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Quantification of Urban Runoff Reaching to the Upper Bhopal Lake, M.P., India

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ABSTRACT: The Upper Bhopal Lake in the city of Bhopal in the State of Madhya Pradesh of India is the only source of water for the city of Bhopal. Economic as well as recreational activities of the city of Bhopal is dependent on the water availability in the Upper Bhopal Lake which receives water as surface runoff only during monsoon period of every year. Though, the lake exists for more than 1100 years, neither any data on hydrological characteristics of catchment of the lake was available nor any hydrological model was available for predicting runoff reaching to the lake from its catchment. The Upper Bhopal Lake has a catchment area of 362.35 square kilometer. The land use pattern of about 80% of the catchment is agricultural, where as 5% is of forest and the rest is urban. Since the onset of monsoon in the catchment area by 15th June every year, the agricultural area starts contributing by the end of August where as the lake stars receiving surface runoff right from the beginning of monsoon season as runoff from the urban area. In this paper detailed features of catchment of the lake, inventory of the available data for the lake and its catchment has been investigated, report on the requisite hydrological data generated in the catchment have been presented. Daily water balance of the lake has been carried out. From the daily water balance flow from the agricultural area and urban area were quantified and presented in this paper.

INTRODUCTION

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. To conduct water balance study, the foremost thing is to know the runoff reaching to the lake from its catchment area so that water availability in the Upper Bhopal Lake can be known on real time basis. Thus, an urgent need was felt for development of simulation models for estimation of runoff from the catchment of the Upper Bhopal Lake.

STUDYAREA

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 11th 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

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Bhoj wetland. UBL receives water mainly through the river Kolans and surface flow from the urban areas in the catchment. Outflow from UBL is controlled by a waste weir.

UBL, in a linear east-west alignment, has a catchment area of 362.636 square kilometer (sq. km.), which is about ten times the area ofUBL 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). 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.

River Kolans originates 34 kilometer upstream of the lake and flows from southwest to east. 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. Flow in the river Kolans occur when sufficient rainfall has occurred to satisfy the antecedent soil moisture condition in the catchment. But flow to the UBL starts reaching just after onset of the monsoon season. This flow is the sheet flow from urbal catchment of 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.

The area has a dry climate except during the southwest monsoon season (15th June to 15th 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%. For simulation of runoff from catchment of 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.

