India Water Week 2012 – Water, Energy and Food Security : Call for Solutions, 10-14 April 2012, New Delhi

WATER QUALITY MODELING FOR SELECTING THE SUITABLE LOCATION FOR POINT-SOURCE POLLUTION IN A LARGE RESERVOIR

Dr. V.M.Prabhakar and Dr. Shanti Vaidya
Central Water and Power Research Station, Pune

ABSTRACT

Freshwater is fundamental for all life because water is finite in quantity. Natural and artificial reservoirs contain more than 90% of liquid freshwater on our planet's surface. The lakes provide the greatest range of ecosystem services to humanity. These are generally interlinked with other lake, river, groundwater or coastal water systems. The hydrologic linkages between lotic (flowing) and lentic (pooled) water systems influence the availability and nature of all water systems. 'Access to safe and sufficient water and sanitation are the basic needs and are essential to health, well-being and empowerment of people' this fact was stressed in The Hague conference at the break of new millennium. In India, reservoirs are the most easily accessible freshwater source and are also prone to pollution. It is observed that water pollution is initially noticed near outfall; spreads over the whole reservoir and further to down-stream areas. Thus, preserving the water quality in reservoir would ensure the good quality in the river stretches down-stream of dam. The ever increasing capabilities of computers to simulate the spatial and temporal evolution of systems have lead to identification of hydrodynamic and water quality simulation model as an essential tool in management and planning for sustainable use of the reservoirs.

Application of the above aspects in 2D simulation of a large reservoir in Gujarat state is presented. The studies highlight a number of combinations of runs to decide the location in each of three different zones namely 1) Lacustrine Zone 2) Transitional Zone and 3) Riverine Zone of the reservoir and concentration of a pollutant load in terms of BOD to be let out in reservoir that would lead to minimum damage to ambient water quality. Threshold value of a pollutant load of BOD 200 mg/l is derived for use, satisfying Class A and B criteria of CPCB. Higher concentrations would lead to deterioration of water quality under Class D as well as for fisheries and wildlife propagation. It was found that spatial variation of pollution load has a significant effect on the resultant BOD and DO concentrations in the reservoir. It was observed that keeping pollution source in Riverine Zone and Transitional Zone yielded almost same results, where as keeping the source in Lacustrine Zone improved the resultant quality of water with respect to DO. Hence this zone for outfall is preferred for survival of fish. Present study would be helpful in designing the strategy of pollution control.

INTRODUCTION

Our fresh water resources are very precious because they are limited. Their continued use with the growing demand can only be assured by planning their use in a prudent and the sustainable way. Reservoirs cater to major water demands hence the study of water quality of such resources is imperative. They are created with multiple objectives and operated to realize their maximum utilization for various uses; nevertheless the management planning of reservoirs must be done with ecological considerations too. Water quality is a major part of this consideration. Different platforms like Hague conference (2000) to National water policy 2002 and the India water week 2012, highlight the need of sustainable use of water resources incorporating quantity and the quality aspects, as well as environmental considerations. Reservoirs have certain schedule as function of demand for power generation, irrigation, industry and the urban-rural supply. The streams, tributaries and the nallahs joining the reservoir bring in-flows, varying in magnitude seasonally and in quality as per the land use from their vicinity. Thus such point sources keep adding the inevitable pollutants to the reservoir, as an aftermath of the developmental activities. If not managed well, gradually the problem of pollution becomes apparent, to some degree at least, through out the whole reservoir and further to down-stream waters. To circumvent such problem probable distribution of the pollutant over the reservoir may be predicted by using mathematical model as a tool.

Among the top 10 hydropower projects of India with more than 1000 MW capacity, Sardar Sarovar of Gujarat stands sixth with capacity of 1450 MW. Besides power generation, this reservoir irrigates huge area up to Kuchch and caters the need of drinking water also. Hence the compliance with ‘A class’ criterion with respect to DO and BOD should be met while scheduling the reservoir operations considering its many objectives. Preserving the reservoir water quality within the allowable/required limits of quality parameters ensures the quality of water in the down-stream. Presently the land use pattern in the vicinity of Sardar Sarovar reservoir and the upstream area causes minimal disturbance to the ambient water quality, however, with the thrust of growth in industries due to easier availability of electricity and water, it is likely to cause higher burden of organic pollution. In most water resources projects, there is a need to predict receiving water quality. Water quality models are the strong analytical tools for sustainable water management strategies [1,2]. World Bank typically uses models to establish priorities for reduction of existing wastewater discharges or to predict the effects of a proposed new discharge. The World Band Environmental Assessment Sourcebook [3,4] specifies that the effluent limitations on loading for each water quality parameter be determined by mathematical modeling. Water quality models (both spatially and temporally variable) are used extensively for different purposes. It is important to select the simplest model that will satisfy the prediction requirements [4,5].The state of the art is sufficiently advanced for models to be applied in a range of physical settings and for a range of parameters (Palmer, 2001). The fuzzy set theory is applied for the definition of the imprecise parameters, which are used in a water pollution model [6]. Models are also used to locate and design wastewater outfalls [7] and to evaluate the impact of different land development and land use options. Shresta [8] estimated pollutant export coefficients and were used to estimate non-point source pollution loadings and point source loadings were estimated using the data collected from major wastewater treatment plants within a catchment. Non-point source pollution is an important factor that affects the river water quality [9]. Some ecological models incorporate the planktonic productivity and chlorophyll concentrations as the component in nutrient cycle [10,11]. The most precise and accurate model prediction is achieved when there are site-specific data sets for calibration and verification [12]. Water quality model for Sardar Sarovar reservoir was developed, calibrated and verified based on the seasonally collected in situ data [13,14].

