CHAPTER-III

HYDROLOGY AND WATER ASSESSMENT

3.0 General climate and hydrology

The project area under study is semi-arid to dry sub-humid. The climate is tolerable except during the months of May and June. The air is mostly dry except during south-west monsoon season. Summer is hot and winter is generally mild. So far hydrology of the project is concerned, it is based on hydrology of Ken river at Daudhan. Ken river has been found to be surplus at 75% dependability and as such after meeting in-basin requirement of Ken, surplus water of 1074 MCM has been proposed for diversion to Betwa basin. Hydrological studies of this project has been carried out by National Institute of Hydrology, Roorkee in four parts. Phase-I of the study deals with assessment of yield, water balance, design flood & diversion flood, sedimentation studies & simulation studies for Ken river at Daudhan dam whereas Phase-II(a) deals with the same studies in respect of upper Betwa Projects i.e., Makodia, Kesari & Barari Projects. Similarly Phase-II(b) covers dam break analysis of Daudhan dam, back water studies of Daudhan & Makodia dams whereas Phase-II(c) covers integrated simulation of dams involved in Ken-Betwa link, morphological studies etc. Reports of different phases of Hydrological studies are placed in Appendix Volume-III.

3.1 General information about regions

Ken basin

The climate of the area is semi-arid to dry sub-humid. Summer is hot and winter is generally mild. About 90% of the annual rainfall is received during the monsoon period, i.e. from June to October. The average maximum and minimum temperatures are 44.2°C and 6.7°C respectively. The monthly mean relative humidity data of the basin (for five IMD stations) show that the maximum and minimum values of humidity are 95% and 9% during monsoon and summer seasons respectively. The maximum and minimum wind velocities are 16.1 km/hr and 1.0 km/hr respectively at Sagar and Nowgong stations. Usually the maximum cloud cover is observed during the months of July or August whereas the minimum cloud cover is observed during December. The monthly average coefficients of sunshine vary from 0.469 and 0.736. There is no pan-evaporimeter installed in the basin. The monthly average evaporation of two nearby stations (Sagar and Damoh) varies from 6.35 cm (in December) to 40.01 cm (in May).

Betwa basin

The climate of the basin is characterized by hot summer and mild winter. The temperature in the upper reaches some times goes beyond 40 °C. The maximum and minimum mean monthly relative humidity are reported to be 83% (August) and 20.5% (April) respectively. The wind velocities in the upper reaches (varying between 6.6 km/h to 18.9 km/h) of the basin are generally higher than that of the lower reaches in the basin (varying between 2.9 km/h to 13.0 km/h). The cloud cover is also reported to be higher in the upper part of the basin compared to the lower part. However, the highest and lowest cloud covers are experienced in the entire basin are during the months of August and November respectively.

3.1.1 Specific information

3.1.1.1 Drainage basin

Ken basin

The Ken River originates from the Ahirgawan village on the north- west slopes of the Kaimur hills in the Jabalpur district of Madhya Pradesh at an elevation of about 550 m above mean sea level. The total length of the river from its origin to its confluence with the Yamuna River is 427 km, out of which 292 km lies in Madhya Pradesh, 84 km in Uttar Pradesh and 51 km of its course forms the common boundary between the two states. The river joins the Yamuna River near village Chilla in Uttar Pradesh at an elevation of about 95 m. The river is the last tributary of Yamuna before the Yamuna joins the Ganga. The river basin lies between 23°12' – 25°54' N latitudes and 78° 30' – 80° 36' E longitudes. The total catchment area of the river is 28058 sq. km, out of which 24472 sq. km lies in Madhya Pradesh and the remaining 3586 sq. km in Uttar Pradesh. The river network in Ken-Betwa system is presented in Fig. 3.1. Fig. 3.2 shows the railway & road network in the basin.

The Ken basin covers Sagar, Damoh, Panna, Satna, Chhatarpur, Katni, Narsinghapur and Raisen districts of Madhya Pradesh and Mahoba and Banda districts of Uttar Pradesh. It is bounded by Vindhyan range in the south, Betwa basin on west, free catchment of Yamuna below Ken on east, and the river Yamuna on north. The important tributaries of Ken are Alona, Bearma, Sonar, Mirhasan, Shyamari, Banne, Kutni, Urmil, Kail and Chandrawal.

The longest tributary of Ken River is Sonar which is 199 km in length and lies wholly in M.P. in the upstream of the Daudhan dam site. In terms of catchment area also, Sonar is the largest tributary with a catchment area of 12620 sq. km. Out of the others, Alona, Bearma, Mirhasan and Shyamari join Ken River upstream of the proposed Daudhan dam. River Banne on which the

Rangawan dam is constructed joins Ken River between the proposed dam site and the existing Bariyarpur Pick Up Weir (P.U.W.), while Kutni, Urmil, Kail and Chandrawal join downstream of Bariyarpur P.U.W. Urmil and Kail rivers have part of their catchments in Uttar Pradesh while river Chandrawal has the most of its catchment area in Uttar Pradesh.

Betwa basin

The Betwa River originates in the Raisen district of Madhya Pradesh near Barkhera village south-west of Bhopal at an elevation of about 576 m above mean sea level. It flows in a north-easterly direction through Madhya Pradesh and enters into Uttar Pradesh near village Bangawan of Jhansi district. The total length of the river from its origin to its confluence with the Yamuna River is 590 km, out of which 232 km lies in Madhya Pradesh and the rest 358 km in Uttar Pradesh. The river joins the Yamuna near Hamirpur in Uttar Pradesh at an elevation of about 106 m. The Betwa is an interstate river between the two states, viz. Madhya Pradesh and Uttar Pradesh. The river basin lies between 22° 54' – 26° 00' N latitudes, and 77°10' – 80°20'E longitudes. The total catchment area of the basin is 44335 sq km out of which 30238 sq km lies in Madhya Pradesh and the remaining 14097 sq km lies in Uttar Pradesh. The basin is saucer shaped with sandstone hills around the perimeter.

During its course from the source up to the confluence with the Yamuna, the river is joined by a number of tributaries and sub- tributaries; the important among them being the Bina, Jamini, Dhasan and Birma on the right bank and Kaliasote, Halali, Bah, Sagar, Narain and Kethan on the left bank. Out of the 14 principal tributaries 11 lie completely in Madhya Pradesh and 3 lie partly in Madhya Pradesh and partly in Uttar Pradesh. The Halali is the largest tributary of Betwa River having a length of 180.32 km.

Betwa covers the areas of Bundelkhand uplands, the Malwa plateau and the Vindhyan scrap lands in the districts of Tikamgarh, Sagar, Vidisha, Raisen, Bhopal, Guna, Shivpuri and Chhatarpur of Madhya Pradesh and Hamirpur, Jalaun, Jhansi and Banda districts of Uttar Pradesh.

3.1.1.2 Command area

The project has four commands as described below:

(i)Ken command (M.P.):The Ken command area of M.P comprising 2,41,306 ha CCA is spread over Chhatarpur and Panna districts of Madhya Pradesh.

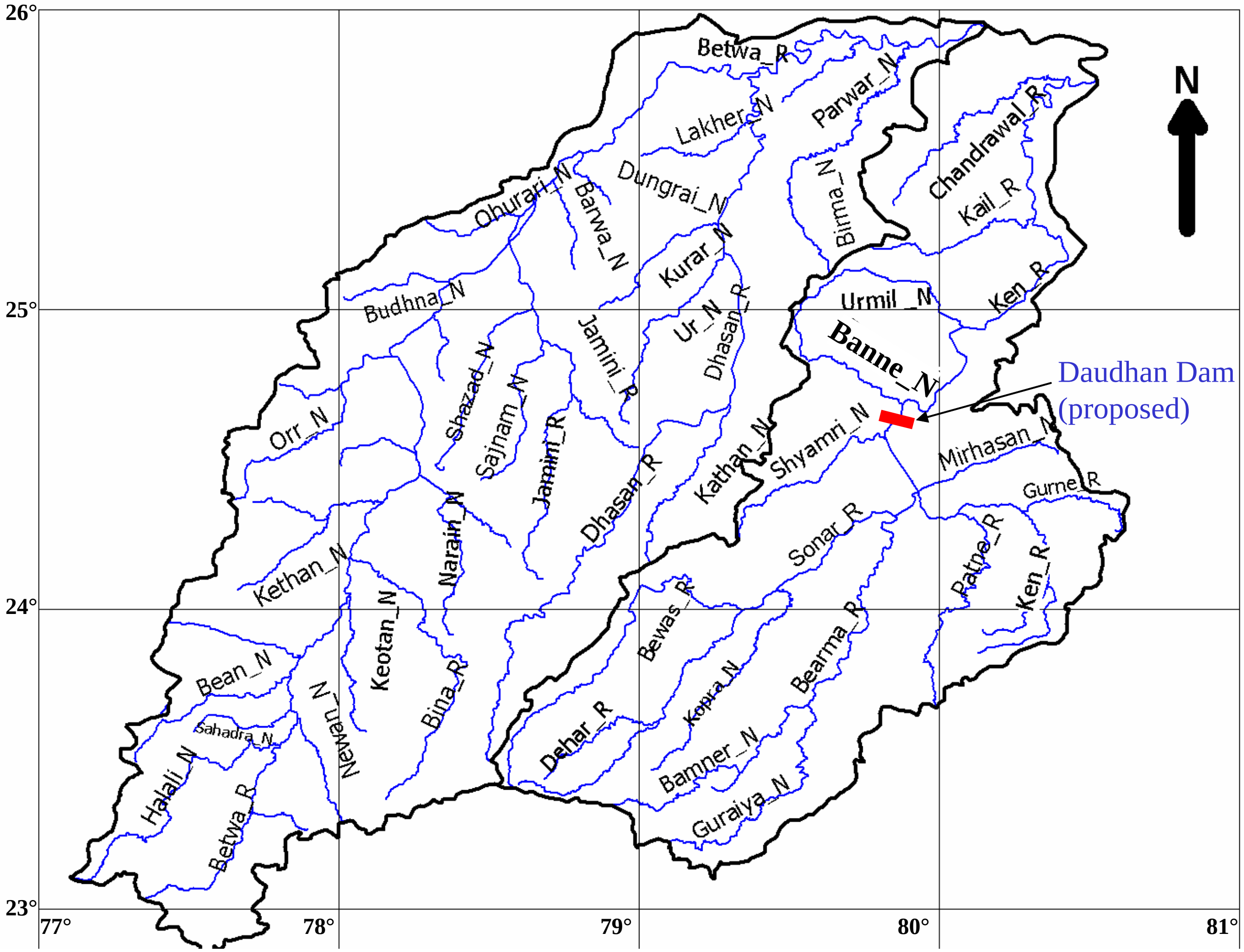

Fig. -3.1. River network in Ken-Betwa system

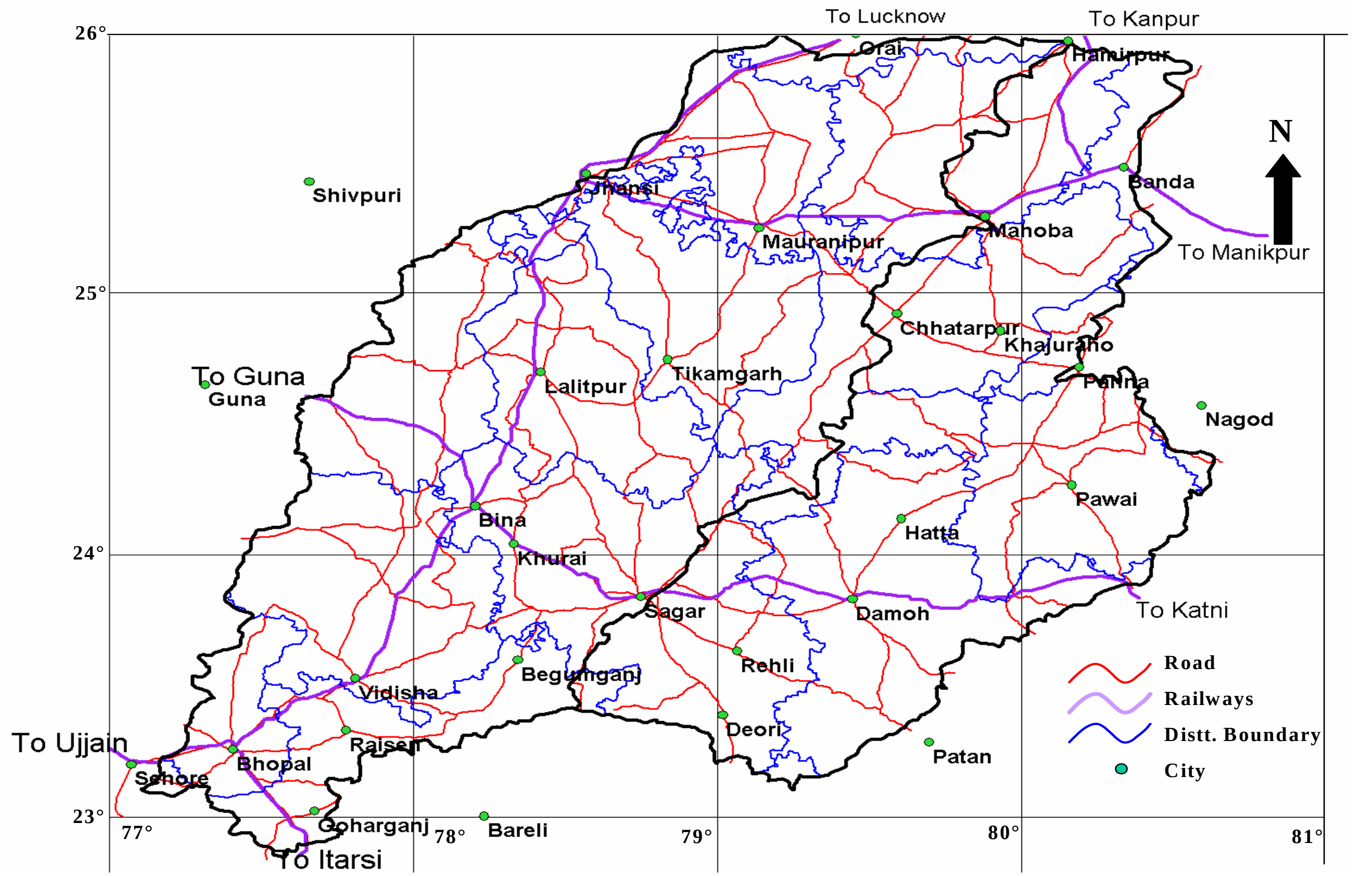

Fig.- 3.2. Road and rail network in Ken-Betwa system

(ii)Ken command (U.P.):The Ken command area of 2.13 lakh ha is spread over Banda district of Uttar Pradesh. This command is the existing command of Bariarpur RBC.

