM2
      WRITE(NJ,801) DUM1,DUM2
      IF(DUM1.NE.ENDF) GO TO 777
      WRITE(NJ,912)
912   FORMAT(32X,'* * * FILE H - MEAN MONTHLY TEMPERATURES * * *',//)
      WRITE(NJ,611)
611   FORMAT(15X,'CARD               STREAM TEMPERATURE IN DEGREES
     1 CENTIGRADE     ',/,15X,'TYPE                OCT  NOV  DEC  JAN  FEB
     2  MAR  APR  MAY  JUN  JUL  AUG  SEP'/)
      READ(NI,6) DUM1,DUM2,(TEMMO(I),I=1,12)
6     FORMAT(2A4,12X,12F5.0)
      WRITE(NJ,813) DUM1,DUM2,(TEMMO(I),I=1,12)
813   FORMAT(15X,2A4,12X,12F5.1)
      READ(NI,1) DUM1,DUM2
      WRITE(NJ,801)DUM1,DUM2
      IF(DUM1.NE.ENDF) GO TO 777
      WRITE(NJ,913)
913   FORMAT(31X,'* * * FILE I - MEAN MONTHLY HEADWATER FLOWS * * * '//)
      WRITE(NJ,612)
612   FORMAT(15X,'CARD     NO.  OF          HEADWATER  FLOWS IN
     1 CFS            ',/,15X,'TYPE     HEADWATER   OCT  NOV  DEC  JAN
     2  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP'/)
      DO 250 K=1,NINIT
      READ(NI,260) DUM1,DUM2,I,(HWFLOW(I,J),J=1,12)
260   FORMAT(2A4,3X,I2,7X,12F5.0)
      WRITE(NJ,270) DUM1,DUM2,I,(HWFLOW(I,J),J=1,12)
270   FORMAT(15X,2A4,2X,I5,5X,12F5.1)
250   CONTINUE
      READ(NI,1) DUM1,DUM2
      WRITE(NJ,801) DUM1,DUM2
      IF(DUM1.NE.ENDF) GO TO 777
      DO 25 L=1,NINIT
      CONDZ(L,1)=CONDZ(L,1)/100.0
25    CONTINUE
      NRUN=0
      DO 13 I=1,4
      IF(DOL(I)) 20,13,20
20    DOLEV=DOL(I)
      DO 14 J=1,4
      IF(TRFAC(J)+TRFACN(J)) 21,14,21
21    TF=TRFAC(J)/100.0
      TFN=TRFACN(J)/100.0
      DO 15 K=1,12
      IF(TEMMO(K)) 22,15,22
22    TEMP=TEMMO(K)
      NSEAS=K
      DO 24 L=1,NINIT
      CONDZ(L,4)=HWFLOW(L,K)
```

```
24      CONTINUE
        IF(ICK) 3335,3335,3336
3335    WRITE(NJ,2055)
        WRITE(NJ,334)
334     FORMAT(26X,'* * * *  INTERMEDIATE SUMMARY  * * * *',//)
        WRITE(NJ,8011)(TITLE(L),L=1,18)
8011    FORMAT(19X,18A4//)
        NRUN=NRUN+1
        WRITE(NJ,335) NRUN,DOLEV,TF,TFN,SEASON(NSEAS),TEMP
335     FORMAT(15X,'NUMBER OF RUN =',I5,36X,'TARGET D.O. LEVEL =',
        1F5.2,/,15X,'TREATMENT (C) =',F5.2,36X,'TREATMENT(N) =',
        3F5.2/15X'SEASON OF YR. = ',A3,36X,'MEAN TEMPERATURE =',F5.2//)
3336    CALL RUNON
C       STEP 4
C       REPEAT STEP 2 THRU STEP 3 UNTIL ALL COMBINATIONS OF BASIN
C       CONDITIONS HAVE BEEN ANALYZED
15      CONTINUE
14      CONTINUE
13      CONTINUE
        GO TO 7777
777     WRITE(NJ,778)
778     FORMAT(1H1,21X,'* * * * * * * * * * * * * * * * * * * * * * * * * * *
        1 * * * * * * * * * * * * * * * '//22X'* EXECUTION  WAS TERMINATED
        2 BECAUSE OF'/23X'*  ERRORS  IN  INPUT DATA    *'//21X,'* * * * * *
        3 * * * * * * * *  * * * * * * * * * * * * * * * * * * * * * * * * ')
        GO TO 9999
7777    CONTINUE
9999    CONTINUE
        STOP
        END
C**********************************************************************
C######################################################################

        SUBROUTINE DOSAT
        COMMON CRMIN(50),JNIT(20),F(10),C(11),IONE(20),G(15),TITLE(20),
        1IORD(20,20),JUNC(20,3),INIT(10),IAUG(20),DOL(10),TRFAC(10),
        2CONDZ(20,4),TEMMO(12),DATA(50,25),FINIS(50,16),CONDI(20,4),
        3IDMCH(20,10),CONDE(20,4),RIDENT(50,5),HWFLOW(10,12),
        4TRFACN(10),K2OPT(50),SEASON(12)
        COMMON/C2/ JJ,KK,II,B,RMLOW,MAX,CLOW,NTRIB,NREA,NINIT,NJUNC,ELEV,
        1DOLEV,TF,TEMP,CSAT,M,QUP,FINL,FINC,JA,IA,ICK,FINLN,DELQ,
        2NI,NJ,K2,VEL,NSEAS,NRUN,TFN
        REAL K2
        CSAT=(14.62-(0.3898*TEMP)+(0.006969*TEMP**2)-(0.00005897*TEMP**3))*(
        1(1.0-(0.00000697*ELEV))**5.167)
        RETURN
        END
C**********************************************************************
C######################################################################
        SUBROUTINE CHKPO
```

