CHAPTER - V

HYDROLOGY

5.0 General climate and hydrology

The Kosi basin mainly falls in the sub-tropical belt and humid zone. The basin experiences very hot summer and severe winters except in the snow bound area and the hills of Nepal. The monsoon period is from middle of June to middle of October. The winter season is from November to March. The normal daily mean temperature of the sub-basin varies from 16.5^0 C to 30.4^0 C in the plains. The maximum annual humidity at Darbhanga, Bhagalpur and Purnea at 8.30 AM during the years 1980-82 as reported by IMD, Patna are 69%, 79% & 79% respectively. The winds are generally light particularly during the morning hours with a mean speed of the order of 3-5 km/hour. The wind direction is North-Westerly or South-Easterly in the Eastern and Western portion and North-Westerly in the Central area on a few days.

So far hydrology of the project is concerned; it is based on hydrology of Kosi river at Hanuman Nagar barrage. It has been found to be surplus at 75% dependability after meeting in-basin requirement of Kosi. Surplus water of 1,741 MCM during monsoon months in case of pre Sapt Kosi high dam and 2,292 MCM annually in case of post Sapt Kosi high dam has been proposed for diversion through link canal. A hydrological study of this project has been carried out departmentally dealing with assessment of yield & water balance for Kosi river at Hanuman Nagar barrage.

5.1 General information about regions of Kosi-Mechi link project

5.1.1 Kosi basin

The Kosi basin mainly falls in the sub-tropical belt and humid zone. The basin experiences very hot summer and severe winters except in the snow bound area and the hills of Nepal. The monsoon period is from middle of June to middle of October. The winter season is from November to March. Heavy rainfall in Kosi catchment occurs during South-West monsoon period (June to Sept).

The normal daily mean temperature of the sub-basin varies from 16.5^0 C to 30.4^0 C in the plains. The maximum temperature observed in the sub-basin is 31.2^0 C during the month of May whereas the minimum temperature observed is 16^0 C in the month of January.

The winds are generally light particularly during the morning hours with a mean speed of the order of 3-5 km/hour. The wind direction is North-Westerly or South-Easterly in the eastern and western portion and North-Westerly in the central area for a few days. When the winds are not calm, the predominant direction is westerly at Barahkshetra & Okhaldunga and southerly at Taplejung.

There are three observatories in the vicinity of Kosi basin namely Darbhanga, Sabour and Purnea, where monthly and annual values of potential evapotranspiration are worked out from Penman's formula. Also the potential evapotranspiration of Bhagalpur station in the adjoining basin is considered according to report No.136 IMD (1971).

5.1.2 Mahananda basin

The river Mahananda is one of the major northern tributary of the river Ganga, passing through Nepal, India and Bangladesh. It is bounded on the North by the Himalayas, the ridges separating it from the Teesta river system in the East, the Ganga on the South and the Kosi river system in the West. It is spread over districts of Purnea, Kishanganj, Araria and Katihar in Bihar and Malda, West Dinajpur and Darjeeling in West Bengal. It drains a total catchment area of 23,700 sqkm over a length of 137 km. The hilly catchment in Nepal pertains to tributaries of the Mahananda river namely Padma, Bekra, Eastern Kankai, Western Kankai and the Mechi, while that of the main river Mahananda lies in the Darjeeling district of West Bengal.

5.1.2.1 Mechi sub-basin

The river Mechi is a major western tributary of Mahananda. The river Mechi a perennial river which rises in the inner valley of the Himalaya in Mahabharat range of hills in Nepal near Sindhuliagarhi at an elevation of 2,423 m at the Latitude 26^0 50′N and Longitude 88^0 7′E.

5.2 Specific information about drainage basins

5.2.1 Kosi basin

The river Kosi being one of the major tributaries of the Ganga is also one of the ancient rivers of India which is flowing since the formation of the Great Himalayas and is mentioned as "Kaushik" in the ancient literature. The river Kosi rises at an altitude of over 7,000 m at Longitude 85^0 2′ E and Latitude 28^0 30′ N in the Himalayas in Tibet. Two of the highest peaks in the world, the Mt. Everest and the Kanchanjunga fall in the Kosi catchment. The total length of river Kosi from its origin to its confluence with river Ganga is about 310 km.

The Kosi sub-basin is bounded in the North by the Tsangpo (Brahmaputra) basin, on South by the Ganga basin, on East by the Mahananda basin and on West by the Gandak / Burhi Gandak basins. The two major tributaries of River Kosi are Kamla and Bagmati, which join it upstream of its confluence with Ganga (much below the Barahkshetra dam site and Hanuman nagar barrage) from right. Therefore, the catchment areas of Kamla and Bagmati are not considered because of their distinct identity and significant catchment areas. Various organizations report different catchment areas for the Kosi, Kamla and Bagmati. One of the probable main reasons for such differences may be the Kosi's unique feature of shifting its course laterally due to its meandering nature. However, in this study, the catchment area given in the perspective plan of water resources development of Kosi-Mahananda sub-basin by GBWS of CWC is considered.

The catchment area of the Kosi upto Barahkshetra dam site is 59,540 sqkm, which falls entirely in Tibet (China) and Nepal only. The catchment area of the Kosi at Hanuman Nagar barrage is 61,792 sqkm.

As per the "History of Kosi Project" WRD, Govt. of Bihar the total catchment area of river Kosi including Kamla and Bagmati is 93,355 sqkm, out of which 32,671 sqkm lies in Tibet, 39,678 sqkm in Nepal and 21,006 sqkm is in India. However, as per the National Perspective Plan of Water Resources Development, Vol-II, CWC, 1994, the total catchment area of Kosi river excluding Kamla & Bagmati is

74,500 sqkm, out of which 11,265 sqkm lies in India in Bihar state. The details are given in Table 5.1.

The river Kosi is famous for the changing course by meandering & unstable morphological behavior. During past two hundred years, it has been changing its course generally in a Westward direction and has shifted across a width of about 120 km. In these movements it has laid waste a vast area of agricultural land of about 77,000 sqkm in Bihar and 1,295 sqkm in Nepal.

Table-5.1

Country wise/district wise breakup of Kosi basin

Sl. No.	Country/District	Catchment area (sqkm)
1	**Tibet**	**32671**
	Nepal	**39678**
2	**India**	
i	Darbhanga	66
ii	Madhubani	1715
iii	Supaul	2366
iv	Khagaria	691
v	Saharsa	1646
vi	Araria	835
vii	Purnea	1172
Viii	Madhepura	1796
ix	Katihar	446
x	Bhagalpur	512
	Total (India)	**11265**
	Total catchment area of Kosi (excluding Kamla & Bagmati)	**74,500**

More details in respect of districtwise geographical area of kosi basin in India is given in Annexure 5.1.After flowing through Tibet the river enters Nepal where it is known as “Sapt Kosi” (deriving its name from the seven streams viz. Sunkosi, Bhotia Kosi, Tamba Kosi, Dudh Kosi, Barun Kosi, Arun Kosi and Tamur Kosi united above at Triveni in

Nepal to form the main river). However, for all practical purposes, the confluence is considered to be formed by the three major tributaries, "the Arun" from North, "the Sunkosi" from West and "the Tamur" from East at Tribeni. All these three tributaries are having their origin in the Himalayan region of Nepal and Tibet.

The river Arun is the longest of these tributaries drains highest peak Mt. Everest and has cut through a gorge in the great Himalayan range and drains under the name Phung Chu, the entire Tibetian through from Gosaintham to Kanchanjunga. The Tamur drains the second highest peak Mt. Kanchanjunga and join from the East. The Sunkosi drains the Eastern Kathmandu valley and join the main river from the West.

Below the confluence of Triveni the Kosi flows in a narrow gorge for a length of about 10 km till it debouches into the plains near Chatra in Nepal. Below Chatra, after flowing for about 50 km to Hanuman Nagar the river enters Indian Territory. In the portion below Chatra, the river divides itself into several channels; spread over 6 to 16 km width. About 100 km below Hanuman Nagar barrage, the river flows in a South-West direction and then in Easterly direction upto confluence with Ganga.

The Kosi is the third biggest river in India. Kosi river is one of the highest silt carrying river in the world. One of the main reasons for heavy silt load in the river is steep bed gradient. The bed gradient in different length of Kosi river are shown in Table 5.2.

Table 5.2

Length wise bed gradient of river Kosi

Sl. No.	Extent of reach	Existing bed gradient
1.	0 to 42 km	1 in 714
2.	42 to 68 km	1 in 1396
3.	68 to 134 km	1 in 2222
4.	134 to 310 km	1 in 9090

Source: History of Kosi Project, WRD, Govt. of Bihar

Kosi river deposits around 25 million cubic meter of sand/silt per year. This quantity is much more in comparison to other rivers originating from Himalayas.

The river Kosi can be broadly divided into two parts from hydrology and hydro-meteorological point of view. The upper catchment, which lies in Tibet and Nepal, comprises of about 80% of total basin area, has quite different characteristics with respect to the lower basin area (i.e. about 20% of the total area) falling in Bihar. The upper catchment is mainly responsible for the hydrological behavior of the river, while the lower catchment has little contribution to it.

5.2.2 Mahananda basin

The river Mahananda is one of the major northern tributary of the river Ganga, passing through Nepal, India and Bangladesh. It is bounded on the North by the Himalayas, the ridges separating it from the Teesta river system in the East, the Ganga on the South and the Kosi river system in the West. It is spread over districts of Purnea, Kishanganj, Araria and Katihar in Bihar and Malda, West Dinajpur and Darjeeling in West Bengal. It drains a total catchment area of 23,700 sqkm over a length of 137 km. From its origin near Chimali in the Mahabharat range to its confluence with Ganga lying between longitude 87° 45' E to 88° 15' E and between latitudes 25° 15' N and 26° 15' N. The Mahananda catchment is rectangular in most of the upper catchment and triangular in the lower portion below Bagdob and as a whole it is appreciably wedge shaped. The catchment is 281 km long and the average width of the upper catchment is 116 km. The maximum width of catchment is 125 km. The triangular portion of the lower catchment is about 147 km long. The total catchment area is about 23,700 sqkm of which about 16,100 sqkm lies in India, about 4,500 sq km in Nepal and the balance 3,100 sqkm in Bangladesh. In India, the catchment is spread over an area of about 6,340 sqkm in Bihar and 9,760 sqkm in West Bengal.

The hilly catchment in Nepal pertains to tributaries of the Mahananda river namely Padma, Bekra, Eastern Kankai, Western Kankai and the Mechi, while that of the main river Mahananda lies in the

Darjeeling district of West Bengal. In the high hills, the Mahananda river and its tributaries flow in zigzag direction. Hills and valleys are covered with dense mass of Forest, Festoon and drippings with marsh. This situation generally exists above 1520 m. altitude. The hills descend steeply to the plains, which are vast in expanse. The details of catchment are given in Table 5.3.

Table 5.3

Catchment area of Mahananda river system (sqkm)

Catchment area	Nepal	India			Bangla-desh	Total catchment area of basin
		West Bengal	Bihar	Total		
Total	4,500	9,760	6,340	16,100	3,100	23,700
Hill	4,280	523	---	523	---	4,803
Plain	220	9,237	6,340	15,577	3,100	18,897

5.2.3 Mechi sub-basin

The river Mechi is a major western tributary of Mahananda. The river Mechi a perennial river rises in the inner valley of the Himalaya in Mahabharat range of hills in Nepal near Sindhuliagarhi at an elevation of 2,423 m at the Latitude 26^0 50′ N and Longitude 88^0 7′ E. It is joined by a number of hill streams during its flow in the Mahabharat range. It flows in south easterly direction and after flowing 35 km it enters in Darjeeling district of West Bengal. After traveling a total distance of 62 km river Mechi joins the Mahananda at village Makhanpur (Bihar).

