CHAPTER - 5

HYDROLOGY

5.1 General climate and hydrology

The climate of the area upto Daudhan dam site is semi arid to dry sub-humid, the weather being mostly dry except in the monsoon season. Summer is hot and winter is mild. About 90% of the annual rainfall is received during the monsoon i.e. from June to October. The average maximum and minimum temperatures are 44.0°C and 6.7°C respectively.

5.1.1 General hydrologic information about the region

5.1.1.1 Rainfall

There are 21 rain gauge stations in and around the Ken basin up to the Banda gauge and discharge site at which the equation (i.e. rainfall-runoff relationship) for working out the annual series has been developed. 16 rain gauge stations (out of 21 stations), influence the catchment upto the proposed Daudhan dam site.

The normal annual rainfall of the Ken basin upto Daudhan dam site is 1174.07 mm. The monsoon rainfall constitutes as much as 90%. The maximum, minimum and the average annual weighted rainfall values are 1662.1 mm, 660.0 mm and 1181.3 mm respectively for the period from 1901 to 1983.

5.1.1.2 Relative humidity

The monthly mean relative humidity data for five IMD stations have been considered. The maximum and minimum values of humidity are 95% and 9% during monsoon and summer seasons respectively.

5.1.1.3 Wind velocity

The normal monthly wind velocity data for the five IMD stations are considered. The maximum and minimum wind velocities are 16.1 km/hr and 1.0 km/hr respectively at Sagar and Nowgong IMD stations.

5.1.1.4 Cloud cover

The normal monthly cloud cover data for three stations viz. Chhatarpur, Jabalpur and Sagar are considered. The maximum cloud cover occurs in July or August whereas the minimum cloud cover occurs in December.

5.1.1.5 Sunshine

The monthly average coefficients of sunshine values at three different stations namely Satna, Jabalpur and Guna are considered. The sunshine values vary between 0.469 and 0.736.

5.1.1.6 Temperature

The monthly average and monthly maximum and minimum temperatures for the five stations namely Nowgong, Panna, Damoh, Jabalpur and Sagar falling in the sub-basin have been considered. It is seen that the maximum and minimum temperatures in Ken basin vary between 45°C and 6°C respectively.

5.1.1.7 Evaporation

There is no pan-evaporimeter installed in any of the districts in the sub-basin. However, the pan evaporation data recorded in Sagar and Damoh stations have been considered for this study.

5.2 Ken drainage basin

5.2.1 General

The catchment of Ken basin upto the Daudhan dam site is 19534 Sqkm, which is 69.62% of the total basin area. The length of Ken river upto the proposed Daudhan dam site is approximately 143 km. The upper reaches of the Ken river are flanked by undulating plateau with sandstone, shale and limestone. Down below, recent alluvium engrosses the river upto the existing Gangau weir. The stratigraphy of rock formations found in the region is mostly alluvial soil, deccan traps, lameta beds and Vindhyan system.

5.2.2 Soil types

Although the soil type is mixed red and black as per the general classification. The soils of the basin have been broadly grouped into five

categories by the National Bureau of Soil Survey and Land Use Planning (under Indian Council for Agricultural Research), Nagpur, as given below:

	Category	**% area in the sub-basin**
i	Soil on hill and hill ridges (Entisols)	7.3
ii	Plateau soils (Entisols, Inceptisols and Alfisols)	44.0
iii	Pediment soils (Entisols and Alfisols)	2.1
iv	Soils of level alluvial plain and undulating flood plain (Inceptisols and Vertisols)	43.6
v	Soils of Dissected flood plain (Inceptisols)	3.0

A brief description of these soils is given in the following paragraphs.

(i) Soils on hill and hill ridges (Entisols)

These soils are fine loamy to coarse loamy in texture and greyish brown to dark reddish brown in colour. These soils are highly erodible, excessively drained, stony and gravelly in nature. These soils are of shallow depth with low nutrient status and are slightly acidic to neutral in reaction. They are low in organic matter content and have poor water retention capacity. These soils are unsuitable for normal crop husbandry. However, they may be utilised for the purposes of forestry, pasture development and growing grasses.