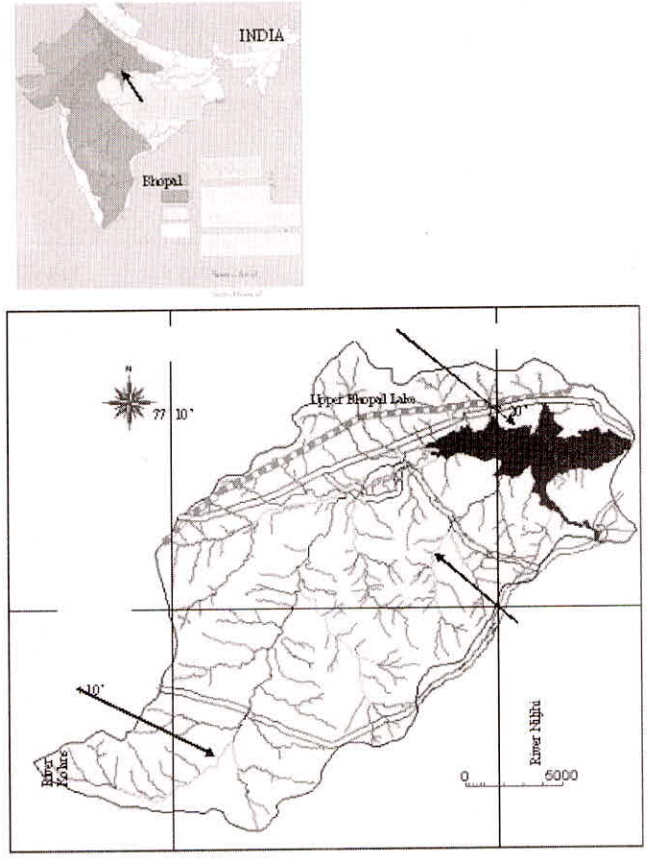

Fig. 1: Topographical layout of the Upper Bhopal Lake

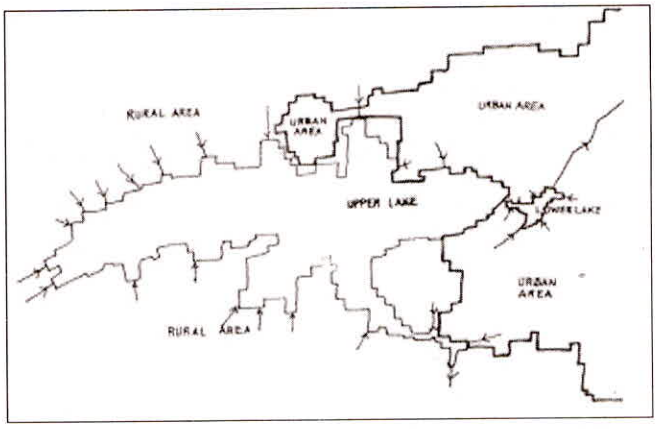

Fig. 2: Orientation of the Upper Bhopal Lake and the Lower Bhopal Lake

Ascertaining Land Use Pattern of the Catchment Area

Division of total catchment area of the Bhopal Lake into 23 sub-catchments on the basis of drainage pattern of the streams is shown in Figure 3. With the help of land use pattern of the catchment, land use for each sub-catchment was ascertained and mentioned in the Table 4. Area, perimeter and mean slope of each sub-catchment are also given in Table 1 on the basis of Barne (1990), Manning's roughness coefficient for overland flow and channel flow in each sub-catchement was selected and given in the same. From Table 4 it can be inferred that catchment area under agricultural use is 301.347 sq.km. where as catchment area under urban use is only 26.979 sq.km on the eastern periphery of the lake.

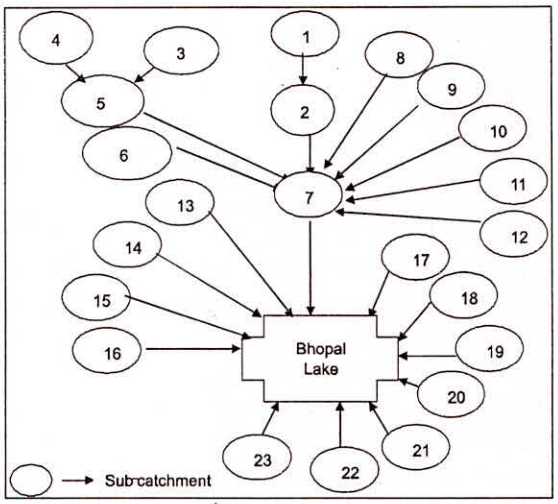

Fig. 3: Inter-connectivity of sub-catchments in the catchment of the Upper Bhopal Lake

Table 1: Morphological Characteristics of Sub-Catchments of Catchment Area of Bhopal Lake

Sub-Catchment	*Landuse*	*Manning's Coefficient for Overland Flow*	*Manning's Coefficient for Channel Flow*	*Area of Sub-Catchment*	*Perimeter of Sub-Catchment*	*Mean Slope of Sub-Catchment*
				(sq. km)	*(km)*	*(%)*
1.	Agricultural	0.2	0.03	41.85	34.159	0.418
2.	Agricultural	0.2	0.03	60.28	33.545	0.572
3.	Agricultural	0.2	0.03	13.41	15.139	0.449
4.	Agricultural	0.2	0.03	4.87	10.787	0.701
5.	Agricultural	0.2	0.03	9.57	14.474	0.700
6.	Agricultural	0.2	0.03	21.19	21.826	0.533
7.	Agricultural	0.2	0.03	15.44	29.945	0.260
8.	Agricultural	0.2	0.03	30.74	32.175	0.418
9.	Agricultural	0.2	0.03	13.825	17.994	0.272
10.	Agricultural	0.2	0.03	2.61	8.172	0.352
11.	Agricultural	0.2	0.03	21.44	23.394	0.721
12.	Agricultural	0.2	0.03	3.854	10.611	1.187
13.	Agricultural	0.2	0.03	34.162	27.000	0.798
14.	Agricultural	0.2	0.03	10.949	15.816	0.598
15.	Agricultural	0.2	0.03	2.853	9.094	1.283
16.	Agricultural	0.2	0.03	3.172	6.766	1.658
17.	Agricultural	0.2	0.03	1.643	7.508	0.608
18.	Agricultural	0.2	0.03	9.489	13.347	0.615
19.	Urban	0.01	0.03	3.621	7.958	0.884
20.	Urban	0.01	0.03	5.772	10.720	1.938
21.	Urban (steep slope)	0.001	0.03	6.041	12.547	3.592
22.	Hills	0.01	0.03	6.173	13.046	12.543
23.	Urban	0.01	0.03	5.372	10.997	0.969