5.2.4 Floods and drainage

Kosi Basin

There are three G&D sites on river Kosi out of which two namely Barahkshetra and Birpur (Hanuman Nagar barrage) sites lies in Nepal while third namely Baltara site lies in India. The details of these sites are given Table 5.4.

Table 5.4

Sl. No.	Name of site	Maintained By	Catchment area (Sqkm)	Period of availability of data
1	Barahkshetra	CWC	59,540	1947-1990
2	Birpur (Hanuman Nagar Barrage)	WRD, Govt. of Bihar	61,792	1964-2013
3	Baltara	CWC	88,480	1960-2013

The discharge data of Barahkshetra site are not available for the period 1990 to 2011.The Baltara discharge site is located about 140 Km downstream of the Hanuman Nagar barrage. The observed discharge data at Birpur G&D site at Hanuman Nagar barrage itself is available for a longer period of 33 years ie 1980-81 to 2012-13. As per the guidelines of CWC a data of 25 to 30 years is sufficient for assessment of annual yields. The observed discharge data of Hanuman Nagar barrage also called Birpur G&D site, have been collected and utilized for the assessment of yield.

5.2.5 Kosi basin upto Hanuman Nagar barrage

As per agreement signed between Govt. of India and the then H.M.G. of Nepal in 1953, Kosi barrage was constructed as a component of Kosi Project 1953. Accordingly a 1149 m long Hanuman Nagar barrage (Kosi barrage) was constructed near Bhimnagar village located at a distance of 48 km below Chatra with pond level of 74.69 meters. The details of barrage are furnished in Para 2.4 of Chapter II.

5.3 Hydrological studies of river Kosi at Hanuman Nagar barrage

5.3.1 Previous studies

Studies Carried Out by Central Water Commission (CWC)

(i) The Central Water Commission has assessed the yield at various dependabilities based on the annual flows at the Barahkshetra G&D site on river Kosi in the year 1982 as given in Table 5.5.

Table 5.5

Annual flows at the Barahkshetra G&D site

Sl. No.	Dependability	Annual flow in MCM
1	25%	57,739.5
2	50%	50,967.6
3	75%	47,096.2
4	90%	42,814.3
5	98%	41,531.5

Source: WRD, Govt. of Bihar.

(ii) As per the report of perspective plan of water resources development for Kosi-Mahananda sub-basin Vol.-I prepared by CWC, 1984, the annual yield at Kosi high dam site, at 75% and 50% dependability were found to be 45,443 MCM and 52,350 MCM respectively.

(iii) As per the feasibility report of Kosi High Dam Project 1984, the Central Water Commission assessed the 75% and 50% dependable yield at Kosi High Dam as 45,113 MCM & 50,989 MCM respectively.

(iv) Recently, the flow series of river Kosi at Barahkshetra dam site has been worked out by Hydrological Studies Organization, CWC, New Delhi. In that CWC has assessed annual river flow at 75% dependability as 44,688 MCM.

5.4 Surface water availability as per pre-feasibility report proposed by NWDA

In the PFR of Kosi–Mechi Intra State link Project, NWDA has assessed the surface water availability at Barahkshetra G&D site (Kosi High Dam site, located in Nepal) by accounting the monthly flow data of that site which is available for a long and continuous period of 43 years, since 1947 to 1990. After accounting the upstream utilization, the annual yield series of river Kosi at Barahkshetra G&D site were assessed. The 75% and 50% dependable annual yields were found as 41,896 MCM and 47,285 MCM respectively.

Further, assuming annual available yield at 75% dependability as 41,896 MCM, the breakup of monthly available yields have been done on the basis of average of 43 years monthly flow on proportionate basis. The yield at Hanuman Nagar Barrage was computed on proportionate area basis which works out to 43,480.6 MCM at 75% dependability.

5.5 Surface water availability under present study at Detailed Project Report level

5.5.1 Availability of rainfall data

The Hanuman Nagar barrage is constructed at Birpur in Nepal near Indo-Nepal border. Since, the entire upper catchment area of river Kosi upstream of Hanuman Nagar barrage is lying in Tibet and Nepal, the details of rain gauge stations upto Hanuman Nagar barrage are not available.

5.5.2 Availability of observed discharge data

The discharge data of Barahkshetra dam site could not be available for the period 1990 onwards. The Baltara discharge site is located about 140 km downstream of the Hanuman Nagar barrage. The observed daily discharge data of Birpur G&D site at Hanuman Nagar barrage itself maintained by water Resources Department, Govt. of Bihar is available for a longer period of 33 years i.e. 1980-81 to 2012-13.

As per the guidelines of CWC a data of 25 to 30 years is sufficient for assessment of annual yields. The observed discharge data of Hanuman Nagar barrage have been collected and utilized for the assessment of yield. Since these discharge data belong to the downstream discharge of barrage. Therefore the daily discharge data of Eastern and western main canals offtaking from right and left head regulators of Hanuman Nagar barrage have also been collected for assessment of overall inflows of river Kosi at barrage site.

5.5.3 Processing of data

The daily observed discharge data of Hanuman Nagar barrage along with daily releases into western and eastern main canal were collected from WRD, Govt. of Bihar. The average ten daily and monthly discharges and corresponding average monthly yield were computed.

The observed inflows of each month during period 1980-81 to 2012-13 are given in Annexure 5.2 and in fig 5.1 to fig 5.12.