```
      COMMON CRMIN(50),JNIT(20),F(10),C(11),IONE(20),G(15),TITLE(20),
     1IORD(20,20),JUNC(20,3),INIT(10),IAUG(20),DOL(10),TRFAC(10),
     2CONDZ(20,4),TEMMO(12),DATA(50,25),FINIS(50,16),CONDI(20,4),
     3IDMCH(20,10),CONDE(20,4),RIDENT(50,5),HWFLOW(10,12),
     4TRFACN(10),K2OPT(50),SEASON(12)
      COMMON/C2/ JJ,KK,II,B,RMLOW,MAX,CLOW,NTRIB,NREA,NINIT,NJUNC,ELEV,
     1DOLEV,TF,TEMP,CSAT,M,QUP,FINL,FINC,JA,IA,ICK,FINLN,DELQ,
     2NI,NJ,K2,VEL,NSEAS,NRUN,TFN
      REAL K2
      I=0
      B=B-0.000001
3     IF(B+(10.0**(-I))) 2,2,1
1     I=I+1
      GO TO 3
2     BA=(10.0**I)*B
      BB=BA-B
      BC=EXP(BA)
      BD=EXP(BB)
      B=BC/BD
      RETURN
      END
C*********************************************************************
C#####################################################################
      SUBROUTINE REPRE
      COMMON CRMIN(50),JNIT(20),F(10),C(11),IONE(20),G(15),TITLE(20),
     1IORD(20,20),JUNC(20,3),INIT(10),IAUG(20),DOL(10),TRFAC(10),
     2CONDZ(20,4),TEMMO(12),DATA(50,25),FINIS(50,16),CONDI(20,4),
     3IDMCH(20,10),CONDE(20,4),RIDENT(50,5),HWFLOW(10,12),
     4TRFACN(10),K2OPT(50),SEASON(12)
      COMMON/C2/ JJ,KK,II,B,RMLOW,MAX,CLOW,NTRIB,NREA,NINIT,NJUNC,ELEV,
     1DOLEV,TF,TEMP,CSAT,M,QUP,FINL,FINC,JA,IA,ICK,FINLN,DELQ,
     2NI,NJ,K2,VEL,NSEAS,NRUN,TFN
      REAL K2
      G(1)=DATA(IA,3)*1.047**(TEMP-20.0)
      G(2)=QUP+DATA(IA,7)+DATA(IA,11)
      G(5)=DATA(IA,2)
      G(7)=TEMP
      G(9)=CSAT
      G(10)=DATA(IA,1)
      G(11)=DATA(IA,4)*1.047**(TEMP-20.0)
      IF(DATA(IA,11)) 1,2,2
1     G(6)=((QUP*FINL)+(DATA(IA,7)*DATA(IA,9))+(DATA(IA,11)*FINL))/G(2)
      G(8)=((QUP*FINC)+(DATA(IA,7)*DATA(IA,8))+(DATA(IA,11)*FINC))/G(2)
      G(12)=((QUP*FINLN)+(DATA(IA,7)*DATA(IA,10))+(DATA(IA,11)*FINLN))/G(2)
      GO TO 3
2     G(6)=((QUP*FINL)+(DATA(IA,7)*DATA(IA,9))+(DATA(IA,11)*DATA(IA,13)*
     1(1.0-TF)))/G(2)
      G(8)=((FINC*QUP)+(DATA(IA,7)*DATA(IA,8))+(DATA(IA,11)*DATA(IA,12))
     1)/G(2)
      G(12)=((QUP*FINLN)+(DATA(IA,7)*DATA(IA,10))+(DATA(IA,11)*DATA(IA,14)
```

```
        1*(1.0-TFN)))/G(2)
3       CONTINUE
        RETURN
        END
C************************************************************************
C######$################################################################
        SUBROUTINE BLEND
        COMMON CRMIN(50),JNIT(20),F(10),C(11),IONE(20),G(15),TITLE(20),
        1IORD(20,20),JUNC(20,3),INIT(10),IAUG(20),DOL(10),TRFAC(10),
        2CONDZ(20,4),TEMMO(12),DATA(50,25),FINIS(50,16),CONDI(20,4),
        3IDMCH(20,10),CONDE(20,4),RIDENT(50,5),HWFLOW(10,12),
        4TRFACN(10),K2OPT(50),SEASON(12)
        COMMON/C2/ JJ,KK,II,B,RMLOW,MAX,CLOW,NTRIB,NREA,NINIT,NJUNC,ELEV,
        1DOLEV,TF,TEMP,CSAT,M,QUP,FINL,FINC,JA,IA,ICK,FINLN,DELQ,
        2NI,NJ,K2,VEL,NSEAS,NRUN,TFN
        REAL K2
        CONDI(KK,4)=CONDE(JJ,4)+CONDE(II,4)
        DO 3 I=1,3
2       CONDI(KK,I)=((CONDE(JJ,4)*CONDE(JJ,I))+(CONDE(II,4)*CONDE(II,I)))
        1/CONDI(KK,4)
3       CONTINUE
        RETURN
        END
C************************************************************************
C########################################################################
        SUBROUTINE DOEQU
        COMMON CRMIN(50),JNIT(20),F(10),C(11),IONE(20),G(15),TITLE(20),
        1IORD(20,20),JUNC(20,3),INIT(10),IAUG(20),DOL(10),TRFAC(10),
        2CONDZ(20,4),TEMMO(12),DATA(50,25),FINIS(50,16),CONDI(20,4),
        3IDMCH(20,10),CONDE(20,4),RIDENT(50,5),HWFLOW(10,12),
        4TRFACN(10),K2OPT(50),SEASON(12)
        COMMON/C2/ JJ,KK,II,B,RMLOW,MAX,CLOW,NTRIB,NREA,NINIT,NJUNC,ELEV,
        1DOLEV,TF,TEMP,CSAT,M,QUP,FINL,FINC,JA,IA,ICK,FINLN,DELQ,
        2NI,NJ,K2,VEL,NSEAS,NRUN,TFN
        REAL K2
        MAX=10
        XSUM=0.0
        TSUM=0.0
        VSUM=0.0
        HSUM=0.0
        DO 1,I=1,10
        Z=I
        F(I)=G(5)-G(10)*Z/10.
        DELQ=QUP+((G(2)-QUP)*Z/10.0)
        VEL=DATA(IA,5)*(DELQ**DATA(IA,6))
        IF(DATA(IA,1)) 40,40,50
40      VEL=0.0
50      CONTINUE
        IF(VEL-.0001) 10,20,20
10      G(3)=0.0
```

