# Assessing Risks of Climate Variability on Water Availability of The Upper Bhopal Lake, M.P., India

**Vijay K. Dwivedi[1], V.K. Choubey[2] and Omkar Singh[3]**

[1]*Professor, Dept. of Civil Engg. NIT, Durgapur, W. Bengal, India*
[2]*Sc. 'F, NIH Roorkee Uttarakhand, India*
[3]*Sc. 'E1, NIH Roorkee Uttarakhand, India*
*e-mai:vkdwivedi10725@yahoo.co.in*

## ABSTRACT

Climate change is the long term shift in the climate of a specific location and it can be measured by the changes in features associated with average weather, such as temperature, wind patterns, runoff and precipitation. The climate change has lead to an intensification of the global hydrological cycle and has a major impact on regional water resources. In many parts of the world, variability in climate conditions, next to many socio-economic and environmental developments, is already having major impacts and that such variability is increasing. Climate change occurs when the climate of a specific area is altered between two different periods of time. Lakes are badly hit by climate change by the increased incidences of weather related disaster. Both present variability and long-term climate change impacts on lakes would be most severe in the developing world.

The Upper Lake, also known as *Bada Talaab* ("Big Lake") is a large artificial lake which lies on the western side of the capital city of Madhya Pradesh Bhopal. It is an only source of potable water to the residents of the city, supplying nearly 30 million gallons per day. The average annual rainfall in the catchment area of the lake is about 1050 mm with about 45 rainy days starting from mid of June. The lake receives runoff only from the monsoon rainfall. The rainfall has not been able to generate sufficient runoff to the lake to meet the demand from the lake over couple of decades. But during recent years, extreme rainfall events over catchment of the Upper Bhopal Lake lead to catastrophic flood in the catchment area. Therefore, due to changed climatic conditions, water balance analysis of the lake has been conducted to account for the hydro-meteorological variables due to climate change.

## INTRODUCTION

There is tremendous stress on scare natural water resources of India. It is estimated that availability of water in India is going to fall short of demand beyond 2025. With the increasing urbanization and rapid development of cities, the problem of urban areas have become more complex even today. Due to increase in population density and high standard of living, total demand for water supply has increased tremendously which require a provision of sufficient water resources. One of such

important water resource is the Upper Bhopal Lake in the State of Madhya Pradesh, India. The Upper Bhopal Lake at Bhopal is the only source of water for city of Bhopal. Due to continued reduction of volume of water in the Upper Bhopal Lake due to sedimentation, supply of drinking water to city of Bhopal has been cut down drastically over the years. Still hydrological study for the Upper Bhopal Lake was not thought by the administrators and managers for the Upper Bhopal Lake. Without hydrological studies water balance of the lake can not be computed to regulate different activities dependent on the lake. To conduct water balance study, the foremost thing is to know the runoff reaching to the lake from its catchment area under changed climatic condition so that water availability in the Upper Bhopal Lake can be known on real time basis for planning and evolving management strategies for its water resources.

Thus, an urgent need was felt for development of simulation models for estimation of total inflow reaching to the Upper Bhopal Lake. Hydrological process of prediction of runoff is so complex that model developed for one catchment can not be directly applied to another catchment due to geographical and climatological heterogeneity of the catchment area and/or intensive data requirement for the developed model for a particular catchment area which is ungauged and data availability is practically nil. Therefore, for development of simulation model for hydrological processes of ungauged catchment, fresh approach has to be applied, though over the years, several hydrological models ranging from empirical relationships to physically based models have been developed for simulation of runoff from a drainage basin. Physically based models consider the physics of the controlling mechanism of hydrological processes of the catchment. But to express different hydrological processes in the catchment, intensive time series data of all the hydrological processes are required. These data are generally not available for the catchment under consideration. Therefore, application of already developed physically based models or development of physically based models are ruled out and there is need for development of alternative methods for simulation of total inflow reaching the lake.

## STUDY AREA

Catchment of the Upper Bhopal Lake in Bhopal district of Madhya Pradesh of India was selected for the study. The Upper Bhopal Lake (UBL) and Lower Bhopal Lake (LBL), also designated as Bhoj Wetland are urban water bodies in the city of Bhopal. UBL is the only sources of drinking water for the people of the city of Bhopal. UBL and LBL, both man made reservoirs, along with their catchment areas, as a comprehensive system constitute the extent of the Bhoj Wetland. UBL, the largest fresh water lake in the state of Madhya Pradesh of India, was created by Raja Bhoj, the King of Dhar in Central India, in the 11$^{th}$ century by constructing an earthen dam across the Kolans River and now it is meeting drinking water requirement of a population of about 2.5 million people (Bhopal Development Plan, 2005) of city of Bhopal. The topographical feature of UBL is shown in Figure 1. LBL is about one-thirtieth of UBL and is used for disposing sewerage from some parts of city of Bhopal. Moreover, LBL receives its input in the form of seepage

from UBL. Therefore, studying UBL is mainly important for describing hydrology of catchment of the Bhoj wetland. UBL receives water mainly through the river Kolans and outflow from UBL is controlled by a waste weir.