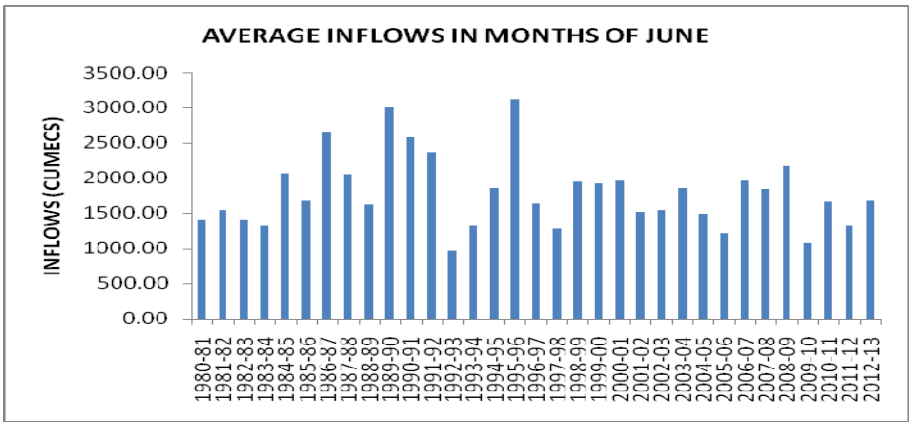

Fig.5.1

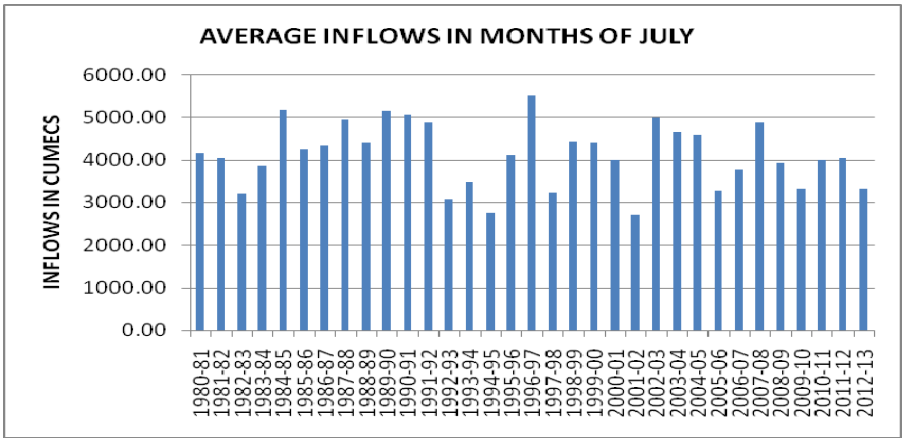

Fig 5.2

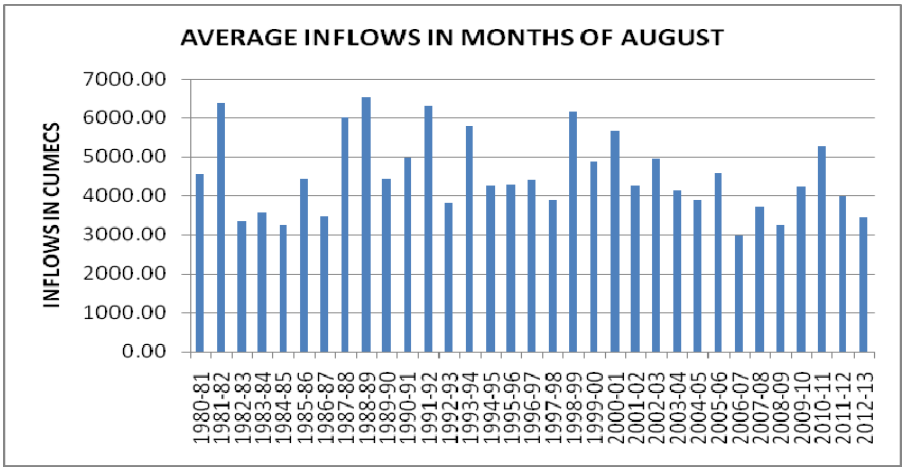

Fig.5.3

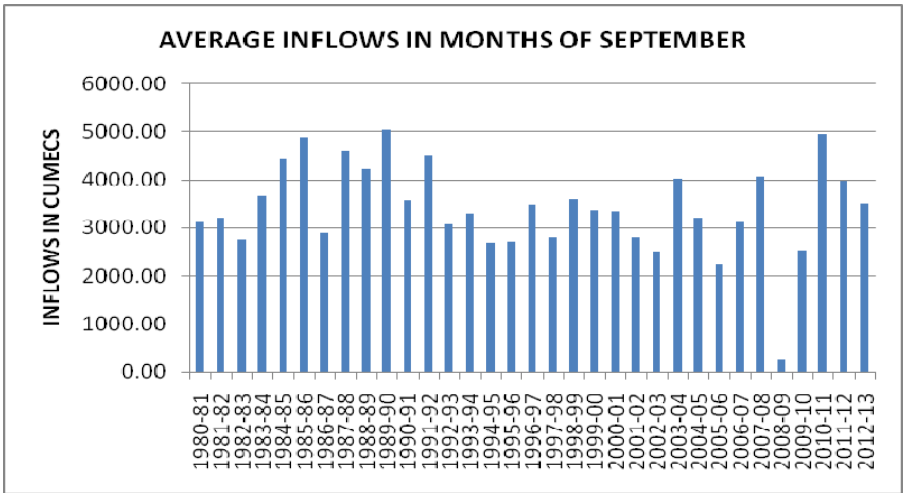

Fig.5.4

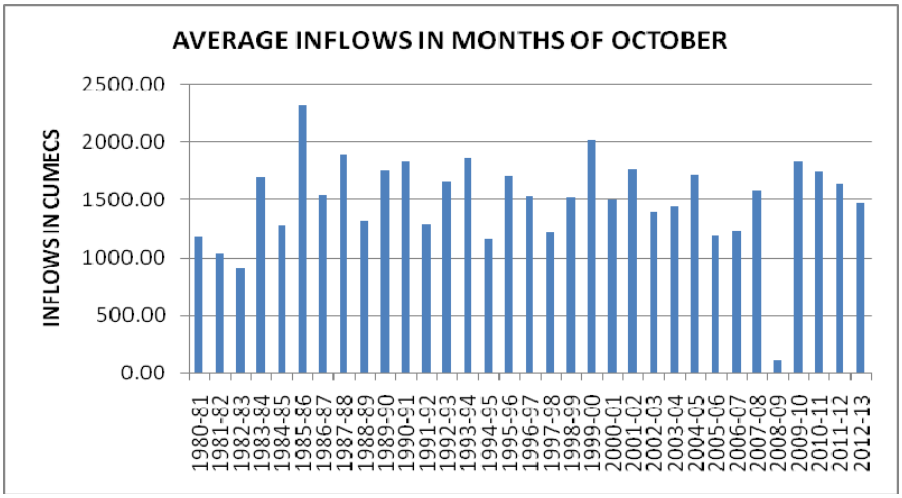

Fig.5.5

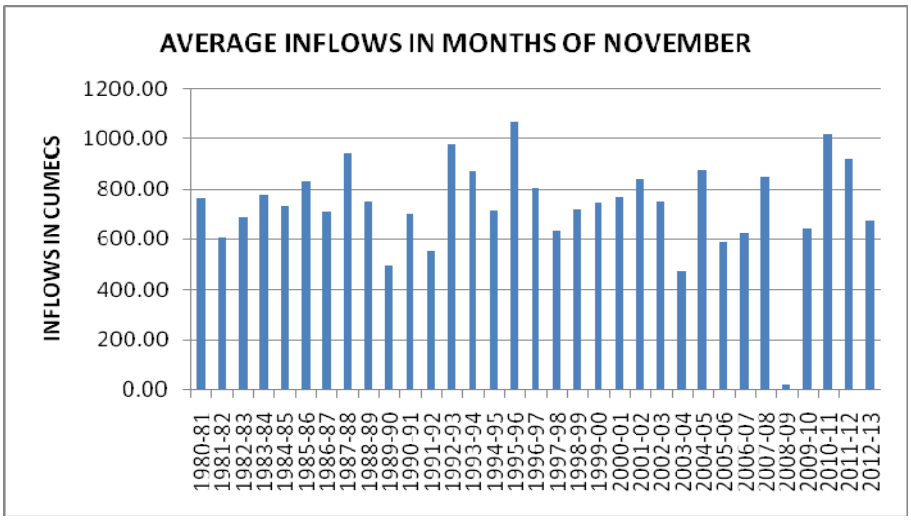

Fig.5.6

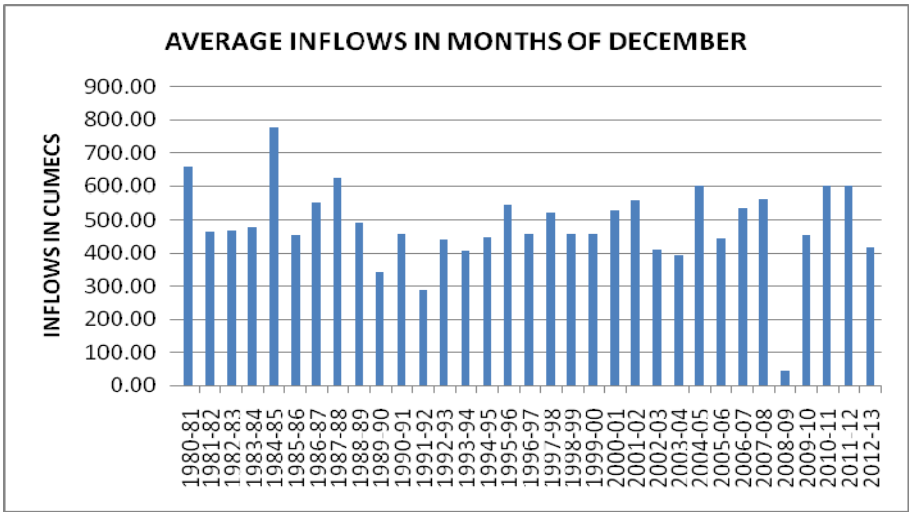

Fig.5.7

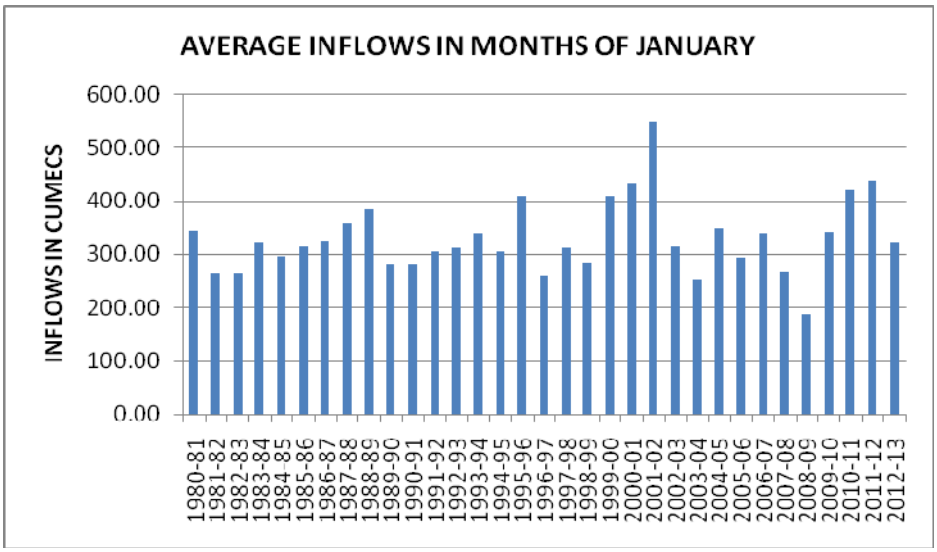

Fig.5.8

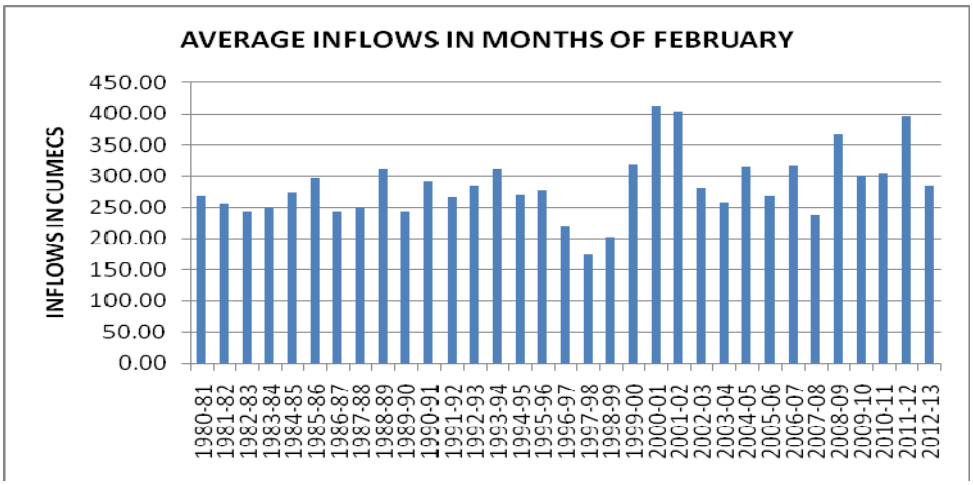

Fig.5.9

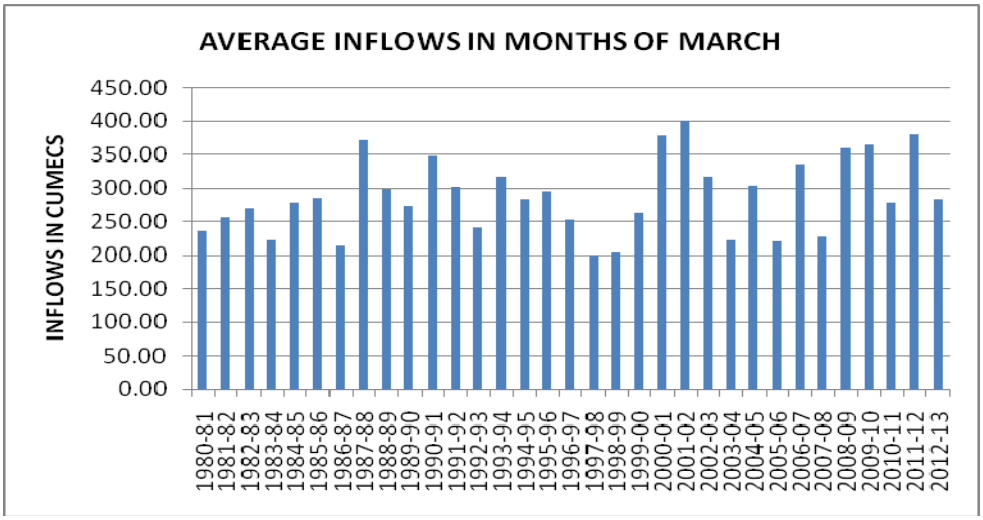

Fig.5.10

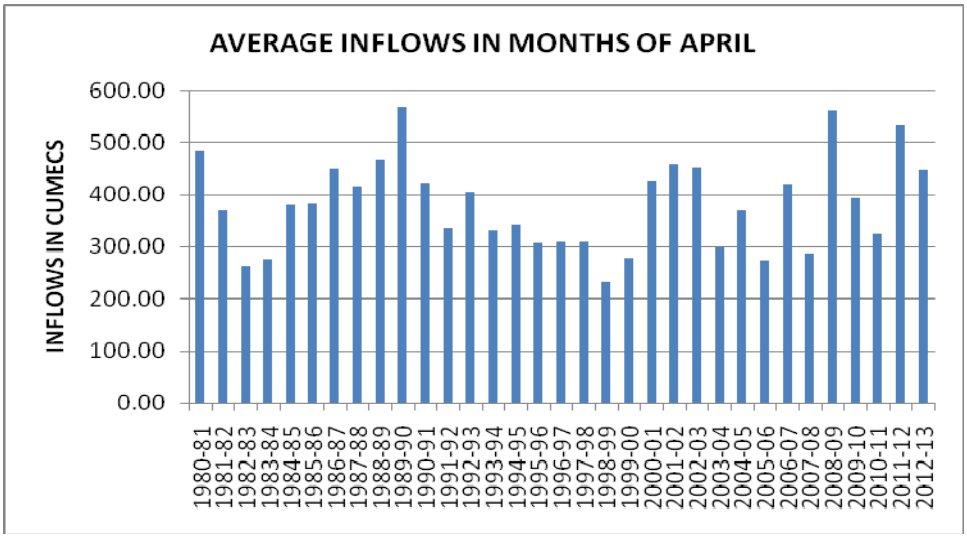

Fig.5.11

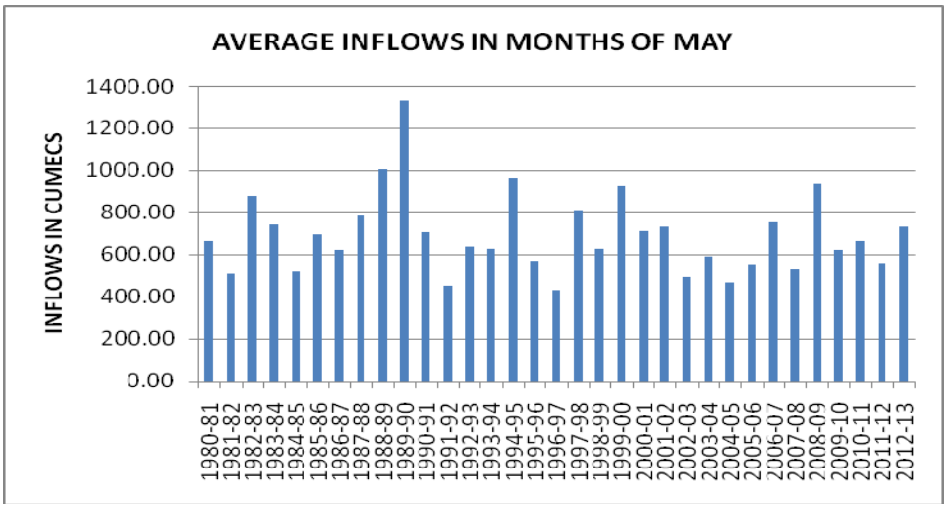

Fig.5.12

5.5.4 Consistency of data

It is observed from the above figures that the inflows available in the months of September 2008 to January 2009 are on much lower side as compared to average monthly inflows as indicated in bar charts as given in figure 3.4, 3.5, 3.6 and 3.7. The reason for this reduction is the historical incident of breaching of the embankment.