In this paper two dimensional model is described, which considers the combined hydrodynamic (HD) and water quality (WQ) processes. State variables for water quality include BOD, DO and its budget components like inflows, bio-processes (photosynthesis and respiration), surface aeration and DO from the pool at initial condition. The model was run with the time step of 30 seconds and forcing input for HD and WQ was given on daily basis. Simulations were run for non-monsoon condition which is representative of about 9 months of a normal flow year. Monsoon scenario was exceedingly better as these months experienced 10 to 20 times more discharge from upstream, hence the effect of dilution dominated the water quality processes.

MATERIALS AND METHODS

Study area

The Narmada, is a west flowing river which rises near Amarkantak in Shahdol district of Madhya Pradesh, India and travels about 1312 km before joining Gulf of Khambat in Arabian sea. A concrete dam is constructed at Navagaon in Rajpipla taluka, Gujarat state, about 235 km before the confluence, to create Sardar Sarovar (SS) reservoir with gross storage of 0.322 million ha m and present height of 121.92m. The reservoir area modeled up to 50 km upstream from dam, which is the political boundary of Gujarat and Madhya Pradesh states (Fig.1).

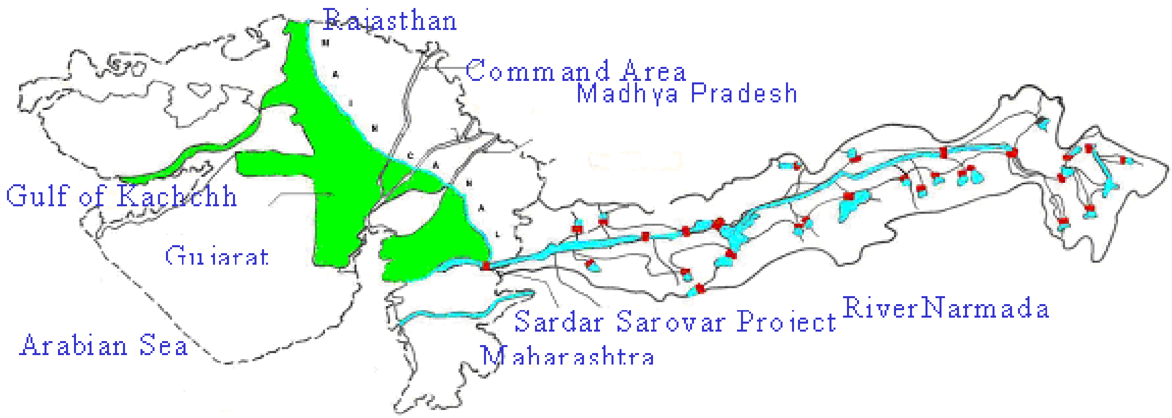


Fig1: Study area

Nine locations were selected within reservoir for seasonal sampling and *in-situ* observation of unstable parameters. These locations were identified taking into consideration confluence with any stream or the physiography of banks in that region because such locations are likely to highlight the change in water quality (Fig.2).

Fig 2: Sampling locations

Modeling Software

MIKE21, a software developed by Danish Hydraulics Institute (DHI), Denmark is used for the studies. MIKE21 (HD) is a two-dimensional hydrodynamics module, which computes the variation in water levels and velocities in the model region. This module solves the vertically integrated equations of continuity and conservation of momentum in two horizontal dimensions. The water levels and flows are resolved on a rectangular grid covering the area of interest when provided with the bathymetry, bed resistance coefficients, wind field, hydrographic boundary conditions, etc. The water quality (WQ) module is used to compute the water quality, in terms of different parameters like dissolved substances, particulate matter of dead or living material, living biological organisms and other components (all referred to as state variables in this context). The module is developed to describe chemical, biological, ecological processes and interactions between state variables. It can be applied to any two-dimensional free-surface flows where stratification can be neglected. The water quality module is used to investigate the environmental problems connected with pollution sources such as domestic and industrial wastewater, sewage and agricultural run-off in the given areas. The model describes the resulting concentrations of non-conservative parameters like DO, BOD, nutrients that define the water quality. Processes like oxygen depletion due to the degradation of BOD (both suspended and dissolved), and other chemical substances, cycling of nutrients etc are simulated while being integrated with the advection-dispersion module, which describes the physical transport processes at each grid-point covering the area of interest. Other data required are concentrations at model boundaries, flows and concentrations from pollution sources, water temperature, etc.