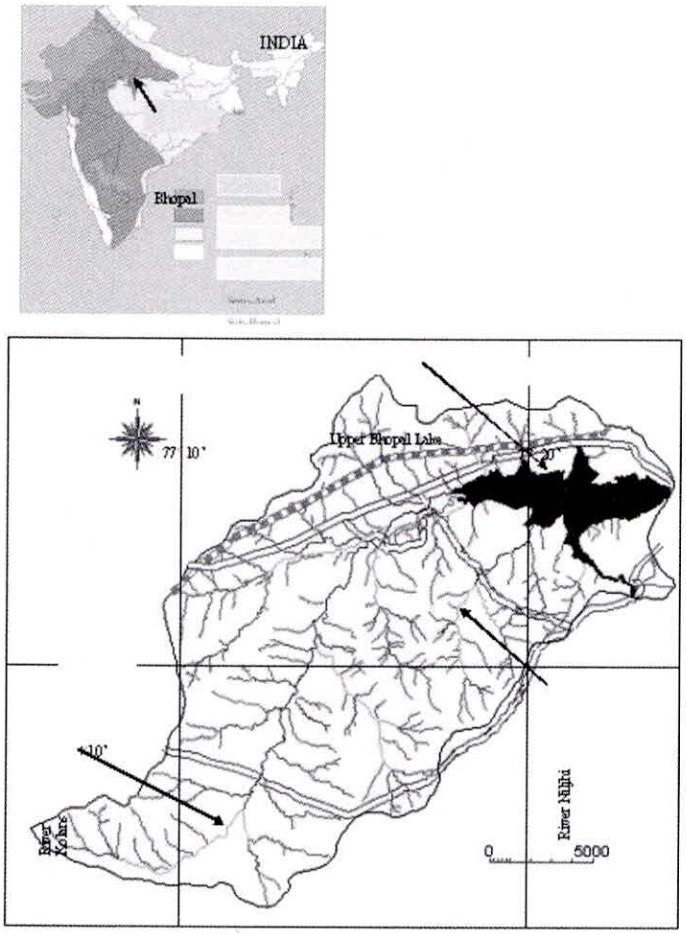


**Fig. 1 : Topographical Layout of The Upper Bhopal Lake**

UBL, in a linear east-west alignment, has a catchment area of 362.636 square kilometer (sq. km.), which is about ten times the lake area of about 34.54 sq. km. at full lake level and about 20 times the lake area of about 17 sq. km. averaged during any particular year. UBL has a partial urban component in its catchment on the eastern end while the remainder is rural (figure 2). LBL, locally known as Chhota Talab (Small Lake), is situated towards the east end of the UBL and is fully surrounded by built-up areas. LBL has a small catchment area of 9.60 sq. km. and a water spread of 1.29 sq. km. Both the Lakes are separated in a terraced manner (figure 3) by the earthen dam on river Kolans. The lowest level of UBL is just below the highest level of LBL.

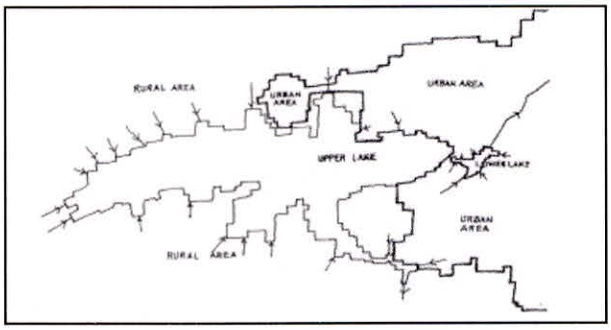


**Fig. 2 : Orientation of the Upper Bhopal Lake and the Lower Bhopal Lake**

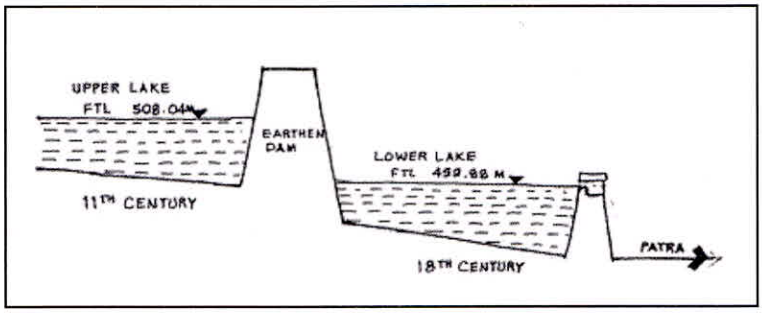


**Fig. 3 : Relation between the Upper Bhopal Lake and the Lower Bhopal Lake**

River Kolans originates 34 kilometer upstream of the lake and flows from southwest to east direction. The total length of the river Kolans up to the confluence with the lake is 38.215 km. The non-perennial river Kolans flows for one or two days immediately after heavy rainfall. There is no other source of water for the lake. There is no underground feeding of the lake by underground water (Bhopal Development Plan, 2005). Towards the northern side of the lake, there is a spillway channel, being regulated by sluice gates for overflow from the lake above its full lake level of 1666.80 feet (508.65 meter) above mean sea level.

## CLIMATE

The climate of Bhopal is tropical but quite variable with hot summers and mild winters. The area has a dry climate except during the southwest monsoon season (15$^{th}$ June to 15$^{th}$ October). The average annual temperature over UBL ranges between 18.5° C and 31.5° C. During summer, the maximum temperature over UBL varies from 34 ° C to 39° C, and minimum temperature from 24° C to 29° C. During summer, the maximum temperature in the catchment goes up to 44° C to 46° C and minimum up to 20° C to 22° C. Post-monsoon period extends up to mid December, and winter season up to February

with January as generally the coldest month with a mean daily maximum temperature of 25.7° C and the mean daily minimum temperature of 10.4°C. The average annual rainfall in the catchment is 1050 mm though the annual rainfall varies from 652 mm to 1750 mm. About 92% of the annual rainfall are received during the monsoon months. On an average there are 53 rainy days during the year. During the monsoon, relative humidity is usually about 70%. During rest of the year, the air is generally dry and the relative humidity is less than 20%. However, in the areas adjacent to the lakes, the relative humidity is about 40%. In general, the catchment area is covered by agricultural land with almost no forest cover. Nearly 90% of the catchment area is under cultivation on gentle sloping fields, while only about 5% of the catchment area is covered with forest which houses open wild animal park called "Van Vihar". Rest 5% of the catchment area is under urban use. The predominant soil is clay covering the total catchment area.

## DATA GENERATION

For estimation of runoff the lake, hydro-meteorological data (rainfall, maximum & minimum temperature, sunshine duration, vegetation cover over the catchment area, discharge in the major river Kolans) were generated. Generated data only during monsoon season (15th June to 15th October) were used in this work due to bulk nature of the data. Morphometry of the lake is given in table-I.

**Table 1 : Morphology of the Upper Bhopal Lake**

| Water Level (m) | Water Level (feet) | Water Spread Area (Sq.Km.) | Volume of Water ( M. Cubic Meter) |
|---|---|---|---|
| 506.0 | 1660.1 | 29.72 | 57.21 |
| 506.1 | 1660.4 | 30.3 | 62.19 |
| 506.2 | 1660.8 | 30.89 | 63.24 |
| 506.3 | 1661.1 | 31.82 | 66.31 |
| 506.4 | 1661.4 | 32.2 | 69.49 |
| 506.5 | 1661.7 | 33.17 | 72.72 |
| 506.6 | 1662.1 | 33.92 | 76.04 |
| 506.7 | 1662.4 | 34.75 | 79.42 |
| 506.8 | 1662.7 | 36.09 | 82.96 |
| 506.9 | 1663.1 | 37.54 | 86.57 |

## INVENTORY OF THE HYDRO-METEOROLOGICAL DATA FOR THE UPPER BHOPAL LAKE

Land-use/Land-cover of catchment of the Upper Bhopal Lake is given in table – 2 Available hydro-meteorological data for the Upper Bhopal Lake and its catchment are given in table –3.