In view of this the inconsistent discharge data of Kosi barrage for the year 2008-09 is not considered in this study for assessment of yield.

5.5.5 Monsoon and lean season flow

The monthly inflow data observed at Hanuman Nagar barrage for the period from 1980-81 to 2012-13 indicate that the lowest flow in the river occurs during the month of February (174 cumecs in 1998), followed by March, April and January in ascending order. The month wise maximum, minimum observed flow, 75% dependable flow and year of occurrence are shown in Table 5.6 below.

The maximum flow in the river was 6,531 cumec in August, 1988 followed by 5,497 cumec in July, 1996, 5038 cumec in September, 1989, 3,120 cumec in June 1985 and 2,307 cumec in October, 1985.

Table 5.6

Monthly maximum, minimum and 75% dependable monthly flow (in cumec)

Sl. No.	Months	Maximum flow	Year of occurrence	Minimum flow	Year of occurrence	75% dep. flow during the month
1	January	549	2001-02	252	2003-04	284
2	February	411	2000-01	174	1997-98	251
3	March	400	2001-02	199	1997-98	237
4	April	567	1989-90	232	1998-99	308
5	May	1331	1989-90	432	1996-97	553
6	June	3120	1995-96	960	1992-93	1412
7	July	5497	1996-97	2717	2001-02	3354
8	August	6531	1988-89	2975	2006-07	3819
9	September	5038	1989-90	2241	2005-06	2834
10	October	2307	1985-86	898	1982-83	1278
11	November	1066	1995-96	468	2003-04	633
12	December	775	1980-81	287	1991-92	442

5.5.6 Flood frequency analysis

Since it is difficult to predict the exact sequence of stream flow for future years, probability concepts is used to study the probable variation in flow so that the design can be done on the basis of a calculated risk.

Recurrence interval (Tr) is also very important in flood analysis, and it is denoted by the number of years in which a flood can be expected once and it is given by Tr=100/f. Recurrence interval is calculated by

(a) California Method: $Tr = N/M$

(b) Hazen's Method: $Tr= 2/M^{-1}$

(c) Gumbel's Method: $Tr= N/MC^{-1}$

Where N= Number of years, M=Serial number of flood, C= Gumbel's correction.

Flood frequency analysis considers the annual peak flows at a site for all the years. It gives only the magnitude of flood peak of desired recurrence interval. The flood frequency analysis is utilized in the future probabilities of such occurrence. The estimation of frequencies of floods is an important parameter for the quantitative assessment of the flood problem.

For flood frequency analysis, two types of data are generally selected e.g. (i) the partial duration series and (ii) the extreme value series. The partial duration series is obtained from daily stage of flow values by selecting the values greater than a certain base value. The extreme value or annual series, as such can improve the reliability of analysis of extreme events for large return periods, when the available data is limited.

For the precise knowledge of distribution, extreme value is essential for the flood frequency analysis. The Gumbel's Distribution and the Log Pearson type-III distribution are two most commonly used statistical distribution for flood frequency analysis. In the present analysis, the methods of Gumbel's method and Log Pearson Type-III method have been used to find out the values of flood for 50 and 100 years return period.

Observed annual maximum discharge of Hanuman Nagar barrage site for the period 1964 to 2010 are shown in figure 5.13 & 5.14.

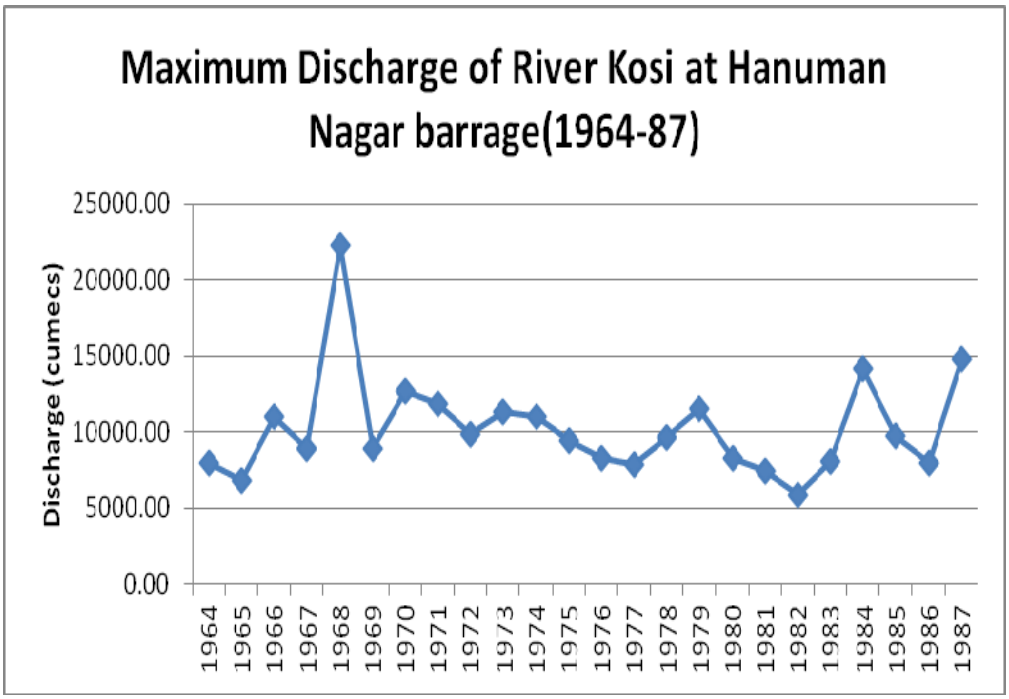

Fig-5.13

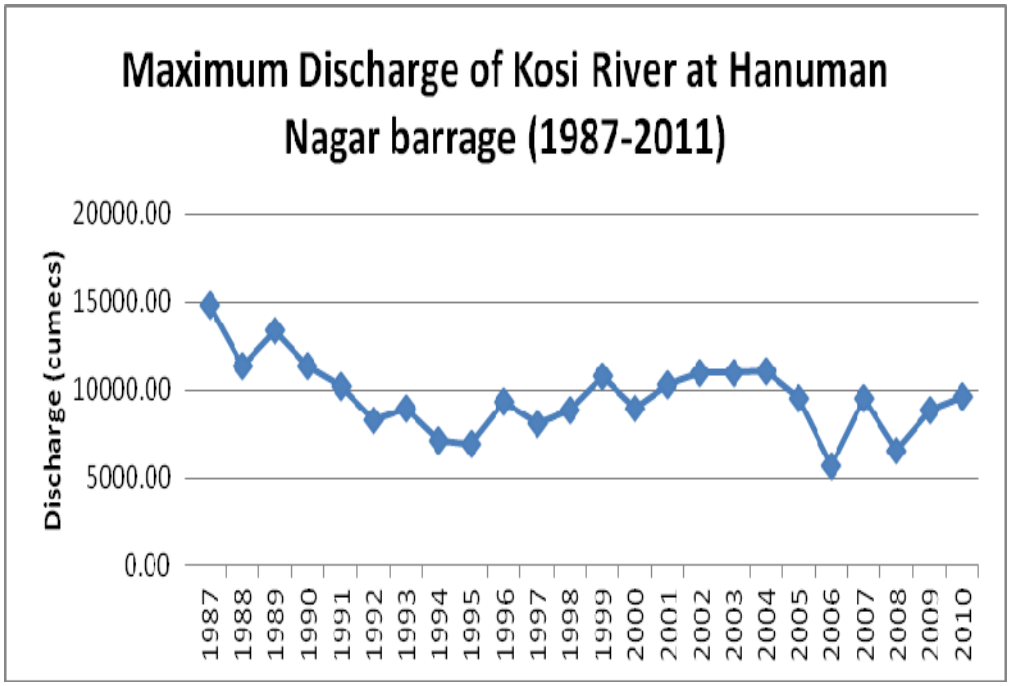

Fig-5.14

The design flood of river Kosi at Barahkshetra discharge site and at Hanuman Nagar barrage for 50 and 100 years frequencies have been worked out by using Gumbel's method and log Pearson method. The conclusions are given in Table 5.7.

Table 5.7
Design flood at various frequencies

Unit: cumec

Sl. No.	Return Periods (Years)	By Gumbel's Method		By Log Pearson Method	
		Hanuman Nagar	Barahkshetra	Hanuman Nagar	Barahkshetra
1	50	17812	20235	17157	18519
2	100	18783	21555	18633	18994

As per project report of Kosi barrage project, Hanuman Nagar barrage at Kosi river was designed with a design flood of 26,900 cumec. Therefore, same has been adopted in the study.

5.5.7 Assessment of yield

In the present study water availability at Hanuman Nagar barrage also called Kosi barrage, has been assessed by accounting the average monthly inflow data of Birpur discharge site at Hanuman Nagar barrage which is available for a period of 33 years, from 1980-2013. The discharge data for the year 2008-09 has been discarded due to its inconsistency. The following procedure was adopted while working out the annual yields:

- The total discharge of Kosi river computed as sum of daily discharge of barrage and daily discharges of Eastern & Western Kosi Main Canals.
- The average monthly discharge of Kosi river at Hanuman Nagar barrage was computed from daily discharge of Kosi river.
- The monthly yield was computed from the average monthly inflows.

- The total monthly yields and annual yield series at Hanuman Nagar barrage are given in Annexure 5.2.

- The Monsoon, Non – Monsoon and annual yield were computed from the month wise yield.

- The gross annual yield at different dependabilities is derived by placing the annual yields in descending order.

- The gross annual yield at 50% & 75% dependability works out to 49,889 MCM & as 43,972 MCM respectively.

- The percentage of average non-monsoon yield to the average monsoon yield works out to 22.49%.

- The monsoon, non-monsoon and annual yield series in descending order are given in Annexure 5.4.

- The monsoon, non-monsoon and annual inflow yield for various years has been arranged in descending order and plotted against percentage of exceedance. A plot of probability of exceedance at Hanuman Nagar barrage against Monsoon, Non-Monsoon & annual yield are shown in Table-5.8 to 5.10 and Fig. 5.15 to 5.17.

