National Symposium on Hydrology
Dec.16-18,1987, N.I.H., Roorkee

DISSOLVED OXYGEN MODELLING IN HINDON RIVER (U.P.)

K.K.S. BHATIA*

ABSTRACT

Rivers are one of our most important natural resources. However rivers also continue to be the carriers of waste water. Those who deal in water management will have to make many critical decisions concerning the treatment necessary before discharge into the streams, or whether the discharge, in fact, can be made. In many cases the decisions will be critical in that the results of the decisions will not be undone easily. A prime consideration in stream assimilative capacity is dissolved oxygen. A positive dissolved oxygen content must be maintained to prevent putrefecation. In the process of assimilation, oxygen is consumed by organic load carried in the stream, by the benthal demand, and by the respiration of plants and plankton. Oxygen is provided to the stream by diffusion from the atmosphere and by photosynthesis. These elements of oxygen production and oxygen consumption are interrelated.

The use of mathematical models for water quality studies has gained wide acceptance. Many of them models are complex and use sophisticated rate constaints and interrelationships of a wide variety of parameters, which results in extensive calibration and field verification. Complex models are too detailed for many planning studies. In this paper, a model to simulate dissolved oxygen concerntration and to calculate biochemical oxygen demand, has been presented. The model has the capability to check dissolved oxygen 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 capacity 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 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 paper gives all the details of the model and output. The paper 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.

1.0 INTRODUCTION

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

*Scientist 'E' & Head, Man's Influence Division, National Institute of Hydrology, Jal Vigyan Bhawan, Roorkee-247 667

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 deficit 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 5 mg/1 or higher. The Indian Standards specify a DO level of 6.0 mg/1 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 interrelated. 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 organic 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 plants and 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), 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 arount it. The river was chosen 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-11/780 computing system of NIH 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 curves (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 has been tested, used and is readily available.

2.0 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.

2.1 Location

The area under study is a part of the Indogangetic plain and lies in the Upper Hindon basin, bounded between latitude $29^{\circ}52'$ and $30^{\circ}0'$N and longitudes $77^{\circ}32'30''$ and $77^{\circ}37'15''$ E (Figure 1). 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 the 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 by cart-tracks or seasonal roads only.

FIG : 1
MAP SHOWING SAMPLING SITES

INDEX: SW1-SW29 : SURFACE WATER SAMPLING SITES ×

(From Patel, 1985)

2.2 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 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.

2.3 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 emphemeral 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.

2.4 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 processing, 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 pre-treatment which ultimately join the river Hindon or its tributaries. The description of the study area has been given in detail by Patel (1985).

3.0 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 Sukhara 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} and 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 values of reaeration and reoxygenation coefficients as given by Patel (1985) have been used.

4.0 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).

4.1 Basic Equations

The concentration of a water quality constituent such 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 :

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

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 equation used in DOSAG-I originally were derived in this fashion.

4.2 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.

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

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

where

- t = time of travel (days) = x/u, $u = Q/A$
- L = carbonaceous BOD concentration, mg/1
- L^N = nitrogeneous BOD concentration, mg/1
- 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 values 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 discharge 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.

4.3 Dissolved Oxygen

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

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

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,

$$\frac{\text{mg } O_2 \text{ removed/time}}{\text{mg NBOD}} \text{ or } t^{-1}$$

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.

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

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. 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.

4.4 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/techniques 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 down stream. In this way, the stream system is modeled from its upper 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.

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

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

$$C(t) = C_s - \frac{K_d L_o}{K_2 - K_r} (e^{K_r t} - e^{-K_2 t}) \qquad \ldots (7)$$

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

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

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

where,

L_o = initial (ultimate) carbonaceous BOD in the river (mg/1)

L_o^N = initial (ultimate) nitrogenous BOD in the river (mg/l) where nitrogenous BOD = 4.57 x (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)

5.0 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 assess 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 were 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 Figures 2 and 3. It is seen from these s figures that DO sag curve is closely matching the actual