```
      GO TO 30
20    G(3)=(DATA(IA,1)/10.0)/(VEL*16.36)
30    CONTINUE
      CALL K2CAL
      HSUM=HSUM+FINIS(IA,13)
      TEMPC=1.0159**(TEMP-20)
      G(4)=K2*TEMPC
      VSUM=VSUM+VEL
      TSUM=TSUM+G(3)
      XSUM=XSUM+G(4)
      G(4)=XSUM/Z
      IF(G(1).EQ.0.0) GO TO 5
      A=G(1)*G(6)/(G(4)-G(1))
      GO TO 6
5     A=0.0
6     CONTINUE
      IF(G(11).EQ.0.0) GO TO 7
      AA=G(11)*G(12)/(G(4)-G(11))
      GO TO 8
7     AA=0.0
8     CONTINUE
      TA=TSUM
      B=TA*(-G(1))
      CALL CHKPO
      DD=B
      B=TA*(-G(11))
      CALL CHKPO
      DN=B
      B=TA*(-G(4))
      CALL CHKPO
      DR=B
      C(I)=A*(DR-DD)+AA*(DR-DN)+DR*(G(8)-G(9))+G(9)
      IF(C(I).LE.0.0) C(I)=0.0
1     CONTINUE
      XK2A=XSUM/10.0
      VELA=VSUM/10.0
      FINL=G(6)*DD
      FINLN=G(12)*DN
      FINC=C(10)
      CALL CMIN
      IF(ICK) 91,91,92
91    V=G(6)
      Y=G(2)
      X=G(3)
      VV=G(12)
      XX=C(1)
      WRITE(NJ,2) IA,X,Y,CLOW,RMLOW,XX,FINC,V,FINL,VV,FINLN
2     FORMAT (7X,I3,4X,F7.1,2X,F7.1,2X,F5.2,3X,F7.1,5X,F5.2,4X,F5.2,
      13X,F6.2,3X,F6.2,3X,F6.2,3X,F6.2)
92    FINIS(IA,1)=IA
```

```
      FINIS(IA,2)=G(5)
      FINIS(IA,3)=G(10)
      FINIS(IA,4)=G(2)
      FINIS(IA,5)=CLOW
      FINIS(IA,6)=RMLOW
      FINIS(IA,7)=FINC
      FINIS(IA,8)=XK2A/TEMPC
      FINIS(IA,9)=TSUM
      FINIS(IA,10)=VELA
      FINIS(IA,11)=FINL
      FINIS(IA,12)=FINLN
      FINIS(IA,13)=HSUM/10.0
      FINIS(IA,14)=C(1)
      FINIS(IA,15)=G(6)
      FINIS(IA,16)=G(12)
      RETURN
      END
C***********************************************************************
C#######################################################################
      SUBROUTINE CMIN
      COMMON CRMIN(50),JNIT(20),F(10),C(11),IONE(20),G(15),TITLE(20),
      1IORD(20,20),JUNC(20,3),INIT(10),IAUG(20),DOL(10),TRFAC(10),
      2CONDZ(20,4),TEMMO(12),DATA(50,25),FINIS(50,16),CONDI(20,4),
      3IDMCH(20,10),CONDE(20,4),RIDENT(50,5),HWFLOW(10,12),
      4TRFACN(10),K2OPT(50),SEASON(12)
      COMMON/C2/ JJ,KK,II,B,RMLOW,MAX,CLOW,NTRIB,NREA,NINIT,NJUNC,ELEV,
      1DOLEV,TF,TEMP,CSAT,M,QUP,FINL,FINC,JA,IA,ICK,FINLN,DELQ,
      2NI,NJ,K2,VEL,NSEAS,NRUN,TFN
      REAL K2
      ITER=MAX-1
      DO 1 I=1,ITER
      IF(C(I)-C(I+1))2,1,1
2     C(I+1)=C(I)
      F(I+1)=F(I)
1     CONTINUE
      RMLOW=F(MAX)
      IF(RMLOW.LE.0.0) RMLOW=0.0
      CLOW=C(MAX)
      RETURN
      END
C***********************************************************************
C#######################################################################
      SUBROUTINE K2CAL
      COMMON CRMIN(50),JNIT(20),F(10),C(11),IONE(20),G(15),TITLE(20),
      1IORD(20,20),JUNC(20,3),INIT(10),IAUG(20),DOL(10),TRFAC(10),
      2CONDZ(20,4),TEMMO(12),DATA(50,25),FINIS(50,16),CONDI(20,4),
      3IDMCH(20,10),CONDE(20,4),RIDENT(50,5),HWFLOW(10,12),
      4TRFACN(10),K2OPT(50),SEASON(12)
      COMMON/C2/ JJ,KK,II,B,RMLOW,MAX,CLOW,NTRIB,NREA,NINIT,NJUNC,ELEV,
      1DOLEV,TF,TEMP,CSAT,M,QUP,FINL,FINC,JA,IA,ICK,FINLN,DELQ,
```