Elevation-Capacity Curve for the Bhopal Lake

Lake elevation-area-capacity data were obtained from the office of Public Health Engineering Department at Bhopal. The observed lake elevation is in feet and capacity is in million cubic feet (M.C.ft.). The logarithmic formula given below was adopted to predict lake capacity corresponding to the lake water level,

$$y = 8820.7 (\text{Log}(x)) - 65335 \quad \ldots (1)$$

where x is the lake water level in feet and y is lake capacity in M.C.M.

Elevation-Area curve for the Upper Bhopal Lake

The observed lake elevation is in feet and area is in square kilometre (sq. km.). Water spread area of the lake has been found to be illustrated by the equation,

$$y = 2.5403\, x - 4186.8 \quad \ldots (2)$$

where y is the water spread area of the lake in sq. km., x is the elevation of water surface in the lake above mean sea level in meter. The coefficient of correlation is 0.9914.

Water Availability

Water availability studies on daily basis for the lake were carried out for monsoon season (15th June to 15th October) for the years 2002 to 2005 after considering evaporation losses and reduction in useful storage due to daily withdrawal. Lake water level of 1666.80 above mean sea level is the maximum water level above which the gates of spillway at Bhadabhada are opened to release the flood water from the lake to the river Kalisoth, downstream of the spillway. Runoff coefficient from catchment of the lake have been computed and given in Table 2.

Table 2: Runoff Coefficients for Catchment of the Bhopal Lake

Sr. No.	Year	2002	2003	2004	2005
1.	Runoff coefficient for the catchment of UBL	0.318	0.230	0.323	0.236

Calculating Rainfall-Excess

The mean annual precipitation in the catchment is 1050 milimeter. The major part of rain falls mainly between July and September every year. The precipitation is usually of high intensity, short duration, and large spatial and temporal variability. Rainfall data were recorded twice a day, once at 08:00 AM and another at 17:00 PM. Observed rainfall data at 08:00 AM and 17:00 PM were then distributed on hourly basis by dividing the total rainfall recorded between the time intervals by the number of hours in the time interval.

The rainfall events were identified on the basis of observed rainfall data. The start and end of an event, duration of events, total rainfall in the particular events during monsoon season of the year 2002 to 2005 were identified and for illustration, given respectively in Table 6.

Arrangements were made ready for measurement of flow in the identified streams right from the first day (15th June) of monsoon season for each year of 2002 to 2005. It was observed in the field that runoff in the streams does not start from the first spell of rainfall in the catchment. Moreover early spells of rainfall are widely variable in space over catchment area of the lake. First appearance of flow in identified streams was related to the events with effect from which the runoff in streams starts. That means runoff producing events during monsoon season of each year from 2002 to 2005 were identified and for illustration, mentioned in Table 6. It is worth mentioning that practically there is no pre-mosoon rainfall. It means that even during monsoon season, the total rainfall before the runoff producing event is lost as initial infiltration loss. This is identified from the facts that infiltration characteristics of the catchment is really prominent in the agricultural land-use.

While doing water balance analysis, it was observed that inflow from the catchment reaches to the lake after every rainfall event, even when the runoff has not started from the agricultural land use area. This indicated that runoff from the urban land use area reaches to the lake, because in the urban area infiltration is practically negligible, except some interception losses. In the urban area rainfall is directly converted to runoff and reaches to the lake. The urban area is on the periphery of the lake and close to the water level measurement station at Bhadabhada. Hence, the runoff produced from urban area reaches to the lake and produces increased water level, evident from the recorded water level of the lake. Outlet of the agricultural area is about 17 kilometer from the measuring station of lake water level at Bhadabhada. Hence, the effect of runoff from agricultural area on the water level of the lake has a lag time of at least one day and the flow is also attenuated before reaching to the measuring station due dispersion and diffusion in the lake.

