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

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ABSTRACT

The Upper Bhopal Lake 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. Monsoon sets in the catchment area by 15th June every year. The agricultural area starts contributing by the end of August, whereas 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 were quantified and presented in this paper.

INTRODUCTION

There is tremendous stress on scarce 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 problems 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 supply from available 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. 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.

Since catchment area of the lake is predominantely agricultural, an urgent need was felt for development of simulation models for estimation of runoff from agricultural catchment of 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 models of rainfall-runoff for the catchment under study on the basis of limitations in terms of data availability and constraints in data generation. These constraints are in terms of time required in generation of required data and the pressing need for development of simulation model.

STUDY AREA

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 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). 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.

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.

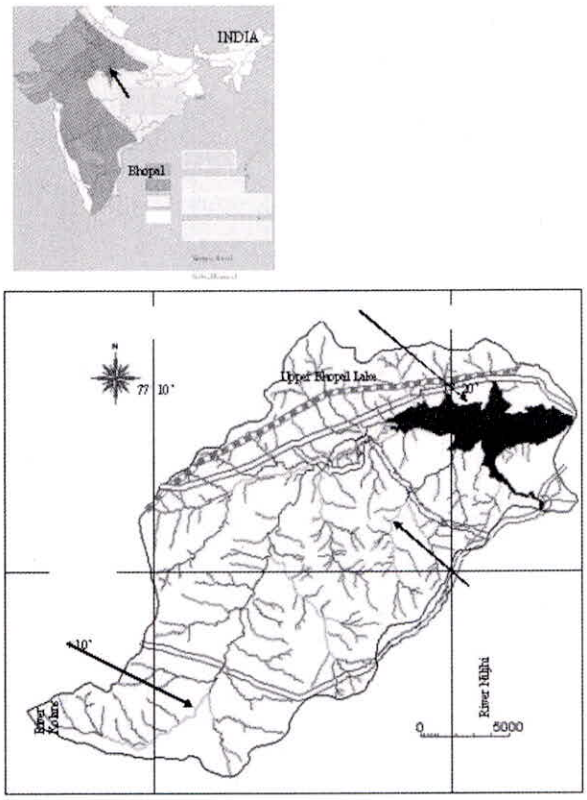

Fig. 1 : Topographical layout of the Upper Bhopal Lake

CLIMATE

The catchment 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. 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. 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.

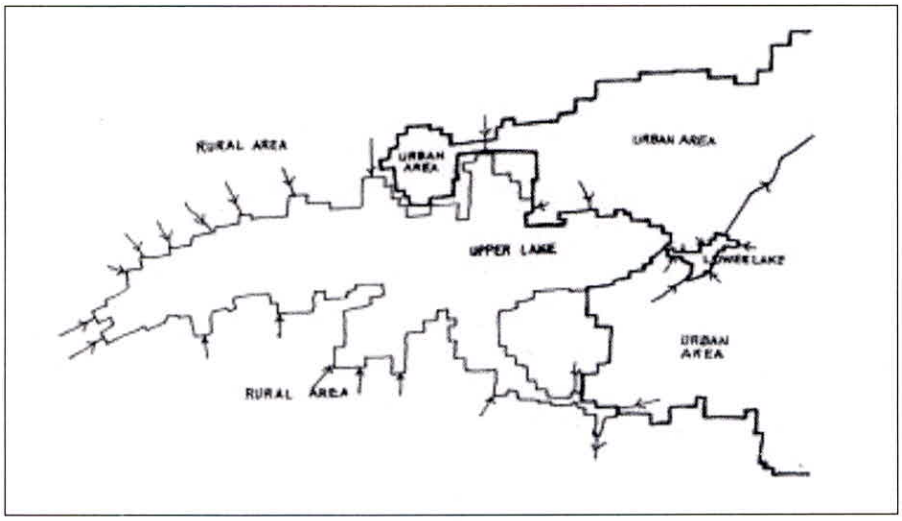

Fig. 2 : Orientation of the Upper Bhopal Lake and the Lower Bhopal Lake

ASCERTAINING LAND USE PATTERN OF THE CATCHMENT AREA

Land-use/Land-cover of catchment of the Upper Bhopal Lake is given in Table 1.

Table 1 : 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.