```
      2NI,NJ,K2,VEL,NSEAS,NRUN,TFN
      REAL K2
      H=DATA(IA,21)*(DELQ**DATA(IA,22))
      FINIS(IA,13)=H
      IOPT=K2OPT(IA)
      GO TO (1,2,3,4),IOPT
1     K2=DATA(IA,15)
      GO TO 100
2     K2=DATA(IA,16)*(VEL**DATA(IA,17))/(H**DATA(IA,18))*2.31
      GO TO 100
3     K2=DATA(IA,19)*(G(2)**DATA(IA,20))*2.31
      GO TO 100
4     K2=10.8*(1+((VEL/SQRT(32.17*H))**.5))*SQRT(DATA(IA,23)*2.17/
      1H)*2.31
100   CONTINUE
      RETURN
      END
C**********************************************************************
C######################################################################
      SUBROUTINE RUNON
      COMMON CRMIN(50),JNIT(20),F(10),C(11),IONC(20),G(15),TITLE(20),
      1IORD(20,20),JUNC(20,3),INIT(10),IAUG(20),DOL(10),TRFAC(10),
      2CONDZ(20,4),TEMMO(12),DATA(50,25),FINIS(50,16),CONDI(20,4),
      3IDMCH(20,10),CONDE(20,4),RIDENT(50,5),HWFLOW(10,12),
      4TRFACN(10),K2OPT(50),SEASON(12)
      COMMON/C2/ JJ,KK,II,B,RMLOW,MAX,CLOW,NTRIB,NREA,NINIT,NJUNC,ELEV,
      1DOLEV,TF,TEMP,CSAT,M,QUP,FINL,FINC,JA,IA,ICK,FINLN,DELQ,
      2NI,NJ,K2,VEL,NSEAS,NRUN,TFN
      REAL K2
C     STEP 1
C     SET ALL HEADWATER CONDITIONS
C     EQUAL. TO ZERO.
      DO 1 I=1,20
      DO 1 J=1,4
1     CONDI(I,J)=CONDZ(I,J)
C     STEP 2
      CALL DOSAT
C     STEP 3
C     CALCULATE D.O. LEVEL FOR ALL
C     HEADWATER STRETCHES.
      DO 2 I=1,20
2     CONDI(I,1)=CONDI(I,1)*CSAT
3     M=0
      IF(ICK) 3335,3335,3333
C     STEP 4
C     WRITE HEADING FOR INTERMEDIATE
C     REACH SUMMARY.
3335  WRITE(NJ,388)
388   FORMAT(1H0)
      WRITE(NJ,333)
```

```
333     FORMAT(8X,'NO.',2X,'RIVER MILE',2X,'FLOW',4X,'D.O.',2X,'RIVER MILE
        1',2X,'DISSOLVED',1X,'OXYGEN',2X,'CARBONACEOUS',1X,'BOD',2X,
        2'NITROGENOUS',2X,'BOD'/8X,'OF',5X,'TO HEAD',3X,'RATE',4X,'MIN.',
        34X,'AT MIN.',3X,'AT START',2X,'AT END',2X,'AT START',2X,'AT END',2X,
        4'AT START',2X,'AT END'/7X,'REACH',2X,'OF REACH',3X,'(CFS)',2X,'(MG/L)'
        5,4X,'D.O.',6X,'(MG/L)',3X,'(MG/L)',3X,'(MG/L)',3X,'(MG/L)',3X,'(MG/L)'
        6,3X,'(MG/L)'/7X,5(','),1X,9(','),3X,5(','),2X,6(','),1X,10(','),2X,
        78(','),2X,6(','),2X,8(','),2X,6(','),2X,8(','),2X,6(','))
C
C       STEP 5
C                                         CALL REINI
3333    CALL REINI
        IF(M) 4,4,3
C       STEP 6
C       CALL R MATC
4       CALL RMATC
        IF(M) 5,5,3
5       WRITE(NJ,2055)
2055    FORMAT(1H1)
        WRITE(NJ,24)
24      FORMAT (33X,'* * * * * FINAL SUMMARY * * * * * * ',//)
        WRITE(NJ,336)  (TITLE(I),I=1,18)
336     FORMAT(19X,13A4,//)
        WRITE(NJ,335) NRUN,DOLEV,TF,TFN,SEASON(NSFAS),TEMP
335     FORMAT(15X,'NUMBER OF RUN =',I5,36X,'TARGET D.O. LEVEL =',
        1  F5.2,/,
        215X,'TREATMENT (C) =',F5.2,36X,'TREATMENT (N)   =',
        3F5.2,/,
        415X,'SEASON OF YR. = ',A3,36X,'MEAN TEMPERATURE =',
        5F5.2,//)
        WRITE(NJ,25)
25      FORMAT(11X,'NO.',5X,'IDENTIFICATION',4X,'RIVER MILE',2X,'REACH',3X,
        1'FLOW',4X,'D.O.',2X,'RIVER MILE',2X,'DISSOLVED',1X,'OXYGEN'/11X,
        2'OF',12X,'OF',11X,'TO HEAD',3X,'LENGTH',3X,'RATE',4X,'MIN.',4X,
        3'AT MIN.',3X,'AT START',2X,'AT END'/10X,'REACH',9X,'REACH',9X,
        4'OF REACH',2X,'(MILES)',2X,'(CFS)',2X,'(MG/L)',4X,'D.O.',6X,'(MG/L)
        5',3X,'(MG/L)'/10X,5(','),1X,20(','),1X,10(','),1X,7(','),2X,5(','),
        62X,6(','),1X,10(','),2X,8(','),2X,6(','))
        DO 88 I=1,NREA
        IR=FINIS(I,1)
        WRITE(NJ,28) IR,(RIDENT(I,J),J=1,5),(FINIS(I,J),J=2,6),
        1FINIS(I,14),FINIS(I,7)
88      CONTINUE
28      FORMAT(10X,I3,3X,5A4,2X,F7.1,4X,F5.1,1X,F7.1,2X,F5.2,3X,F7.1,
        15X,F5.2,4X,F5.2)
        WRITE(NJ,2055)
        WRITE(NJ,24)
        WRITE(NJ,336) (TITLE(I),I=1,18)
        WRITE(NJ,335) NRUN,DOLEV,TF,TFN,SEASON(NSEAS),TEMP
        WRITE(NJ,30)
```