- In order to plot a flow duration curve, the observed yield series is arranged in descending order and ranks for each value in the series are assigned in ascending order. Thus, the rank of the highest value is 1 and that of the lowest value is the number of data in series. The probability of exceedance is computed using Weibull formula as follows:

$$P = \frac{I}{(n+1)}$$

(Where, I is the rank and n is the number of data in series)

Table 5.8
Monsoon yield (in MCM)

Sl. No.	Year	Monsoon yield	Rank	% of exceedance	Monsoon yield in descending order
1	1980-81	38227.92	1	3.03	51517.48
2	1981-82	43022.96	2	6.06	51165.77
3	1982-83	30706.47	3	9.09	51145.53
4	1983-84	37325.85	4	12.12	47909.36
5	1984-85	42770.39	5	15.15	47693.22
6	1985-86	46396.16	6	18.18	46696.43
7	1986-87	39346.79	7	21.21	46574.77
8	1987-88	51517.48	8	24.24	46396.16
9	1988-89	47909.36	9	27.27	43828.88
10	1989-90	51145.53	10	30.30	43821.44
11	1990-91	47693.22	11	33.33	43543.04
12	1991-92	51165.77	12	36.36	43022.96
13	1992-93	33273.93	13	39.39	42770.39
14	1993-94	41774.91	14	42.42	42533.74
15	1994-95	33598.78	15	45.45	42521.63
16	1995-96	42160.61	16	48.48	42160.61
17	1996-97	43821.44	17	51.52	41774.91
18	1997-98	32907.20	18	54.55	40818.97
19	1998-99	46696.43	19	57.58	39577.28
20	1999-00	43828.88	20	60.61	39397.48
21	2000-01	43543.04	21	63.64	39346.79
22	2001-02	34568.51	22	66.67	38227.92
23	2002-03	40818.97	23	69.70	37325.85
24	2003-04	42533.74	24	72.73	35389.24
25	2004-05	39397.48	25	75.76	34568.51
26	2005-06	33132.62	26	78.79	34515.57
27	2006-07	34515.57	27	81.82	34463.94
28	2007-08	42521.63	28	84.85	33598.78
29	2009-10	34463.94	29	87.88	33273.93
30	2010-11	46574.77	30	90.91	33132.62
31	2011-12	39577.28	31	93.94	32907.20
32	2012-13	35389.24	32	96.97	30706.47
	Yield at 75% dependability				**34773.70**

Table 5.9
Non-Monsoon Yield (in MCM)

Sl. No.	Year	Non-monsoon yield	Rank	% of exceedance	Non-monsoon yield in descending order
1	1980-81	8954.09	1	3.03	10326.36
2	1981-82	7156.59	2	6.06	10038.20
3	1982-83	8079.18	3	9.09	9860.01
4	1983-84	8063.91	4	12.12	9735.34
5	1984-85	8544.51	5	15.15	9562.89
6	1985-86	8536.39	6	18.18	9446.01
7	1986-87	8169.10	7	21.21	9281.64
8	1987-88	9860.01	8	24.24	9112.93
9	1988-89	9735.34	9	27.27	8954.09
10	1989-90	9281.64	10	30.30	8934.91
11	1990-91	8405.14	11	33.33	8731.72
12	1991-92	6554.49	12	36.36	8725.84
13	1992-93	8621.72	13	39.39	8621.72
14	1993-94	8387.90	14	42.42	8585.32
15	1994-95	8731.72	15	45.45	8544.51
16	1995-96	9112.93	16	48.48	8536.39
17	1996-97	7171.33	17	51.52	8405.14
18	1997-98	7792.47	18	54.55	8387.90
19	1998-99	7143.92	19	57.58	8275.59
20	1999-00	8934.91	20	60.61	8171.35
21	2000-01	9562.89	21	63.64	8169.10
22	2001-02	10326.36	22	66.67	8079.18
23	2002-03	7908.79	23	69.70	8063.91
24	2003-04	6526.01	24	72.73	7908.79
25	2004-05	8585.32	25	75.76	7792.47
26	2005-06	6915.13	26	78.79	7785.50
27	2006-07	8725.84	27	81.82	7171.33
28	2007-08	7785.50	28	84.85	7156.59
29	2009-10	8171.35	29	87.88	7143.92
30	2010-11	9446.01	30	90.91	6915.13
31	2011-12	10038.20	31	93.94	6554.49
32	2012-13	8275.59	32	96.97	6526.01
		Yield at 75% dependability			**7821.55**

Table 5.10

Gross annual yields (in MCM)

Sl. No.	Year	Annual Yield	Rank	% of exceedance	Annual Yield in descending order
1	1980-81	47182.01	1	3.03	61377.48
2	1981-82	50179.56	2	6.06	60427.17
3	1982-83	38785.65	3	9.09	57720.26
4	1983-84	45389.76	4	12.12	57644.71
5	1984-85	51314.90	5	15.15	56098.36
6	1985-86	54932.55	6	18.18	56020.78
7	1986-87	47515.88	7	21.21	54932.55
8	1987-88	61377.48	8	24.24	53840.35
9	1988-89	57644.71	9	27.27	53105.93
10	1989-90	60427.17	10	30.30	52763.79
11	1990-91	56098.36	11	33.33	51314.90
12	1991-92	57720.26	12	36.36	51273.54
13	1992-93	41895.65	13	39.39	50992.77
14	1993-94	50162.80	14	42.42	50307.13
15	1994-95	42330.50	15	45.45	50179.56
16	1995-96	51273.54	16	48.48	50162.80
17	1996-97	50992.77	17	51.52	49615.48
18	1997-98	40699.67	18	54.55	49059.75
19	1998-99	53840.35	19	57.58	48727.77
20	1999-00	52763.79	20	60.61	47982.80
21	2000-01	53105.93	21	63.64	47515.88
22	2001-02	44894.87	22	66.67	47182.01
23	2002-03	48727.77	23	69.70	45389.76
24	2003-04	49059.75	24	72.73	44894.87
25	2004-05	47982.80	25	75.76	43664.82
26	2005-06	40047.75	26	78.79	43241.41
27	2006-07	43241.41	27	81.82	42635.29
28	2007-08	50307.13	28	84.85	42330.50
29	2009-10	42635.29	29	87.88	41895.65
30	2010-11	56020.78	30	90.91	40699.67
31	2011-12	49615.48	31	93.94	40047.75
32	2012-13	43664.82	32	96.97	38785.65
		Yield at 75% dependability			**43972.34**

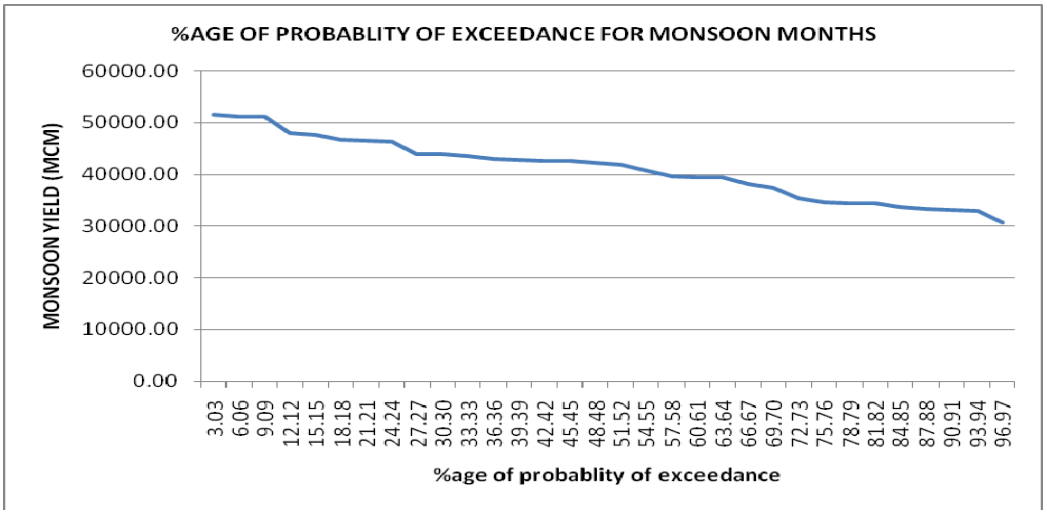

Fig. 5.15

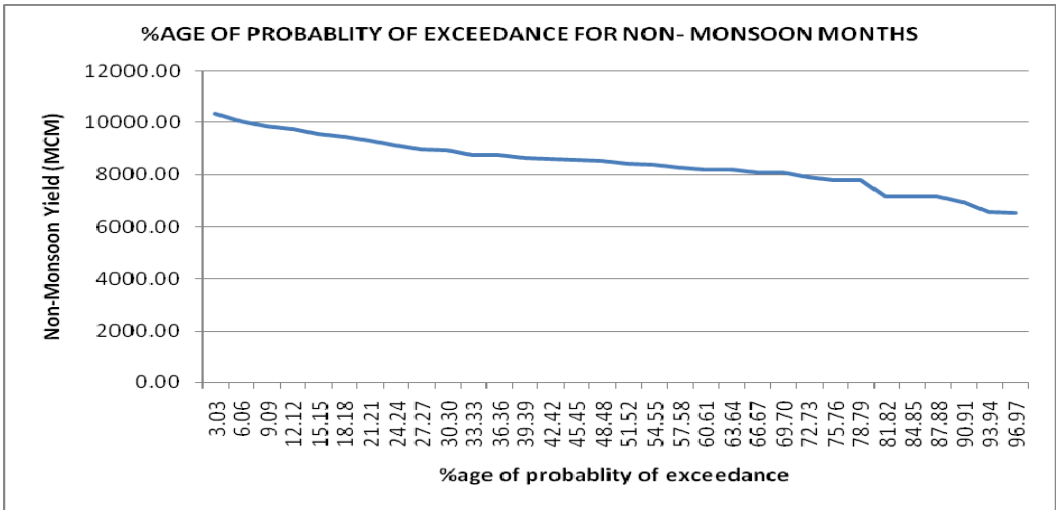

Fig. 5.16

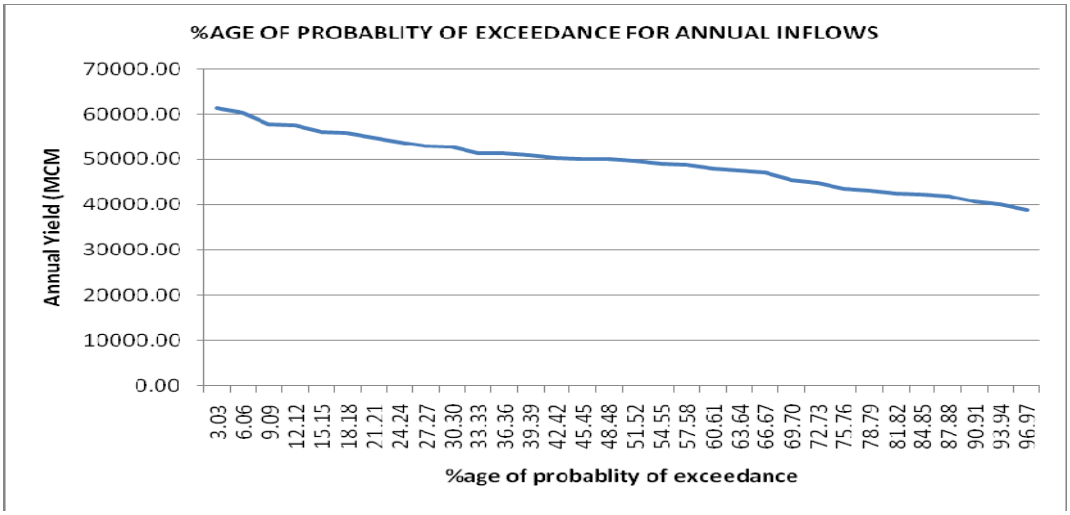

Fig. 5.17

5.5.8 Impact of climatological changes on yield

The mass curve of available annual yields at Hanuman Nagar barrage indicates that during period 1980 to 2013, there is no any significant change in water availability at Hanuman Nagar barrage as shown in mass curve of annual yields figure 5.18.