**Table 2 : Land-use/Land-cover of catchment of the Upper Bhopal Lake**

| Sl. No. | Description | 1984-1985 (Sq. Km) | 1988 (Sq.Km) | 1992-1993 (Sq. Km) | 1999-2000 (Sq. Km) | Remarks |
|---|---|---|---|---|---|---|
| 1. | Built-up land | 14.24 | 19.075 | 20.855 | 25.667 | Area increasing because of urbanization |
| 2. | Crop land | 258.817 | 250.911 | 219.05 | 197.265 | |
| 3. | Plantation | -- | 0.67 | 0.67 | .58 | Agricultural activity decreasing |
| 4. | Open Forest | 5.0 | 4.939 | 4.225 | 3.825 | Area decreasing |
| 5. | Land with/without scrub | 41.355 | 52.827 | 90.292 | 106.45 | Highly increasing |
| 6. | Barren Rocky/Stony | 13.645 | 10.975 | 8.465 | 3.295 | Decreasing due to urbanization |
| 7. | Waterlogged | 3.75 | - | - | - | Waterlogged area had vanished |
| 8. | Aquatic Vegetation | 0.77 | 1.075 | 5.875 | 9.175 | Increasing rapidly |
| 9. | Exposed Lake Bed | 12.525 | 11.351 | 5.745 | 2.325 | Reducing |
| 10. | Lakes and Ponds | 22.32 | 20.075 | 16.17 | 9.095 | Water spread area of the lake drastically reduced |
| 11. | Total Geographical Area | 372.352 | 372.352 | 372.352 | 372.352 | |

*Source : (i) Municipal Corporation, Bhopal 2005.*

## ANALYSIS

Water balance of the lake was conducted on daily basis for the monsoon season of the years 2002 to 2005 by considering all climatic parameters affecting availability of water in the lake and presented in figures 4 to 7 Illustratiove calculation for the year 2002 is given in table 4.

**Table 3 : Availability of data for the Upper Bhopal Lake and its Catchment**

| Meteorological Data | | | | |
|---|---|---|---|---|
| Source | Parameters Available | Period of Availability | | Remarks |
| | | From | To | |
| Indian Meteolorogical Department | • Twice Daily Rainfall<br>• Maximum & Minimum Temperature<br>• Dry & Wet Bulb Temperature<br>• Relative Humidity<br>• Vapor Pressure<br>• Sunshine Duration<br>• Wind Speed and Direction | 1975 | 2005 | Acquisition on payment basis from Indian Meteorological Department. |
| Central Institute of Agricultural Engineering, Bhopal, India | • Twice Daily Rainfall<br>• Twice Daily Pan Evaporation Data<br>• Maximum & Minimum Temperature<br>• Dry & Wet Bulb temperature<br>• Relative Humidity<br>• Vapor Pressure<br>• Sunshine Duration<br>• Wind Speed and Direction | 1980 | 2005 | Acquisition free of cost from Central Institute of Agricultural Engineering, Nabibagh, Bhopal |
| Public Health Engineering Department, Govt. of M.P., Bhopal | • Daily Rainfall (During monsoon season) | 1980 | 1988 | Acquisition, free of cost from Public Health Engineering Department, Bhopal |
| | • Daily Rainfall (During monsoon season) | 1980 | 1998 | |
| National Institute of Hydrology, Roorkee | Twice daily Rainfall, Max. & Min. Temperature, Dry & Wet Bulb Temperature, Evaporation, Soil Temperature and daily sunshine duration | 2002 | 2005 | Acquisition, free of cost from National Institute of Hydrology, Roorkee |

**Table 3 : Availability of data for the Upper Bhopal Lake and its Catchment (Contd...)**

| Source | Parameters Available | Period of Availability | | Remarks |
|---|---|---|---|---|
| | | From | To | |
| **Hydrological Data** | | | | |
| Public Health Engineering Department, Govt. of M.P., Bhopal | • Twice Daily Water Surface Level of Upper Bhopal Lake<br>• Hourly water Surface Level of Upper Bhopal Lake during period of heavy rainfall<br>• Opening of gate of spillway | 1980<br><br>1988 | 2001<br><br>1994 | Acquisition without any cost from Public Health Engineering Department, Bhopal |
| Public Health Engineering Department, Govt. of M.P., Bhopal | • Twice Daily Gauge Reading of river Kolans at Uljawan | 1980 | 1994 | Acquisition on payment basis from Public Health Engineering Department, Bhopal. |
| | • Twice Daily Gauge Reading of river Kolans at Kolans | 1980 | 1994 | Acquisition from Public Health Engineering Department, Bhopal. |
| Department of Agriculture, Govt. of M.P., Bhopal | • Soil Survey of Bhopal District | 1999 | | Available from Department of Agriculture, Vindhyachal Bhawan, Bhopal |
| Ground Water Survey Circle of Water Resources Dept. of Govt. of M.P. | • Data of Ground Water observation wells in the area surrounding the lake and its catchment<br>• Data from DWLR in the observation wells in the catchment | 1978<br><br>Available from 2002 onwards | 1992 | Available from Department of Agriculture, Vindhyachal Bhawan, Bhopal |
| National Institute of Hydrology, Roorkee | Twice daily water level reading of UBL | 2002 | 2005 | Acquisition, free of cost from National Institute of Hydrology, Roorkee |