```
30      FORMAT(8X,'NO.',5X,'IDENTIFICATION',6X,'CARBONACEOUS',1X,'BOD'
        1,2X,'NITROGENOUS',2X,'BOD',4X,'K2',4X,'TRAVEL',5X,'MEAN',5X,
        2'MEAN'/8X,'OF',12X,'OF',12X,'AT START',2X,'AT END',2X,'AT START',2X,
        2'AT END'
        3,2X,'VALUE',4X,'TIME',3X,'VELOCITY',2X,'DEPTH'/7X,'REACH',9X,
        4'REACH',11X,'(MG/L)',3X,'(MG/L)',3X,'(MG/L)',3X,'(MG/L)',1X,
        5'BASE  E',2X,'(DAYS)',4X,'(FPS)',3X,'(FT)'/7X,'.....',1X,
        621('.'),4X,8('.'),2X,6('.'),2X,8('.'),2X,6('.'),1X,7('.'),
        72X,6('.'),2X,8('.'),2X,5('.'))
        DO 89 I=1,NREA
        IR=FINIS(I,1)
        WRITE(NJ,32) IR,(RIDENT(I,J),J=1,5),FINIS(I,15),FINIS(I,11),
        1FINIS(I,16),FINIS(I,12),(FINIS(I,J),J=8,10),
        2FINIS(I,13)
89      CONTINUE
32      FORMAT(8X,I3,3X,5A4,1X,FR.2,3X,F6.2,3X,F6.2,3X,F6.2,1X,F7.3,
        12X,F7.3,2X,F6.2,3X,F5.1)
        WRITE(NJ,2055)
        WRITE(NJ,24)
        WRITE(NJ,336) (TITLE(I),I=1,18)
        WRITE(NJ,335) NRUN,DOLEV,TF,TFN,SEASON(NSEAS),TEMP
        WRITE(NJ,55)
55      FORMAT(34X,'NO.',7X,'NO.',4X,'INITIAL',2X,'FINAL',2X,'AUGMENTATION'/
        134X,'OF',8X,'OF',7X,'FLOW',4X,'FLOW',4X,'REQUIRED'/31X,'HEADWATER',2X
        2'STRETCH',3X,'(CFS)',3X,'(CFS)',5X,'(CFS)'/31X,9('.'),2X,7('.'),2X,
        37('.'),2X,5('.'),2X,12('.'))
        DO 100 I=1,NINIT
        QAUG=CONDI(I,4)-CONDZ(I,4)
        WRITE(NJ,56) I,INIT(I),CONDZ(I,4),CONDI(I,4),QAUG
56      FORMAT(31X,I5,5X,I5,4X,F7.1,1X,F7.1,3X,F7.1)
100     CONTINUE
        RETURN
        END
C************************************************************************
C########################################################################
        SUBROUTINE REINI
        COMMON CRMIN(50),JNIT(20),F(10),C(11),IONE(20),G(15),TITLE(20),
        1IORD(20,20),JUNC(20,3),INIT(10),IAUG(20),DOL(10),TRFAC(10),
        2CONDZ(20,4),TEMMO(12),DATA(50,25),FINIS(50,16),CONDI(20,4),
        3IDMCH(20,10),CONDE(20,4),RIDENT(50,5),HWFLOW(10,12),
        4TRFACN(10),K2OPT(50),SEASON(12)
        COMMON/C2/ JJ,KK,II,B,RMLOW,MAX,CLOW,NTRIB,NREA,NINIT,NJUNC,ELEV,
        1DOLEV,TF,TEMP,CSAT,M,QUP,FINL,FINC,JA,IA,ICK,FINLN,DELQ,
        2NI,NJ,K2,VEL,NSEAS,NRUN,TFN
        REAL K2
        DO 1 I=1,NINIT
        JA=INIT(I)
        IF(IAUG(JA))2,2,3
3       IDMCH (JA,1)=JA
        IDMCH(JA,2)=0
```

```
      GO TO 4
2     IDMCH(JA,1)=0
4     QUP=CONDI(JA,4)
      FINLN=CONDI(JA,3)
      FINL=CONDI(JA,2)
      FINC=CONDI(JA,1)
      CALL TRIBD
      CALL SCAN
      CONDE(JA,3)=FINLN
      CONDE(JA,4)=QUP
      CONDE(JA,2)=FINL
      CONDE(JA,1)=FINC
      IF(M) 1,1,5
1     CONTINUE
5     RETURN
      END
C**********************************************************************
C######################################################################
      SUBROUTINE RMATC
      COMMON CRMIN(50),JNIT(20),F(10),C(11),IONE(20),G(15),TITLE(20),
     1IORD(20,20),JUNC(20,3),INIT(10),IAUG(20),ICL(10),TRFAC(10),
     2CONDZ(20,4),TEMMO(12),DATA(50,25),FINIB(50,16),CONDI(20,4),
     3IDMCH(20,10),CONDE(20,4),RIDENT(50,5),HHFLOW(10,12),
     4TRFACN(10),K2OPT(50),SEASON(12)
      COMMON/C2/ JJ,KK,II,R,RMLOW,MAX,CLOW,NTRIB,NREA,NINIT,NJUNC,ELEV,
     1DOLEV,TF,TEMP,CSAT,M,QUP,FINL,FINC,JA,IA,ICK,FINLN,DELQ,
     2NI,NJ,K2,VEL,NSEAS,NRUN,TFN
      REAL K2
      DO 1,I=1,20
1     IONE(I)=0
      IF(NJUNC) 333,333,334
333   IONE(1)=1
334   DO 2 I=1,20
2     JNIT(I)=0
      IINIT=NINIT
      DO 3 I=1,IINIT
      JNIT(I)=INIT(I)
      J=INIT(I)
3     IONE(J)=I
16    DO 4 I=1,NJUNC
      DO 5 J=1,IINIT
      IF(JUNC(I,1)-JNIT(J)) 5,6,5
5     CONTINUE
      GO TO 4
6     DO 7 J=1,IINIT
      IF(JUNC(I,2)-JNIT(J)) 7,8,7
7     CONTINUE
      GO TO 4
8     II=JUNC(I,1)
      JJ=JUNC(I,2)
```