(iii) Enroute command: The enroute command area comprising 60,294 ha CCA is covered in Chhatarpur and Tikamgarh districts of Madhya Pradesh and Mahoba and Jhansi districts of Uttar Pradesh.

(iv)Upper Betwa command: The Upper Betwa command area is covered under three projects proposed in the Upper Betwa region namely Makodia dam, Barari and Kesari barrages. These areas are covered in the districts of Vidisha and Raisen of Madhya Pradesh. The total CCA under these three projects is 42,300 ha. Break-up is as given below:-

Name of project	CCA (ha)
Makodia dam	37,900
Barari	2,000
Kesari	2,400
Total	42,300

3.1.1.3 Floods and drainage

Ken Basin

The observed 10-daily discharge data (3 values per month) of two gauging sites namely, Banda and Madla, both downstream of Daudhan are available for 45 and 25 years, respectively, with some missing records. The annual maximum series (25 years of data) for Madla is also available. As per the AMS, the maximum observed flood was 20150 Cumecs in the year 2005.

Betwa Basin

The observed daily gauge and discharge data of only one G&D site in the Upper Betwa basin, i.e., Basoda are available for 30 years (1976 to 2005) with some missing records. The maximum observed discharge at the G&D site was 9289.1 Cumecs on 24th July 1986.

3.1.1.4 River geometry

The schematic diagram of Ken-Betwa river system (Fig. 3.4) gives an overview of the river geometry.

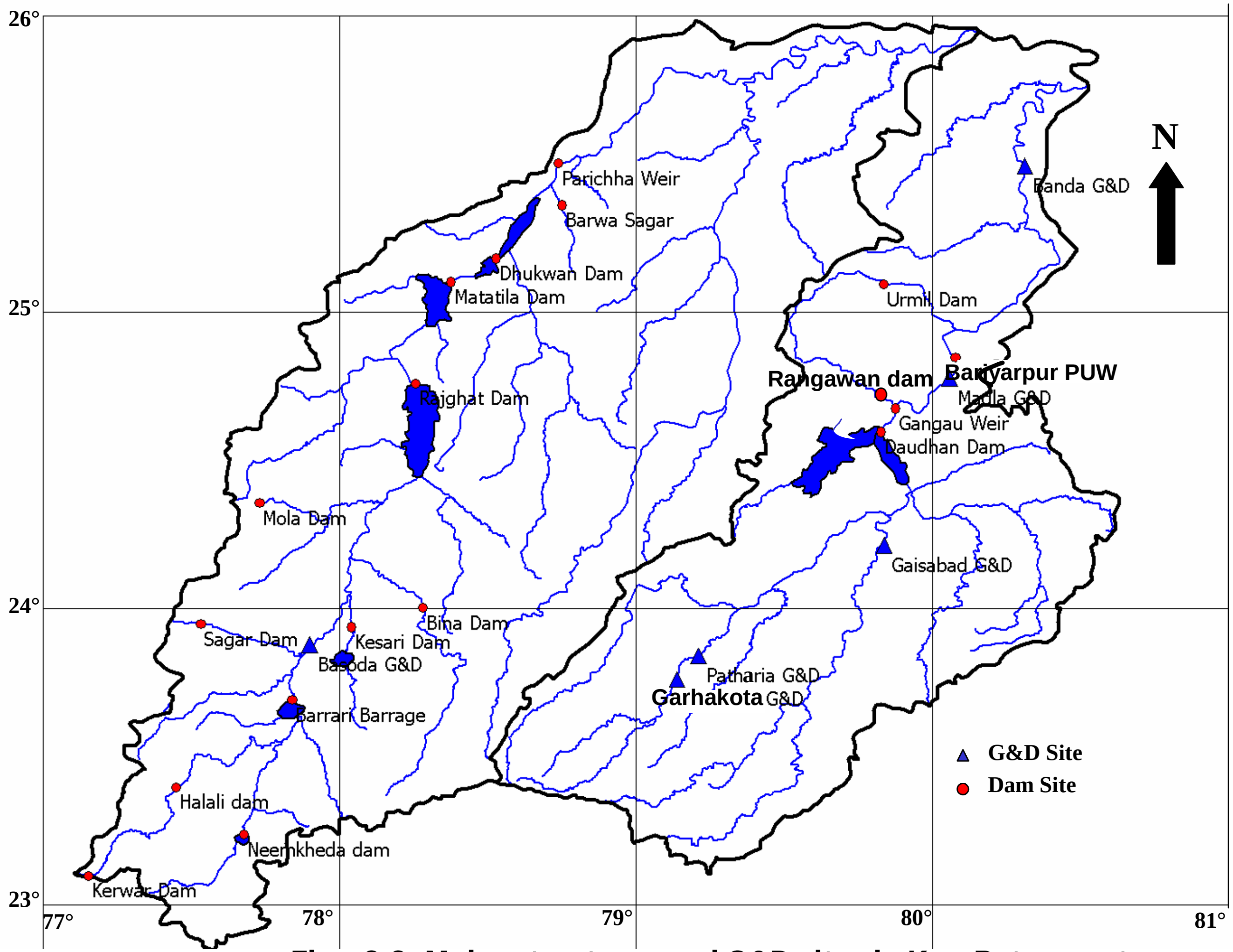

Fig.- 3.3. Major structures and G&D sites in Ken-Betwa system

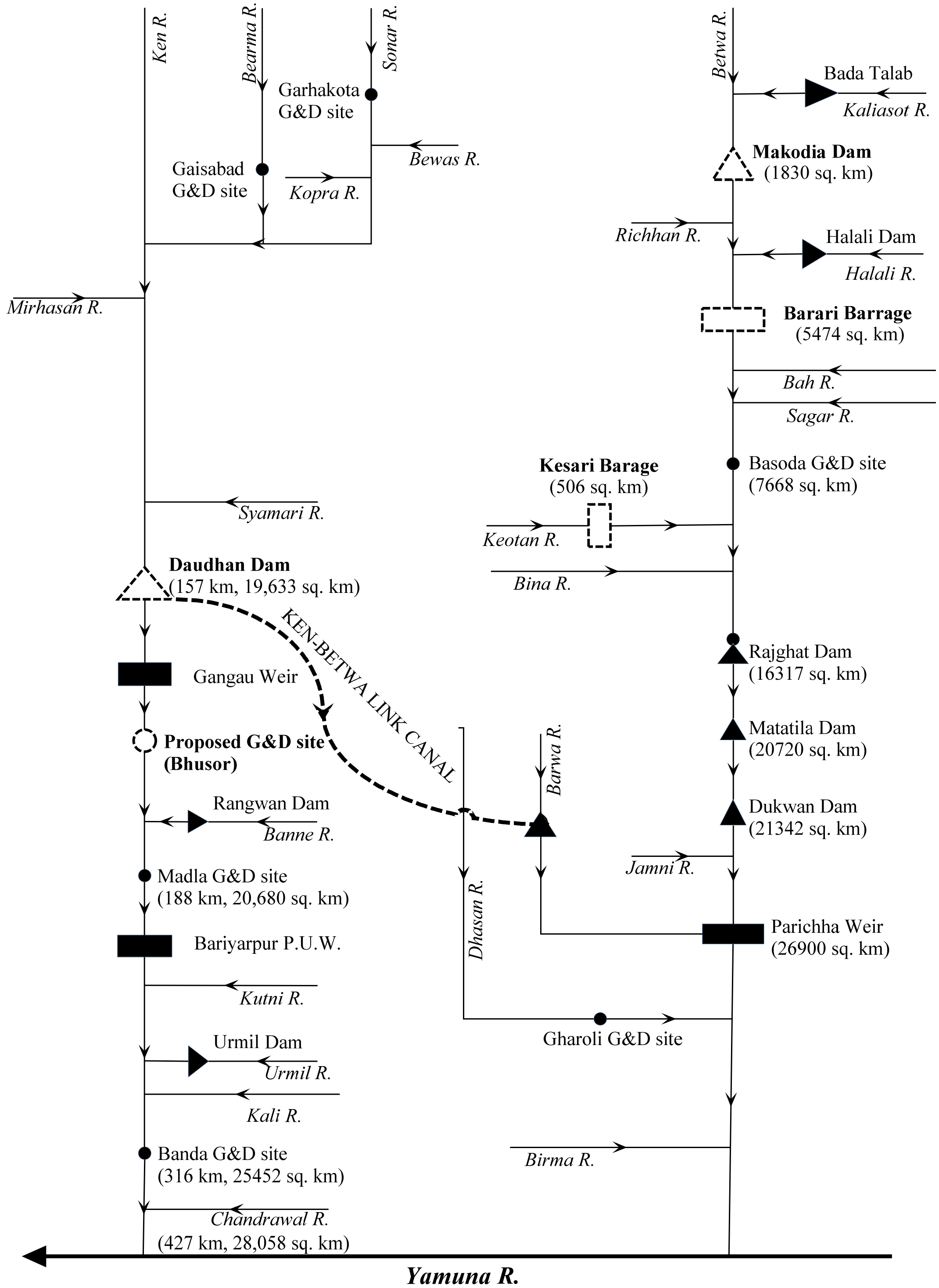

Fig. -3.4. Schematic diagram of the Ken-Betwa river system with major structures (existing and proposed) and the link canal

3.1.1.5 Ground water recharge

During environmental impact assessment of Ken-Betwa link, detailed study of ground water quality, ground water levels, ground water fluctuations have been carried out for 2006-07. The details are furnished in Chapter-VIII "Environmental Impact Assessment & Environment Management Plan". The analysis of water level data in project area indicates a general rise in water level during rainy season. The reservoir and link canal are likely to have a long term increase in water levels of the phreatic zones.

3.1.1.6 Reservoir area

There are two proposed reservoirs viz. Daudhan and Makodia. Project area of the Daudhan dam is located in the Panna and Chhatarpur districts of Madhya Pradesh. The dam site is situated in the Chhatarpur district near the Daudhan village at 24°36' 5.1" N latitude and 79° 50' 30" E longitude and is about 2.5 km upstream of the old Gangau Weir. The area of the reservoir at FRL is estimated as 9000 ha. The project area is approachable by road from Chhatarpur-Panna state highway. It is about 19 km (WBM road) from this road. The dam site is approachable by a dry weather motorable road of about 5 km from the Irrigation Inspection Bunglow at Gangau. The project site is also approachable by rail up to Satna railway station, which is about 110 km by road towards Chhatarpur. Khajuraho is the nearest airport, which is 31 km away from the dam site, which is also recently connected by new railway line from Mahoba.

About 74 percent of the reservoir submerged area comes under forests. Parts of these forests are reserved and a part on the north and south bank of Ken River is under Panna National Park. Almost all the forests are dense and mixed jungles comprising deciduous, a few evergreen to semi-evergreen and a few xerophytic to semi- xerophytic types of species.

Extensive geological survey made by the Madhya Pradesh State Geology and Mining Department reveals that large quantities of limestone occur in the project area. These areas are highly siliceous and magnesious and do not fetch much economic value. No other valued mineral mines are found in the project area. The Panna diamond mine is nearby the project area but does not fall in the jurisdiction of the proposed project boundary.