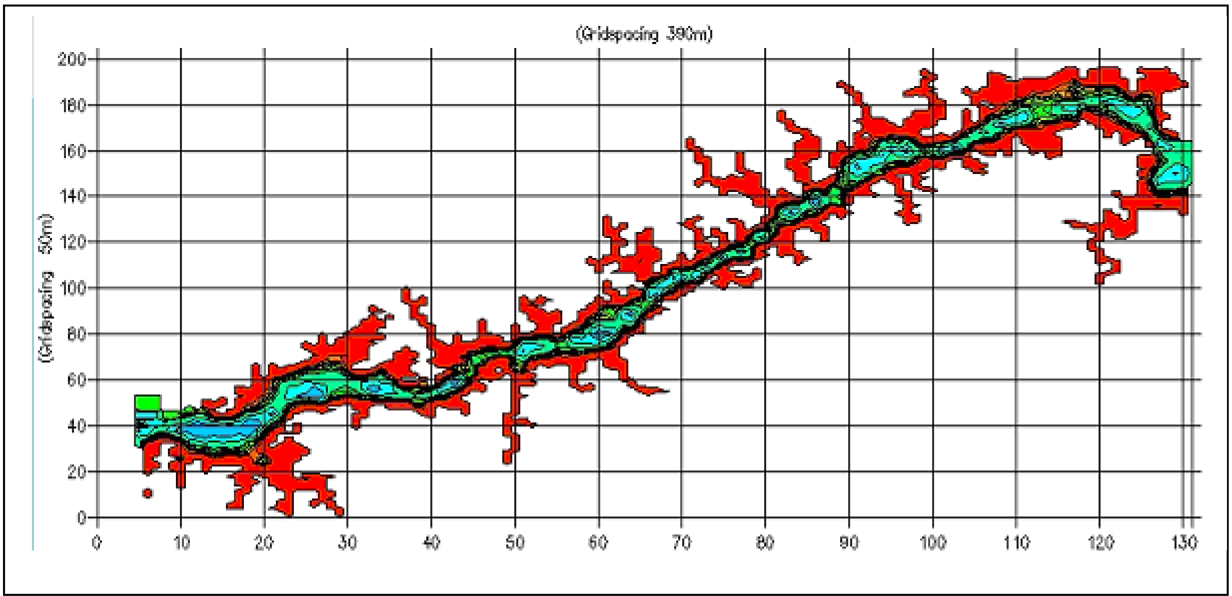
Model Set up

Bathymetry

The bathymetry of model covering the area of 50 km upstream from the Dam wall was generated by digitisation of maps and refining the depth profiles using 16 cross-sections of the river. Fig. 3 shows the bathymetry for this part of reservoir, admeasuring 50 km by 10 km divided in rectangular grid of 390m X 50m in X and Y directions respectively. The origin of the grid area matched with the point at latitude 21.7959^0 N and longitude 73.7351^0 E, orientating the model at 0^0 with true North. The true land was taken as +10.0 m and depths were given with model zero reference as 140.21m elevation (MSL).

Hydrodynamic (HD) aspect of model

Five sources along the left bank and six along the right bank represented the small rivulets/ run-offs from this part of catchments. Inflow-discharge from these 11-point sources was given as the set for normal flow year from data sets collected from project. In both the seasons the discharge from source points were given matching the seasonally observed discharges. (2 to 4 $m^3.s^{-1}$ in non-monsoon and 20 to 40 $m^3.s^{-1}$ in monsoon season). At all source points, the flow velocities given were 0.2 $m.\ s^{-1}$. Evaporation and precipitation were given for respective months, as reported. Wind data for velocity and direction was given as recorded on site. Bed Resistance given as Chezy number $40m^{1/2}.\ s^{-1}$, Eddy viscosity taken as flux-based constant value 4 $m^2.s^{-1}$ and Pier resistance and the wave radiation were excluded. A time step of 30 seconds was used for the hydrodynamic (HD) simulation during non-monsoon season. For monsoon months the time step was reduced to 5 seconds to handle the higher discharges (2000 to 8000 $m^3.s^{-1}$) successfully. One eastern open boundary simulating river discharges from upstream. In-coming discharge from upstream boundary (flux-type) was given as daily-observed data in the field (Annual average flux of 327 $m^3.s^{-1}$ and 2811 $m^3.s^{-1}$ in Non-monsoon and monsoon respectively). The proximity of the open boundary was smoothened for better functionality in the model. One



closed boundary near dam, on right bank, was provided to simulate the withdrawals from the dam. Reservoir levels as observed daily at dam were simulated at this closed boundary. The flow field under such conditions is shown in Fig. 4.