## Table 4 : Daily water balance of the Bhopal Lake for monsoon period of the year 2002

| Date | Water level of the lake at Bhadabhada | Area correspond-ing to the lake water level | Volume correspon-ding to the lake water level | Fixed abstraction in last 24 hours | Evapor-ation in last 24 hrs. | Evaporation loss in last 24 hrs. | Total Loss in last 24 hrs. | Average rainfall in last 24 hours | Volume due to rainfall over water surface area in the last 24 hrs | Runoff from catchment in last 24 hrs | Rainfall Event | No. of days in the event (Total rainfall in mm during the event) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (feet) | (Sq. Km.) | (M. C. M) | (M. C. M.) | (mm/day) | (M.C.M.) | (M.C.M.) | (mm) | (M.C.M.) | (M.C.M.) | | | |
| 6/15/02 | 1650.80 | 6.73 | 17.70 | 0.11 | 12.50 | 0.084 | 0.198 | 0.00 | 0.000 | 0.000 | E 01/02 | 6 (34.06) | Runoff only from urban area reaching to the lake |
| 6/16/02 | 1650.75 | 6.60 | 17.43 | 0.11 | 2.50 | 0.017 | 0.130 | 3.13 | 0.021 | 0.000 | | | |
| 6/17/02 | 1650.73 | 6.55 | 17.33 | 0.11 | 7.00 | 0.046 | 0.160 | 2.06 | 0.014 | 0.010 | | | |
| 6/18/02 | 1650.70 | 6.47 | 17.17 | 0.11 | 3.60 | 0.023 | 0.137 | 0.85 | 0.006 | 0.000 | | | |
| 6/19/02 | 1650.72 | 6.52 | 17.27 | 0.11 | 7.60 | 0.050 | 0.163 | 22.35 | 0.145 | 0.099 | | | |
| 6/20/02 | 1650.70 | 6.47 | 17.17 | 0.11 | 7.70 | 0.050 | 0.164 | 5.67 | 0.037 | 0.019 | | | |
| 6/21/02 | 1650.67 | 6.40 | 17.01 | 0.11 | 7.80 | 0.050 | 0.164 | 0.00 | 0.000 | 0.003 | E02/02 | 6 (44.62) | Runoff only from urban area reaching to the lake |
| 6/22/02 | 1650.65 | 6.35 | 16.90 | 0.11 | 2.10 | 0.013 | 0.127 | 13.97 | 0.089 | 0.000 | | | |
| 6/23/02 | 1650.60 | 6.22 | 16.63 | 0.11 | 2.10 | 0.013 | 0.127 | 4.06 | 0.026 | 0.000 | | | |
| 6/24/02 | 1650.60 | 6.22 | 16.63 | 0.11 | 6.50 | 0.040 | 0.154 | 14.14 | 0.088 | 0.039 | | | |
| 6/25/02 | 1650.59 | 6.19 | 16.58 | 0.11 | 3.50 | 0.022 | 0.135 | 9.91 | 0.062 | 0.039 | | | |
| 6/26/02 | 1650.55 | 6.09 | 16.37 | 0.11 | 4.10 | 0.025 | 0.139 | 2.54 | 0.016 | 0.000 | | | |
| 6/27/02 | 1650.45 | 5.84 | 15.83 | 0.11 | 2.00 | 0.012 | 0.125 | 0.00 | 0.000 | 0.000 | E 03/02 | 5 (21.93) | Runoff only from urban area reaching to the lake |
| 6/28/02 | 1650.44 | 5.81 | 15.78 | 0.11 | 3.80 | 0.022 | 0.136 | 8.97 | 0.052 | 0.019 | | | |
| 6/29/02 | 1650.42 | 5.76 | 15.67 | 0.11 | 3.40 | 0.020 | 0.133 | 3.89 | 0.023 | 0.006 | | | |
| 6/30/02 | 1650.40 | 5.71 | 15.56 | 0.11 | 0.00 | 0.000 | 0.114 | 4.32 | 0.025 | 0.001 | | | |
| 7/1/02 | 1650.39 | 5.69 | 15.51 | 0.11 | 5.20 | 0.030 | 0.143 | 4.74 | 0.027 | 0.033 | | | |
| 7/2/02 | 1650.35 | 5.58 | 15.30 | 0.11 | 6.30 | 0.035 | 0.149 | 0.00 | 0.000 | 0.000 | | | |
| 7/3/02 | 1650.30 | 5.46 | 15.03 | 0.11 | 7.20 | 0.039 | 0.153 | 0.00 | 0.000 | 0.000 | | | |
| 7/4/02 | 1650.25 | 5.33 | 14.76 | 0.11 | 6.97 | 0.037 | 0.151 | 0.00 | 0.000 | 0.000 | | | |
| 7/5/02 | 1650.20 | 5.20 | 14.49 | 0.11 | 7.05 | 0.037 | 0.150 | 0.00 | 0.000 | 0.000 | | | |
| 7/6/02 | 1650.15 | 5.08 | 14.23 | 0.11 | 7.65 | 0.039 | 0.152 | 0.00 | 0.000 | 0.000 | | | |
| 7/7/02 | 1650.10 | 4.95 | 13.96 | 0.11 | 7.80 | 0.039 | 0.152 | 0.00 | 0.000 | 0.000 | | | |
| 7/8/02 | 1650.05 | 4.82 | 13.69 | 0.11 | 6.90 | 0.033 | 0.147 | 0.00 | 0.000 | 0.000 | | | |
| 7/9/02 | 1649.95 | 4.57 | 13.16 | 0.11 | 6.66 | 0.030 | 0.144 | 0.00 | 0.000 | 0.000 | | | |

**Table 4 : Daily water balance of the Bhopal Lake for monsoon period of the year 2002 Contd.....)**

| Date | Water level of the lake at Bhadabhada | Area correspond -ing to the lake water level | Volume correspon- ding to the lake water level | Fixed abstraction in last 24 hours | Evapor- ation in last 24 hrs. | Evaporation loss in last 24 hrs. | Total Loss in last 24 hrs. | Average rainfall in last 24 hours | Volume due to rainfall over water surface area in the last 24 hrs | Runoff from catchment in last 24 hrs | Rainfall Event | No. of days in the event (Total rainfall in mm during the event) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7/11/02 | 1649.85 | 4.31 | 12.62 | 0.11 | 8.62 | 0.037 | 0.151 | 0.00 | 0.000 | 0.000 | | | |
| 7/12/02 | 1649.80 | 4.19 | 12.36 | 0.11 | 8.37 | 0.035 | 0.149 | 0.00 | 0.000 | 0.000 | | | |
| 7/13/02 | 1649.75 | 4.06 | 12.09 | 0.11 | 7.41 | 0.030 | 0.144 | 1.27 | 0.005 | 0.000 | | | |
| 7/14/02 | 1649.70 | 3.93 | 11.82 | 0.11 | 6.84 | 0.027 | 0.141 | 0.00 | 0.000 | 0.000 | | | |
| 7/15/02 | 1649.65 | 3.81 | 11.55 | 0.11 | 8.28 | 0.032 | 0.145 | 0.00 | 0.000 | 0.000 | | | |
| 7/16/02 | 1649.60 | 3.68 | 11.29 | 0.11 | 7.50 | 0.028 | 0.141 | 0.00 | 0.000 | 0.000 | | | |
| 7/17/02 | 1649.55 | 3.55 | 11.02 | 0.11 | 7.95 | 0.028 | 0.142 | 0.00 | 0.000 | 0.000 | E 04/02 | 5 | Runoff only from urban area reaching to the lake |
| 7/18/02 | 1649.53 | 3.50 | 10.91 | 0.11 | 3.50 | 0.012 | 0.126 | 9.23 | 0.033 | 0.002 | | (40.13) | |
| 7/19/02 | 1649.53 | 3.50 | 10.91 | 0.11 | 5.50 | 0.019 | 0.133 | 18.97 | 0.066 | 0.060 | | | |
| 7/20/02 | 1649.51 | 3.45 | 10.81 | 0.11 | 3.00 | 0.010 | 0.124 | 1.35 | 0.005 | 0.021 | | | |
| 7/21/02 | 1649.50 | 3.42 | 10.75 | 0.11 | 3.54 | 0.012 | 0.126 | 10.58 | 0.037 | 0.034 | | | |
| 7/22/02 | 1649.48 | 3.37 | 10.65 | 0.11 | 4.20 | 0.014 | 0.128 | 0.00 | 0.000 | 0.019 | | | |
| 7/23/02 | 1649.46 | 3.32 | 10.54 | 0.11 | 6.20 | 0.021 | 0.134 | 0.00 | 0.000 | 0.021 | | | |
| 7/24/02 | 1649.43 | 3.25 | 10.38 | 0.11 | 6.50 | 0.021 | 0.135 | 0.00 | 0.000 | 0.000 | | | |
| 7/25/02 | 1649.40 | 3.17 | 10.22 | 0.11 | 6.40 | 0.020 | 0.134 | 0.00 | 0.000 | 0.000 | | | |
| 7/26/02 | 1649.38 | 3.12 | 10.11 | 0.11 | 6.48 | 0.020 | 0.134 | 0.00 | 0.000 | 0.000 | | | |
| 7/27/02 | 1649.35 | 3.04 | 9.95 | 0.11 | 6.54 | 0.020 | 0.134 | 0.00 | 0.000 | 0.000 | | | |