(ii) Plateau soils (Entisols, Inceptisols and Alfisols)

These soils occur on level to gently undulating terrain. They are yellowish brown to dark brown in colour. These soils are shallow to deep coarse with medium textured and low nutrient status. These soils are moderately eroded. Their water retention capacity varies with the soil texture and organic matter content. In this category too, the shallow soils are unfit for normal crop husbandry whereas deep soils are suitable for growing kharif crops like sorghum, millets, pulses and bajra.

(iii) Pediment soils (Entisols and Alfisols)

These soils occur on gently to undulating gnessic terrain comprising the vast pediment and piedmont plains characterised by intermittent rocky waste lands and shallow water bodies. They are shallow to deep, coarse to medium in texture and poor in nutrient status. They are moderately eroded. The deep soils in this category are fit for cultivation of crops like sorghum,

til, bajra, millets and groundnut. Shallow soils are best suited for raising pastures.

(iv) Soils of level alluvial plain and undulating flood plain (Inceptisols and Vertisols)

These soils occur on level to undulating terrain. These are deep to very deep, fine to fine loamy, well to moderately well drained and contain calcium carbonate deposits. They are neutral to slightly alkaline in reaction. They are low in organic matter content, fairly rich in nutrient status and are moderately eroded. These soils are best suited to crops like jowar, arhar, soyabean and moong under dry land and sugarcane under irrigated conditions. Wheat, gram and linseed may be grown during the rabi season.

(v) Soils of dissected flood plain (Inceptisols)

These soils are very deep, well drained, calcareous, and gravelly with abundant lime nodules in the soils. These are fine loamy in texture, yellowish brown in colour with low organic matter content. They possess moderate water retention capacity. These soils are severely eroded during floods and need extensive conservation measures. Lands situated away from the streams can be put under cultivation for kharif crops viz. jowar, bajra and arhar.

5.2.3 Present land use

5.2.3.1 Pattern

The total geographical area of upper Ken sub-basin up to Daudhan dam site is 19534 Sqkm. The annual land use particulars for the basin have been worked out from available districtwise statistics of 1991-92 obtained from the Land Records and Settlements Department, Madhya Pradesh. It is seen that the areas under forest and land under non-agricultural use are 6.97% and 6.45% respectively. The net area sown is 60.23% and the area sown more than once under miscellaneous crops is 0.16%. Thus the gross cropped area works out to 60.39%.

An extract of the average land use statistics for the Ken basin is given in table-5.1.

Table - 5.1
Average land use in Ken sub-basin upto Daudhan dam site (based on 1991-92 Statistics)

	Type of land	Area in ha.	Basin area in %
1	Forests	136152	6.97
2	Land under non-agricultural use	125994	6.45
3	Barren and unculturable land	122674	6.28
4	Permanent pastures and other grazing land	169360	8.67
5	Land under miscellaneous crops	3125	0.16
6	Culturable waste land	136347	6.98
7	Old fallows	43561	2.23
8	Current fallows	39654	2.03
9	Net area sown	1176533	60.23
	Total Area	1953400	100.00

Source: Land Records Office, Gwalior (M.P.)

5.2.3.2 Culturable area

The culturable area of the basin comprises of culturable waste land, land under miscellaneous crops and trees, fallow land and net area sown. Maximum culturable area of the Ken basin upto Daudhan dam site is 1399220 ha (71.63% of the total area) in the year 1991-92.

5.2.3.3 Land holdings

The land holdings in the Ken sub-basin, as per 1990-91 statistics, have been obtained from the information on land holdings in the eight districts falling in the basin and are given in table-5.2.