Fig 3: Bathymetry

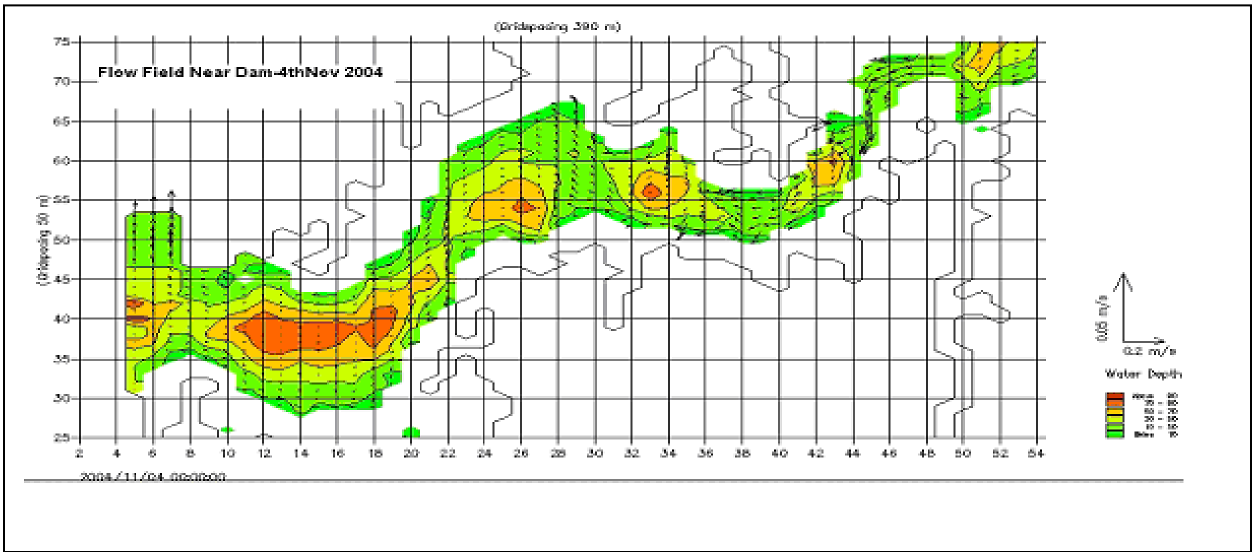


Fig 4: The flow field

Identification of Calibration periods

The calibration period for Water quality simulation was taken approximately equal to the period required to replace the complete reservoir volume. This period was found to be more than the period required for stabilisation but it was found to represent the respective seasonal scenario well. Running the model for the same simulation period at different time span did verify the model. One month in non-monsoon and 6 days in monsoon season was the duration taken for calibration and verification process.

Water Quality (WQ) aspect of model

The data for temperature, DO, EC and pH was measured in field visits during summer, monsoon and winter. The overall quality of reservoir water is found to be homogeneous horizontally. However, weak (difference of 2 to 4^0 C) vertical stratification in respect of temperature observed on some days of summer season at some locations, is ignored in this study. The water quality data for point sources was used as observed season-wise. After calibration the resultant average parameters were tried to be matched with the spatially average observed values. The data files for water quality of first eight point-sources were generated by interpolating the seasonally observed data at corresponding points for daily basis (Data observed at points near Devganga, Katkhadi, Sinduri, Bamni, Danel, Paula, Turkheda and Hapeshwar respectively).

Three point sources near the upstream boundary are located near the political state border of Gujarat and Madhya Pradesh. The quality-file of influx from these points and the main influx from upstream boundary was generated by interpolating the spatially averaged observed seasonal data (from 9 points between dam and Hapeshwar) for calibration-verification runs. The quality files thus generated contained the information regarding concentrations of BOD (dissolved), DO, Nitrate and Phosphate in the influxes. At the downstream boundary also daily averaged quality file was given which gave information about the quality of water going out of the reservoir from the dam.

Calibration

While calibrating the model for this specific part of reservoir, the above variations over the specified time have to be achieved by changing one/more state variable(s) to calibrate the model. For non-monsoon period, the initial concentration of reservoir was taken as observed on 1^{st} Nov 2004. Giving all such specific conditions of HD and WQ, the calibration runs were taken for the month of November 2004 and verification for the month of January 2005.

RESULTS AND DISCUSSION

Experimental pollution loads

In the absence of any data available about water quality of runoffs into the reservoir from up-stream, it was decided to check the probable quality-distribution-pattern in the reservoir, when the worst pollution is caused by the three contributing states viz. Maharashtra, Gujarat and Madhya Pradesh. Schematic diagram (Fig 5) shows the spatial distribution of pollution sources in 3 different zones. Subsequently, the concentration of effluents was paced down, step-by-step to achieve reservoir water quality to acceptable level (Class A criteria). These cases were run to mimic scenario due to waste water generated from a medium size town of say, of 10 lakh population, from each state. To account for typical/maximum total of domestic, industrial and a little part of agricultural runoffs, the quality of waste water was roughly worked out. It is observed that from a typical medium sized town the waste water is only partially treated which results in the BOD load of the order of 700 to 800 mg/l in waste water being flown to rivers. Considering the land use pattern in Narmada basin spreading over three states, and the anticipated development scenario in upstream area, it was decided to run the first (pilot) case with incoming discharge of $6m^3/s$, with BOD load at its worst, i.e. 700 mg/l. All domestic wastewater discharges have large temporal variations, typically 400-1000 percent during the day [15]. By using models, it is possible integrate all the temporal and spatial variables into the water quality predictions [16].