Due to creation of the Daudhan dam and reservoir, about 900 families having a total population of approximately 8550 persons will be uprooted from 10 villages, at full reservoir level. A few clusters of population in the periphery of the reservoir will also be affected as lands of these villages may come under submergence. The majority of population in the submergence area is dependent on forest products as the reservoir area is covered mostly by forests. A few of them are either agricultural or industrial workers. About 15 to 20% of the people to be affected in the submergence have agriculture as their occupation. On the other hand, most of the people to be benefited in the command area are dependent on agriculture, either cultivating their own lands or working as labourers in agriculture fields.

Makodia reservoir area is located in the Raisen district of Madhya Pradesh. The dam site is situated in the Goharganj near the Makodia village at 23°14'05" N latitude and 77°41'00" E longitude. The area of the reservoir at FRL (437.5 m) is estimated as 10486 hectare. The live storage capacity of the dam is 295 MCM.

The Makodia dam is expected to deliver 303 MCM water for irrigating 37900 ha of land and provide 13 MCM of water for drinking and domestic uses.

3.1.1.7 Other water usage

The water stored in the Daudhan and Makodia dams, and Barari and Kesari barrages, will mostly be used for irrigation and drinking purposes only. However, due to presence of urban areas (Bhopal) in the catchment of Makodia, with expected growth of industries in the surroundings of Bhopal, its water may be used for industrial purposes in the future.

3.1.1.8 Navigation

Rivers in the Ken-Betwa system are presently not used for any major navigational purpose. There is no provision for navigation in the proposed Ken-Betwa link also.

3.1.2 Data Availability

3.1.2.1 Rainfall and snowfall

There is no snowfall in Ken or Betwa basins. Rainfall data availability is described in following paragraphs.

Ken Basin

The precipitation on the basin is in the form of rainfall and the intensity of rainfall varies fairly in time and space as observed from the database. The inventory of existing database for the basin is given in Table-3.1. The distribution of the existing rain gauges in the Ken basin is shown in

Fig.- 3.5. There are twenty one rain gauge stations in and around Ken basin that are being maintained by IMD.

Table -3.1: Rain gauge stations in Ken basin and their period of availability

RG No.	Station Name	Period of availability	Record length in years
1	Bijawar	1901-2002	101
2	Hatta	1901-2002	101
3	Borina	1927-1994	67
4	Banda	1901-2002	101
5	Rehli	1901-2002	101
6	Majhgawan Hansraj	1927-1992	65
7	Damoh	1901-2002	101
8	Jabera	1901-2002	101
9	Malla	1927-1993	66
10	Hardua Morar	1927-2001	74
11	Deori	1916-2002	86
12	Patan	1913-2002	89
13	Chhatarpur	1901-2002	101
14	Panna	1901-2002	101
15	Ajaigarh	1901-2002	101
16	Nowgong	1901-2002	101
17	Chandia Nalla	1927-1992	65
18	Sagar	1901-2002	101
19	Mahoba	1901-1992	91
20	Naraini	1921-1983	62
21	Murwara/Pawai	1901-1999	98

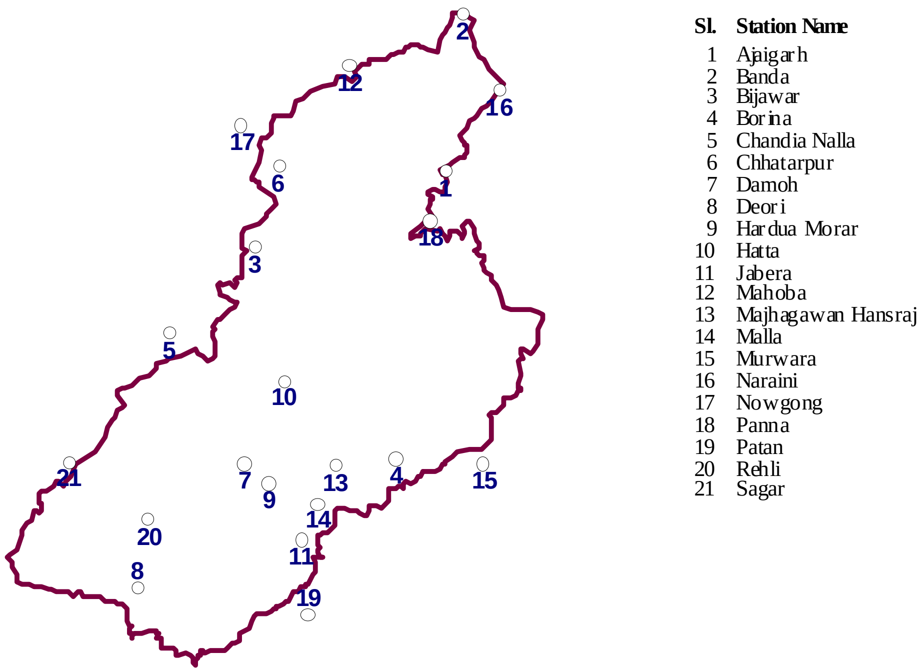

Figure-3.5: Raingauge stations of Ken basin up to Banda gauging site

Betwa Basin

There are 25 raingauge stations in and around Betwa basin that are being maintained by IMD. Out of these 25 stations, only 8 stations are located in and around the Upper Betwa basin up to the gauge and discharge (G&D) site at Basoda. The inventory of these is given in Table 3.2. The distribution of the existing raingauges in the basin is shown in Fig.- 3.6.

Table -3.2: Raingauge stations (IMD) in Upper Betwa basin and their period of data availability

RG No.	Station Name	Period of availability	Record length in years
1	Basoda	1906-2002	97
2	Berasia	1906-2002	97
3	Bhopal	1929-2005	77
4	Gairatganj	1923-2002	80
5	Raisen	1907-2004	98
6	Sehore	1929-2002	74
7	Sironj	1936-2002	67
8	Vidisha	1901-2004	104

Fig. -3.6: Raingauge stations of Upper Betwa basin up to Basoda G&D site

3.1.2.2 Pan evaporation

There is no pan-evaporimeter installed in the Ken basin. The monthly average evaporation of two nearby stations (Sagar and Damoh) varies from 6.35 cm (in December) to 40.01 cm (in May). Normal monthly pan evaporation data for Bhopal station are available and have been used for estimation of other parameters in the upper Betwa projects.

3.1.2.3 Climatological parameters like temperature, humidity, wind etc.

Climatic parameters for Daudhan and Upper Betwa commands are as follows:

		Daudhan command		Upper Betwa command	
		Max.	Min.	Max.	Min.
(a)	Air temperature(^{0}c)	44.2	6.7	44.2	6.7
(b)	Humidity (Per cent)	95	9.0	83	20.5
(c)	Wind (km/hr)	16.1	1.0	18.9	6.6

3.1.2.4 River gauge and discharge

There are four gauge and discharge sites in the whole Ken basin. Gauge and discharge measurements at Patharia site on Sonar tributary of Ken River was stopped in 1982 and the site was shifted to up-stream location Garhakota. The details of all G&D sites in Ken basin is given in Table- 3.3.

Table- 3.3: Details of gauge and discharge sites in Ken basin

S. No	Name	River	Catchment area (sq km)	Data availability	
				From	To
1	Patharia	Sonar	1634	1974	1982
2	Garhakota	Sonar	1313	1982	2005
3	Gaisabad	Bearma	5758	1974	2005
4	Madla	Ken	20680	1981	2005
5	Banda	Ken	25452	1960	2005

The observed daily gauge and discharge data of only one G&D site in the Upper Betwa basin, i.e., Basoda are available for 30 years (1976 to 2005) with some missing records.

3.1.2.5 Sediment (suspended and bed load) inflow and grain size composition

The sediment data are collected by CWC at only one G&D site, *viz.* Banda, in the Ken Basin.

3.1.2.5 Water quality

As a part of the field study done for socio economic studies, surface water samples were collected from Ken and Betwa river basins and analyzed for various physio-chemical parameters and details are furnished in Chapter-VIII "Environmental Impact Assessment". The test results presented in this study indicate that quality of surface water is generally of safe category.

Ground water analysis for EIA studies has been done for the monsoon season 2007. It is found that the quality of ground water is satisfactory in the project area. Thus, it may be generally said that the ground water in the area is good and fresh for use.

3.2 Hydrological data requirement

3.2.1 Alternatives and classifications

This information was not necessary for the present study.

3.2.2 Inputs

3.2.2.1 Type of inputs

Temporal data

Estimation of design flood is required for economic design of any hydraulic structure such as spillways, barrages etc. For estimation of carrying capacity of the diversion channels during construction of a structure, diversion flood is required to be estimated. Guidelines are available for selection of methodology for estimation of design flood. For major structures, the design flood is estimated using hydro-meteorological approach. The diversion flood is estimated mainly by frequency analysis of non-peak period flood. Hence, for estimation of design flood short duration rainfall-runoff data are required. Short duration rainfall data are generally measured at the gauging stations using self recording raingauges. Since the short duration discharge data are estimated from the river stage, hourly gauge data are also required. For estimation of diversion flood the non monsoon peak flow data are required.

To estimate the reservoir inflow, daily discharge series are required. In absence of daily series, ten-daily series can be used. For development of rainfall-yield relationship, daily/ monthly average rainfalls are required. To estimate the average rainfall in the basin, the rainfall of all raingauge stations lying inside or around the basin are required. The inflow to the reservoir is abstracted by water utilization at the upstream. Hence the temporal utilization of water by the upstream projects is also necessary to compute the reservoir inflow.

The periodic water demands and releases from the reservoir, and evaporation rates in the reservoir area are also required for simulation of a reservoir.

Spatial data

For estimation of average rainfall, the locations of raingauges and the delineated basin boundary are required. The basin boundary also gives the area of the basin which can be used for other purposes such as synthetic hydrograph generation, application of conceptual models etc. For reservoir simulation the elevation-area-capacity data are required which can also be used for reservoir routing.

3.2.2.2 Time units for simulation studies

Two types of simulations are mainly carried out: (a) routing of design flood in the reservoir to estimate the dam height, (b) continuous simulation of the reservoir with a series of inflows and demands to estimate the reliability of the reservoir. For reservoir routing, hourly time unit is used. For reservoir simulation, monthly time unit is used.

3.2.2.3 Hydrological Inputs

These inputs are explained in details in section 3.2.2.1.

3.2.3 Requirement of the inputs for the project

The relevant information are provided in sections 3.1.2 and 3.2.2.

3.3 Compilation and processing of basic hydrological data

3.3.1 Hydrological investigation

No G&D site is available on the Ken river nearer to Daudhan dam site. There are however, four G&D sites in entire Ken basin as detailed below:

S.no	Name	River	Catchment area(sq.km)
1.	Patheria*	Sonar	1634
2.	Garhakota	Sonar	1313
3.	Gaisabad	Bearma	5758
4.	Madla	Ken	20680
5.	Banda	Ken	25452

- site shifted to Garhakota.

The hydrological studies upto Daudhan dam site have been carried out by using the data of Banda & Madla G&D sites located about 31 km & 150 km respectively downstream of Daudhan dam. However, in order to observe the actual runoff data at the proposed dam site, one G&D site has been established by NWDA at Bhusor, on river Ken d/s of existing Gangau weir near Daudhan dam site and observations have been started w.e.f. 1.10.2006.

No gauge and discharge site is available in the vicinity of Makodia dam. One Gauge & Discharge site was opened by NWDA at Neemkheda on Betwa river, 7 km d/s of Makodia dam site and observations were started from 01.10.2006.

In addition to the above, Gauge and Discharge data being observed by CWC at Basoda on river Betwa have been collected and the same for the period from 1976 to 2005 (30 years) have been utilized in hydrological study carried out by NIH, Roorkee for this project.

3.3.2 Data from other sources

Most of the data used in this study were collected from other agencies. Rainfall and evaporation data were collected from IMD, and river G&D and sediment data were collected form CWC. Other data such as location and water utilization of upstream projects were collected from field agencies of the State Govt.

3.3.3 Processing of data

The time units of available and required time series data are often different. Further, the short duration discharges are not measured but are estimated from the gauge records. This requires preliminary processing of the time series data. Following hydrological variables were processed in this study: (i) rainfall data (ii) gauge and discharge data.

3.3.3.1 Quality of data

As mentioned earlier, there are some missing records in daily/ ten-daily discharge and daily rainfall data. However these missing records are not significant in number to adversely affect the data analysis. Further, no discharge data are available at the project locations (the discharge data available are at the gauging sites only). Hence, suitable methodology needs to be applied to estimate the yield data at the project locations.

3.3.3.2 Filling of short data gaps

Rainfall being random process in nature, its missing values has not been filled. However, there were fillings in gaps of yield data. The data gaps in yield during monsoon months have been filled using monthly regression of rainfall and yield and the gaps in the non-monsoon yield have been filled using the average values (regression analysis of non-monsoon rainfall-yield does not give good relationship).

3.3.4 Adjustment of records

For this study, the double mass curve (DMC) analysis is used to check the consistency of a rainfall series and adjustment of records. This analysis is based on the principle that when each recorded data comes from the same parent population, they are consistent.