The catchment is devoid of forest cover, its land use is largely characterised as agricultural, except some urban land in the catchment. Therefore, a detailed survey of land use pattern in the catchment area of the lake was undertaken. Out of total catchment area of 362.636 square kilometre (sq. km.), water surface area of the lake is 34.31 sq. km., agricultural land use area is 301.347 sq. km. and urban land use area is 26.979 sq. km.

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-II. 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.

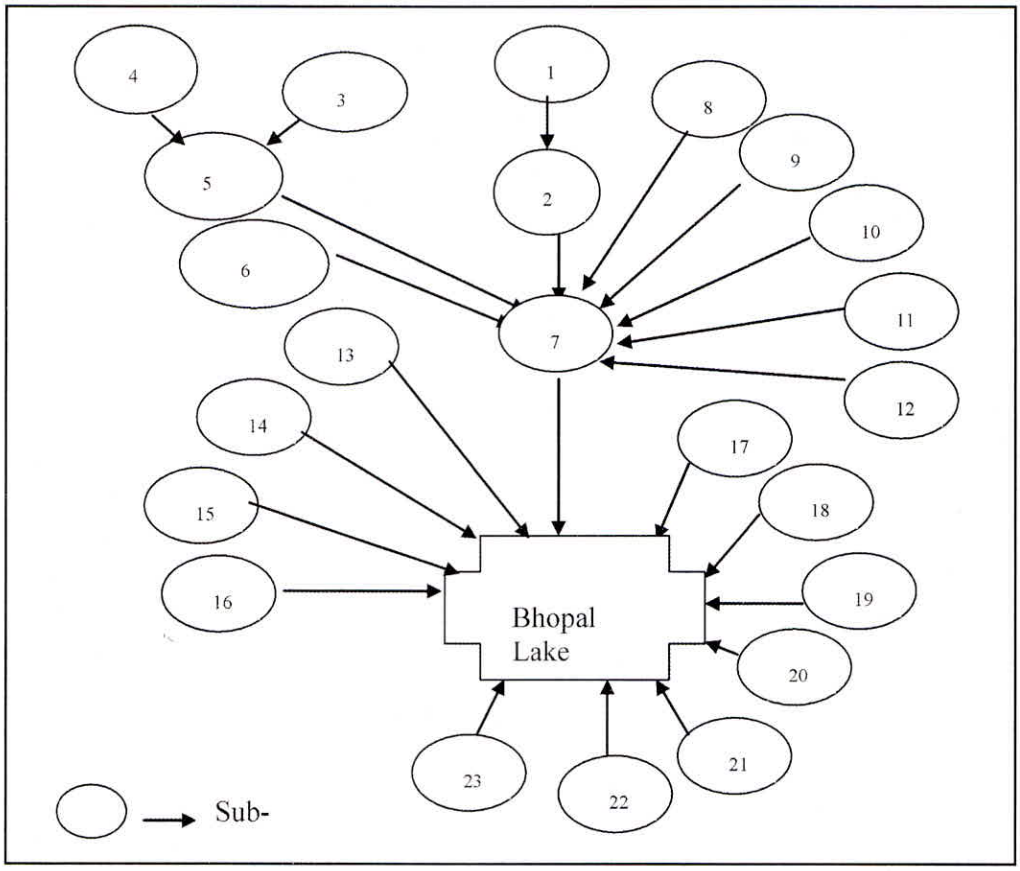

Fig. 3 : Inter-connectivity of sub-catchments in the catchment of the Upper Bhopal Lake

CALCULATING RAINFALL-EXCESS

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- 3.

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 -3. 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.

Table 2 : 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

Table 3: Daily water balance 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			

Table 3: Daily water balance of the Bhopal Lake for monsoon period of the year 2002 (Contd.)