Three point-sources causing different levels of pollution were placed in each of three zones (Lacustrine, Transition and Riverine). Lacustrine zone was considered to be from17 km to 27 km from dam, the transition zone from 33 km to41 km from dam, and the riverine zone from 46 km to50 km from dam. In addition to these three polluting sources, the inflows from eight remaining point sources and the discharge from the upstream boundary were kept same as observed data used for November simulations earlier. Gradually the BOD load from polluting points was softened to achieve the resultant water quality that will meet the class A criteria as given in Table 1, meaning the suitability of water for all purposes including drinking after adequate disinfection[17]. In each zone five different cases were run varying the quality (BOD 700, 400, 200,100 and 30 mg/l) from these polluting points. In all the cases the concentration of DO and nitrate in the polluting discharge was taken zero and that of ammonium and phosphate was taken as 5mg/l. It was assumed that the load from all three zones is equal in quality and quantity.

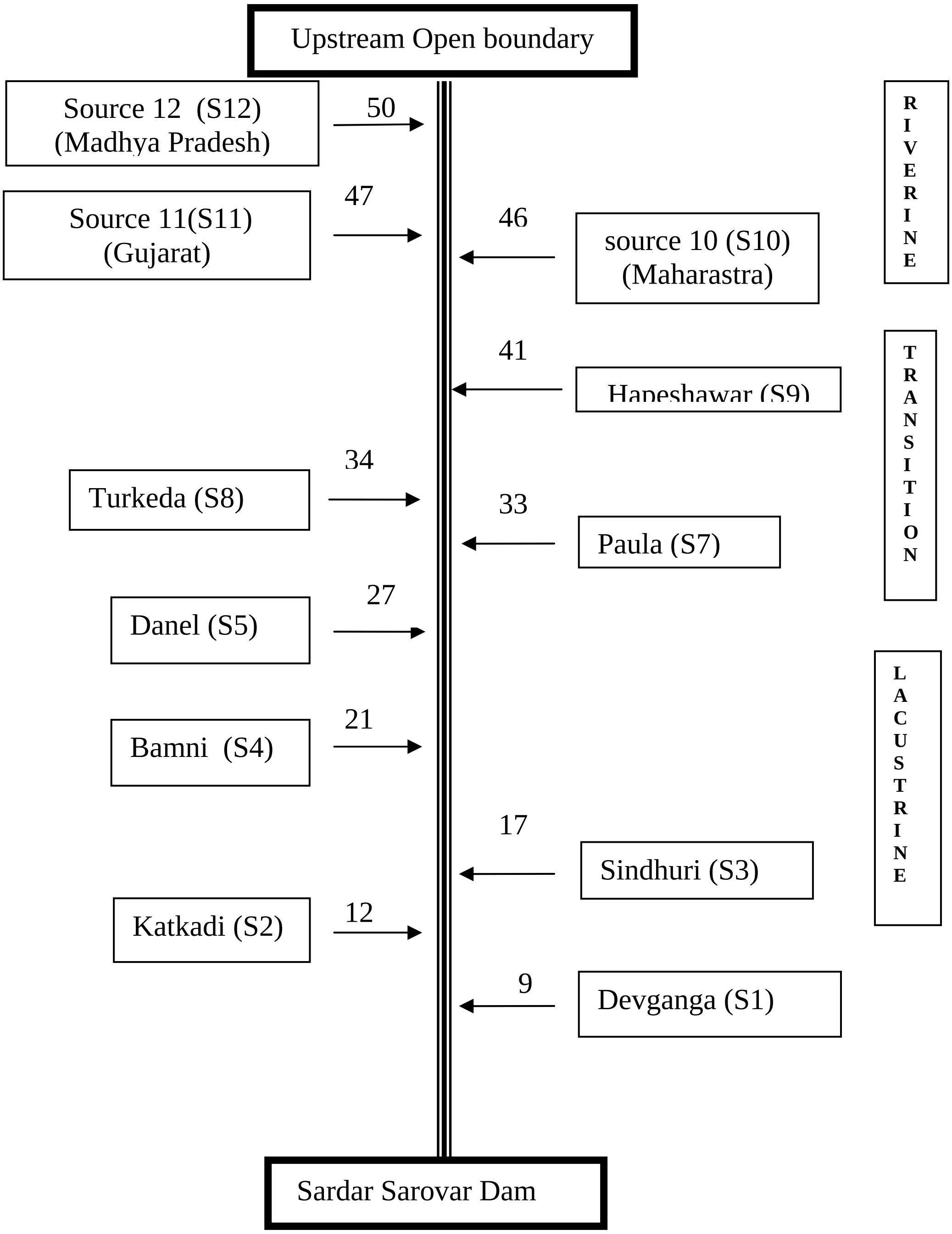


Fig 5 Schematic diagram of source loadings at different zones and distances in Km from Dam