Due to different land use, rainfall excess was determined separately for agricultural land use and urban land use. The rainfall recorded at three observation stations was averaged arithmetically to get average rainfall recorded at 08:00 hrs and 17:00 hrs. The average rainfall was converted to hourly rainfall by dividing the total rainfall by the number of hours corresponding to the total rainfall.

Rainfall Excess for Agricultural Land Use

For agricultural land use drainage area (sub-catchment 1 to 12, 13, 14, 15, and 16), all the rainfall occurring before runoff producing event was considered to be lost. For the rainfall event from which the runoff starts and subsequent rainfall events, the hourly rainfall excess was derived by subtracting hourly infiltration loss rate (1.2 mm/hr) determined from the field experiment from the hourly rainfall to get the hourly rainfall excess. These rainfall excess were used for generating surface runoff from agricultural catchment area of the lake.

Rainfall Excess for Urban Land Use

For urban land use drainage area (sub-catchment 17 to 23), all the rainfall events produce runoff right from the first spell of rainfall in the monsoon season. Since the rainfall over the urban land use gets directly converted into runoff, the infiltration loss has been assumed to be zero. These rainfall excess were used for generating direct runoff hydrograph from urban sub-catchments.

Estimation of Runoff from Different Parts of the Catchment on the Basis of Daily Water Balance of the Upper Bhopal Lake

Daily water balance of the Upper Bhopal Lake was computed for the monsoon period of the year 2002 to 2005 in a tabular form and from the computation of water balance, the runoff reaching to the lake was differentiated as runoff from only urban area reaching to the lake and runoff from total catchment area of the lake reaching to the lake. For illustration, computation for monsoon season of the year 2002 is given in Table 3. Inflow reaching to UBL from total catchment and from only urban catchment of the lake for the monsoon season of the year 2002 is shown in Figure 4(a) and 4(b) respectively. Inflow reaching to UBL from only urban catchment of the lake for the monsoon season of the year 2003, 2004 and 2005 is shown in Figures 5, 6 and 7 respectively.

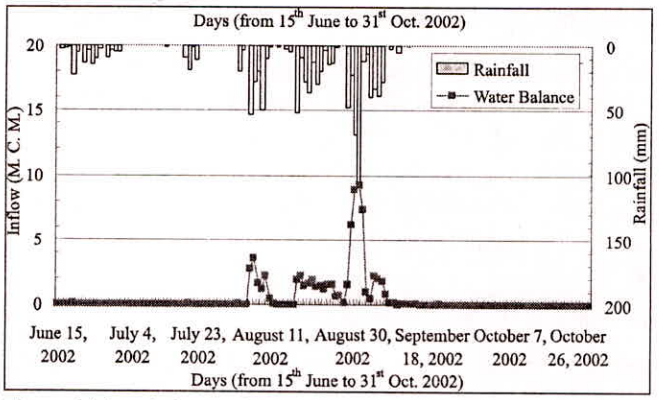

Fig. 4(a): Inflow from the urban and agricultural sub-catchments reaching to the Bhopal Lake for monsoon season of the year 2002

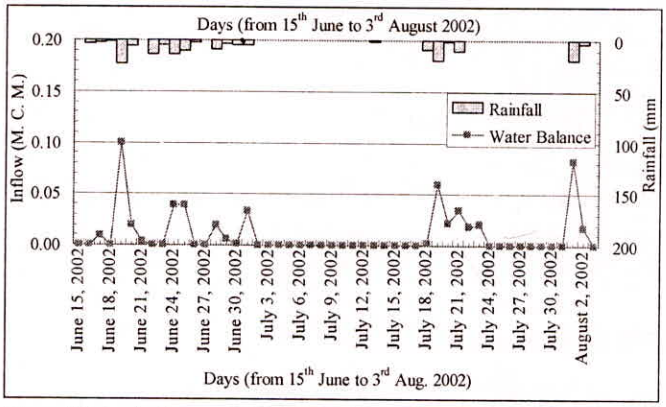

Fig. 4(b): Inflow only from the urban sub-catchments reaching to the Bhopal Lake for monsoon season of the year 2002