```
        KK=JUNC(I,3)
        JA=KK
        IAUG(KK)=1
        CALL BLEND
        FINLN=CONDI(KK,3)
        QUP=CONDI(KK,4)
        FINL=CONDI(KK,2)
        FINC=CONDI(KK,1)
        L=1
        LL=1
13      IF(IDMCH(JJ,L)) 9,9,10
10      IDMCH (KK,L)=IDMCH(JJ,L)
        L=L+1
9       IF(IDMCH(II,LL)) 11,11,12
12      IDMCH(KK,L)=IDMCH(II,LL)
        LL=LL+1
        L=L+1
        GO TO 9
11      IDMCH(KK,L)=0
        CALL TRIBD
        CALL SCAN
        CONDE(JA,1)=FINC
        CONDE(JA,2)=FINL
        CONDE(JA,3)=FINLN
        CONDE(JA,4)=QUP
        IF(N) 14,14,15
14      IONE(KK)=1
        IINIT=IINIT+1
        JNIT(IINIT)=KK
4       CONTINUE
        DO 17 I=1,NTRIB
        IF(IONE(I))16,16,17
17      CONTINUE
15      RETURN
        END
C****************************************************************************
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
        SUBROUTINE TRIBD
        COMMON CRMIN(50),JNIT(20),F(10),C(11),IONE(20),G(15),TITLE(20),
       1IORD(20,20),JUNC(20,3),INIT(10),IAUG(20),DOL(10),TRFAC(10),
       2CONDZ(20,4),TEMMO(12),DATA(50,25),FINIS(50,16),CONDI(20,4),
       3IDMCH(20,10),CONDE(20,4),RIDENT(50,5),HWFLOW(10,12),
       4TRFACN(10),K2OPT(50),SEASON(12)
        COMMON/C2/ JJ,KK,II,B,RMLOW,MAX,CLOW,NTRIB,NREA,NINIT,NJUNC,ELEV,
       1DOLEV,TF,TEMP,CSAT,M,QUP,FINL,FINC,JA,IA,ICK,FINLN,DELQ,
       2NI,NJ,K2,VEL,NSEAS,NRUN,TFN
        REAL K2
        I=1
2       IF(IORD(JA,I))1,1,3
3       IA=IORD(JA,I)
```

```
        CALL REPRE
        CALL DOEQU
        QUP=G(2)
        IF(QUP)10,10,20
10      CRMIN(IA)=CONDI(JA,1)
        GO TO 30
20      CRMIN(IA)=CLOW
30      CONTINUE
        I=I+1
        GO TO 2
1       RETURN
        END
C*************************************************************************
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
         SUBROUTINE SCAN
        COMMON CRMIN(50),JNIT(20),F(10),C(11),IONE(20),G(15),TITLE(20),
        1IORD(20,20),JUNC(20,3),INIT(10),IAUG(20),DOL(10),TRFAC(10),
        2CONDZ(20,4),TEMMO(12),DATA(50,25),FINIS(50,16),CONDI(20,4),
        3IDMCH(20,10),CONDE(20,4),RIDENT(50,5),HMFLOW(10,12),
        4TRFACN(10),K2OPT(50),SEASON(12)
        COMMON/C2/ JJ,KK,II,R,RMLOW,MAX,CLOW,NTRIB,NREA,NINIT,NJUNC,ELEV,
        1DOLEV,TF,TEMP,CSAT,M,QUP,FINL,FINC,JA,IA,ICK,FINLN,DELQ,
        2NI,NJ,K2,VEL,NSEAS,NRUN,TFN
        REAL K2
        I=0
        IF(IAUG(JA)) 1,1,2
2       I=I+1
        IF(IORD(JA,I))1,1,3
3       IA=IORD(JA,I)
        Z=DOLEV-CRMIN(IA)
        IF(Z-0.05)2,2,5
4       CONTINUE
5       QADD=QUP*(Z/DOLEV+0.25*(Z/DOLEV)**2)
        L=1
        LL=0
        M=1
7       IF(IDMCH(JA,L))1,8,6
6       LL=LL+1
        L=L+1
        GO TO 7
8       W=LL
        QPLUS=QADD/W
        L=1
10      IF(IDMCH(JA,L))1,1,9
9       IB=IDMCH(JA,L)
        CONDI(IB,4)=CONDI(IB,4)+(0.5*QPLUS)
12      L=L+1
        GO TO 10
1       RETURN
        END
```