Table 1: Classes and acceptability criteria of BOD-DO

Class = Best Designated Use	**Acceptability Criteria**	
	BOD mg/l	**DO mg/l**
A=Drinking after disinfection	<2	>6
B=Outdoor organised bathing	<3	>5
C=Drinking after conventional treatment, disinfection	<3	>4
D=Propagation of Wildlife and fisheries	-	>4
E=Irrigation, industrial cooling etc	-	-

Pollution load from other inflows

Apart from 3 sources used in each zone at a time as polluting sources, inflow discharge (flux) conditions from other contributing point-sources, and incoming discharge through the upstream boundary, simulating the flow from upstream dams, were kept same as in calibration conditions. The quality of other eight point sources and upstream boundary is detailed in Table-2

Table-2: Description of Quality parameters for all inflow waters in Non-monsoon and Monsoon seasons

Inflow location / Bank				
	BOD (mg/l)	**DO (mg/l)**	**N (mg/l)**	**P (mg/l)**
Devganga (LB)	0.8-1.2	7.8-8.9	0.67-0.98	0.041-0.07
Katkhadi (RB),	0.52-0.64	6.7-7.2	0.6-0.72	0.076-0.15
Sinduri (LB),	0.9-1.4	7.1-7.4	0.75-0.8	0.08-0.15
Bamni (RB),	0.34-0.48	7.7-8.3	0.83-0.91	0.08-0.012
Danel (RB)	1.1-1.9	6.7-7.0	0.48-0.55	0.06-0.11
Paula (LB)	0.95-1.2	6.5	0.75-0.99	0.11-0.16
Turkheda (RB)	0.37-0.44	6.6-6.9	0.47-0.63	0.05- 0.1
Hapeshwar (LB)	0.34-0.39	7.7-8.3	0.71-0.92	0.15-0.23
Upstream boundary	1.3-1.5	9.2-9.7	0.71-0.84	0.11-0.16

LB= Left Bank RB= Right Bank,

Lacustrine Zone (LZ)

Results obtained with different pollution loads (BOD load 700, 400, 200,100 and 30 mg/l) at the rate 6m^3/s simulated in Lacustrine zone are presented in Table 3 and Fig. 6 and 7

Table 3: Resultant BOD, DO and the corresponding class when different Pollution loads are used from Lacustrine zone of the reservoir.

Pollution Load (mg/l)	Resultant BOD and DO mg/l		Corresponding Classes (CPCB)		
BOD	BOD	DO	BOD	DO	Over all Class
30	0.7392	6.3906	A	A	A
100	1.3859	6.1222	A	A	A
200	2.318	5.7495	B	B	B
400	4.2105	5.0427	D	B	D
700	7.1275	4.0826	D	D	D

Transition Zone (TZ)

Results obtained with different pollution loads (BOD load 700, 400, 200,100 and 30 mg/l) at the rate $6m^3/s$ simulated in Lacustrine zone are presented in Table 4 and Figs 6 and 7

Table 4: Resultant BOD, DO and the corresponding class when different Pollution loads are used from Transition zone of the reservoir

Pollution Load (mg/l)	Resultant BOD and DO mg/l		Corresponding Classes (CPCB)		
BOD	BOD	DO	BOD	DO	Over all Class
30	0.618	6.349	A	A	A
100	0.976	5.998	A	B	B
200	1.4971	5.5204	A	B	B
400	2.5913	4.6274	B	C	C
700	4.3631	3.4768	D	E	E

Riverine Zone (RZ)

Results obtained with different pollution loads (BOD load 700, 400, 200,100 and 30 mg/l) at the rate $6m^3/s$ simulated in Lacustrine zone are presented in Table 5 and Figs 6 and 7

Table 5: Resultant BOD, DO and the corresponding class when different Pollution loads are used from Riverine zone of the reservoir

Pollution Load (mg/l)	Resultant BOD and DO mg/l		Corresponding Classes (CPCB)		
BOD	BOD	DO	BOD	DO	Over all Class
30	0.603	6.33	A	A	A
100	0.914	5.915	A	B	B
200	1.3774	5.3567	A	B	B
400	2.9744	4.3522	B	D	D
700	4.0975	3.0741	D	E	E

BOD load 700 mg/l

Through out the month, gradual spread of the area of unacceptable quality (BOD more than 7mg/l and DO less than 4mg/l) over the water was seen progressing. This quality is unsuitable for any beneficial use (Class E) hence the wastewater with BOD concentration 700mg/l at the rate of $6m^3/s$ cannot be assimilated by this reservoir to keep sustainable quality. With Pollution load 700 mg/l pollution sources from all three zones resulted in the water quality criteria D or E.