Table -5.2
Land holding particulars

Land size	Number	Area in ha
Below 1 ha	139448	69596
Between 1 and 2 ha	136148	197001
Between 2 and 4 ha	124487	344805
Between 4 and 10 ha	92541	559043
Above 10 ha	26726	461852

Source: District Statistical book of 1990-91.

5.3 Command area

5.3.1 General

About 156 villages are coming under the command area of enroute irrigation from K-B link. District and tehsilwise break-up of these villages on the basis of census booklet is given in Table- 9.1 of chapter-9 'Command Area Development'. The link canal provides annually enroute irrigation to an area of 47000 ha.

Daudhan reservoir is also to provide irrigation in the downstream areas of 3.23 lakh ha annually as proposed in the Ken Multipurpose Project Report prepared by the State Government of Madhya Pradesh.

K-B link project also envisages transfer of 1020 Mm^3 of water from Ken basin. Out of which 659 Mm^3 is meant for substitution of water in the upper reaches of Betwa basin for irrigating the water short areas of 1.27 lakh ha annually through four projects viz. Barari barrage, Neemkheda, Richhan and Kesari in Upper Betwa sub-basin

5.3.2 Normal and yearly average rainfall of the command area

Districtwise normal and yearly average rainfall from 1987 to 1991 (January to December) of the districts constituting the enroute command, Ken command and Betwa command areas are given in table-5.3.

Table - 5.3
District wise normal and yearly rainfall

Unit : mm

Rainfall	Name of districts				
	Chhatarpur	Tikamgarh	Panna	Raisen	Raisen
Normal	1987	1001.1	1176.4	1330.4	1133.8
1987	1107.5	1193.6	1178.8	975.3	1451.5
1988	891.3	732.8	1040.8	854.3	1018.0
1989	716.0	676.4	819.2	967.2	894.9
1990	1270.0	1392.3	1622.5	1378.8	1049.7
1991	808.9	704.4	910.7	1061.2	838.0

5.4 Availability of data

5.4.1 Availability of gauge and discharge data

There are four gauge and discharge sites in the Ken basin out of which two fall within the catchment area upto the proposed dam site. The particulars of the sites are given in table-5.4.

Table -5.4
Location of gauge and discharge sites in Ken basin

Site	River on which located	Catchment area (Sqkm)	Site maintained by
Gaisabad	Bearma	5803	C.W.C.
Patheria	Sonar	1778	C.W.C.
Banda	Ken	25320	C.W.C.
Madla	Ken	N.A.	C.W.C.

The gauge and discharge data at Banda has been considered for the present study since the durations of records for the other two sites are very short.

The ten daily observed flows at the Banda gauge and discharge sites for the period from 1960-1990 have been used for the studies, in this report.

5.4.2 Availability of rainfall data

As stated earlier there are 21 raingauge stations in and around the catchment area of Ken upto Banda G&D site, out of which 16 raingauge stations influence the catchment upto the Daudhan site. The monthly rainfall data of these stations for varying periods from 1901 to 1992 have been collected and utilised in the study.

5.4.3 Temperature

The monthly average, monthly maximum and monthly minimum temperatures for five stations namely Nowgong, Sagar, Damoh, Panna and Jabalpur are considered.

5.5 Yield and water balance

Various studies have been made by different organisations for assessment of surface water availability of Ken. The Government of Madhya Pradesh

(Water Resources Department) estimated the total surface flow at the proposed Greater Gangau dam to be 4490 Mm^3 at 75% dependability and 5280 Mm^3 at 50% dependability based on the limited time scale rainfall-runoff relationship developed for Rangwan dam site across the Banne river, a tributary of Ken. The committee on the southern tributaries of Yamuna constituted by the Planning Commission has assessed the total annual yield of Ken as 12006 Mm^3 at 50% dependability and 9785 Mm^3 at 75% dependability based on 19 years observed data at Banda G&D site. The Government of Uttar Pradesh, Irrigation Department in their report of Bundelkhand region has assessed the annual yield of Ken upto Greater Gangau dam site as 8992 Mm^3 at 50% dependability and 5556 Mm^3 at 75% dependability based on 12 years computed inflow data of existing Bariyarpur weir located 17 km downstream of existing Gangau weir on Ken.