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.)			
7/28/02	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
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)	from urban as well as
8/2/02	1649.13	2.48	8.77	0.11	7.80	0.019	0.133	3.47	0.009	0.017			agricultural
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	area starts
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)	reaching to
8/5/02	1650.15	5.08	14.23	0.11	0.00	0.000	0.114	27.94	0.096	3.519			the lake with effect
8/6/02	1650.45	5.84	15.83	0.11	0.00	0.000	0.114	20.07	0.102	1.615			from 6th
8/7/02	1650.70	6.47	17.17	0.11	0.00	0.000	0.114	49.45	0.289	1.161			event,
8/8/02	1651.10	7.49	19.30	0.11	5.50	0.041	0.155	9.99	0.065	2.186			having 165.04 mm
8/9/02	1651.15	7.62	19.57	0.11	6.51	0.050	0.163	0.85	0.006	0.416			of rainfall
8/10/02	1651.13	7.57	19.46	0.11	6.76	0.051	0.165	0.00	0.000	0.056			over 48
8/11/02	1651.07	7.41	19.14	0.11	6.85	0.051	0.164	1.19	0.009	0.000			days of
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	monsoon
8/13/02	1650.85	6.85	17.97	0.11	3.63	0.025	0.139	2.29	0.016	0.000			season.
8/14/02	1650.83	6.80	17.86	0.11	5.72	0.039	0.153	4.23	0.029	0.003		(6.52)	
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			
8/17/02	1651.50	8.51	21.44	0.11	0.80	0.007	0.120	9.31	0.070	2.181		(219.29)	
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			
8/30/02	1655.70	19.17	43.84	0.11	0.00	0.000	0.114	22.86	0.369	6.140		(407.16)	
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 3 : Daily water balance of the Bhopal Lake for monsoon period of the year 2002 (Contd.)

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.)			
9/8/02	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			

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 lad use drainage area (sub-catchment 1 to12, 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.

ESTIMATION OF RUNOFF FROM AGRICULTURAL 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–III. Inflow reaching to UBL from agricultural catchment of the lake for the monsoon season of the year 2002 is shown in figure 4. Inflow reaching to UBL from agricultural catchment of the lake for the monsoon season of the year 2003, 2004, and 2005 is shown in figure 5, 6, and 7 respectively.

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. Knowing inflow from agricultural sub-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.

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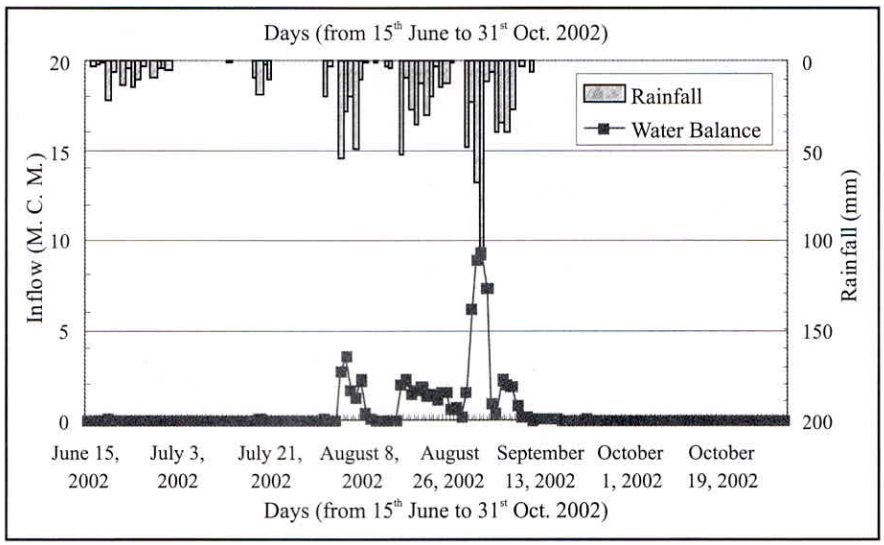

Fig. 4 : Inflow from agricultural sub-catchments reaching to the Bhopal Lake for monsoon season of the year 2002