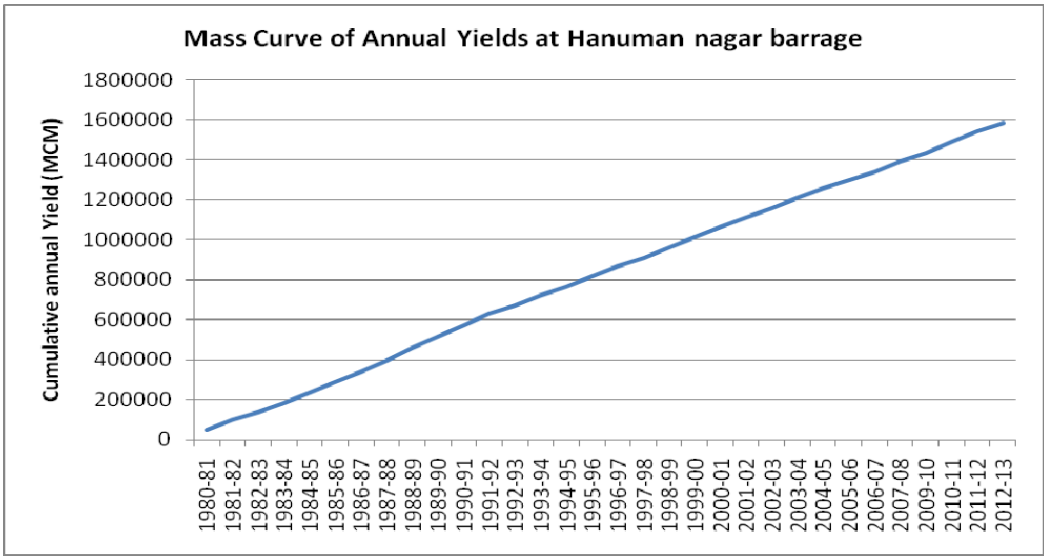

Fig.-5.18

5.6 Water balance studies at Hanuman Nagar barrage

5.6.1 Upstream requirements

The upstream catchment of river Kosi is lying in Tibet and Nepal. A major part of its catchment is in high mountain region. Considering the fact that the major part of Kosi basin is covered by glaciers and thick snow cover, the upstream utilization in Tibet has not been considered in this study. The river Kosi enters in plains in terai region of Nepal near Chatra upstream of Hanuman Nagar barrage. The terai region is fertile. Sufficient information like arable land in Kosi basin, existing irrigated area, proposed projects, land use pattern etc. for this region are not available. However, provision has been made for upstream utilization adopting guidelines formulated by Technical Advisory Committee (TAC) of National Water Development Agency.

The water requirement for various purposes viz., domestic, irrigation, industry and hydropower use for the Nepal portion has been assessed as detailed below.

(i) Domestic needs

As reported by Institute for Social and Environmental Transition-Nepal, the population of Nepal in Kosi basin is 50,81,463 as per 2001 census. The district wise breakup of population is given in **Annexure 5.5**. Based upon this population and an average compound growth rate of 2.25%, the projected population for year 2050 AD is worked out as 1,54,58,046. 10% of the population is considered as urban population.

As per the decisions of TAC of NWDA, the per capita demand is considered as 135 liters and 70 liters for urban & rural population respectively. The entire urban and half of rural domestic requirements are proposed to be met from surface water. 80% of the requirement is considered as regeneration. The total domestic requirement and regeneration in Kosi basin upstream of Hanuman Nagar barrage is worked out as 254 MCM and 203 MCM respectively. The details are given in Table 5.11.

Table 5.11

Domestic water requirement

Sl. No.	Partic-ulars	Projected Population by 2050 AD	Per Capita Demand (lpcd)	Total Water needs (MCM)	Provision from surface water (MCM)	Regen-eration (MCM)	Net Water Needs (MCM)
1	Urban	1545805	135	76	76	61	15
2	Rural	13912242	70	356	178	142	36
	Total	**15458046**		**432**	**254**	**203**	**51**

(ii) Industrial needs

Due to non-availability of sufficient information on industrial water use, the industrial water requirement of the basin is considered to be the same as the domestic water requirement. The entire industrial water need is proposed to be met from surface water resources. 80% of surface water utilized for industrial use is considered as return flow to

the streams. Thus, the total industrial requirement and regeneration works out to 432 MCM and 346 MCM respectively.

(iii) Irrigation needs

The details of irrigation projects of Kosi basin in Nepal are not available. In absence of any data, the following provisions have been made towards upstream needs of Hanuman Nagar Barrage.

Table 5.12

Sl. No.	Months	Upstream requirements(MCM)					Discharge (cumecs)
		Irrigation	Domestic	Industrial	Regenera-tion from D&I	Net require-ments	
1	2	3	4	5	6	7	8
1	Jun	28.3	21.57	36.69	46.61	39.9	15.40
2	Jul	28.3	19.48	33.14	42.10	38.8	14.48
3	Aug	33.0	21.57	36.69	46.61	44.7	16.68
4	Sep	11.2	20.88	35.51	45.11	22.5	8.68
5	Oct	19.1	21.57	36.69	46.61	30.8	11.49
6	Nov	48.6	20.88	35.51	45.11	59.9	23.11
7	Dec	100.1	21.57	36.69	46.61	111.7	41.71
8	Jan	106.8	21.57	36.69	46.61	118.4	44.21
9	Feb	106.8	20.88	35.51	45.11	118.0	48.79
10	Mar	118.4	21.57	36.69	46.61	130.1	48.57
11	Apr	26.2	20.88	35.51	45.11	37.5	14.47
12	May	26.2	21.57	36.69	46.61	37.9	14.15
Total		**653**	**254**	**432**	**549**	**790**	

The existing Chatra Main Canal (Inundation canal) is providing annual irrigation of 68000 ha in Nepal The exact month wise utilization of this scheme is not available. Therefore, month wise utilization has been worked out by providing a delta of 0.96 m as computed for major projects, thus the annual utilization worked out to be 653 MCM.

Thus, total irrigation needs for upstream of Hanuman Nagar Barrage works out to 653 MCM. The total upstream needs for domestic, industrial and irrigation needs are summarized in Table 5.12 given above.

5.6.2 Water need at Hanuman Nagar barrage

The Hanuman Nagar Barrage on river Kosi came into existence as a component of Kosi Project in 1953. It is an irrigation, flood control and hydropower generation project on the river Kosi built under a bilateral agreement between Nepal and India. Two main canals, Eastern Kosi Main Canal (EKMC) aimed for providing irrigation in India and Western Kosi Main Canal (WKMC) for providing irrigation in Nepal and India offtake from the barrage. The system serves with 90.80 km long main canal of which 31.10 km is in Nepal and 56.70 km is in India, respectively. The water utilisations from these two canals are as follows:

(i) Western Kosi Main Canal

The Western Kosi Main Canal had been designed for a discharge of 210 cumecs to irrigate 3,56,610 hectare in Nepal and India. It offtakes from the right bank head regulator of Hanuman Nagar barrage. The total annual water utilisation from this canal is 3188.02 MCM. The month wise water requirements are given in Table 5.13.

Table 5.13
Month wise water requirements of
Eastern and Western Kosi Main Canal

Unit: MCM

Sl. No.	Months	Monthly requirement of WKMC	Monthly requirement of EKMC	Total
1	**2**	**3**	**4**	**5**
1	January	137.95	263.35	401.30
2	February	137.95	263.35	401.30
3	March	161.21	307.74	468.95
4	April	54.8	104.61	159.41
5	May	93.35	178.26	271.61
6	June	237.38	453.11	690.49
7	July	488.5	928.72	1417.22
8	August	521.23	995.02	1516.25
9	September	521.23	995.02	1516.25
10	October	578.26	1103.88	1582.14
11	November	128.08	244.50	372.58
12	December	128.08	244.50	372.58
	Total	**3188.02**	**6082**	**9270.02**

(ii) Eastern Kosi Main Canal and Rajpur canal system:

The Eastern Kosi Main canal has been designed for a discharge of 425 cumecs to irrigate 4.4 lakh ha CCA including Rajpur canal system. This canal off takes from the left bank head regulator of Hanuman Nagar barrage. The total length of Eastern Kosi main Canal is 41.30 km. There is a canal power house at RD 3.66 km.

Rajpur canal system: Initially there was a proposal for diverting a discharge of 1415.80 cumec through the old dhars of the river Kosi to improve the drainage conditions and this intervening area was not included in the original command area of Eastern Kosi Main Canal. Later on, in response to the public demand, irrigation was provided to this area through a branch canal named as Rajpur canal. This canal off takes at RD 4.42 km on Eastern Kosi Main Canal to cater a gross command area of 1,76,000 ha. The month wise water requirement of Eastern Kosi Main Canal including Rajpur canal system is given in Table 5.13 above.

5.6.3 Review of existing requirements by CWC

The designed command area of Eastern and Western main canal could not be fully developed so far. The Central Water Commission has reassessed the existing utilization and it has been proposed to irrigate the remaining undeveloped command The re-assessed existing and proposed utilization has been collected from CWC and adopted in this study as given in Annexure 5.7 and Annexure 5.8. The overall utilisation of Hanuman Nagar barrage on the basis of data collected from CWC is given in Table-5.14.

Table 5.14

Existing and Proposed requirements of Hanuman Nagar Barrage (As per CWC)

Sl. No.	Month	Barrage requirements (cumec)			Barrage requirements (MCM)		
		Existing	Proposed	Total	Existing	Proposed	Total
1	Jun	184.3	169.70	354.00	477.71	439.86	917.57
2	Jul	406.1	292.10	698.20	1087.70	782.36	1870.06
3	Aug	98.77	277.20	375.97	264.55	742.45	1007.00
4	Sep	263.9	271.60	535.50	684.03	703.99	1388.02
5	Oct	91.83	301.40	393.23	245.96	807.27	1053.23
6	Nov	49.18	211.10	260.28	127.47	547.17	674.65
7	Dec	82.64	335.30	417.94	221.34	898.07	1119.41
8	Jan	136	341.20	477.20	364.26	913.87	1278.13
9	Feb	199.1	237.90	437.00	481.66	575.53	1057.19
10	Mar	92.63	330.00	422.63	248.10	883.87	1131.97
11	Apr	230.8	341.30	572.10	598.23	884.65	1482.88
12	May	311.6	250.70	562.30	834.59	671.47	1506.06
		Total			**5635.60**	**8850.57**	**14486.17**

5.6.4 Downstream requirements

i) Irrigation needs

The Bihar State Hydroelectric Power Corporation (BHPC) has proposed a hydro electric power station located about 15 Km downstream of Hanuman Nagar barrage near village Dagmara having a installed capacity of 25X5 MW.

ii) Ecological needs.

As per the decision taken during the 23rd meeting of TAC of NWDA, wherein it was decided that after meeting the downstream requirements, a minimum of 10% of the inflow at diversion structures should be maintained for environmental & ecological purposes with storages, and this should be of the order of 10 % of the average lean season flow downstream of the storage. Accordingly, 832 MCM (10% of the average non monsoon yield of 8,324 MCM) of water is considered towards ecological needs in non-monsoon season.

5.6.5 Ground water potential

Assessment of ground water potential for development of irrigation in Kosi basin (Indian portion) has been made based on the assessment made by Central Ground Water Board for the year 2009 of the project area are given in Annexure 5.6. The status of total replenishable ground water resources and net draft in the project area are furnished in Table 5.15.

Table 5.15
Balance ground water potential

Sl. No.	Particulars	Balance ground water potential (MCM)
1.	Total replenishable ground water resources	3366.25
2.	Provision for drinking, industrial & other use	298.24
3.	Utilizable ground water resources for irrigation	3068.01
4.	Net draft	1172.41
5.	Balance ground water potential available for exploitation (3-4)	1895.60

The district wise ground water potential is given in Annexure-5.6.

5.6.6 Water balance at Hanuman Nagar barrage

The annual water balance assessed at Hanuman Nagar barrage is given in Table 5.16.

Table 5.16
Water balance at Hanuman Nagar barrage (MCM)

Sl. No.	Particulars	Annual
	Surface Water:	
1	Gross yield at:	
	(i) 50% dependability	49889
	(ii) 75% dependability	43972
2	Upstream utilisation (-)	
	(i) Domestic	254
	(ii) Industrial	432
	(iii) Irrigation	653
	Sub-total (2)	(-) 1339
3	Regeneration (+)	
	(i) Domestic	203
	(ii) Industrial	346
	(iii) Irrigation	--
	Sub-total (3)	(+) 549
4	Requirements at Hanuman Nagar barrage (-)	
	(i) Existing requirements	5636
	(ii) Proposed irrigation needs through Dagmara	8851
	Sub-total (4)	(-) 14486
5	Downstream requirements i.e. for ecological needs (-)	(-) 832
6	Net water availability at	
	(i) 50% dependability	33781
	(ii) 75% dependability	27864
	Ground Water	
7	(i)Total replenishable ground water resources	3366.25
	(ii)Provision for drinking, industrial & other use	298.24
	(iii)Utilizable ground water resources for irrigation	3068.01
	(iv)Net draft	1172.41
	(v)Balance ground water potential available for exploitation ((iii)-(iv))	1895.60

5.6.7 Water transfer through link

5.6.7.1 Status of water availability as per observed inflows of Hanuman Nagar barrage.

The Kosi- Mechi intra-state link is the extension of existing Eastern Kosi Main canal to provide irrigation in new command of un-irrigated areas lying between river Parman and Mechi and falling in the districts of Araria, Kishanganj, Purnea and Katihar of Bihar.