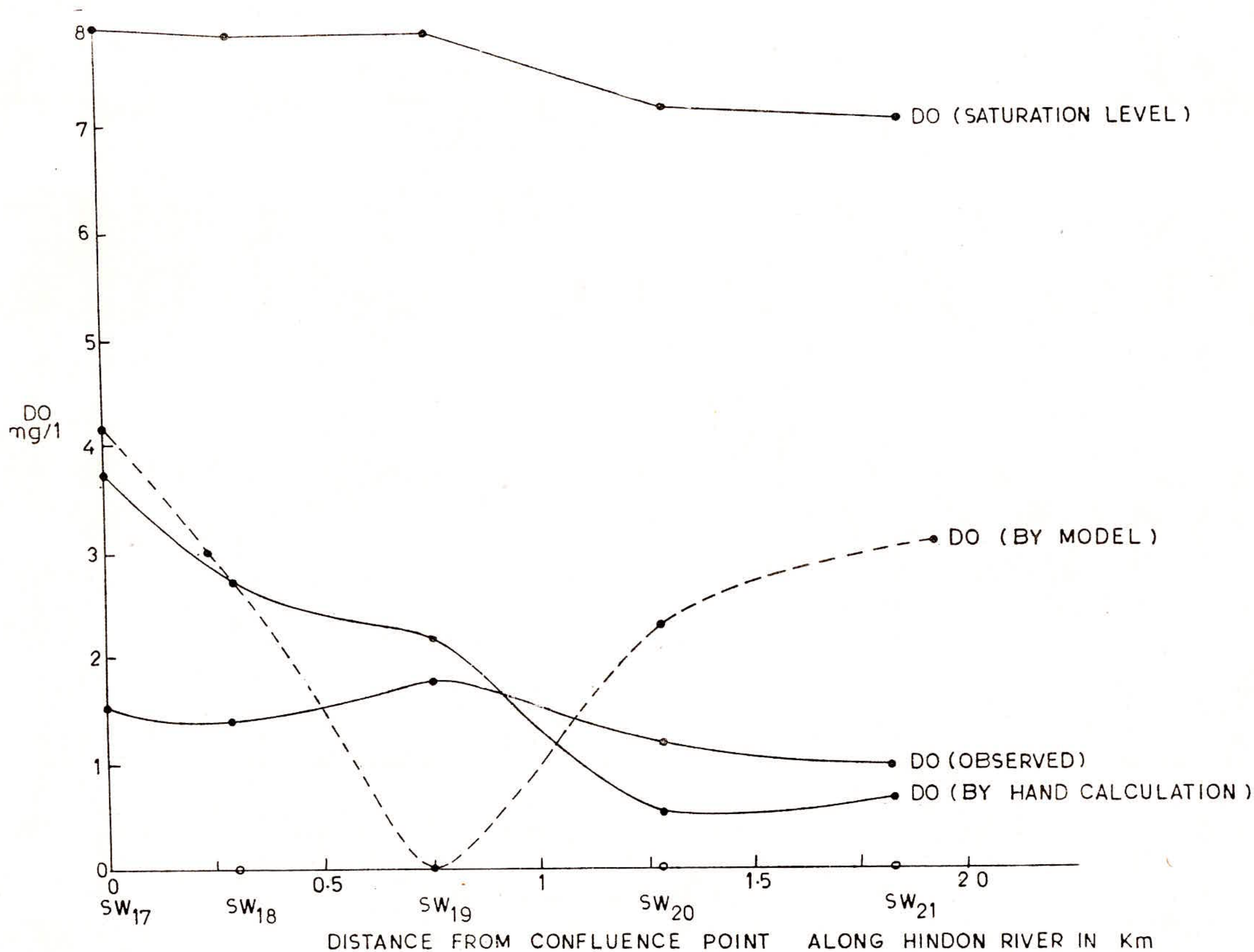

FIG.2- DISSOLVED OXYGEN SAG CURVE (APRIL,1985;PHASE I)