A group of stations in neighborhood of the index station (for which the consistency test is required) is selected. The data of the annual (or monthly mean) rainfall of the index station X and also the average rainfall of the group of base stations covering a long period is arranged in the reverse chronological order, i.e. the latest record as the first entry and the oldest record as the last entry in the list. The accumulated precipitation of the station X and the accumulated values of the average of the group of base stations are calculated starting from the latest record. Individual cumulative rainfall values of the index station are plotted against mean cumulative values for various consecutive time periods. A break in the slope of the resulting plot indicates a change in the precipitation regime of the index station. The precipitation values at the index station prior to the change of regime can be corrected by using the initial slope of the line as follows:

$$P_X(i) = m \times C_A(i) - C_X(i-1) \quad \text{... (3.1)}$$

where $P_X(i)$ is the corrected rainfall at the index station *X* during year *i*; *m* is the initial slope of the line; $C_A(i)$ is the cumulative mean rainfall up to the year *i*; C_X(i-1) is the cumulative rainfall at the index station X till the year *i-1*.

For the study area, the consistency of rainfall series was checked for all the raingauge stations and necessary corrections were made as follows.

First of all, the annual rainfall series of all the stations were computed. The average areal rainfall series, for each station, was computed by taking arithmetic mean of the annual rainfall data of all the stations excluding the data of the station for which the average areal rainfall series was being computed. For each station, the annual rainfall series and average areal rainfall series were arranged in reverse chronological order, and the cumulative annual and average areal rainfall were computed. Graphs were plotted taking cumulative annual average areal rainfall in the X-axis and cumulative annual rainfall of each station. When a change in slope of the line for a station was observed, Eq. (3.1) was used to compute the corrected areal rainfall for the station. The monthly rainfalls were adjusted on the ratio of corrected annual rainfall to the recorded annual rainfall.

For Ken basin the DMC analysis was carried out on monthly basis and for the Upper Betwa basin, the same was carried out on annual total rainfall basis. It was observed that the rainfall records of Ken basin did not require any correction. However, the rainfall records of Basoda, Berasia and Vidisha were required to be adjusted.

3.3.5 Consistency of data

3.3.5.1 Internal

After necessary adjustment of records of rainfall data, and estimating the average areal rainfall by Thiessen Polygon method, the annual average areal rainfall series was tested for consistency by statistical tests (*t* and *F*). The annual average areal rainfall series (1907-2003) was divided into two parts (1907-1953 and 1954-2003) and the tests were performed. The results of these tests indicate that the mean and standard deviation of both the parts are not different statistically and hence, the series is consistent.

Next, *t* and *F* tests were performed for the annual yield series of Basoda, Madla and Banda gauging sites by splitting the series appropriately. The results of t-test and *F*-test for Basoda, Madla and Banda showed that the yield data are consistent.

The annual rainfall and runoff volumes were plotted for Banda, Madla and Basoda sites to check any inconsistency (Figs 3.7a-c). It can be observed from these figures that the data are consistent. Further the runoff factor for Banda, Madla and Basoda sites during the monsoon period were estimated to be 0.345, 0.392 and 0.367 respectively which indicates that the rainfall-runoff data are consistent.

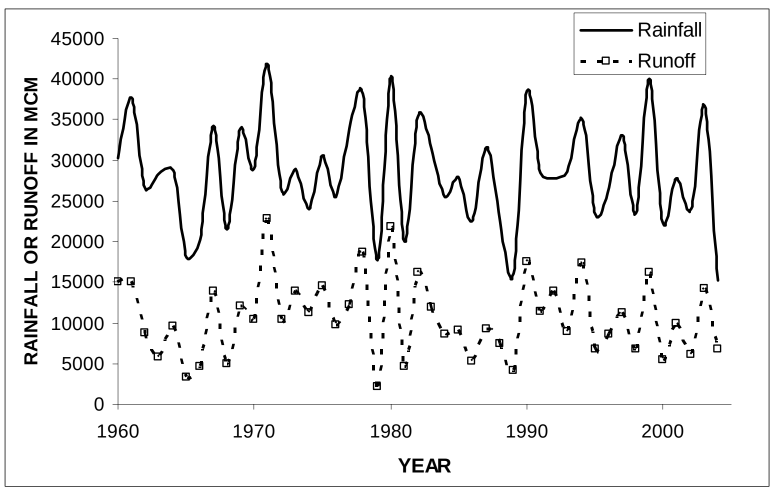

Fig.- 3.7a: Rainfall and runoff series for Banda (1960-2004)

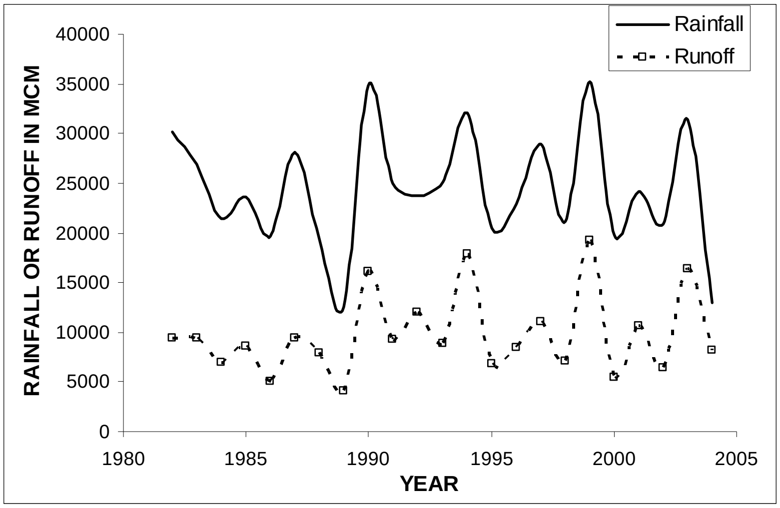

Fig.- 3.7b: Rainfall and runoff series for Madla (1982-2004)

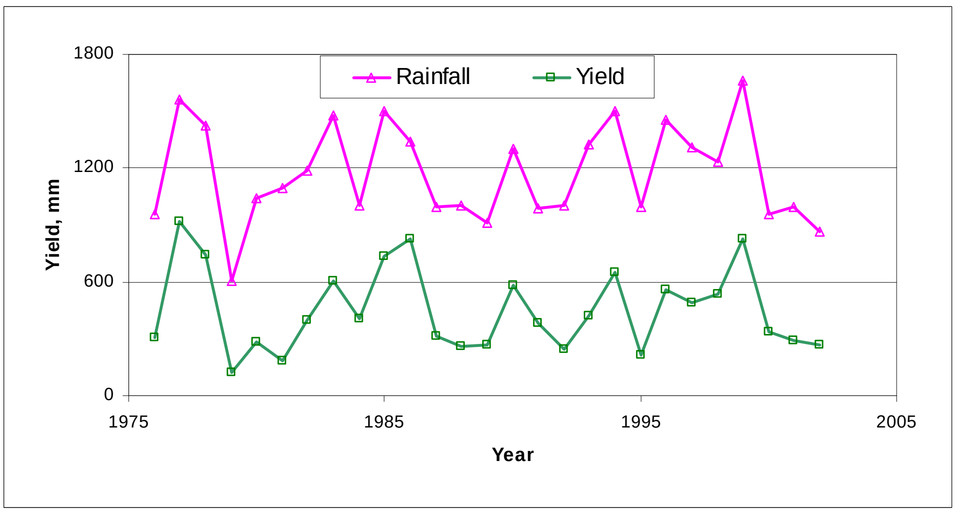

Fig. -3.7c: Rainfall and runoff series for Basoda (1976-2003)

3.3.5.2 External

No external consistency tests could be conducted due to unavailability of data.

3.3.6 Presentation of data

Rainfall data

In any hydrological analysis the knowledge of the average rainfall over an area is required. However, a raingauge represents only point sampling of the areal distribution of a storm. Generally three methods are practiced to convert the point rainfall values at various stations into an average value over an area. These are: (i) arithmetic average or mean (AM) method, (ii) isohyetal method, and (iii) Thiessen polygon (TP) method. In the present study, the AM and TP methods have been used to calculate the average areal rainfall over the study area.

In the AM method, the arithmetic average of rainfall observed at all the stations is assumed as representative of the mean areal rainfall. This method was used for double mass curve analysis only. TP method is a weighted average method in which weights to each gauging site is assigned according to the fraction of area it represents in the basin. Since weightings are assigned to the gauges, in case data are not available for few gauges, the estimated average areal rainfall is not affected much. Hence, this method was used for estimation of average areal rainfall for rainfall-runoff analysis and estimation of yields through regression from rainfall.

A computer program was developed for estimation of average areal rainfall of the catchment and sub-catchments using the Thiessen polygon method. For each month, the program forms the combination of raingauges as per data availability and estimates the Thiessen weights for the stations in the combination.

Discharge / yield data

The observed 10-daily discharge data (3 values per month) of two gauging sites namely, Banda and Madla, both downstream of Daudhan are available for 45 and 25 years, respectively, with some missing records. These 10-daily data were used to compute the average daily discharge for each month using the following equation:

$$q_m = \left[\frac{Q_{1,m} + Q_{2,m} + Q_{3,m}}{n_m} \right] \quad \text{... (3.2)}$$

where, q_m is the average daily discharge for month m (cumec); $Q_{1,m}$, $Q_{2,m}$ and $Q_{3,m}$ are the 1st, 2nd and 3rd ten-daily discharge for the month m (total of daily discharges for consecutive 10 days); and n_m is the number of days in the month m.

The average daily discharge for the month was then used to compute the monthly yield, $Y_O(m)$ (MCM) as follows:

$$Y_O(m) = \frac{q_m \times 3600 \times 24 \times n_m}{10^6} = 0.0864 \times n_m \times q_m \quad \text{... (3.3)}$$

The observed daily gauge and discharge data of Basoda are available for 30 years (1976 to 2005) with some missing records. The daily discharge data were used to compute the monthly yield using the following equation:

$$Y_m = 0.0864 \sum_{i=1}^{n_m} Q_i \quad \text{... (3.4)}$$

where, Y_m is the monthly yield for month m (MCM); Q_i is the daily discharge (cumec) for the i^{th} day of month m; and n_m is the number of days in the month m.

Yield assessment refers to estimation of available water at a particular point in the basin with certain degree of dependability. Water availability or/ and yield at different dependabilities at a specific G&D site is generally estimated from the flow duration curve at that site. However, during the course of development of a watershed, water harvesting structures (projects) come up at various locations. These structures utilize a portion of the available water for various purposes and thereby impact the natural flow of water to the outlet. Depending upon the type and size of a project and its water use, it may also produce some return (delayed) flow. Therefore, the observed discharge series at a G&D site of a developed watershed does not refer to its natural or virgin flow series, and water availability analysis using the observed discharge series alone will lead to erroneous results, if the upstream utilization is significant. The monthly virgin yield is nothing but the sum of the observed yield and the upstream utilization during the month and is estimated as follows:

$$Y_V(m) = Y_O(m) + Y_U(m) \qquad \text{... (3.5)}$$

where, $Y_V(m)$ is the virgin yield for month m; $Y_O(m)$ is the observed yield for month m; and $Y_U(m)$ is the utilization of water by upstream projects during the month m (excluding the return flow from the major & medium projects, if any), all in MCM.

Since the monthly utilization series of upstream projects were not available, climatological approach is used to estimate the monthly utilization. In this approach, the cropping pattern, evaporation and rainfall data of the project command area is used to estimate the potential water requirement.

$$WR(m) = \frac{CA}{10^5} \times \sum_{i=1}^{n} \left[\frac{\left(ET(m) \times K_{C(i)}(m) - RF_{eff}(m)\right) \times P_{C(i)}}{IE_i} \right] \qquad \text{... (3.6)}$$

where, $WR(m)$ is water requirement for month m (MCM); CA is the project command area (ha); $ET(m)$ is the normal evapotranspiration (mm) for month m; $K_{C(i)}(m)$ is the crop coefficient of crop i for month m; $P_{C(i)}$ is the percentage of crop i in the command area; IE_i is the irrigation efficiency for crop i (%); n is the total number of crops in the project command area; and $RF_{eff}(m)$ is the effective rainfall in the month m, estimated using the USDA method.

3.3.7 Data for studies other than simulation

For estimation of design flood hydrograph, unit hydrographs (UH) for the project sites need to be developed. The flood events selected for development of UH for Ken and Betwa basins are presented in Table 3.4.

Table -3.4: Flood events selected for derivation of UH

Gauging site	Date
Banda	16-09-1987
	21-08-1992
Gaisabad	15-09-1987
	20-08-1992
Basoda	13-9-1977
	16-8-1984
	3-8-1988
	7-8-1989
	23-8-1991
	7-9-1993
	1-8-1994
	23-7-1999
	18-7-2000

3.4 Presentation of hydrologic inputs for simulation

3.4.1 Water inflows

Water inflows of Madla G&D site on Ken river and of Basoda G&D site for Betwa river were used for simulation study.

3.4.1.1 Storage projects

Daudhan dam across Ken river and Makodia dam across Betwa river are two storage projects, envisaged in this link project, for which simulation study was carried out.

3.4.2 Extension of data

The rainfall data for the basins are available for a fairy long period whereas, the lengths of yield data series are short. Extension of yield series (during monsoon months) was carried out using regression analysis of monthly rainfall-yield data.