BOD load 400 mg/l

Wastewater having BOD 400mg/l with same quantum ($6\ m^3/sec$) was simulated, Though the area of unacceptable quality reduced as compared to previous case , it did not disappear for most part of the simulation period, thus 400mg/l load at $6\ m^3/sec$ rate is also unmanageable for this reservoir. With Pollution load 400 mg/l pollution sources from all three zones resulted in the water quality criteria C (in TZ) D 9in LZ and RZ).

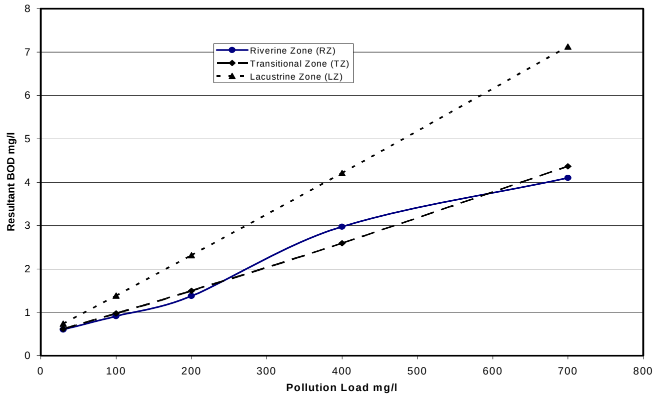


Fig 6 : BOD scenario near dam region when different pollution loads were given at three different zones (Riverine, Transition and Lacustrine) of the reservoir

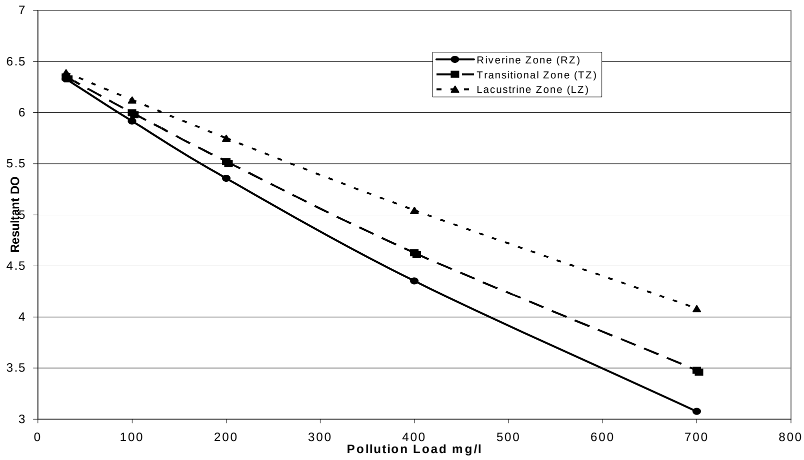


Fig 7: DO scenario near dam region when different pollution loads were given at three different zones (Riverine, Transitional and Lacustrine) of the reservoirs

BOD load 200 mg/l

Further dilute pollution load having BOD concentration 200mg/l with same quantum (6 m^3/sec) was simulated. Here also through the one month period, reservoir showed BOD more than 3 mg/l; however, all through the DO was more than 4mg/l. Thus in terms of BOD-levels, this load is not manageable Resultant quality was of class B. When BOD load was increased to 200 mg/l pollution load from all three zones resulted .in the water quality criteria of Class B.

BOD load 100 mg/l

The pollution load having BOD concentration 100mg/l with same quantum (6m^3/sec) was simulated. With this dilute BOD input, the reservoir showed now the good quality water i.e. BOD less than 1.5 mg/l and the DO more than 6 mg/l. BOD load scaled up to 100 mg/l at the rate of 6 m^3/sec water quality can be assimilated without causing much deterioration of the reservoir quality and meeting the criteria of Class B in RZ and TZ where as Class A criteria in case of LZ.

BOD load 30 mg/l

The guidelines of Bureau of Indian Standards [18] for the disposal of wastewater to surface water systems and land disposal, mention the upper limit of BOD concentration as 30 mg/l. Hence the case was run with this concentration at the rate of 6 m^3/sec distributed over 3 points. The results (Figs 5&6) show that the WQ complies with class A. BOD load up to 30 mg/l at the rate of 6 m^3/sec can be assimilated by maintaining water quality meeting the criteria of Class A in all 3 zones where pollution source tried. Among the three zones tested

Lacustrine one working better in connection with better DO and Riverine Zone working better in connection with BOD.

In all the cases discussed above the mean concentrations of nitrate and phosphate remained within the observed range of ambient concentrations. This indicates that ammonium and phosphate loads of 5 mg/l each is assimilated well under given conditions.