## Table 4 : Daily water balance of the Bhopal Lake for monsoon period of the year 2002 Contd.....)

| Date | Water level of the lake at Bhadabhada | Area correspond-ing to the lake water level | Volume correspon-ding to the lake water level | Fixed abstraction in last 24 hours | Evapor-ation in last 24 hrs. | Evaporation loss in last 24 hrs. | Total Loss in last 24 hrs. | Average rainfall in last 24 hours | Volume due to rainfall over water surface area in the last 24 hrs | Runoff from catchment in last 24 hrs | Rainfall Event | No. of days in the event (Total rainfall in mm during the event) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (feet) | (Sq. Km.) | (M. C. M) | (M.C. M.) | (mm/day) | (M.C.M.) | (M.C.M.) | (mm) | (M.C.M.) | (M.C.M.) | | | |
| 7/28/02 | 1649.30 | 2.92 | 9.68 | 0.11 | 6.92 | 0.020 | 0.134 | 0.00 | 0.000 | 0.000 | | | |
| 7/29/02 | 1649.25 | 2.79 | 9.42 | 0.11 | 7.40 | 0.021 | 0.134 | 0.00 | 0.000 | 0.000 | | | |
| 7/30/02 | 1649.20 | 2.66 | 9.15 | 0.11 | 7.60 | 0.020 | 0.134 | 0.00 | 0.000 | 0.000 | | | |
| 7/31/02 | 1649.15 | 2.54 | 8.88 | 0.11 | 7.32 | 0.019 | 0.132 | 0.00 | 0.000 | 0.000 | E 05/02 | 3 | Runoff from urban as well as agricultural area starts reaching to the lake with effect from 6th event having 165.04 mm of rainfall over 48 days of monsoon season. |
| 8/1/02 | 1649.15 | 2.54 | 8.88 | 0.11 | 7.50 | 0.019 | 0.133 | 19.56 | 0.050 | 0.083 | | (23.03) | |
| 8/2/02 | 1649.13 | 2.48 | 8.77 | 0.11 | 7.80 | 0.019 | 0.133 | 3.47 | 0.009 | 0.017 | | | |
| 8/3/02 | 1649.00 | 2.15 | 8.08 | 0.11 | 7.90 | 0.017 | 0.131 | 0.00 | 0.000 | 0.000 | E 06/02 | 7 | |
| 8/4/02 | 1649.50 | 3.42 | 10.75 | 0.11 | 7.50 | 0.026 | 0.139 | 53.76 | 0.116 | 2.689 | | (162.05) | |
| 8/5/02 | 1650.15 | 5.08 | 14.23 | 0.11 | 0.00 | 0.000 | 0.114 | 27.94 | 0.096 | 3.519 | | | |
| 8/6/02 | 1650.45 | 5.84 | 15.83 | 0.11 | 0.00 | 0.000 | 0.114 | 20.07 | 0.102 | 1.615 | | | |
| 8/7/02 | 1650.70 | 6.47 | 17.17 | 0.11 | 0.00 | 0.000 | 0.114 | 49.45 | 0.289 | 1.161 | | | |
| 8/8/02 | 1651.10 | 7.49 | 19.30 | 0.11 | 5.50 | 0.041 | 0.155 | 9.99 | 0.065 | 2.186 | | | |
| 8/9/02 | 1651.15 | 7.62 | 19.57 | 0.11 | 6.51 | 0.050 | 0.163 | 0.85 | 0.006 | 0.416 | | | |
| 8/10/02 | 1651.13 | 7.57 | 19.46 | 0.11 | 6.76 | 0.051 | 0.165 | 0.00 | 0.000 | 0.056 | | | |
| 8/11/02 | 1651.07 | 7.41 | 19.14 | 0.11 | 6.85 | 0.051 | 0.164 | 1.19 | 0.009 | 0.000 | | | |
| 8/12/02 | 1650.95 | 7.11 | 18.50 | 0.11 | 6.95 | 0.049 | 0.163 | 0.00 | 0.000 | 0.000 | E 07/02 | 3 | |
| 8/13/02 | 1650.85 | 6.85 | 17.97 | 0.11 | 3.63 | 0.025 | 0.139 | 2.29 | 0.016 | 0.000 | | (6.52) | |
| 8/14/02 | 1650.83 | 6.80 | 17.86 | 0.11 | 5.72 | 0.039 | 0.153 | 4.23 | 0.029 | 0.003 | | | |
| 8/15/02 | 1650.70 | 6.47 | 17.17 | 0.11 | 3.90 | 0.025 | 0.139 | 0.00 | 0.000 | 0.000 | E 08/02 | 12 | |
| 8/16/02 | 1651.10 | 7.49 | 19.30 | 0.11 | 0.00 | 0.000 | 0.114 | 51.99 | 0.337 | 1.940 | | (219.29) | |
| 8/17/02 | 1651.50 | 8.51 | 21.44 | 0.11 | 0.80 | 0.007 | 0.120 | 9.31 | 0.070 | 2.181 | | | |
| 8/18/02 | 1651.80 | 9.27 | 23.04 | 0.11 | 0.50 | 0.005 | 0.118 | 27.69 | 0.235 | 1.487 | | | |
| 8/19/02 | 1652.15 | 10.16 | 24.91 | 0.11 | 5.22 | 0.053 | 0.167 | 35.81 | 0.332 | 1.655 | | | |
| 8/20/02 | 1652.50 | 11.05 | 26.78 | 0.11 | 0.62 | 0.007 | 0.121 | 12.70 | 0.129 | 1.906 | | | |
| 8/21/02 | 1652.80 | 11.81 | 28.38 | 0.11 | 0.81 | 0.010 | 0.123 | 30.06 | 0.332 | 1.390 | | | |
| 8/22/02 | 1653.10 | 12.57 | 29.98 | 0.11 | 0.75 | 0.009 | 0.123 | 19.73 | 0.233 | 1.491 | | | |
| 8/23/02 | 1653.30 | 13.08 | 31.05 | 0.11 | 0.00 | 0.000 | 0.114 | 3.47 | 0.044 | 1.147 | | | |
| 8/24/02 | 1653.60 | 13.84 | 32.65 | 0.11 | 0.00 | 0.000 | 0.114 | 14.14 | 0.185 | 1.529 | | | |
| 8/25/02 | 1653.90 | 14.60 | 34.25 | 0.11 | 0.00 | 0.000 | 0.114 | 13.12 | 0.182 | 1.532 | | | |
| 8/26/02 | 1654.00 | 14.86 | 34.78 | 0.11 | 3.40 | 0.051 | 0.164 | 1.27 | 0.019 | 0.628 | | | |
| 8/27/02 | 1654.10 | 15.11 | 35.32 | 0.11 | 4.50 | 0.068 | 0.182 | 0.00 | 0.000 | 0.697 | | | |
| 8/28/02 | 1654.10 | 15.11 | 35.32 | 0.11 | 0.00 | 0.000 | 0.114 | 0.00 | 0.000 | 0.182 | E 09/02 | 11 | |
| 8/29/02 | 1654.50 | 16.13 | 37.45 | 0.11 | 0.00 | 0.000 | 0.114 | 48.09 | 0.727 | 1.520 | | (407.16) | |
| 8/30/02 | 1655.70 | 19.17 | 43.84 | 0.11 | 0.00 | 0.000 | 0.114 | 22.86 | 0.369 | 6.140 | | | |
| 8/31/02 | 1657.60 | 24.00 | 53.96 | 0.11 | 0.00 | 0.000 | 0.114 | 68.66 | 1.317 | 8.913 | | | |
| 9/1/02 | 1659.20 | 28.07 | 62.47 | 0.11 | 2.60 | 0.073 | 0.187 | 109.30 | 2.623 | 6.000 | | | |
| 9/2/02 | 1660.60 | 31.62 | 69.91 | 0.11 | 0.00 | 0.000 | 0.114 | 11.43 | 0.321 | 7.305 | | | |
| 9/3/02 | 1660.80 | 32.13 | 70.97 | 0.11 | 0.00 | 0.000 | 0.114 | 6.35 | 0.201 | 0.975 | | | |
| 9/4/02 | 1661.10 | 32.89 | 72.57 | 0.11 | 0.00 | 0.000 | 0.114 | 39.71 | 1.276 | 0.431 | | | |
| 9/5/02 | 1661.70 | 34.42 | 75.75 | 0.11 | 0.00 | 0.000 | 0.114 | 33.78 | 1.111 | 2.188 | | | |
| 9/6/02 | 1662.30 | 35.94 | 78.94 | 0.11 | 2.00 | 0.072 | 0.186 | 39.20 | 1.349 | 1.949 | | | |
| 9/7/02 | 1662.80 | 37.21 | 81.59 | 0.11 | 3.60 | 0.134 | 0.248 | 27.77 | 0.998 | 1.840 | | | |