The National Water Development Agency had however made an independent study of yield assessment based on gauge and discharge data at Banda G&D site maintained by C.W.C. and the annual yield was worked out as 6211 Mm^3 at 75% dependability. This study was sent to Central Water Commission for taking a final view as advised by the T.A.C. of NWDA in its 9^{th} meeting. The C.W.C. has finally suggested to adopt 6188 Mm^3 as gross availability of water at 75% dependability at Greater Gangau site. As the catchment area at Daudhan dam site is only 0.16% less than that of Greater Gangau, the annual yield at Greater Gangau has been taken as valid at Daudhan dam site also.

Water balance at Daudhan dam site on the basis of this yield has been worked out as given in table-5.5.

Table - 5.5
Water availability in Ken basin at proposed Daudhan dam site

Sl. No.	Details	Quantity of water in Mm^3		
		M. P.	U. P.	Total
I	Gross availability at 75% dependability			6188
II	Requirements (-ve)			
	(i) upstream water needs, Inbasin use			
	(a) Irrigation			2988
	(b) Domestic			131
	(c) Industrial			238
	Sub-total			3357
III	Regeneration from (+ve)			
	(i) Irrigation			165
	(ii) Domestic			105
	(iii) Industrial			190
	Sub-total			460
IV	Net availability of water			3291
V	Requirements for use in downstream command of KMPP	1375	850	2225

5.6 Water quality

There is a water quality site at Banda, which is maintained by Central Water Commission. Different parameters of water quality are observed regularly at this site. Based on these water quality parameters, it is observed that quality of water of Ken river is in general fit for domestic, industrial and agricultural purposes.

5.7 Reservoir area

The Daudhan reservoir water spread covers an area of 86 Sqkm. The capacity of the reservoir was determined from the reservoir area map prepared by the Survey of India, to a scale of l cm = 158.40 m (1 inch = 1320 ft) with contour intervals of 3.048 m (10 ft). The capacity between two contours is worked out by using the following formula.

$$V = \frac{h}{3} - [\ A_1 + A_2 + \sqrt{(A_1 \times A_2)}\ ]$$

where, h = difference of elevation between two contours
A_I = Area of first contour
A_2 = Area of the second contour

The elevation area capacity table thus worked out and the area capacity curve has been prepared.

5.8 Estimation of sedimentation in Daudhan reservoir

5.8.1 Catchment area

The catchment area of Ken upto Daudhan dam site is 19534 Sqkm of which 10194 Sqkm is expected to be covered by the upstream projects. For the purpose of calculations the areas contributing the sediment, are assumed as under:

(a) For the sedimentation period of 50 years, full catchment area of 19534 Sqkm has been considered for the first 15 years while balance catchment area of 9340 (19534-10194) Sqkm has been considered for the next 35 years.

(b) For the sedimentation period of 100 years, full catchment area of 19534 Sqkm has been considered for the first 15 years while balance catchment area of 9340 Sqkm has been considered for the next 85 years.

5.8.2 Sediment rate

The silt observation site on Ken river is located at Banda, which is about 150 km downstream of the proposed Daudhan dam site. Sediment data of six years (1986 to 1991) collected at this site are considered for arriving at the silt rate to the Daudhan reservoir as detailed below.

Calculation of sediment rate for Daudhan reservoir

Total sediment transport (average of six years)	= 9000612 Tonnes/yr.
Catchment area of Ken upto Banda gauge and discharge site	= 25320 Sqkm
Considering 15% bed load, the total sediment transport per year	=1.15×9000612=10350704 Tonnes/yr.