Table 5.17

Month wise water balance
(As per observed flow of Hanuman Nagar barrage)

Sl. No.	Months	Observed inflows @ 75% dependability (cumecs)	Barrage demand on full development (cumecs)	Balance (cumecs)
1	Jun	1411.53	354.00	3304.68
2	Jul	3354.18	698.20	8285.62
3	Aug	3818.56	375.97	9851.65
4	Sep	2833.61	535.50	6809.23
5	Oct	1277.77	393.23	3029.14
6	Nov	632.51	260.28	1379.17
7	Dec	442.07	417.94	766.11
8	Jan	284.01	477.20	283.50
9	Feb	250.67	437.00	169.42
10	Mar	236.61	422.63	211.09
11	Apr	307.94	572.10	226.09
12	May	552.83	562.30	918.40

While analyzing the observed inflows at Hanuman Nagar barrage and monthly demand, it observed that after meeting all the existing and proposed requirements of Hanuman Nagar barrage as assessed by CWC, sufficient inflows are available in the months of June to October. The month wise flows at 75% dependability available at Hanuman Nagar barrage and the requirements of barrage with full development of its canal commands are shown in Table 5.17.

A curve between the available inflows and requirements of barrage with full irrigation development of its existing canal system is shown in fig 5.19

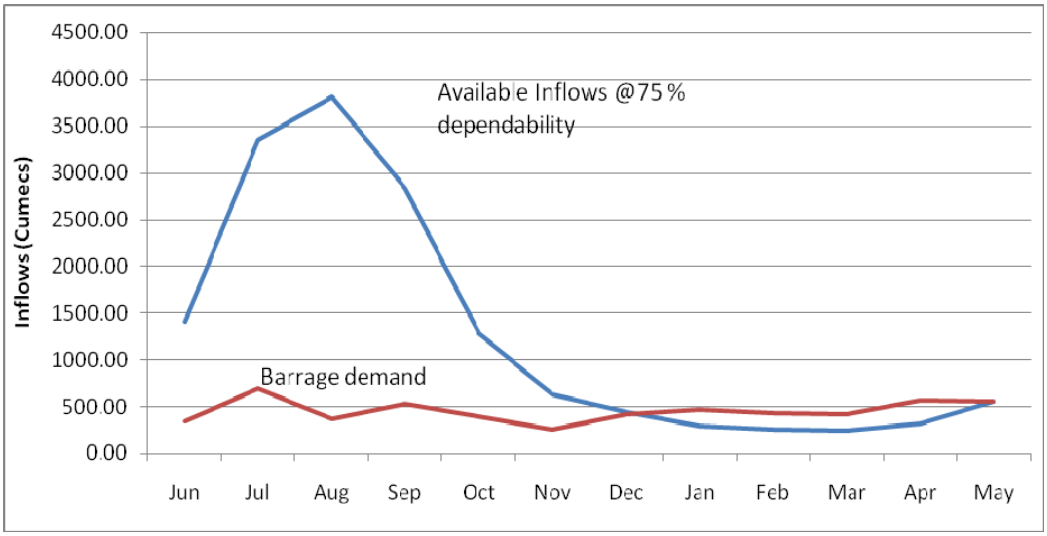

Fig 5.19

As shown in the curve, there is a considerable shortage in non-monsoon months. Therefore in view of the above, it is proposed in present scenario to divert a part of monsoon water only through the link canal for providing irrigation in new command during period June to October.

5.7 Studies of Kosi basin done by Central Water Commission.

As per the Detailed Project Report of Dagmara H.E. project of Bihar State Hydro-electric Power corporation, prepared by WAPCOS, the Central Water Commission has recommended the net inflows available at Kosi barrage after meeting the full irrigation potential under its canal system as given in Annexure 5.9. The 75% dependable inflows including irrigation utilization of barrage and the net demands of barrage are given in Table 5.18.

Similarly, a curve between the total inflows and requirements of barrage with full irrigation development of its existing canal system is shown in fig 5.20.

Table 5.18

Month wise Water Balance (As per CWC recommendation)

Sl. No.	Months	Total inflows at 75 % dependability (cumecs)	Barrage demand on full development (cumecs)	Balance (cumecs)
1	Jun	1721.52	354.00	1367.52
2	Jul	4321.75	698.20	3623.55
3	Aug	5376.05	375.97	5000.08
4	Sep	2504.40	535.50	1968.90
5	Oct	3361.27	393.23	2968.04
6	Nov	820.44	260.28	560.16
7	Dec	840.84	417.94	422.90
8	Jan	607.67	477.20	130.47
9	Feb	495.66	437.00	58.66
10	Mar	576.64	422.63	154.01
11	Apr	704.32	572.10	132.22
12	May	764.79	562.30	202.49

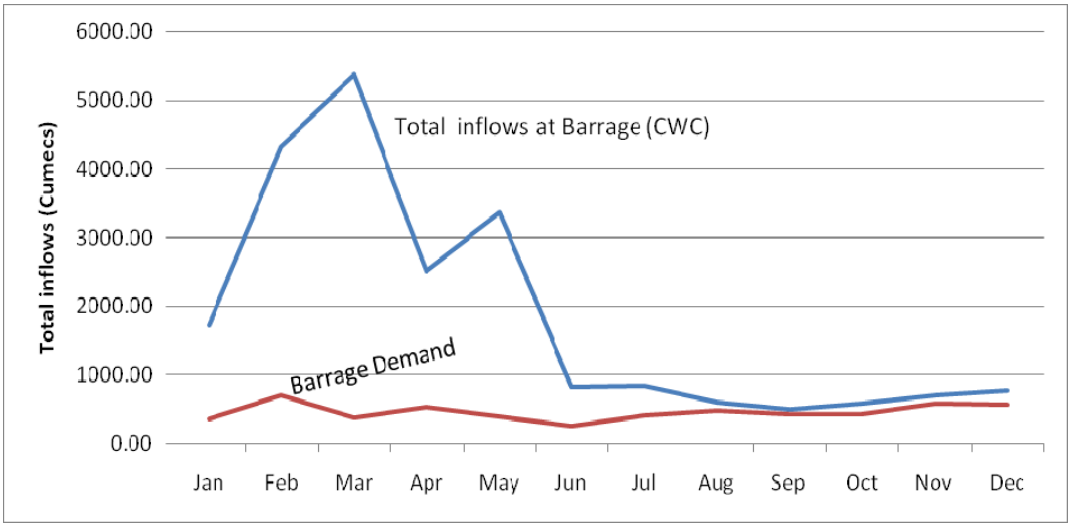

Fig 5.20

From the above , it can be concluded that there is a little variation between ihe discharge data collected from Birpur site (Hanuman Nagar barrge) which is on lower side and net inflows recommended by CWC. As per the net downstream discharge data as recommended by CWC, a marginal balance flow is available in non-monsoon season also. Since the Central Water Commission is the apex organisation in the field of

hydrology, therefore the data recommended by CWC is adopted in the study. The monthwise, monsoon and non-monsoon yield from the sum of barrage requirement and net flows available as recommended by CWC are given in Annexure 5.12, However, both the studies firm up the availability of water in monsoon season, out of which a part can be diverted through Kosi-Mechi link canal for irrigation purposes.

5.8 Water availability with consideration of releases from Sapt Kosi high dam

As envisaged in National Perspective Plan prepared by CWC & MoWR, a 269.0 m high dam namely Kosi High Dam Project is proposed to be constructed on river Kosi in Nepal at Barahkshetra 56 km upstream of Hanuman Nagar barrage. The proposed Kosi High Dam is multi-purpose in scope and envisages power generation with an installed capacity of 3000 MW at the dam toe power house.

The Central Water Commission has carried out studies for firming up the parameters. The proposed release pattern including spills is collected from CWC and given in Annexure 5.10 and Annexure 5.11. Total releases from Sapt Kosi high dam is obtained as the sum of releases from power house and spills. The contribution from intervening catchment between Sapt Kosi high dam and Hanuman Nagar barrage is neglected due to its negligible contribution in non-monsoon months.

Prima facie, for firming up the water transfer through the link canal, the 75% dependable releases available at Hanuman Nagar barrage i.e. releases from Sapt Kosi high dam including spills have been computed and the same are given in Annexure 5.12. The releases available at 75% dependability and demand of barrage with full development of irrigation potential are given in Table 5.19.

A curve between overall available releases of Sapt Kosi high dam at Hanuman Nagar barrage and requirements of barrage with full development irrigation potential as recommended by CWC are shown in fig 5.21.

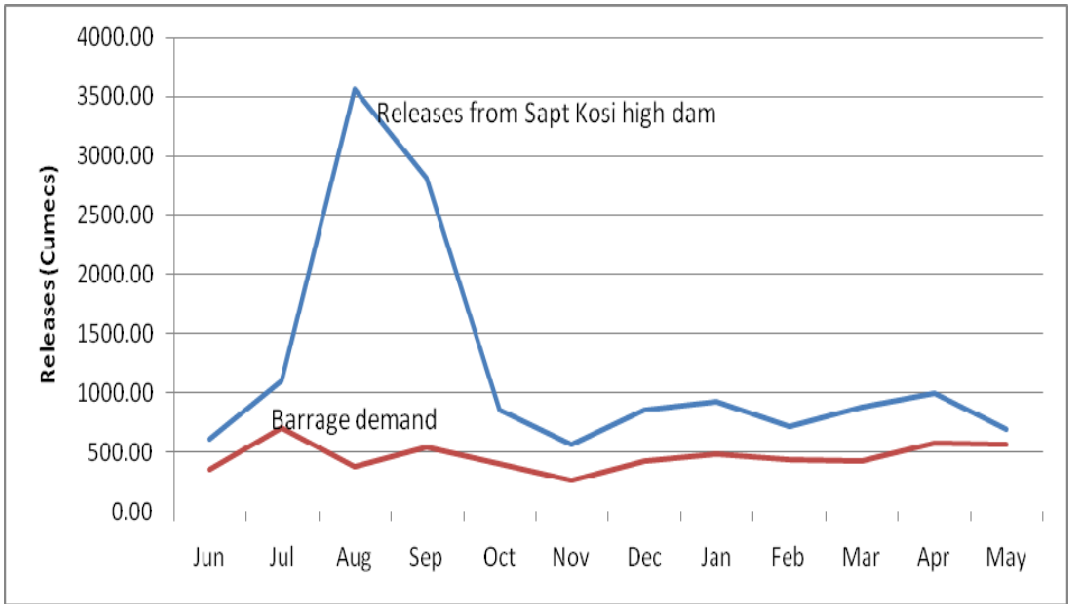

Fig.5.21

It is seen that there is a lot of scope for providing annual irrigation in new command of link canal in post Sapt Kosi scenario.

Table 5.19

Availability of balance water (as per releases of Sapt Kosi High dam)

Unit:cumec

Sl. No.	Months	Availability of releases @75% dependability	Barrage demand on full development	Balance
1	Jun	616.89	354.00	262.89
2	Jul	1100.37	698.20	402.17
3	Aug	3560.22	375.97	3184.25
4	Sep	2809.47	535.50	2273.97
5	Oct	855.04	393.23	461.81
6	Nov	566.21	260.28	305.93
7	Dec	863.22	417.94	445.28
8	Jan	928.41	477.20	451.21
9	Feb	719.61	437.00	282.61
10	Mar	882.66	422.63	460.03
11	Apr	993.89	572.10	421.79
12	May	699.68	562.30	137.38

5.9 Requirement of new link canal

As compared to the pre-feasibility and Preliminary Project Report, some modifications have been made in DPR in respect of water quantum to be diverted through the link canal.