For developing rainfall-yield relationships on monthly basis for the monsoon months (June to October) both univariate and bivariate regression analyses were carried out using the following equations.

$$Y_m = A + BR_m \quad \text{... (3.7)}$$
$$Y_m = A + B_1 R_{m-1} + B_2 R_m \quad \text{... (3.8)}$$

where, Y_m is the yield (mm) in the month m; R_m is the rainfall (mm) during the month m; and A, B_1 and B_2 are constants.

When the above linear equations are used to relate the monthly yield with the monthly rainfall(s) directly, it is quite natural to get negative values for the constant A, which would accommodate the hydrologic losses during the month. Hence, when the equations are used to estimate the yield from low rainfall months the yield would be negative. To restrict the yields to be positive, the rainfall and yield are transformed to logarithms and regressions are carried out with the log transformed values, which is used in this study.

The results of the regression analyses for monthly yields of the monsoon months (June to October) are presented in Table 3.5.

Table -3.5. Results of regression analysis of monthly yields with rainfall

Regre-ssion	Bivariate					Univariate			
Equa-tion	$y_m = a + b_1 r_{m-1} + b_2 r_m$					$y_m = a + b\ r_m$			
Month	a	b_1	b_2	R^2	SE	a	b	R^2	SE
Up to Madla G&D site									
Jun.	-3.720	0.110	1.929	0.599	0.606	-3.806	1.998	0.592	0.596
Jul.	-2.472	0.432	1.378	0.788	0.208	-1.925	1.499	0.669	0.254
Aug.	-1.605	0.406	1.118	0.794	0.091	-0.239	0.971	0.557	0.130
Sept.	-2.427	0.919	0.924	0.808	0.193	-0.108	0.940	0.704	0.233
Oct.	-0.151	0.578	0.089	0.536	0.252	1.049	0.159	0.200	0.323
Up to Basoda G&D site									
Jun.	-7.3964	-0.0470	1.8762	0.6757	6.3068	-7.4018	1.8701	0.6696	6.3142
Jul.	-8.2534	0.4827	1.7272	0.8323	51.3376	-6.1647	1.7686	0.7663	61.2410
Aug.	-3.2496	0.3343	1.0876	0.6539	58.7937	-0.5114	0.9488	0.5437	67.0509
Sept.	-4.5882	0.6719	1.0057	0.7515	45.5625	-0.9298	1.0723	0.6965	48.7046
Oct.	-1.4048	0.8051	0.1144	0.5999	27.1113	2.0226	0.2870	0.2892	36.5418
y_m = logarithm of yield during month m; r_{m-1} and r_m = logarithm of rainfall during month m and its previous month; a, b, b_1 and b_2 constants; R^2 = coefficient of determination; SE = standard error									

3.4.3 Data generation

The yield data are available at the G&D sites only. The yield data at the project locations were estimated using proportionality (area and rainfall ratio) formula as below:

$$D_Y(m,y) = \frac{D_A \times D_R(y)}{O_A \times O_R(y)} \times O_Y(m,y) \qquad \text{... (5.13)}$$

where, $D_Y(m,y)$ is the estimated yield at any one project site for month m and year y; $O_Y(m,y)$ is the virgin yield at the gauging site for month m and year y; D_A and O_A are the catchment area up to the project site and gauging site respectively; and $D_R(y)$ and $O_R(y)$ are the average annual rainfall in the project and observation site catchments, respectively, during the year y.

3.4.3.1 Diversion and small poundage

There is no diversion of water in the upstream of Daudhan dam. However, 1074 MCM water will be diverted to Betwa and the enroute command of the link canal from the dam.

3.4.4 Extension of data

This aspect has been discussed in section 3.4.2.

3.4.5 Lake evaporation

The lake evaporations are dependent on the water surface area which is again related to the storage in the lake. The monthly evaporation from the reservoirs were computed by simulation of reservoirs.

3.4.6 Sedimentation studies

3.4.6.1 Revised area capacity curves

Daudhan dam

The catchment area of Ken River up to the proposed Daudhan dam site is 19633 sq. km. It is expected that about 10194 sq. km of the area will be intercepted by the projects likely to come in the upstream catchment. These projects may come over a period of next 15 years. Hence, to calculate the areas contributing sediments, the following assumptions have been made:

(a) For the sedimentation period of 50 years, full catchment area of 19633 sq. km has been considered for the first 15 years. For the next 35 years, balance catchment area of 19633-10194 = 9439 sq. km has been considered.

(b) For the sedimentation period of 100 years, full catchment area of 19633 sq. km has been considered for the first 15 years while balance catchment area of 9439 sq. km has been considered for the next 85 years.

There is a silt observation site on the main Ken River at Banda which is about 150 km downstream of the proposed Daudhan dam site. At this site, sediment data of 36 years (1962 to 2004 excluding 1975-1981) was available and used to arrive at the silt rate to the Daudhan reservoir. The worked out silt rate is 329.8 $m^3/km^2/yr$.

The sediment distribution was worked out for two periods, viz. 50 years and 100 years, by Empirical Area Reduction method. For this purpose, the FRL of 288 m is adopted and bed level of the reservoir is considered as 216 m. The type of reservoir is considered as gorge type and the standard classification is taken as Type IV. The new zero elevations after 50 and 100 years will 230.9 and 236.4 m respectively.

The minimum draw down level (MDDL) can be fixed anywhere above 236.4 m which is the new zero elevation after 100 years of operation of the reservoir. The revised elevation area capacity curves are shown in Fig -3.8.

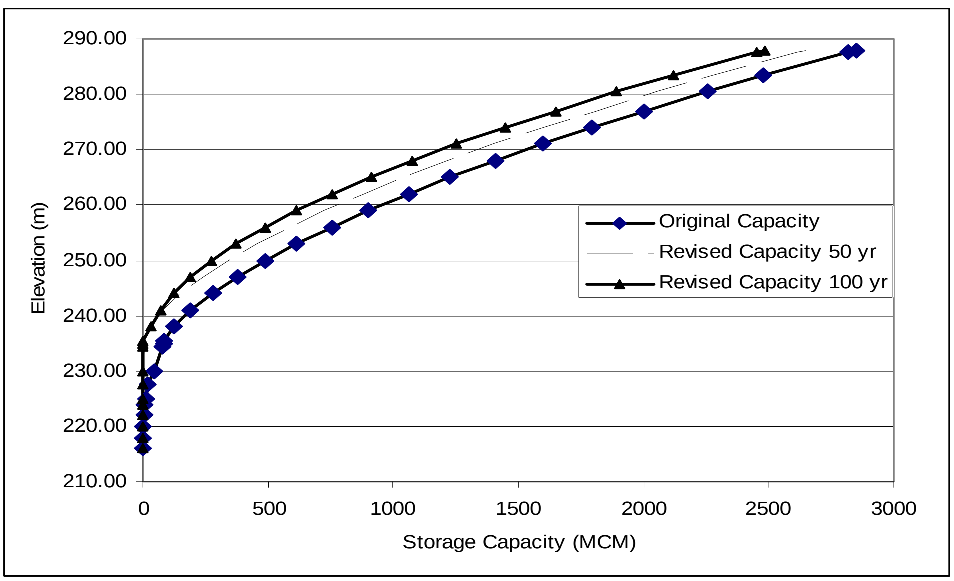

Fig. -3.8: Elevation vs. capacity graph for Daudhan – original and after 50-year and 100-year of operation

Makodia reservoir

The catchment area of Betwa River up to the proposed Makodia dam site is 1830 sq. km. For safer side it is considered that no area will be intercepted by the projects in the upstream catchment. Hence, to calculate the areas contributing sediments full catchment area of 1830 sq. km has been considered for the 50 years and 100 years.

There is no silt observation site in upstream or nearby of Makodia, Barari and Kesari proposed projects whose data can be used for sedimentation studies. However there is an existing project Matatila on main Betwa river. A number of hydrographic surveys have been completed in the Matatila reservoir by the UP Irrigation Research Institute, Roorkee, in the pre-monsoon periods of the year 1962, 1964, 1966, 1969, 1971, 1975, 1985, and 1900. As per the hydrographic survey of 1975, the sedimentation rate worked out was 381.8 m^3/sq. km/year. In 1985, sedimentation rate was 422.63 m^3/sq. km/year while in 1990 it was 408.50 m^3/sq. km/year. Considering these factors, the silt rate for the Makodia dam has been considered as 410.0 m^3/km^2/year.

The sediment distribution is worked out for two periods, viz. 50 years and 100 years, by Empirical Area Reduction method. For this purpose, the FRL of 440 m is adopted and bed level of the reservoir is considered as 423 m. The type of reservoir is considered as Type II. The new zero elevations after 50 and 100 years will 428.24 and 430.00 m respectively.

The minimum draw down level (MDDL) can be fixed at 430.0 m which is the new zero elevation after 100 years of operation of the reservoir. The revised elevation area capacity curves are shown in Fig- 3.9.

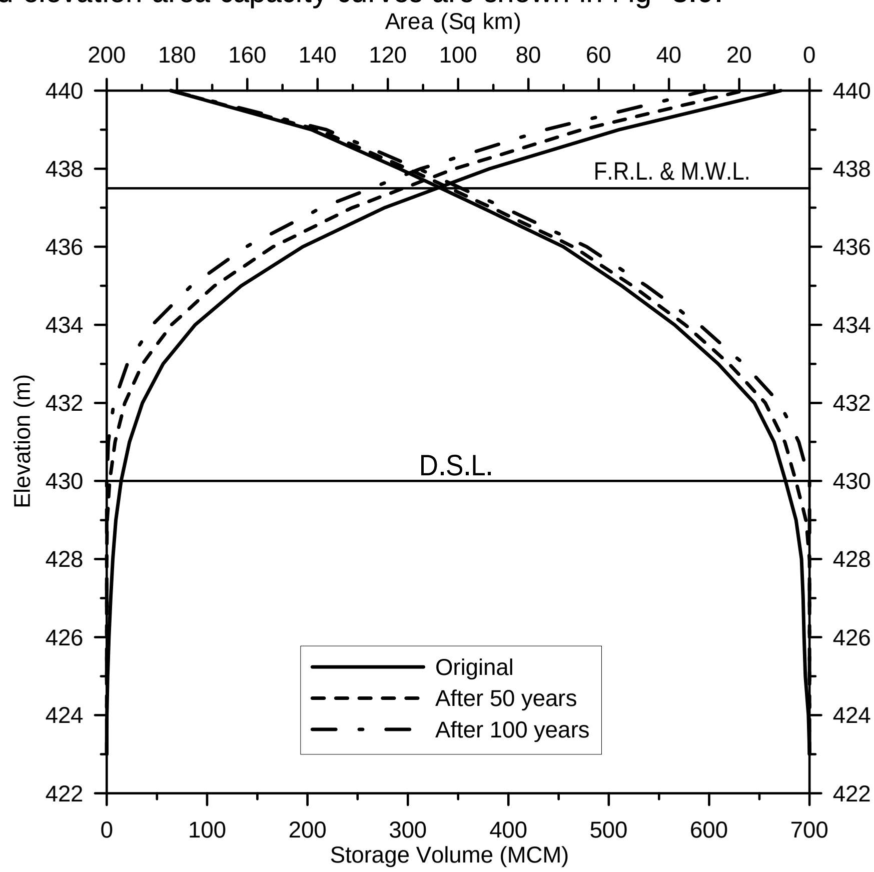

Fig.-3.9: Elevation-Area-Capacity Curves for Makodia – original and after 50-year and 100-year of operation

3.4.6.2 Rate of sedimentation

The total sediment during 50 and 100 years will get distributed up to and above various elevations in Daudhan reservoirs are presented in Table 3.5.

3.4.7 Potential evapotranspiration and rainfall

Normal potential evapotranspiration data of Jabalpur and Bhopal were used for estimation of water utilization of various projects upstream of Daudhan Makodia dams respectively. The estimated areal average data for different sub-basins as discussed in section 3.3.6 were used.

Table -3.6: Rate of sedimentation of proposed reservoirs

Reservoir level	Sediment deposition in MCM	
	After 50 years	After 100 years
Daudhan reservoir		
Up to 231 m	49.3	50.3
Above 231 m	156.8	311.4
Up to 236.4 m	85.7	98.0
Above 236.4 m	120.4	263.7
Up to 244 m	127.5	185.7
Above 244 m	78.6	176.0
Makodia reservoir		
Up to 430 m	11.355	14.240
Above 430 m	26.16	60.790

3.4.8 Flood inputs

With the available short duration rainfall-runoff data the unit hydrographs at Madla and Basoda gauging sites were developed. The unit hydrograph for Madla gave acceptable validation with other observed hydrographs. However, for Basoda the synthetic unit hydrograph provided better validation. Hence for all projects in the upper Betwa basin synthetic unit hydrographs were used.

3.4.9 Inputs for water quality

Different parameters of water quality are observed regularly at Banda G&D site of CWC. It is observed that quality of water of Ken river is, in general, fit for domestic, industrial and agricultural purposes. However, water samples are being collected every month by NWDA from the Ken river at Bhusor near Daudhan dam site with effect from 1-2-2008 and are being tested at the water quality testing Laboratory of CWC at Agra / Delhi.