Average density of silt = 1.145 t/m^3 or 1145 kg/m^3

$$\text{silt inflow} = \frac{\text{Total sediment}}{\text{Density}} = \frac{10350704}{1.145} = 9039916 \ m^3/yr.$$

$$\text{silt rate} = \frac{\text{Silt inflow}}{\text{Catchment Area}} \quad \frac{9039916}{25320} = 357.02 \ m^3/Sqkm/yr.$$

Besides, the sediment rate of 357 m^3/sqkm/year was also adopted for design of Gandhisagar dam, a major project across Chambal in Madhya Pradesh. The catchment areas of two reservoirs viz. Gandhisagar (23140 sqkm) and Daudhan (19534 sqkm) are also quite comparable.

The sediment rate for some of the major projects namely Tawa, Barna, Sondur, Gandhisagar, Mahanadi reservoir and Hasdeo in Madhya Pradesh and Matatila in Uttar Pradesh has also been studied based on the information given in CBIP publication No. 137 on Major Dams in India, 1979. It is found that the designed sediment rates of these projects are in the range from 130 to 706 m^3/sqkm/year. Hence, the silt rate as worked out i.e. 357 m^3/sqkm/year has been considered for design of Daudhan dam. Data obtained from CBIP Publication No. 137 are furnished in table-5.6 for reference.

Table – 5.6
Data from CBIP Publication No. 137

Sl. No.	Name of dam	Catchment Area (sqkm)	Dead storage capacity (Mm^3)	Sediment rate (m^3/sqkm/year)
1	Matatila (U.P.)	20718	269.3	130
2	Gandhisagar (M.P.)	23140	835.0	361
3	Sondur (M.P.)	512	19.0	371
4	Mahanadi Reservoir (M.P)	3670	143.0	390
5	Tawa (M.P.)	5983	260.0	435
6	Hasdeo (M.P.)	6737	370.0	549
7	Barna (M.P.)	1176	83.0	706

5.8.3 Total sediment volume trapped

Based on the above mentioned assumptions of contributing area and the rate of sedimentation, the estimated quantities of sediment deposit in Daudhan reservoir are assessed as follows:

(a) During 50 years

Rate of silt deposition is 357 m^3/SqKm/year

(i) For first 15 years the silt deposition from the catchment area of 19534 Sqkm is

= 357 x 19534 x 15 = 104.60 Mm^3

(ii) For the next 35 years the silt deposition from the catchment area of 9340 Sqkm is

= 357 x 9340 x 35 = 116.70 Mm^3

Total sediment deposition = 104.60+116.70 Mm^3

= 221.30 Mm^3 Say 221 Mm^3

(b) During 100 years

(i) For first 15 years the silt deposition from the catchment area of 19534 Sqkm is

= 357 x 19534 x 15 = 104.60 Mm^3

(ii) For the next 85 years the silt deposition from the catchment area of 9340 Sqkm is

= 357 × 9340 × 85 = 283.42 Mm^3

Total sediment deposition = 104.60+283.42 Mm^3

= 388.02 Mm^3

Say 388 Mm^3

5.8.4 Sediment distribution

The sediment distribution is worked out for two periods viz. 50 years and 100 years by empirical Area Reduction method as given in the Technical Report No. 19 on Life of Reservoir, Published by CBIP, New Delhi. For this purpose, the MWL of 288 m is adopted and bed level of the reservoir is considered as 216 m. The type of reservoir is considered as hill type and the standard classification is taken as type III. The total sediment during 50 years and 100 years will get distributed upto and above new zero elevations as under:

Upto zero elevation:	
For 50 years	25.0 Mm^3
For 100 years	75.0 Mm^3
Above zero elevation:	
For 50 years	199.73 Mm^3
For 100 years	311.76 Mm^3

The new zero elevations after 50 years and 100 years have been found to be as 225.0 m and 235.5 m respectively. However, the Minimum Draw

Down Level (MDDL) is fixed at 268.0 m, which is well above the zero elevation after 100 years. Higher MDDL will result in additional head for more power generation. The distribution of sediments above and below MDDL will be as under:

Above MDDL	
For 50 years	18.07 Mm^3
For 100 years	34.36 Mm^3
Upto MDDL	
For 50 years	206.66 Mm^3
For 100 years	352.40 Mm^3

5.8.5 Revised area capacity curve

Sedimentation analysis has been carried out for Daudhan dam considering 50 years and 100 years sedimentation. The original area capacity curve for Daudhan reservoir has been revised considering the results of sedimentation studies. The revised area capacity curves have been plotted for 50 years and 100 years sedimentation. The original area capacity and revised area capacity curves for Daudhan reservoir are prepared.