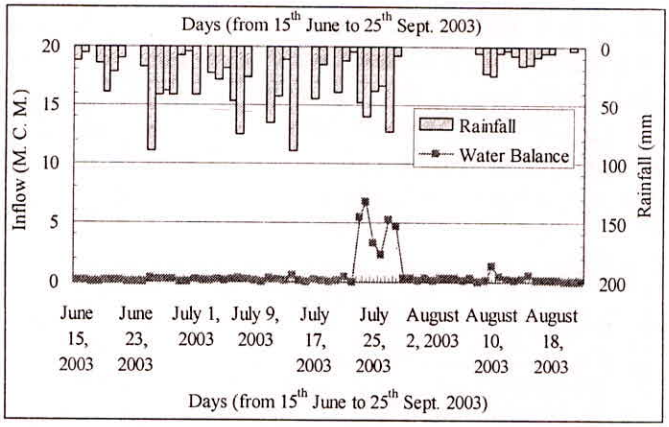

Fig. 5: Inflow only from the urban sub-catchmenst reaching to the Bhopal Lake for monsoon season of the year 2003

CONCLUSIONS

For a stressed water source, it is important to know the contribution of inflow to the source from different parts of the catchment because of spatial and temporal distribution of rainfall over a large catchment area.

Table 3: Daily Water Ralance of the Bhopal Lake for Monsoon Period of the year 2002

Date	Water level of the lake at Bhadabhada	Area corresp-onding to the lake water level	Volume corresp-onding to the lake water level	Fixed abstraction in last 24 hours	Evapor-ation in last 24 hrs.	Evapo-ration 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			
7/10/02	1649.90	4.44	12.89	0.11	6.82	0.030	0.144	0.00	0.000	0.000			
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 (40.13)	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			
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			
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			

Date	Water level of the lake at Bhadabhada	Area corresp-onding to the lake water level	Volume corresp-onding to the lake water level	Fixed abstraction in last 24 hours	Evapor-ation in last 24 hrs.	Evapo-ration 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.)			
7/31/02	1649.15	2.54	8.88	0.11	7.32	0.019	0.132	0.00	0.000	0.000	E 05/02		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			
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	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		(2.71)	
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	
9/11/02	1662.88	37.41	82.01	0.11	3.70	0.138	0.252	5.76	0.215	0.040		(5.76)	
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			

Date	Water level of the lake at Bhadabhada	Area corresp-onding to the lake water level	Volume corresp-onding to the lake water level	Fixed abstraction in last 24 hours	Evapor-ation in last 24 hrs.	Evapo-ration 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.)			
9/18/02	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			

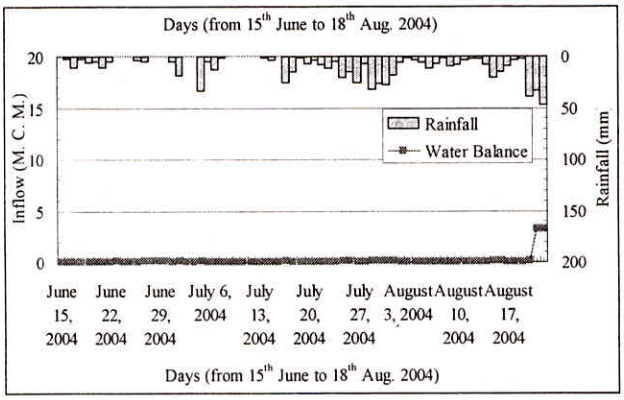

Fig. 6: Inflow only from the urban sub-catchments reaching to the Bhopal Lake for monsoon season of the year 2004

Knowing inflow from urban 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. 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.

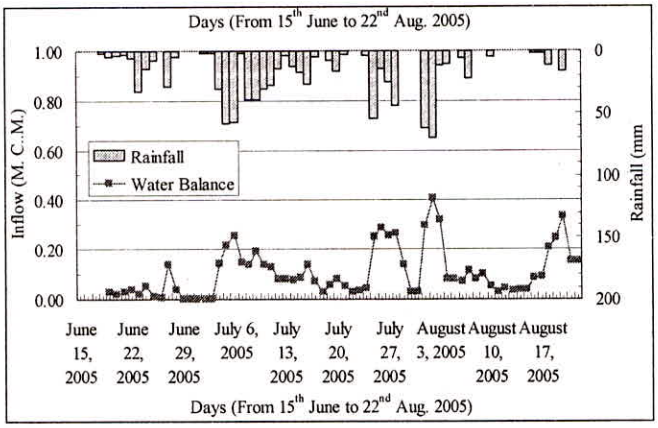

Fig. 7: Inflow only from the urban sub-catchments reaching to the Bhopal Lake for monsoon season of the year 2005

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