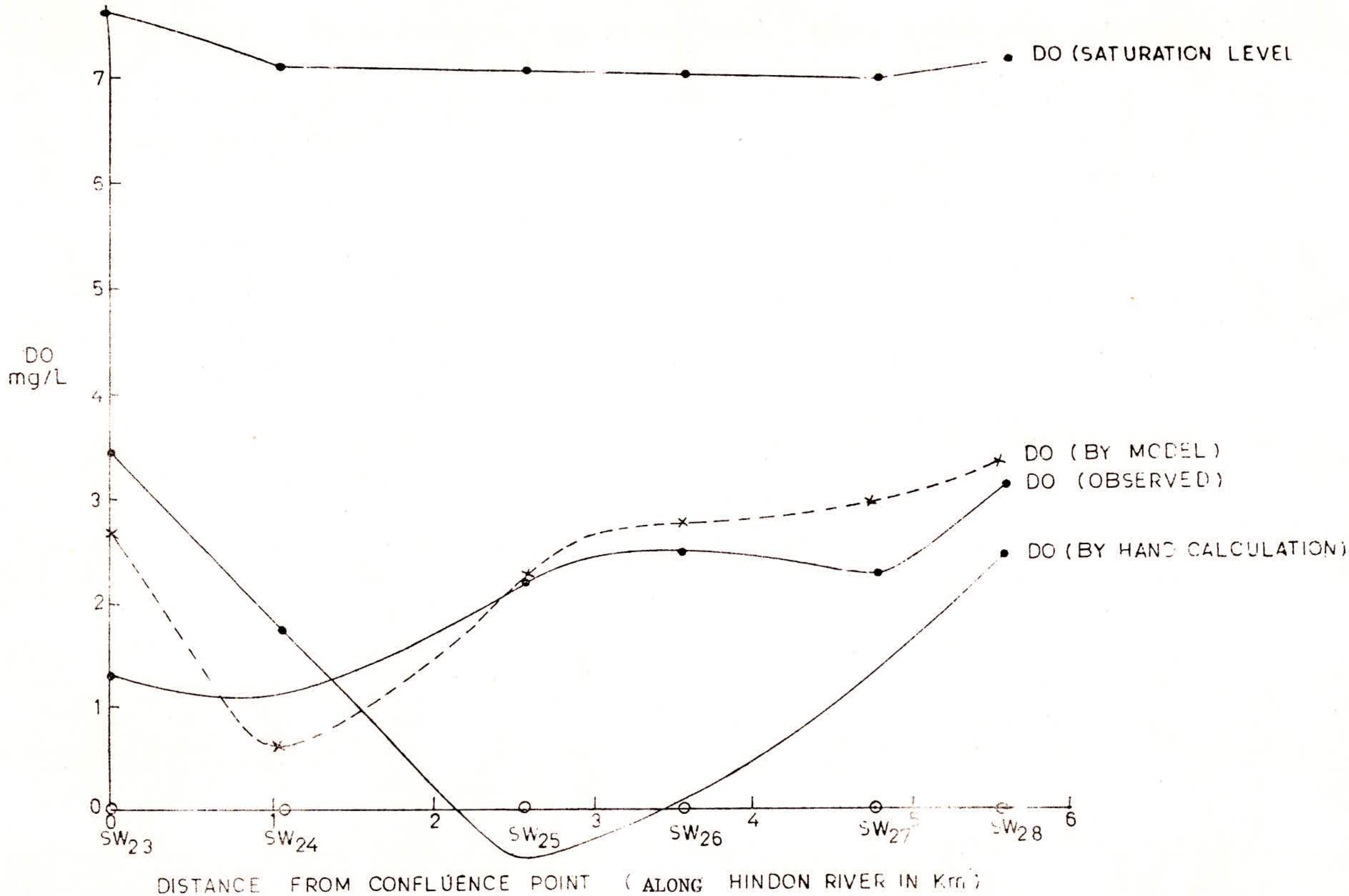

FIG.3- DISSOLVED OXYGEN DO SAG CURVE (MAY,1985;PHASE II)

measurements most of the time. As well, the DOSAG-I gives better results than 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/1, 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.

6.0 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 may 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 the next down - stream section.
6. Information for each river segment is listed out and the 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 system.

The above information is useful for the following:

- 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 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.

ACKNOWLEDGEMENT

The author is grateful to Dr. Satish Chandra, Director, National Institute of Hydrology, Roorkee for constant encouragement during the course of this study and to Dr. D.C. Singhal, Deptt. of Hydrology, University of Roorkee, Roorkee for constructive discussion.

REFERENCE

1. Bhatia, K.K.S.(1984), "Status Report on Water Quality Modelling and Sedimentation in Surface Waters", National Institute of Hydrology, Roorkee, Report SR-3, p.125.

2. Bhatia, K.K.S. and S.M. Seth (1984), "Water Quality Modelling Objectives and Data Requirements", Paper presented at 3rd Annual Convention of Association of Hydrologists of India at Poona, June 29-July 2, 1984.

3. Bhatia, K.K.S. (1985), "Water Quality Modelling and Sediment", Tech.Report of Training, National Institute of Hydrology, Roorkee, p. 105.

4. Central Board for the Prevention and Control of Water Pollution, (1980), "Annual Report", CBPCWP, New Delhi.

5. O'Connor, D.J., (1967), "The Temporal and Spatial Distribution of Dissolved Oxygen in Streams", Water Resources Research, Vol. 3, No.1.

6. Patel, N (1985), "Hydrochemical Studies of Natural Waters with Reference to Waste Effluents Disposal in Upper Hindon Basin-Saharanpur Area, U.P.", M.Tech. Dissertation, (Unpublished), University of Roorkee, Roorkee.

7. Patel, N., Singhal, D.C. and B.B.S. Singhal, (1985), "Development of Dissolved Oxygen Sag Model for Hindon River Downstream of a Paper Mill Near Saharanpur Town, U.P., India", Proc. RInt. Seminar on "Environmental Impact Assessment of Water Resources Projects", University of Roorkee, 12-14 Dec., 1985, pp. 811-819.

8. Streeter, H.W. and E.B. Phelps, (1925), "A Study of the Pollution and Natural Purification of the Ohio River", Bulletin No.146, U.S. Public Health Services.

9. Texas Water Development Board, (1970), "DO SAG-I Simulation of Water Quality in Streams and Canals", Program Documentation and Users Manual, EPA OWP TEX-DO SAG-I, 58 P, PB 202 974.

10. Tuck, J.K., (1980), "A Method to Predict the Distribution of Dissolved Oxygen in Australian Streams", Master of Applied Science Dissertation (Unpublished), University of New South Wales, Australia.

11. Velz, C.J., (1984), "Applied Stream Sanitation", John Wiley and Sons, New York.