5.8.6 Capacity of the pondage in between the existing Gangau dam and the proposed Daudhan dam

The proposed pondage area in between the existing Gangau dam and the proposed Daudhan dam has been surveyed and the contour plan and area capacity curve have been prepared for the purpose.

5.9 Flood studies for the proposed Daudhan dam

5.9.1 General

Studies for probable maximum flood for the proposed Daudhan dam site have been carried out by the unit hydrograph method, based on rainfall in Ken catchment and corresponding observed flows at Banda G&D site. The procedure followed for studies and the results obtained are discussed in subsequent paragraphs.

5.9.2 Data used

An unprecedented flood was observed at Gangau weir site in September, 1992. Therefore, the daily flow data at the Banda and rainfall data upto Banda for September 1992 were used for the analysis. A Thiessen Polygon was first developed for the rainfall stations, from which Thiessen weights and the average rainfall values were computed.

The average rainfall and observed runoff was used for computing the (Ph1) index, excess rainfall, Direct Surface Runoff (DSRO) and Base flow. The excess rainfall and DSRO were used for developing a unit hydrograph by Conventional Nash Model. The unit hydrograph was then transferred to Daudhan dam site by reducing the peak on proportionate area basis. Storm duration of observed flood was taken on 0.13 tp, where tp is time lag between the centroid of rainfall histogram and peak of the corresponding storm hydrograph.

5.9.3 Computation of flood hydrograph at Daudhan dam site

Duration of the probable maximum storm was taken as 24 hours (1.1 tp) to maximize the peak. The point probable maximum precipitation (pmp) of 24 hours duration is 480 mm. IMD monograph Hydrology/No.ll/19889 has been used. Cumulative 6 hour precipitation was computed using the CWC design report no. K&M/19/1992:

24 hours post PMP	:	480 mm
24 hours areal PMP	:	480 x 0.81 = 390 mm

6 hourly cumulative precipitation is as follows:

Time (hrs)	Cumulative Ppt (mm)
6	176
12	273
18	332
24	390

From the cumulative precipitation, hourly precipitation was computed. An initial loss of 10 mm was assumed and uniform loss of 1.95 mm/hr, which was computed from the observed flood data was used. Base

flow has been assumed as 0.15 Mm^3/sqkm as per CWC publication - K&M/19/1992.

The design flood hydrograph (PMF) has a peak of 45104 cumecs and has been used in the study.

5.9.4 Flood routing

Modified Pulse method has been used for flood routing of the Daudhan reservoir. It has been assumed that the inflow and outflow at FRL are same and the routing is started from FRL 287 m. The design flood (PMF) used is 45,104 cumec. There are 15 gates of the size 18 m x 18 m provided over the spillway crest. It is assumed that one of the gates will be inoperative and, therefore, only 14 gates open have been considered for computing the maximum water level. The computations of flood routing have been done with the help of computer. The maximum rise in water level thus obtained is 287.42 m and the corresponding flow passing over the crest is 43993 cumec. The flood routing has also been carried out with 13 gates open (2 gates inoperative) and it has been found that the maximum rise in water level will be upto 288.23 m. Therefore, the maximum water level (MWL) has been fixed as 288.00 m. After providing a free board of 3.0 m above this MWL, the top of dam has been fixed as 291.00 m.

5.10 Navigation

Ken river has not been used for navigational purposes so far and there is no plan for its use for navigation in future also.