```
FILE A  HINDON RIVER BASIN DOSAG VERSION
ENDFILE A
FILE B       1          1           4          01          00'
ENDFILE B
            1          1  2  3  4  0  0  0  0  0  0  0  0  0  0  0  0  0  0
ENDFILE C
                       1        01          2          3
ENDFILE D
                                01          00                     92.5      324.0
ENDFILE E
                  1         00.2      201.0      0.400        0.0       0.560    0
                  2          0.3      200.8      0.380        0.0       0.690    0
                  3          0.4      200.4      0.750        0.0       0.600    0
                  4          0.5      200.0      0.280        0.0       0.630    0
ENDFILE F-1
                  1         5.3      5.4   340.0     0.0        3.5      1.2   340.0
                  2         0.0      0.0     0.0     0.0        0.0      0.0     0.0
                  3         0.0      0.0     0.0     0.0        0.0      0.0     0.0
                  4         0.0      0.0     0.0     0.0        0.0      0.0     0.0
ENDFILE F-2
FILE F-3      4   1         43.1      0.000      0.00     0.000        0.0
                  2         20.7      0.000      0.00     0.000        0.0
                  3         13.2      0.000      0.00     0.000        0.0
                  4         40.6      0.000      0.00     0.000        0.0
ENDFILE F-3
                  1      1      SW17-SW18                  0.000      0.000
                  2      1      SW18-SW19                  0.000      0.000
                  3      1      SW19-SW20                  0.000      0.000
                  4      1      SW20-SW21                  0.000      0.000
ENDFILE F-4
FILE G  901234500.01 0.0  0.0  ..0     0.001
ENDFILE G
FILE H                 0.0  0.   0.0  0.0  0.0  0.0 32.0  0.0  0.0  0.0  0.0
ENDFILE H
FILE I     1           0.0  0.   0.0  0.0  0.0  0.0  8.8  0.0  0.0  0.0  0.0
ENDFILE I
```

```
1
                        * * * FILE A - BASIN TITLE * * *

          CARD                          NAME OF
          TYPE                         RIVER BASIN
          FILE A  HINDON.RIVER BASIN DOSAG VERSION
0          ENDFILE
                      * * * FILE B - PHYSICAL DESCRIPTION * * *



          CARD            NO. OF    NO. OF    NO. OF     NO. OF    INSERT 1           MEAN
          TYPE          HEAD WATERS JUNCTIONS REACHES   STRETCHES FOR FINAL          ELEV.
                         MAX OF 10 MAX OF 10 MAX OF 50  MAX OF 20  SUMMARY            (FT)

          FILE B           1         1         4          1         0               510.0
0          ENDFILE
                        * * * FILE C - REACH ORDER * * *


          CARD      NO. OF             ORDER OF ALL REACHES IN EACH STRE  H
          TYPE      STRETCH                    (UPSTREAM TO  DOWNSTREAM)

                      1       1  2  3  4  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0          ENDFILE
                          *  *  * FILE D  - JUNCTIONS  * * *


          CARD                   NO.     NO. OF      NO. OF     NO. OF
          TYPE                   OF     UPSTREAM    UPSTREAM  DOWNSTREAM
                              JUNCTION   STRETCH     STRETCH    STRETCH
                                 1          1           2          3
0          ENDFILE
                         * * * FILE E - HEAD WATERS * * *


          CARD                    NO. OF                  INSERT 1      PERCENT    CARBON.  NITROG.
          TYPE                   HEADWATER                  FOR          D.O.       BOD      BOD
                                  STRETCH               AUGMENTATION     STAT.     (MG/L)   (MG/L
                                     1                        0          92.5     324.0     0.0
0          ENDFILE
                    * * * FILE F(1) - DATA(I,1) THRU DATA(1,6)  * * *


          CARD              NO. LENGTH OF RIVER MILE CARBON.    NITROG.  COEF.     EXP.
          TYPE               OF    REACH    TO HEAD  REACTION   REACTION ON Q FOR  ON Q FOR
                           REACH  (MILES)  OF REACH  COEF.      COEF.    VELOCITY  VELOCITY

                             1      0.2     201.0     0.400      0.000    0.560     0.335
```

```
                    2        0.3      200.3     0.380      0.000      0.690      0.335
                    3        0.4      200.4     0.750      0.000      0.600      0.335
                    4        0.5      200.0     0.280      0.000      0.630      0.335
0          ENDFILE
                                   * * * FILE F(2) - DATA(I,7) THRU DATA(I,14)  * * *


           CARD            NO.      INCREMENTAL (RUN OFF) FLOWS   SEWAGE AND INDUSTRIAL  FLOWS
           TYPE            OF     FLOW   DISS. CARBON, NITROG.  FLOW   DISS.  CARBON. NITROG.
                          REACH    RATE   OXYGEN BOD     BOD      RATE  OXYGEN    BOD    BOD
                            1      5.3    5.4  340.0    0.0      3.5    1.2  340.0    0.0
                            2      0.0    0.0    0.0    0.0      0.0    0.0    0.0    0.0
                            3      0.0    0.0    0.0    0.0      0.0    0.0    0.0    0.0
                            4      0.0    0.0    0.0    0.0      0.0    0.0    0.0    0.0
0          ENDFILE
                      * * * FILE F(3) - DATA(I,15) THRU DATA(I,20) * * * ,


           CARD            NO.     VALUE  COEF. ON  EXP.  ON  EXP. ON  COEFF.  ON   EXP. ON
           TYPE            OF   FOR  K2    V FOR K2  V FOR K2  D FOR K2  Q FOR K2   Q FOR K2
                        REACH OPTION-1  OPTION-2  OPTION-2  OPTION-2 OPTION-3 OPTION-3

           FILE F-3         1     43.100     0.000      0.000      0.000      0.000      0.000
                            2     20.700     0.000      0.000      0.000      0.000      0.000
                            3     13.200     0.000      0.000      0.000      0.000      0.000
                            4     40.600     0.000      0.000      0.000      0.000      0.000
0          ENDFILE
                      **** FILE F(4)    DATA(I,21) THROUGH DATA(I,23)
            CARD             NO.  OPTION                NAME           COEF.       EXP.    CHANNEL
           TYPE              OF     FOR        OF              ON Q FOR   ON Q FOR    SLOPE
                        REACH     K2        REACH           DEPTH      DEPTH      OPTION-4
                             1      1     SW17-SW18                    0.000      0.000      0.000
                             2      1     SW18-SW19                    0.000      0.000      0.000
                             3      1     SW19-SW20                    0.000      0.000      0.000
                             4      1     SW20-SW21                    0.000      0.000      0.000
0          ENDFILE
                           * * * FILE G - BASIN CHARACTERISTICS * * *