A silt observation site has been established by NWDA at Neemkheda G&D site located 7 km d/s of Makodia dam site on Betwa river and observation started w.e.f. 25.07.2007. Facility for water quality testing is not available with NWDA. So, the water samples from Betwa river taken at the above site were tested at water quality testing laboratory of CWC, Bhopal.

3.4.10 Low flow inputs

After analyzing the ten-daily observed discharge at Madla it was found that the ten-daily discharges are zero during the Months of January to May. The analysis of ten-daily discharge data at Banda shows that the discharge has never been zero. The discharge at this site is minimum during the months of May and June. The minimum ten-daily flow recorded at this site was 3.02 cumec-days during the first ten-daily period of June 1966. The observed daily discharge at Basoda has also been reported zero for many days during summer months. In few years, there has been no discharge in the river even in the months of January and February.

3.4.11 Surface to groundwater recharge

The present ground water level in the phreatic zone, during May 2006 was between 5 to 10 meters below ground water is about 60% of the project area. In the remaining area it varied between 10 to 20 m. As the quantum of water being transferred is of the order of 1074 MCM annually through the link canal taking off from the reservoir to the Betwa river utilizing 415 MCM in the enroute command and dropping remaining 659 MCM (including transmission losses) into Betwa river, the water levels are not likely to rise to any significant level. Thus, the hazards of water logging and salinization is not anticipated in the region to carry out significant extent. The canal systems under the proposed project are expected to be properly lined. Therefore, there may not be much seepage loss to the ground water.

3.5 Preparation of hydrological inputs for studies other than simulation

3.5.1 Design flood for safety of structures

3.5.1.1 Criteria for selection of design flood for each structure taking into account the importance of each structure

It is not practical, from economic point of view, to design a hydraulic structure for the safety at the maximum possible flood in the catchment where as under designed structures pose serious threat to safety. Small structures such as culverts and storm drainages can be designed for less severe floods as the consequences of higher than the design flood may not be very serious. On the other hand, storage structures such as dams require greater attention to magnitude of floods used in the design since the failure of these structures causes heavy loss of property and life on the down stream. Hence, it is apparent that type, importance of the structure and economic development of the surrounding area dictate design criteria for choosing the flood magnitude. The criteria for estimation of design flood vary from one country to other. In India, the following guidelines (CWC, 1969) are adopted.

Table- 3.7: Criteria for selection of design flood estimation method

Sl. No.	Structure	Recommended design flood estimation method
1.	Spillways for major and medium projects with storage more than 60 MCM	(a) PMF determined by unit hydrograph and probable maximum precipitation (b) If the above is not applicable or possible, flood of 1000 years return period
2.	Permanent barrages and minor dams with storage less than 60 MCM	(a) SPF determined by unit hydrograph method and standard project storm, which is usually the largest recorded storm in the region (b) If the above is not possible or applicable, flood of 100 years return period
3.	Pickup weirs	Flood of return period 50 to 100 years depending on the importance of the project
4.	Aqueducts (a) Waterway (b) Foundation and freeboard	 Flood of 50 years return period Flood of 100 years return period
5.	Project with very scanty or inadequate data	Empirical formulae

3.5.1.2 Overall approach adopted

Hydro-meteorological approach has been adopted in this study for estimation of the design flood hydrograph of all the projects. For Daudhan and Makodia dams the unit hydrographs were convoluted with the design hyetograph obtained from the probable maximum precipitation (PMP). Whereas, for Barari and Kesari barrages the unit hydrographs were convoluted with the design hyetograph obtained from the standard projected storm (SPS). The PMP and SPS for various projects were obtained from IMD.

3.5.2 Hydro-meteorological approach

In this approach, the unit hydrograph for the basin and the design excess rainfall hyetograph to be estimated first.

Unit hydrographs for different projects were developed using short duration rainfall-runoff data. The SPS and PMP values and time distribution of rainfall for the project catchments were obtained from IMD. As per the time of concentration of the catchments the design storm hyetographs (24 and 48 hours) were prepared for different catchments. The design flood hydrographs obtained for the projects are presented in Figs. 3. 10a and b. The peak flood estimated for Daudhan, Makodia, Barari and Kesari were 57,202, 10,385, 12,283 and 2,772 cumec respectively.

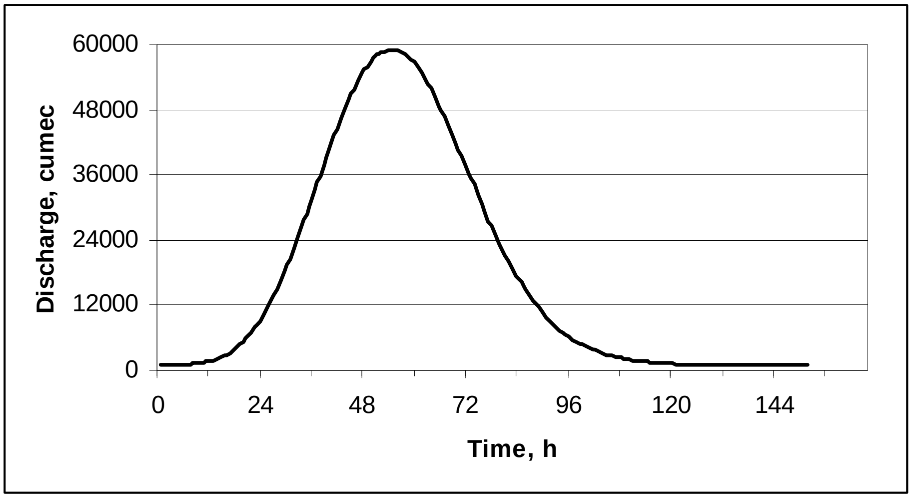

Fig. 3-.10a: Design flood hydrograph for Daudhan dam

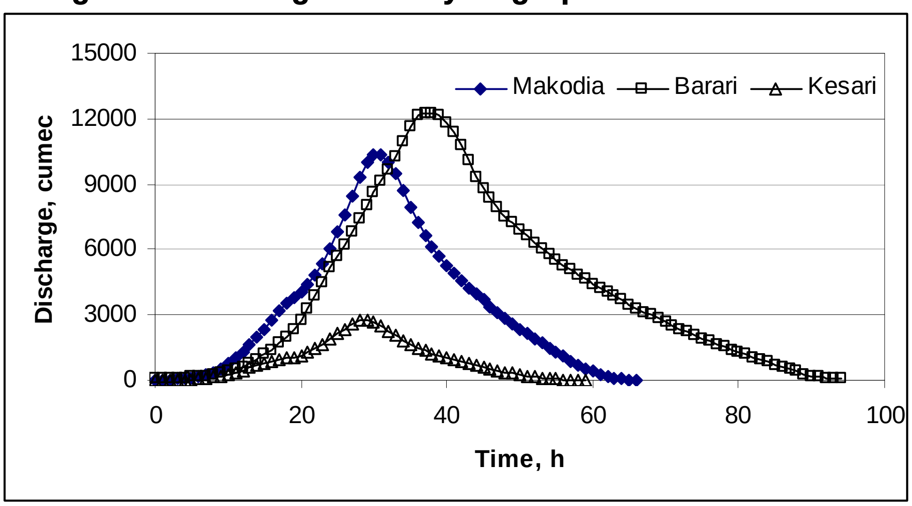

Fig.- 3.10b: Design flood hydrograph for Makodia dam, Barari and Kesari barrages

3.5.3 Frequency approach

At-site flood frequency analysis using annual maximum series (AMS) of gauge site records is used as a check to the derived PMF value. The AMS model is used to arrive at a return period flood growth curve that is eventually used for deriving a design flood q (T) for a specific return period (T). The return period should be selected as per the guidelines of IS code (Table- 3.8).

Table -3.8: Frequency of return period advocated by IS code

S. No.	Structure	Return period of design flood (Yrs)
1.	Major dams with storage more than 6000 ha.m. (50,000 ac. ft.)	1000
2.	Minor dams with storage less than 6000 ha.m.	100*
3.	Barrages and pick up weirs (a) Free board (b) Items other than free board	 500+ 50-100
4.	River Training Works (Calculation of Scour)	50-100@
5.	Water way of bridges	50

Note: * IS 5477 - Method of fixing capacities of reservoirs-Part IV.
+ IS 6966 - Criteria for hydraulic design of barrages and weirs.
@ IS 3408 - Criteria for river training works for barrages and weirs in alluvium.

The annual maximum series (AMS) of Madla and Basoda sites were tested for independence, stationarity and outliers and then fitted to Gumbel (EV1) distribution. The estimated return period flood for different sites are presented in Table- 3.9.

Table -3.9: Return period flood for different sites using Gumbel distribution

S. No.	Return period in years	Return period flood for different sites			
		Daudhan	Makodia	Barari	Kesari
1	500	28734	4597	10487	1753
2	1000	31187	5005	11418	1908
3	5000	36882	5952	13578	2269
4	10000	39334	6360	14508	2425

3.5.3.1 Comparison of design flood estimates

The comparison of design flood estimated by both the approaches is presented in Table 3.10. It is observed that the design flood estimated by hydro-meteorological approach (or UH approach) is significantly higher than those estimated by frequency analysis approach for all the sites except for Barari.

Table- 3.10: Comparison of design flood estimates

Sites	UH Approach	Frequency analysis approach			
		Return period (years)			
		500	1000	5000	10000
Daudhan	57202	28734	31187	36882	39334
Makodia	10385	4597	5005	5952	6360
Barari	12283	10487	11418	13578	14508
Kesari	2772	1753	1908	2269	2425

3.5.4 Design flood for determination of flood storage & flood control works

For the Daudhan dam, both the FRL and MWL are at elevation 288.0 m. Hence, there is no separate flood storage in this reservoir.

3.5.4.1 Flood problems

Studies for probable maximum floods for the proposed Daudhan Dam site was carried out by the unit hydrograph method based on rainfall in Ken catchment and corresponding flows in the river at gauge discharge site at Banda. The daily flows at Banda and rainfall data upto Banda were used for the analysis.

Modified PULS method had been employed for flood routing of the Daudhan Reservoir. It was assumed that the inflow and outflow at Full Reservoir Level (FRL) are same and the routing is started from FRL 288 m. The design flood used is 57202 cumec. As there are 33 gates provided over the spillway crest, it was assumed that three of the gates will be inoperative and therefore 30 gates have been considered for computing the maximum water level. The maximum rise in water level was computed to be 287.88 m. and the corresponding flow passing over the crest was 55099 cumecs. The flood routing had also been carried out with 29 gates open and it was found that the maximum rise in water level would be upto 288.23 m. Therefore, the Maximum Water Level (MWL) had been fixed as 288 m. After providing a free board of 3 m. above the MWL, the top of the dam has been fixed as 291 m.

As the FRL of the proposed Daudhan reservoir had been fixed at 288 m. which was about 53 m above the present FRL of existing Gangau Weir (2.5 km. downstream of the site), it was therefore assessed that the storage of Dhaudhan Dam will definitely contribute in mitigating floods in the downstream portion of Ken basin.

The average annual evaporation losses from the reservoir obtained from the simulation analysis was about 104 MCM. This worked out to be 13.46 % of the total storage of the reservoir. The total water requirement on the downstream side of the proposed dam were estimated to be 3006 MCM which will be released regularly below the dam.

3.5.4.2 Degree of protection

The reservoir at Daudhan dam is expected to completely absorb floods of smaller magnitude and the high floods will be moderated with reduction of peak discharge. This will provide flood protection to the downstream of the dam. The reduction of PMF peak is described in details in the section 3.7.2.

3.5.4.3 Design flood for fixing storage & design of structures downstream

This information was not necessary for the present study.

3.5.5 Studies for design of drainage in the command area

3.5.5.1 The problem

Provision of cross drainage work is being contemplated in the project area. These cross drainage works will be so designed that they do not hamper the width and course of the river streams and therefore, minimized the siltation problem which may arise at the crossings. Thus, little impacts on the drainage aspects are anticipated.

3.5.5.2 Surface drainage

The canals irrigating the command area originate from the High altitudes. Necessary provisions are being made in the project area for suitable cross drainage structures with adequate capacities. Suitable diversion arrangements are being made for small streams to the nearby structures. This shall take care of any adverse impacts in the command area.

3.5.6 Design flood for diversion arrangements

The guidelines laid down for arriving at the diversion design flood according to criteria of risk and damage for different types of dams and barrages are as follows (Report of Ministry of Irrigation, 1980):

(i) Diversion capacity for concrete dams and barrages

The capacity of the diversion flood for concrete dams and barrages may be less because flood higher than the designed one could be passed safely over the partly constructed dam. The following criteria would help in deciding the capacity:

a) Maximum non-monsoon flow observed at the dam site.

OR

b) 25 years return period flow, calculated on the basis of non-monsoon yearly peaks.

The higher of the two should be taken as the design flood for diversion.

(ii) For large dams

For large dams, it is desirable that 100-year flood should be adopted for diversion works.