CONCLUSIONS

Among the three zones 1) Lacustrine 2) Transition 3) Riverine tested for the suitability of locating pollution source, Lacustrine zone observed to be giving better results in connection with maintaining DO condition which is very much essential for fish survival and biological component of ecosystem. This study helps to identify the best suitable zone of choice for disposal of pollutant for better management of reservoir water quality.

ACKNOWLEDGEMENTS

The authors are thankful and acknowledge SSNNL, Gujarat authorities for funding the study and staff of Water Quality Analysis and Modeling Division, CWPRS for their assistance in carrying out this work

REFERENCES

1) Barnwell T.O. and Krenkel P.A. (1982) The use of water quality models in management decision making *Water Science Technology* 14,1095-1107.
2) Sharp J. J. and Moore E. (1989) Marine outfall design-computer models for initial dilution in a current. *Proceedings Institution Civil Engineers, Part 1* 86, 953-961.
3) World Bank (1991) Environmental Assessment source Book. Vol 2-sectoral guidelines. World Bank, Washington, DC. Technical paper no. 144.
4) World Bank, (1998) Pollution Prevention and Abatement- handbook. World Bank, Washington,DC.
5) SWMM (1998) Storm water management model, version 4. Part A: User’s Manual. Environmental Research Laboratory, U.S. Environmental Protection Agency Athens. Georgia 30605. EPA/600/3-88/001a.
6) Hercules M., Petros A. & Jacques G. (2001) Modeling of water pollution in the Thermaikos Gulf with fuzzy parameters. *Ecological Modeling* 142 (1-2), 91-104.
7) Yong L., Pingjian Y., Cheng H. & Huaicheng G. (2008) Water quality modeling for load reduction under uncertinity: A Bayesian approach. *Water Research* 42(13), 3305-3314.
8) Shrestha, S., Kazama F., Newham L.T.H., Babel M. S., Clemente R. S., Ishidaira H., Nishida K. & Sakamoto, Y(2008) Catchment scale modelling of point source and non-point source pollution loads using pollutant export coefficients determined from long-term in-stream monitoring data. Journal of 8. Hydro-environment Research 2 (3): 134-147.
9) LI J., LI H., SHEN B. & LI Y. (2011) Effect of non-point source pollution on water quality of the Welhe River. *International Journal of Sediment Research* 269(I), 50-61 A John Wiley and sons, INC., publication.
10) Harris G. P. (1980) Temporal and spatial scales in phytoplankton ecology, mechanisms, methods, models and management. *Canadian Journal Fisheries Aquatic sciences* 37, 877-900.
11) Schladow S. G. and Hamilton D. P. (1997) Prediction of water quality in lakes and reservoirs: Part II - Model calibration, sensitivity analysis and application, *Ecological Modelling* 96(1-3), 111-123.
12) Palmer., M. D. (2001) Water Quality Modeling- A guide to effective practice. The World Bank, Washington.
13) CWPRS Technical Report No. 4701 (2010) Mathematical Modeling Studies for Assessment of Water Quality of SS Reservoir for SSNNL, Gujarat. Part 1 (Field Investigations).
14) CWPRS Technical Report No. 4763 (2010) Mathematical Modeling Studies for Assessment of Water Quality of SS Reservoir for SSNNL, Gujarat. Part 2 (Simulation studies).
15) Metcalf and Eddy (1991) Wastewater Engineering. McGraw-Hill Inc., New York.
16) Ji, Z. G. (2008) *Hydrodyamics and water quality*: Modeling Rivers, lakes, and Estuaries. John Wiley & Sons, Inc, New Jersey.
17) Central Pollution Control Board (1992) A System for surface water classification in India.
18) Bureau of Indian Standards (1991) Drinking Water specifications 10500.

BRIEF PROFILE OF THE AUTHORS

Dr. V.M.Prabhakar did his M.Tech and Ph.D from the Department of Agricultural and Food Engineering, Indian Institute of Technology, Kharagpur. Presently he is working at Central Water and Power Research Station, Pune, India. He has research experience of more than 17 years in the area of River/Reservoir Water Quality and Modeling dealing with physico-chemical, biological aspects of water quality, Phytoplankton Dynamics, Primary Productivity and Water quality Simulation. Received invitation for presentation of two research papers at the 14th World Lake Conference, Austin, Texas, USA during 31st October-4th November 2011. Two papers were nominated for Ibaraki Kasumigaura Prize awarded by the Ibaraki Prefecture, Japan.

Dr.Shanti Vaidya graduated in Chemistry from Marathwada University in 1978. She obtained a Ph.D in Chemistry at the University of Pune. She joined CWPRS in 1987 and carrying out the various projects related with water quality for various projects rivers and reservoirs of Kali, Tungabhadra, Bhadra, Narmada, Ambi, Mutha, Kukadi Koyna etc. She also carried out a project on Mathematical model studies for assessment of water quality of Sardar Sarovar reservoir for SSNNL, Gujarat. She delivered lectures on various occasions as resource person in Water quality studies. During last 10 years there were 9 papers published, including one in ILEC journal.