## Table 4 : Daily water balance of the Bhopal Lake for monsoon period of the year 2002 Contd.....)

| Date | Water level of the lake at Bhadabhada | Area correspond -ing to the lake water level | Volume correspon- ding to the lake water level | Fixed abstraction in last 24 hours | Evapor- ation in last 24 hrs | Evaporation loss in last 24 hrs | Total Loss in last 24 hrs. | Average rainfall in last 24 hours | Volume due to rainfall over water surface area in the last 24 hrs | Runoff from catchment in last 24 hrs | Rainfall Event | No of days in the event (Total rainfall in mm during the event) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (feet) | (Sq. Km.) | (M. C. M) | (M.C. M.) | (mm/day) | (M.C.M.) | (M.C.M.) | (mm) | (M.C.M.) | (M.C.M.) | | | |
| 9/8/02 | 1662.90 | 37.46 | 82.12 | 0.11 | 3.70 | 0.139 | 0.252 | 0.00 | 0.000 | 0.778 | E 10/02 | 1 (2.71) | Runoff from urban as well as agricultural area reaching to the lake |
| 9/9/02 | 1662.90 | 37.46 | 82.12 | 0.11 | 3.50 | 0.131 | 0.245 | 2.71 | 0.102 | 0.151 | | | |
| 9/10/02 | 1662.88 | 37.41 | 82.01 | 0.11 | 3.80 | 0.142 | 0.256 | 0.00 | 0.000 | 0.139 | E 11/02 | 1 (5.76) | |
| 9/11/02 | 1662.88 | 37.41 | 82.01 | 0.11 | 3.70 | 0.138 | 0.252 | 5.76 | 0.215 | 0.040 | | | |
| 9/12/02 | 1662.85 | 37.34 | 81.85 | 0.11 | 3.70 | 0.138 | 0.252 | 0.00 | 0.000 | 0.093 | | | |
| 9/13/02 | 1662.82 | 37.26 | 81.69 | 0.11 | 3.40 | 0.127 | 0.240 | 0.00 | 0.000 | 0.093 | | | |
| 9/14/02 | 1662.79 | 37.19 | 81.54 | 0.11 | 3.50 | 0.130 | 0.244 | 0.00 | 0.000 | 0.081 | | | |
| 9/15/02 | 1662.76 | 37.11 | 81.38 | 0.11 | 3.30 | 0.122 | 0.236 | 0.00 | 0.000 | 0.085 | | | |
| 9/16/02 | 1662.73 | 37.03 | 81.22 | 0.11 | 3.50 | 0.130 | 0.243 | 0.00 | 0.000 | 0.077 | | | |
| 9/17/02 | 1662.69 | 36.93 | 81.01 | 0.11 | 3.50 | 0.129 | 0.243 | 0.00 | 0.000 | 0.031 | | | |
| 9/18/02 | 1662.65 | 36.83 | 80.79 | 0.11 | 3.40 | 0.125 | 0.239 | 0.00 | 0.000 | 0.031 | | | |
| 9/19/02 | 1662.61 | 36.73 | 80.58 | 0.11 | 3.17 | 0.116 | 0.230 | 0.00 | 0.000 | 0.027 | | | |
| 9/20/02 | 1662.57 | 36.63 | 80.37 | 0.11 | 3.76 | 0.138 | 0.251 | 0.00 | 0.000 | 0.018 | | | |
| 9/21/02 | 1662.53 | 36.52 | 80.16 | 0.11 | 3.01 | 0.110 | 0.224 | 0.00 | 0.000 | 0.039 | | | |
| 9/22/02 | 1662.50 | 36.45 | 80.00 | 0.11 | 3.24 | 0.118 | 0.232 | 0.00 | 0.000 | 0.064 | | | |
| 9/23/02 | 1662.46 | 36.35 | 79.78 | 0.11 | 3.15 | 0.114 | 0.228 | 0.00 | 0.000 | 0.020 | | | |
| 9/24/02 | 1662.42 | 36.25 | 79.57 | 0.11 | 3.13 | 0.113 | 0.227 | 0.00 | 0.000 | 0.016 | | | |
| 9/25/02 | 1662.38 | 36.14 | 79.36 | 0.11 | 3.16 | 0.114 | 0.228 | 0.00 | 0.000 | 0.015 | | | |
| 9/26/02 | 1662.34 | 36.04 | 79.15 | 0.11 | 3.06 | 0.110 | 0.224 | 0.00 | 0.000 | 0.016 | | | |
| 9/27/02 | 1662.30 | 35.94 | 78.94 | 0.11 | 3.06 | 0.110 | 0.224 | 0.00 | 0.000 | 0.012 | | | |
| 9/28/02 | 1662.26 | 35.84 | 78.72 | 0.11 | 3.05 | 0.109 | 0.223 | 0.00 | 0.000 | 0.011 | | | |
| 9/29/02 | 1662.22 | 35.74 | 78.51 | 0.11 | 3.05 | 0.109 | 0.223 | 0.00 | 0.000 | 0.011 | | | |
| 9/30/02 | 1662.18 | 35.64 | 78.30 | 0.11 | 3.04 | 0.108 | 0.222 | 0.00 | 0.000 | 0.010 | | | |
| 10/1/02 | 1662.14 | 35.53 | 78.09 | 0.11 | 3.03 | 0.108 | 0.221 | 0.00 | 0.000 | 0.010 | | | |
| 10/2/02 | 1662.10 | 35.43 | 77.87 | 0.11 | 3.03 | 0.107 | 0.221 | 0.00 | 0.000 | 0.009 | | | |
| 10/3/02 | 1662.06 | 35.33 | 77.66 | 0.11 | 3.00 | 0.106 | 0.220 | 0.00 | 0.000 | 0.009 | | | |
| 10/4/02 | 1662.02 | 35.23 | 77.45 | 0.11 | 3.00 | 0.106 | 0.219 | 0.00 | 0.000 | 0.007 | | | |
| 10/5/02 | 1661.98 | 35.13 | 77.24 | 0.11 | 2.98 | 0.105 | 0.218 | 0.00 | 0.000 | 0.007 | | | |
| 10/6/02 | 1661.93 | 35.00 | 76.97 | 0.11 | 2.95 | 0.103 | 0.217 | 0.00 | 0.000 | 0.000 | | | |
| 10/7/02 | 1661.88 | 34.87 | 76.71 | 0.11 | 2.91 | 0.101 | 0.215 | 0.00 | 0.000 | 0.000 | | | |
| 10/8/02 | 1661.83 | 34.75 | 76.44 | 0.11 | 2.90 | 0.101 | 0.214 | 0.00 | 0.000 | 0.000 | | | |
| 10/9/02 | 1661.78 | 34.62 | 76.18 | 0.11 | 2.85 | 0.099 | 0.212 | 0.00 | 0.000 | 0.000 | | | |
| 10/10/02 | 1661.70 | 34.42 | 75.75 | 0.11 | 2.85 | 0.098 | 0.212 | 0.00 | 0.000 | 0.000 | | | |
| 10/11/02 | 1661.65 | 34.29 | 75.49 | 0.11 | 2.95 | 0.101 | 0.215 | 0.00 | 0.000 | 0.000 | | | |
| 10/12/02 | 1661.60 | 34.16 | 75.22 | 0.11 | 2.95 | 0.101 | 0.214 | 0.00 | 0.000 | 0.000 | | | |
| 10/13/02 | 1661.55 | 34.04 | 74.96 | 0.11 | 2.91 | 0.099 | 0.213 | 0.00 | 0.000 | 0.000 | | | |
| 10/14/02 | 1661.50 | 33.91 | 74.69 | 0.11 | 2.91 | 0.099 | 0.212 | 0.00 | 0.000 | 0.000 | | | |
| 10/15/02 | 1661.45 | 33.78 | 74.42 | 0.11 | 2.90 | 0.098 | 0.212 | 0.00 | 0.000 | 0.000 | | | |