For the Madla site the peak of daily flow for non-monsoon months November to May is available for 25 years. On basis of this data, the 25 year return period flow using the GEV model is calculated as 451 m^3/s. As per clause I(a), the maximum of the non-monsoon flow is 1117.6 m^3/s. As per clause (II), using the AMS, the 100-year return period flood is equal to 30,794 m^3/s. Keeping in view the size of the Daudhan dam, the diversion flood of 1118 m^3/s seems appropriate.

On the basis of analysis of non-monsoon discharge data at Basoda site, the diversion flood for Makodia, Barari and Kesari projects were estimated as 286, 653 and 109 cumec respectively.

3.5.7 Studies for determination of levels for locating structures on outlets

3.5.7.1 Location of structures

The Link Project envisages construction of following components:-

1. An earth fill cum concrete dam across Ken river at Daudhan with FRL 288m.
2. An upper level tunnel about 170 m from the left bank of Daudhan dam for taking water to the link canal.
3. A lower level tunnel about 100 m from the left bank of Daudhan dam axis for taking water to the LBC of earlier proposed Ken Multipurpose Project.
4. Power house-I (2x30 MW) to the right of spillway at the toe of Daudhan dam.
5. Power house-II (3X6 MW) at the outlet of lower level tunnel.
6. A link canal (220.624 km long including length of upper level tunnel) with off take FSL 257 m to existing Barwasagar with FRL 219.20 m across Barwa nallah, a tributary of Betwa river

7. A 2.2 km long canal for connecting power house-II to Ken LBC at FSL 246.00 m
8. Ken LBC (57.3 km long, modified) proposed under Ken Multi Purpose Project (KMPP) (to be taken over by Daudhan dam)
9. Major Cross-drainage/Cross-masonry works (55 Nos.).
10. Upper Betwa Component (3 projects)

(a) Makodia dam:

(i) An earthfill cum concrete dam across Betwa river at Makodia village with FRL 437.50 m in place of Neemkheda dam about 7 km u/s of it.

(ii) Two canals (RBC-83.38 km & LBC-6.74 km).

(b) Barari barrage:

(i) A barrage at Barari village across Betwa river with pond level 407.72 m located in d/s of Makodia dam.

(ii)A pipe line (4 km long) for lifting water by 21 m to an existing tank near village Gulabganj, Gulabganj tehsil in Vidisha district and there from a ridge canal (4.7 km long) to irrigate the proposed command.

(c) Kesari barrage:

(i) A barrage at Kesari village across Keotan river, a tributary of Betwa river with pond level 406 m.

(ii) A pipe line (2.9 km long) for lifting water by 8 m to proposed forebay reservoir near village Amera, Basoda tehsil in Vidisha district and a gravity canal (9.6 km long) from the forebay reservoir to irrigate the proposed command up to Chakra nallah near village Barwasa in Vidisha district.

3.5.7.2 Location of outlets

Outlets provided in Ken-Betwa Link canal to branch canals are given in Table- 3.11.

Table- 3.11:
Details of proposed Branch canals offtaking from main K-B link canal for enroute command of Ken- Betwa link project

Topo sheet Number	Location of Command	Branch Canal No	RD (approx)	FSL at Head of Branch Canal	Discharge	FSL
			m	m	m^3/sec	
54 O/12	Lugasi	Lugasi Branch	69460	248.5	2.348	248.40
54 O/8	Now Gaon	Now Gaon Branch 1	76860	248.5	0.952	247.57
	Now Gaon	Now Gaon Branch 2	80227	248	2.752	247.19

54 P/5	Kiratpura	Kiratpura Branch	86379	247.5	2.195	246.51
	Kiratpura	Kiratpura Branch	87768	247	1.251	246.35
	Gwalta	Gwalta Branch	93227	246.5	1.254	245.65
	Banda	Banda Branch	94418	246.25	1.161	245.51
	Pathada	Pathada Branch	102322	245.75	0.579	244.53
	Didai	Didai Branch	104970	245.5	0.209	244.13
	Pacher	Pacher Branch	109458	244.75	1.195	242.75
	Chhidari	Chhidari Branch	116680	244.25	0.747	242.03
	Purainian	Purainian Branch	121717	243.5	0.971	241.52
54 P/1	Taparian	Taparian Branch	126011	243	1.968	241.52
	Lidhaura	Lidhaura Branch	129684	242.5	0.956	240.70
	Bhatgora	Bhatgora Branch	139242	241.5	0.388	239.74
54 O/4	Rajnagar	Rajnagar Branch	147377	239.5	0.164	238.82
	Barana	Barana Branch	155227	239.5	0.228	238.03
	Itali	Itali Branch	160236	238.5	1.068	237.53
	Bamhori	Bamhori Branch	166991	238	2.670	236.75
	Bonda	Bonda Branch	170956	237.5	0.594	236.24
	Bijrawan	Bijrawan Branch	179756	235.5	0.564	235.36
	Uprara	Uprara Branch	182620	235.5	0.489	235.00
54 O/3	Ratausa	Ratausa Branch	190065	234	1.135	234.34
54 K/15	Dhanahi	Dhanahi branch	193137	233.5	0.773	234.04
	Dhamna	Dhamna Branch	199625	233.5	0.844	233.45
	Rauli	Rauli Branch	201344	233.5	2.397	233.29
	Binuwara	Binuwara Branch 1	206634	224.5	3.185	227.23
	Binuwara	Binuwara Branch 2	209882	224	1.475	226.74
	Kainau	Kainau Branch	216212	223	0.665	223.16
		Total			**35.174**	

3.5.8 Tail water rating curves

One tail race channel is proposed at the exit of power house – I to carry the waters to the Ken river after power generation. The grid surveys carried out for dam axis as well as PH-I, have adequately covered the Tail race channel portion also. Data for Tail water rating curve is given in Table- 3.12 & Fig.- 3.11 .

One tail race channel is proposed at the down stream of Makodia dam to cater the waters to the Betwa river. Data for Tail water rating curve is given in Table 3.13 & Fig. -3.13.

Table-3.12: Tail water rating curve for Daudhan dam (PH-I)

Tail water Level	Discharge	Tail water Level	Discharge
(m)	(cumecs)	(m)	(cumecs)
217.00	0.21	232.50	23118.31
217.50	24.70	233.00	25102.75
218.00	74.75	233.50	26556.93
218.50	144.53	234.00	27560.67
219.00	231.49	234.50	28166.39
219.50	228.76	237.00	29809.99
220.00	389.31	237.50	33036.59
220.50	582.16	238.00	35601.56
221.00	804.74	238.50	39172.86
221.50	832.08	239.00	41988.80
222.00	1160.47	239.50	45957.99
222.50	1334.34	240.00	50101.97
223.00	1800.17	240.50	53999.45
223.50	2320.08	241.00	58109.48
224.00	2891.35	241.50	63175.54
224.50	3015.66	242.00	67520.23
225.00	3802.52	242.50	72956.28
225.50	4660.51	243.00	77567.92
226.00	5586.72	243.50	81804.59
226.50	6446.21	244.00	86175.39
227.00	7577.09	244.50	91858.51
227.50	8779.25	245.00	97149.15
228.00	10050.32	245.50	103178.60
228.50	11388.18	246.00	108121.14
229.00	12790.86	246.50	115208.37
229.50	13612.95	247.00	121052.24
230.00	15175.45	247.50	127762.50
230.50	16803.98	248.00	134656.23
231.00	18496.89	248.50	140966.93
231.50	19805.99	249.00	146724.13
232.00	21198.28	249.50	155056.11

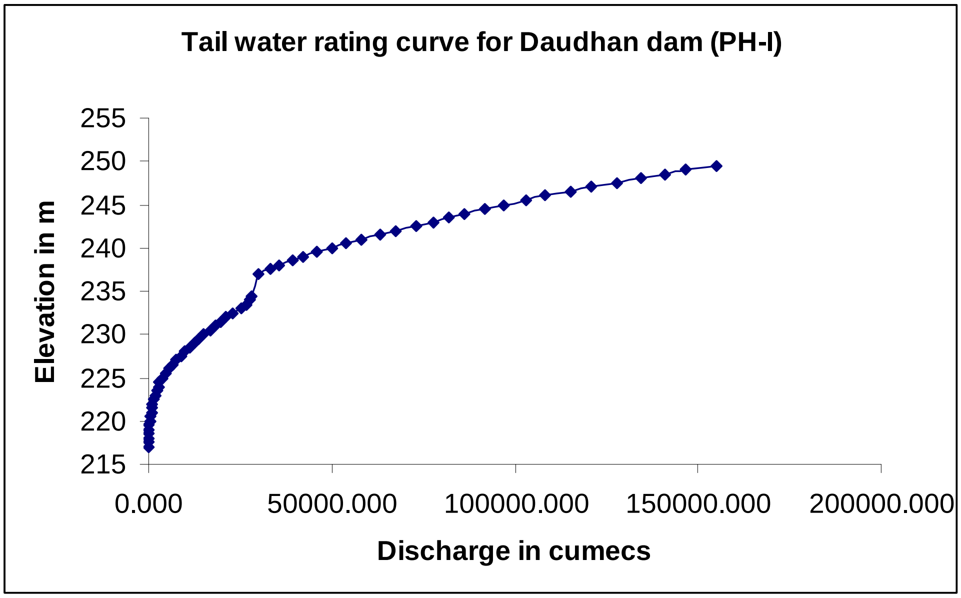

Fig.- 3.11: Tail water rating curve for Daudhan dam (PH-I)

Table-3.13: Tail water rating curve for Makodia dam at 600 m d/s

Tail water Level (m)	Discharge (cumecs)	Tail water Level (m)	Discharge (cumecs)
416.5	0.0	427.0	4120.7
417.0	1.3	427.5	4638.4
417.5	10.3	428.0	4458.6
418.0	30.8	428.5	4630.2
418.5	64.5	429.0	5048.8
419.0	111.8	429.5	4777.3
419.5	174.9	430.0	5598.8
420.0	256.4	430.5	6962.9
420.5	356.7	431.0	7655.8
421.0	471.4	431.5	9949.3
421.5	614.7	432.0	12943.7
422.0	790.2	432.5	16973.1
422.5	983.2	433.0	21502.6
423.0	1211.9	433.5	26601.9
423.5	1478.9	434.0	31536.8
424.0	1763.1	434.5	37518.5
424.5	2061.4	435.0	44002.1
425.0	2364.9	435.5	50869.1
425.5	2717.3	436.0	58765.2
426.0	3145.8	436.5	67111.2
426.5	3618.3	437.0	75895.6

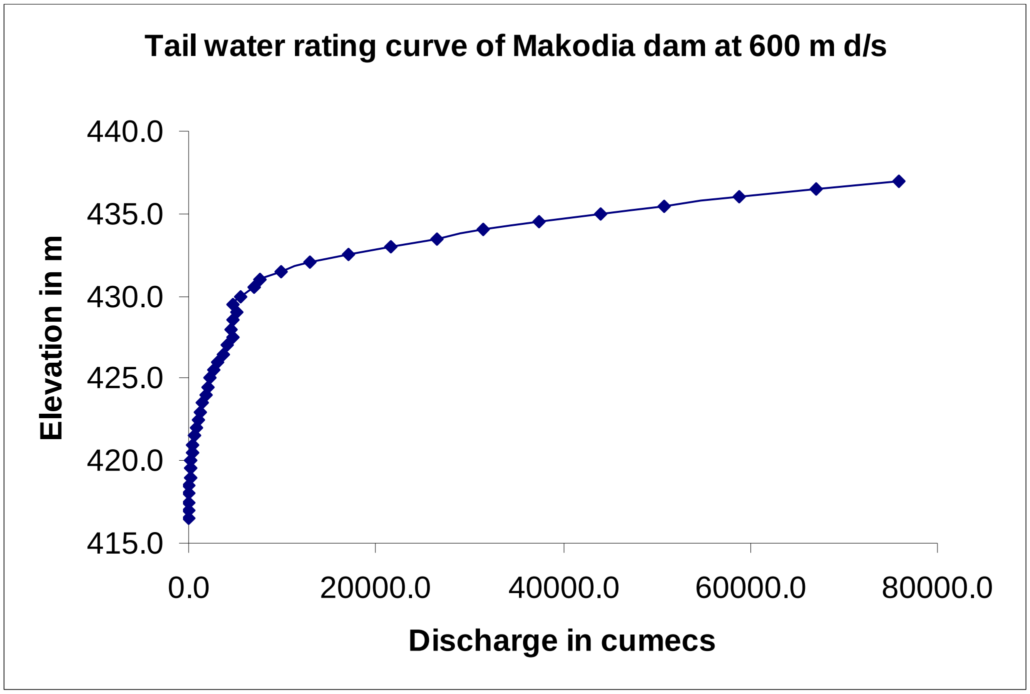

Fig. 3.12 Tail water rating curve for Makodia dam at 600 m d/s

3.6 Simulation studies

3.6.1 Model studies

A detailed simulation model study was conducted as descried below.