           CARD          MINIMUM ALLOWABLE,          PERCENT TREATMENT  (S+ I FLOWS)
           TYPE         D.O. LEVEL  (MG/L)   CAR  NIT  CAR  NIT  CAR  NIT  CAR  NIT  .
           FILE G           0.0  0.0  0.0  0.0        0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
0          ENDFILE
                          * * * FILE H - MEAN MONTHLY TEMPERATURES * * *


           CARD             STREAM TEMPERATURE IN DEGREES CENTIGRADE
           TYPE               OCT  NOV  DEC  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP

           FILE H                 0.0  0.0  0.0  0.0  0.0  0.0 32.0  0.0  0.0  0.0  0.0  0.0
```

```
0          ENDFILE
                         * * * FILE I - MEAN MONTHLY HEADWATER FLOWS * * *


          CARD     NO. OF           HEADWATER  FLOWS IN CFS
          TYPE     HEADWATER   OCT  NOV  DEC  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP

          FILE I       1       0.0  0.0  0.0  0.0  0.0  0.0  8.8  0.0  0.0  0.0  0.0  0.0
0          ENDFILE
1
                    * * * *  INTERMEDIATE SUMMARY  * * * *


             HINDON RIVER BASIN DOSAG VERSION


          NUMBER OF RUN =    1                                          TARGET D.O. LEVEL = 0.01
          TREATMENT (C) = 0.00                                          TREATMENT(N) = 0.00
          SEASON OF YR. = APR                                          MEAN TEMPERATURE =32.00


0
        NO.  RIVER MILE  FLOW   D.O.  RIVER MILE  DISSOLVED OXYGEN  CARBONACEOUS BOD  NITROGENOUS  BOD
        OF    TO HEAD    RATE   MIN.   AT MIN.    AT START  AT END  AT START  AT END  AT START  AT END
       REACH  OF REACH   (CFS) (MG/L)   D.O.       (MG/L)   (MG/L)   (MG/L)   (MG/L)   (MG/L)   (MG/L)

       +++++ +++++++++   +++++ ++++++ ++++++++++  ++++++++  ++++++  ++++++++  ++++++  ++++++++  ++++++
         1      201.0    17.6  4.29    200.8       5.08     4.29    332.00   329.89    0.00     0.00
         2      200.8    17.6  3.00    200.5       4.15     3.00    329.89   327.69    0.00     0.00
         3      200.4    17.6  0.00    200.0       2.45     0.00    327.69   321.11    0.00     0.00
         4      200.0    17.6  0.35    199.9       0.35     2.42    321.11   318.22    0.00     0.00
1
                           * * * * * FINAL SUMMARY * * * * * *


             HINDON RIVER BASIN DOSAG VERSION


          NUMBER OF RUN =    1                                          TARGET D.O. LEVEL = 0.01
          TREATMENT (C) = 0.00                                          TREATMENT (N)   = 0.00
          SEASON OF YR. = APR                                          MEAN TEMPERATURE =32.00


         NO.     IDENTIFICATION     RIVER MILE  REACH   FLOW   D.O.  RIVER MILE  DISSOLVED OXYGEN
         OF            OF            TO HEAD   LENGTH   RATE   MIN.    AT MIN.   AT START  AT END
        REACH        REACH          OF REACH  (MILES)  (CFS)  (MG/L)   D.O.      (MG/L)   (MG/L)

        +++++ +++++++++++++++++++  ++++++++++ +++++++  +++++  ++++++ ++++++++++  ++++++++  ++++++
          1   SW17-SW18               201.0     0.2    17.6   4.29     200.8       5.08     4.29
          2   SW18-SW19               200.8     0.3    17.6   3.00     200.5       4.15     3.00
          3   SW19-SW20               200.4     0.4    17.6   0.00     200.0       2.45     0.00
```

```
      4   SW20-SW21              200.0      0.5    17.6   0.35     199.9      0.35     2.42
1
                               * * * * * FINAL SUMMARY * * * * * *


          HINDON RIVER BASIN DOSAG VERSION



       NUMBER OF RUN =     1                                     TARGET D.O. LEVEL = 0.01
       TREATMENT (C) = 0.00                                      TREATMENT (N)   = 0.00
       SEASON OF YR. = APR                                      MEAN TEMPERATURE =32.00


   NO.     IDENTIFICATION        CARBONACEOUS BOD  NITROGENOUS  BOD    K2     TRAVEL     MEAN     MEAN
   OF            OF              AT START  AT END  AT START  AT END  VALUE     TIME    VELOCITY  DEPTH
  REACH         REACH             (MG/L)   (MG/L)   (MG/L)   (MG/L) BASE E   (DAYS)     (FPS)    (FT)
  *****  ********************     ********  ******  ********  ****** *******  ******   ********  *****
     1    SW17-SW18                332.00   329.89    0.00      0.00  43.100   0.009     1.34     0.0
     2    SW18-SW19                329.89   327.69    0.00      0.00  20.700   0.010     1.80     0.0
     3    SW19-SW20                327.69   321.11    0.00      0.00  13.200   0.016     1.57     0.0
     4    SW20-SW21                321.11   318.22    0.00      0.00  40.600   0.019     1.65     0.0
1
                               * * * * * FINAL SUMMARY * * * * * *


          HINDON RIVER BASIN DOSAG VERSION



       NUMBER OF RUN =     1                                     TARGET D.O. LEVEL = 0.01
       TREATMENT (C) = 0.00                                      TREATMENT (N)   = 0.00
       SEASON OF YR. = APR                                      MEAN TEMPERATURE =32.00


                                 NO.        NO.     INITIAL  FINAL  AUGMENTATION
                                 OF         OF       FLOW    FLOW     REQUIRED
                              HEADWATER  STRETCH    (CFS)   (CFS)     (CFS)
                              *********  *******   *******  *****  ***********
                                  1         1         9.8     9.3       0.0
```