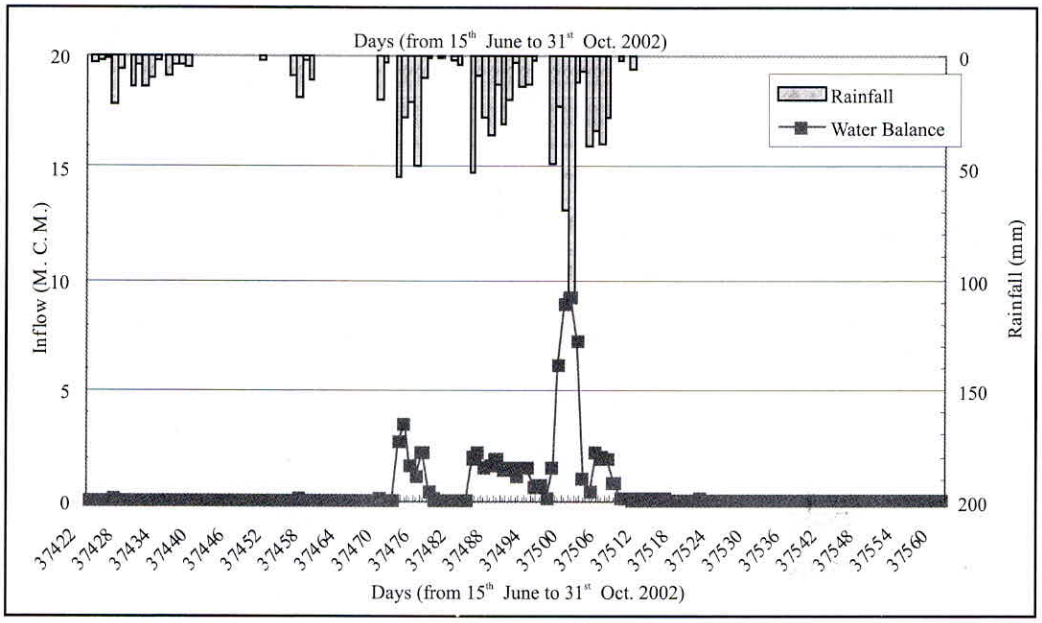


**Fig. 4 : Inflow reaching the Upper Bhopal lake for monsoon season of the year 2002**

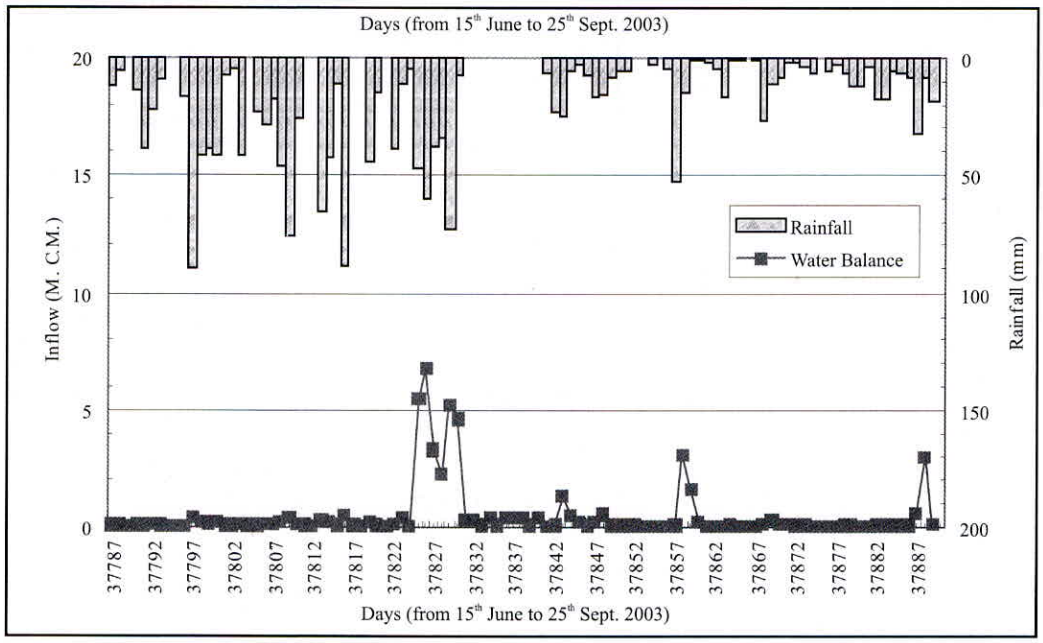


**Fig. 5 : Inflow reaching the Upper Bhopal lake for monsoon season of the year 2003**

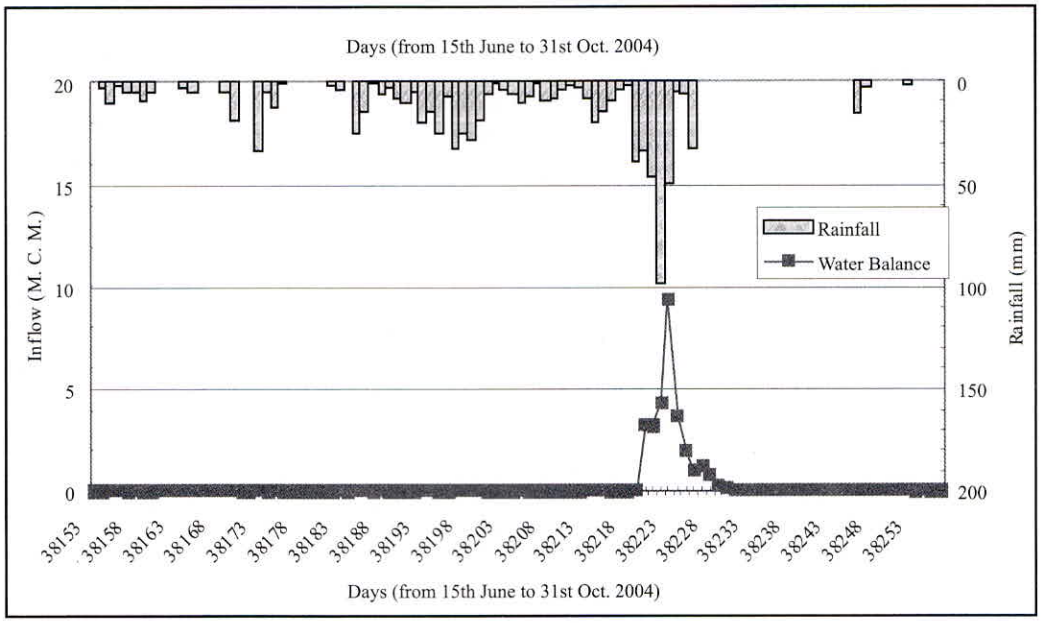


**Fig. 6 : Inflow reaching the Upper Bhopal lake for monsoon season of the year 2003**

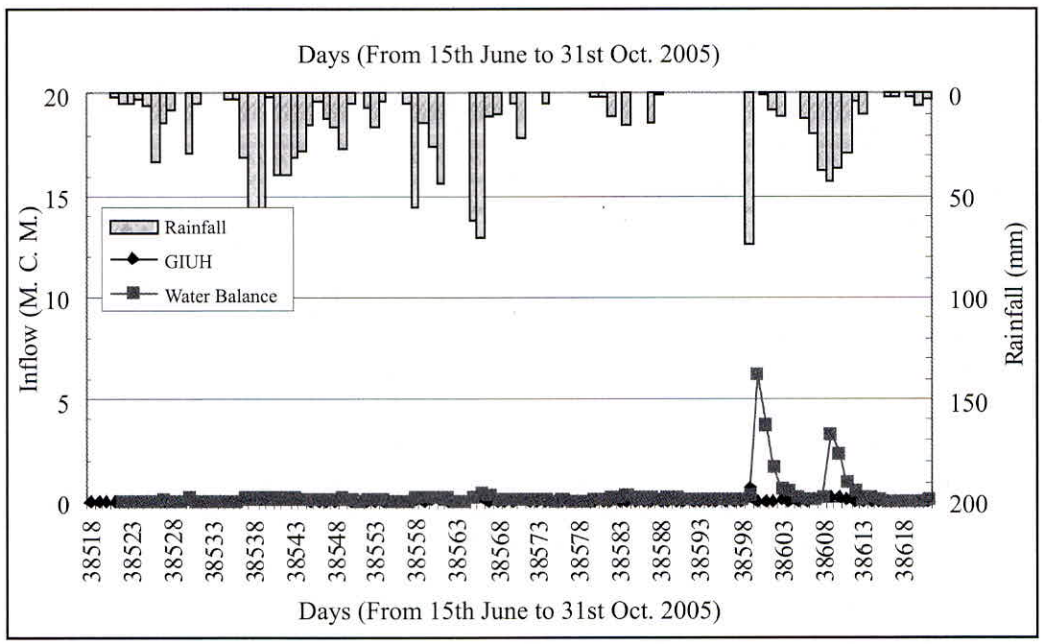


**Fig. 7 : Inflow reaching the Upper Bhopal lake for monsoon season of the year 2004**

## CONCLUSIONS

For a stressed water source due to changing climatic conditions, it is important to know the daily inflow reaching the source from different parts of the catchment because of spatial and temporal distribution of rainfall over a large catchment area. Knowing inflow from the catchment will help in determining the quality of runoff reaching to the water resource to adopt suitable remedial measures and knowing the quantity of flow will assure the fulfillment of demand and adoption of measures for its conservation and rejuvenation. By the procedure adopted in this work, it will be easy to do calculation for estimation of runoff reaching to the lake or water resource by field personnel.

## ACKNOWLEDGEMENT

Authors are grateful to National Institute of Hydrology, which funded the project titled "Integrated Hydrological Studies of the Upper Bhopal Lake and Its catchment", during which the field data were observed. The present paper is from the work done during the mentioned project. Author express thanks to the officials of the Municipal Corporation, Bhopal for allowing conducting experimentation in the Upper Bhopal Lake and putting observational instruments in and around the Upper Bhopal Lake and to the Officials of Department of Public Health Engineering (PHE Dept.), Bhopal for providing infrastructural support for setting up observational network in the city of Bhopal.

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