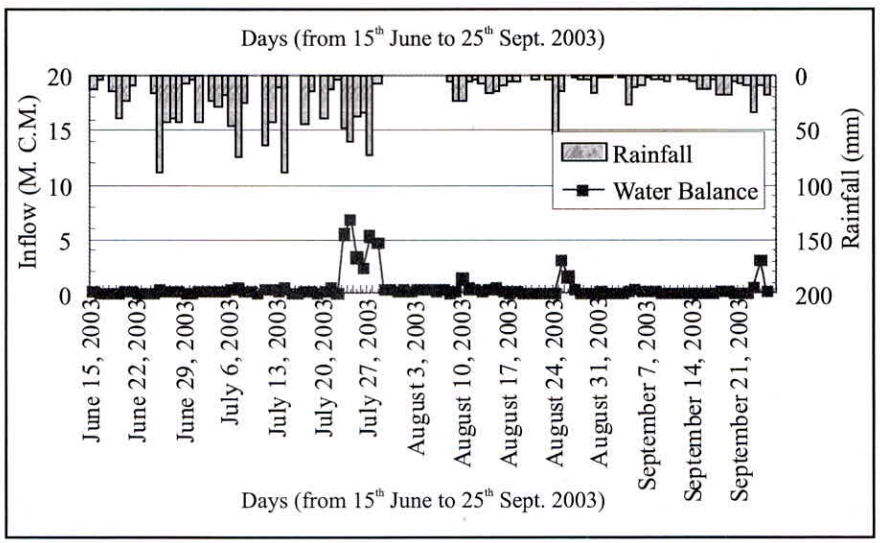

Fig. 5 : Inflow from agricultural sub-catchments reaching to the Bhopal Lake for monsoon season of the year 2003

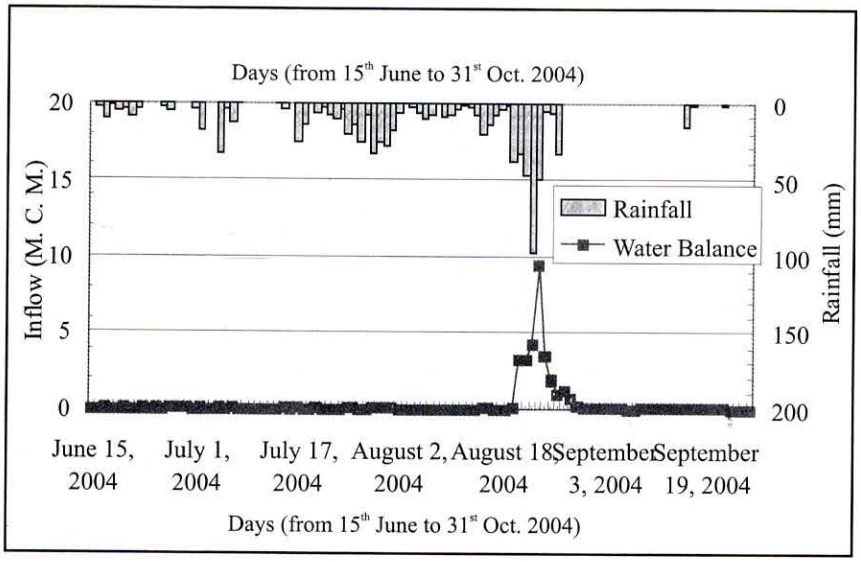

Fig. 6 : Inflow from agricultural sub-catchments reaching to the Bhopal Lake for monsoon season of the year 2004

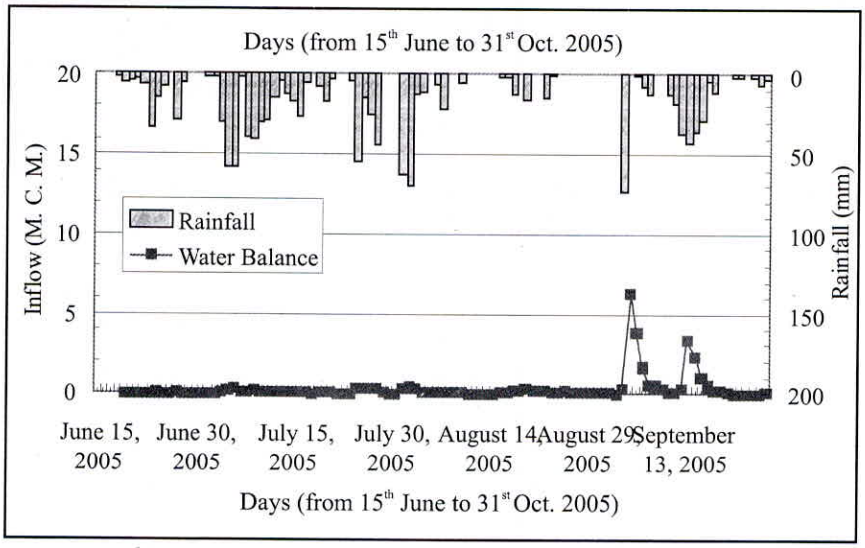

Fig. 7: Inflow from agricultural sub-catchments reaching to the Bhopal Lake for monsoon season of the year 2005

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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