3.6.2 Project performance

Simulation is powerful approach for storage yield analysis. Simulation is essentially a search procedure. It is one of the most widely used techniques to solve a large variety of problems associated with the design and operation of water resources systems. The reason is that this approach can be realistically and conveniently used to examine and evaluate the performance of a set of alternative options available. Furthermore, serial correlations of inflows, seasonality, etc., are easy to account for. Also, it is easy to present the technique and its results to decision makers.

The live storage capacity of the Daudhan and Makodia reservoirs were determined by using the SRA software developed by NIH. This is a simulation program in which operation of the reservoir is simulated by following the rule curves. The input data required for this software include the maximum and dead reservoir storage capacities, the initial storage at the beginning of simulation. Simulation method is also recommended by the IS Code [Fixing the capacities of reservoirs – method, Part 2 Dead storage, IS 5477 (Part 2):1994].

Daudhan Reservoir

For Daudhan reservoir, simulation was carried out for 271 months from June 1981 to Dec. 2003. Since the first month of simulation was June, the initial reservoir storage was set at 300 MCM based on the reservoir working table for previous simulation runs. The elevation-area-capacity table as expected after 50 years of operation was used. Two types of demands have been placed on the Daudhan reservoir: the downstream commitments from UP and MP and the link diversion. It is important to note that there are high irrigation demands to the tune of 3006 MCM due to shares of UP and MP states and the annual link diversion demands are 1074 MCM. The normal monthly depths of evaporation from the reservoir for each month were taken as 0.0699, 0.0889, 0.1714, 0.2921, 0.4, 0.2603, 0.1143, 0.0953, 0.1143, 0.0953, 0.0699, 0.0635 m for January to December respectively.

The gross water availability based on data of Madla are given in Table-3.14

Table-3.14

Water availability at Daudhan at different dependability

At 90 % dependability	**4979 MCM**
At 75 % dependability	**6590 MCM**
At 50 % dependability	**8431 MCM**

The time and volume reliability of the reservoir for various purposes of water use/ demands is presented in Table -3.15.

Table- 3. 15: Reliabilities of the Daudhan reservoir in meeting demands

Purpose	Time reliability	Volume reliability
Meeting irrigation (KMPP) and other demand	0.980	0.990
Meeting link diversion demands	0.900	0.902

Makodia, Barari and Kesari reservoirs

For these reservoirs simulation was carried out for 335 months from Feb. 1976 to Dec. 2003. June was the first month of simulation and the initial reservoir storage was set based on the reservoir working table for previous simulation runs. The elevation-area-capacity table of Makodia reservoir as expected after 50 years of operation was used. Two types of demands have been placed on the Makodia reservoir: the demands of the command and minimum flow requirements in the Betwa River for ecology purposes. In non-monsoon months, flow at Barari is insufficient to meet the demands. Hence, water is released from Makodia dam to meet the demands at Barari. Normal monthly depths of evaporation from these reservoirs for each month were also taken as that of Daudhan reservoir.

The three projects namely Makodia, Barari and Kesari will be operated to meet demands all the projects. For Makodia reservoir, it was found that yields at 90%, 75% and 50% dependabilities are 337 MCM, 508 MCM and 703 MCM respectively if the FRL is kept at 437.15 m (corresponding storage of 260 MCM), the time and volume reliabilities in meeting irrigation demands were 89.1 and 93.4 % and the values for water supply were 96.7 and 96.9%, respectively. The annual irrigation reliability when deficit up to 10% is considered a success was 75.9%.

To know what can be the additional command that can be served if the FRL of the Makodia reservoir is fixed at 437.50 m, operation of Makodia reservoir was simulated by systematically changing the demands in the command (assuming that the monthly distribution of the demands remains the same). It was found that if the demands are increased by an additional 12 %, the reservoir can still meet the stipulated annual reliability.

While computing the industrial water requirement for Makodia reservoir, it was noticed that there are increased industrial activities in the area and consequently, the industrial demands may sharply increase in future. Further, this reservoir will also act storage location for the Barari Barrage. Keeping these in view as well as the plans of M.P. Government, it was decided by the 12th meeting of the Hydrology Review Committee that the FRL of Makodia reservoir may be fixed at 437.5 m (corresponding live storage = 295 MCM). Accordingly, the operation of Makodia, Barari and Kesari projects was simulated. The time and volume reliabilities of Makodia in meeting Water Supply demands were found to be 96.7 and 96.9 % and the same for irrigation demands were 92.7 and 95.6 %. The annual irrigation reliability when deficit up to 10% is considered a success was 86.2%.

Along with Makodia, the operation of Barari Barrage was also simulated. Barari Barrage has small storage capacity and hence some water is released from the Makodia dam to meet the demands at Barari. It was found that for the Barari barrage the 90%, 75% and 50% dependable yields come to 1110 MCM, 1558 MCM and 2292 MCM respectively if the FRL is kept at 407.72 m (corresponding storage 14.0 MCM), the time and volume reliabilities in meeting irrigation demands were 80.1 and 92.6 %. The annual irrigation reliability when deficit up to 10% is considered a success was 79.3 %. For the Kesarri barrage the 90%, 75% and 50% dependable yields come to 102 MCM, 127 MCM and 194 MCM respectively.

3.6.3 Minimum flow for environmental considerations

The minimum flow required at the river course downstream of the projects are estimated as the 10% of the lean season (November to May) flow at respective sites. Accordingly the minimum flows at downstream of Daudhan, Makodia dams, and Barari and Kesari barrages are estimated as 6, 0.8, 3.5 and 0.2 MCM/month respectively.

3.7 Effect of project on hydrologic regime

When a controlled reservoir is in operation, it absorbs a part of the high flood water thereby reducing the risk of flooding in the downstream. Due to storage in the reservoir, the floods with smaller peaks may get fully absorbed resulting in no flood in the downstream. In addition to flood moderation, the reservoir would release only the required amount of water to the downstream so that most of the available water is optimally utilized. The exact reduction in flood peak can be estimated routing the flood hydrograph through the reservoir.

3.7.1 Effect on low flows

While simulating the reservoir operation, the minimum environmental flow were treated as demands and given top priority. Since the reservoirs will store water for lean season demands, it can be made to deliver some water to the downstream during the lean season even when there is no inflow to the reservoir. Hence, the river flow condition in the lean flow season in the downstream of the reservoir will be much better than those without the reservoir. This fact can be ascertained from an examination of the reservoir working tables.

3.7.2 Effect on peak floods

During peak inflows, the water level of the reservoir correspondingly increases. In general, the maximum water level at a reservoir is to be restricted, and to ensure this, spillway gates will have to be judiciously operated. At the same time, it has to be ensured that the peak rate of release does not exceed the safe carrying capacity of the river channel downstream of the reservoir unless absolutely necessary.

The result of reservoir routing for Daudhan and Makodia are presented in Figs. 3.13a and b respectively. It can be observed from the figures that the peak discharge of the design flood hydrograph is moderated from 57202 cumec to 55099 cumec (i.e., moderated by 2103 cumec) with a time delay of three hours for Daudhan whereas the same of Makodia reservoir is moderated from 10384 cumec to 8275 cumec. In other words, if the reservoirs are operational then floods of relatively lower peak will pass to the downstream. Due to a smaller size of the reservoirs compared to the volume of the design flood, significant reduction in peak of the design flood could not be attained. However, many small peaks will be significantly moderated.

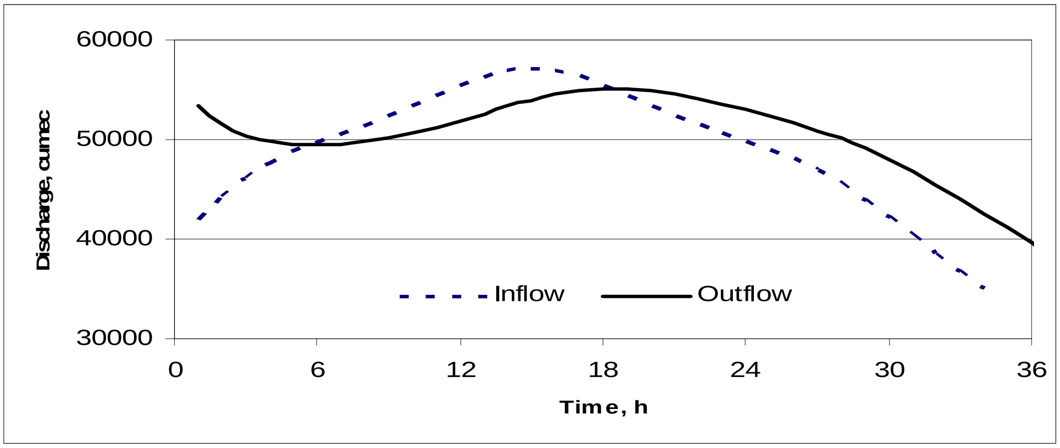

Fig. -3.13a: Design flood hydrograph routing plot of Daudhan reservoir

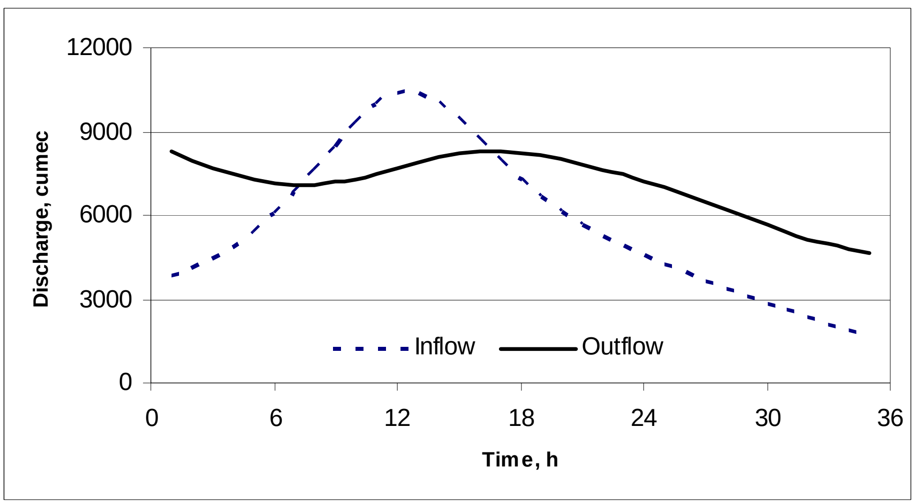

Fig.- 3.13b: Design flood hydrograph routing plot of Makodia reservoir

3.7.3 Effect on total runoff

Mathematically, the total runoff of a specific catchment does not change when the period is long duration, say yearly. However, a reservoir helps the water demand for lean seasons, and dilutes the peak flows during monsoon. The water that are used in the command area, partly comes back to the stream as a return flow.

3.7.4 Effect on sediment flows

The reservoir affects the sediment load in the in-flowing water by a sedimentation method, where the sediment settles slowly. This also assist in the out flowing a clear water to the downstream. From structural point of view in downstream side, the water is clear without any sediment load.

3.8 Water allocation and interstate aspects

3.8.1 Water

An MOU has been signed between U.P and M.P on water sharing for this project. The same is given in below in Table-3.16.

Table-3.16
Agreed water sharing of Ken basin upto Daudhan dam

S. No	Particulars	Agreed quantum of water (MCM [TMC])
1	Gross Water available at proposed Dam	6188[218.54]
2	Madhya Pradesh (MP) requirement in U/S of dam	2266[80.03]
3	Balance Water available	3922[138.48]
	Regeneration (+)	442[15.61]
	Net Water Balance Available	4364[154.12]
4	Total requirement of MP	
	(a) D/s of Ex Daudhan	1375[48.56]
	(b) Enroute use	263[9.29]
	(c)Domestic enroute utilisation & transmission losses	49[1.73]
	Total	1687[59.58]
5	Total Requirement of Uttar Pradesh (UP)	
	D/s of Daudhan including enroute command	1700[60.04]
6	Proposed Water Transfer to Betwa Basin	659[23.27]
7	Requirement for D/s of dam for ecological needs	318[11.23]

The Hydrological study has been carried out by NIH, Roorkee and report submitted by them in three Phases (Phase-I, Phase-II (A) & Phase-II(B&C) and enclosed as Appendix-3.1, 3.2 & 3.3 in Volume: III.

3.8.2 Power

Due to the proposed Upper Betwa projects viz. Makodia, Barari and Kesari u/s of the existing Rajghat and Matatila dams located in Upper Betwa basin, the inflows into Rajghat and Matatila will be reduced which will result in loss of power generation at these dams. The multi reservoir simulation study done by NIH, Roorkee reveals that the monthly loss of power generation at Rajghat dam will be 1.4 MU whereas the same at Matatila dam will be 1.0 MU when all the three projects as well as new projects to be planned by Govt. of M.P. against transported water to Betwa will be fully implemented. Details are furnished in Appendix:3.3. At present, there is no agreement between States on sharing of power. As such, agreement on this aspect will also have to be finalised by both the Govts. of U.P. and M.P. mutually.

3.8.3 Other aspects

Apart from sharing of benefits, States may also mutually decide sharing of cost of the project, mechanism for regulation of release from Daudhan dam and other things for effective implementation and operation of the project.