In earlier studies it was proposed to divert a monthly quantum of 1000 MCM through new link canal during monsoon months, out of which the remaining quantum after catering the enroute irrigation and other requirements, was proposed to drop into river Mechi. However this augmentation to river Mechi is not considered in DPR.

Further, as compared to previous studies, the diversion is proposed for monsoon months only under pre Sapt Kosi high dam scenario due to following considerations.

There is a proposal for development of full irrigation potential of existing Hanuman Nagar barrage. It is proposed to provide irrigation in undeveloped command. The Central Water Commission has reviewed the existing and proposed demand pattern of Hanuman Nagar barrage.

The Bihar Hydro Electric Power Corporation Limited has proposed a hydro electric power station at Dagmara for power generation from the downstream releases of Hanuman Nagar barrage. Augmentation to river Mechi/ river Mahananda by such a large quantum may affect the power generation.

In post Sapt Kosi high dam scenario, the inflows available in monsoon months from the releases of Sapt Kosi dam power house including spills will be in limited quantum.

Since, the link canal will not run throughout the years, provision for drinking water supply is dropped. However, provision may be made after the coming up of Sapt Kosi High dam.

Keeping in view of the above and climatological conditions, a suitable cropping pattern agreed to Agriculture Department, Govt. of Bihar is suggested. Accordingly, the month wise requirements of new command are computed as given in Table 5.20.

Table 5.20

Ten daily water requirements of link canal

	Month	Dates	Demands in cumecs			Demands in MCM			Total
			Irriga-tion needs	Trans-mission losses	D&I needs	Irriga-tion needs	Trans-mission losses	Drinking water needs	
Kharif Season (monsoon)	Jun	1-10	54.61	2.08	0.77	47.18	1.80	0.67	51.79
		11-20	111.58	2.08	0.77	96.41	1.80	0.67	101.02
		21-30	122.70	2.08	0.77	106.02	1.80	0.67	110.63
	Jul	1-10	134.64	2.08	0.77	116.33	1.80	0.67	120.94
		11-20	134.64	2.08	0.77	116.33	1.80	0.67	120.94
		21-31	134.64	2.08	0.77	127.96	1.98	0.73	133.03
	Aug	1-10	132.14	2.08	0.77	114.17	1.80	0.67	118.78
		11-20	140.76	2.08	0.77	121.61	1.80	0.67	126.23
		21-31	141.75	2.08	0.77	134.72	1.98	0.73	139.79
	Sept	1-10	121.52	2.08	0.77	104.99	1.80	0.67	109.61
		11-20	119.30	2.08	0.77	103.07	1.80	0.67	107.69
		21-30	117.12	2.08	0.77	101.19	1.80	0.67	105.81
	Oct	1-10	170.40	2.08	0.77	147.22	1.80	0.67	151.84
		11-20	154.16	2.08	0.77	133.19	1.80	0.67	137.81
		21-31	139.85	2.08	0.77	132.91	1.98	0.73	137.99
Total kharif						**1703.31**	**27.50**	**10.18**	**1740.98**
Rabi Season (Non-monsoon)	Nov	1-10	11.21	2.08	0.77	9.69	1.80	0.67	14.18
		11-20	19.98	2.08	0.77	17.26	1.80	0.67	24.74
		21-30	19.99	2.08	0.77	17.27	1.80	0.67	24.75
	Dec	1-10	16.42	2.08	0.77	14.19	1.80	0.67	20.46
		11-20	20.21	2.08	0.77	17.46	1.80	0.67	25.02
		21-31	30.53	2.08	0.77	29.01	1.98	0.73	41.20
	Jan	1-10	41.25	2.08	0.77	35.64	1.80	0.67	50.38
		11-20	42.05	2.08	0.77	36.33	1.80	0.67	51.34
		21-31	42.05	2.08	0.77	39.96	1.98	0.73	56.48
	Feb	1-10	63.08	2.08	0.77	54.50	1.80	0.67	76.68
		11-20	60.39	2.08	0.77	52.17	1.80	0.67	73.44
		21-28	60.43	2.08	0.77	41.77	1.44	0.53	58.80
	Mar	1-10	68.85	2.08	0.77	59.49	1.80	0.67	83.64
		11-20	51.58	2.08	0.77	44.56	1.80	0.67	62.83
		21-31	31.13	2.08	0.77	29.59	1.98	0.73	42.00
	Apr	1-10	0.00	2.08	0.77	0.00	1.80	0.67	0.67
		11-20	0.00	2.08	0.77	0.00	1.80	0.67	0.67
		21-30	0.00	2.08	0.77	0.00	1.80	0.67	0.67
	May	1-10	0.00	2.08	0.77	0.00	1.80	0.67	0.67
		11-20	0.00	2.08	0.77	0.00	1.80	0.67	0.67
		21-31	0.00	2.08	0.77	0.00	1.98	0.73	0.73
Total rabi						**498.90**	**38.10**	**14.10**	**551.10**

However provision for providing drinking water supply to enroute towns and villages is made. A lump sum quantum of 2 MCM per month is proposed for this purpose.

Keeping in view of the above and climatological conditions, a suitable cropping pattern agreed to Agriculture department, Govt. of Bihar is suggested. Accordingly the month wise requirements of new command are computed as given above in table-5.20.

From the above, it is observed that if Sapt Kosi high dam comes into existence then diversion of water through canal can be made to some extent throughout the year for providing irrigation in new command of Kosi-Mechi link.

Keeping in view of the above, planning of water diversion in link canal is proposed under following two scenarios.

i) Pre-Sapt Kosi high dam scenario

a) *Working table of barrage using observed inflows of Hanuman Nagar Barrage.*

The working table of Hanuman Nagar barrage for meeting the link demands of kharif irrigation alongwith transmission losses and proposed drinking water needs to the enroute towns and villages during period June to October has been carried out by considering the observed inflows from 1980-81 to 2012-13 at Hanuman Nagar barrage site. The working table is given in Annexure 5.13. As per the outcome of the working table no short fall is found

b) Working table using net inflows available at Barrage (As recommended by CWC)

Further a working table considering the net inflows available at Hanuman Nagar barrage after meeting the full irrigation potential as recommended by CWC is also carried out to firm up the Kharif demand pattern of link canal as given in Annexure-5.14. No shortfall is observed in this case also.

Thus availability of water for diversion into the link canal in monsoon season is firmed up in both cases either from observed inflows

data at Hanuman nagar barrage or as per the net inflows available at Hanuman Nagar barrage as recommended by CWC.

In pre Sapt Kosi scenario, Water to the tune of 1,743 MCM is proposed to be diverted through the link canal, out of which 1,718 MCM will be utilized for enroute irrigation in new command, 25 MCM for transmission losses. The existing utilization of EKMC is 6,082 MCM. Thus the total diversion through Kosi-Mechi link including utilization of 6002 MCM work out to 7,896 MCM.

ii) Post-Sapt Kosi high dam scenario

The annual demand pattern of new link canal is also firmed up by considering the release pattern of Sapt Kosi high dam by carrying out a working table at Hanuman Nagar barrage for the period 1975-76 to 2009-10 as given in Annexure-5.15. As per the studies, it is firmed up that if Sapt Kosi high dam comes into existence, then the available regulated flows will be sufficient for providing irrigation in rabi season also as well as kharif season with an irrigation success of about 100%. The deficit is in May month in which the link canal has no demand. The maximum discharge in new canal will be in the month of August as shown in table-3.21. Therefore, the same canal section can be utilized for non-monsoon irrigation also.

In case of annual irrigation under post Sapt Kosi high dam scenario, Water to the tune of 2,307 MCM is proposed to be diverted through the link canal, out of which 2,252 MCM will be utilized for enroute irrigation in new command, 55 MCM for transmission losses. The existing utilization of EKMC is 6,082 MCM. Thus the total diversion through Kosi-Mechi link including utilization of 6,082 MCM work out to 8,389 MCM.

5.10 Impact of Kosi floods on diversion of water in link canal

The Kosi- Mechi intra state link will off take from the left head regulator of existing Hanuman Nagar barrage (Kosi barrage).The link canal will utilize existing Eastern Kosi Main canal after its remodeling. Since the barrage is already designed for a sufficient design discharge of 26900 cumecs. The existing canal systems were designed accordingly and are

intact from any flood of Kosi. Therefore the link canal beyond Eastern Kosi Main canal will not be affected from Kosi flood.

5.11 Impact of water Diversion on International/Interstate Water sharing agreements

(i) Indo-Bangla agreement on Ganga water

The river Kosi is a tributary of river Ganga. There is an agreement between Govt. of India and Govt. of Bangladesh on Ganga water sharing and to maintain a minimum flow in Ganga at Farakka in lean season. The water diversion from Kosi barrage (Hanuman Nagar barrage) to Mechi river is viewed in the light of Indo-Bangla agreement on Ganga water sharing and the same under both cases i.e. (i) providing irrigation in new command in Kharif season only and (ii) providing irrigation annually, are discussed in following paras.

- ***Pre Sapt Kosi high dam scenario***

In existing pre Sapt Kosi high dam scenario, the link canal will divert Kosi water in monsoon months only. Therefore there will be no impact on lean season flow of river Kosi so the Indo-Bangladesh agreement on Ganga water sharing is unaffected.

- ***Post Sapt Kosi high dam scenario***

Studies have been carried out to assess the impact of water diversion through link canal in case of non–monsoon irrigation under post Sapt Kosi high dam scenario.

From the working table under post Sapt Kosi high dam scenario the average monthly inflows available in downstream after diversion of water into the link canal have been computed as given in Annexure 5.16 and these were compared with the net inflows available in downstream of Hanuman Nagar barrage after full development of irrigation potential of its existing canal system as recommended by CWC. The average monthly details are given in Table 5.21.

Table 5.21

Balance flow available in d/s under Pre & Post Sapt Kosi high dam scenario

Unit: cumec

Sl. No.	Month	Existing average flow	Balance flow available in d/s under post Sapt Kosi high dam scenario
1	**2**	**3**	**4**
1	Nov	199.24	291.15
2	Dec	83.20	382.95
3	Jan	194.46	368.31
4	Feb	162.48	178.45
5	Mar	383.62	365.64
6	Apr	162.48	376.52
7	May	383.62	159.28
Average flow in lean season		**224.16**	**303.19**

From the above table, it can be seen that the contribution of river Kosi water to river Ganga in non-monsoon season under post Sapt Kosi high dam scenario will be more even after diversion of water into Kosi–Mechi link canal as compared to existing available flows having no diversion.

In this scenario, the quantum of proposed diversion through link canal in non-monsoon season is the stored monsoon water only and there is no any contribution of non-monsoon flow. The existing average non-monsoon flow will not be reduced even after water diversion into link canal, and thus Indo-Bangladesh agreement on Ganga water sharing will not be violated.

(ii) Interstate agreement between Govt. of Bihar and West Bengal on water sharing of Mahananda water

The Govt. of Bihar and Govt. of West Bengal had reached an agreement on sharing of Mahananda water Since, the Kosi-Mechi intra state link envisages the diversion of Kosi water for providing irrigation in Mahananda basin and does not utilizing any water of Mahananda,

therefore, there is no any adverse impact on the bilateral agreement signed between Govt. of Bihar and Govt. of West Bengal on Mahananda water.

5.12 Brief of hydrological studies and future planning

The outcomes of the hydrological studies carried out in this chapter are summarized as given below:

The water availability is firmed up in monsoon months either from observed data of Birpur collected from WRD, Govt. of Bihar or as per the net inflows availability recommended by CWC in pre Sapt Kosi high dam scenario. The same is also firmed up if Sapt Kosi high dam comes up in near future.

If Sapt Kosi high dam comes into existence, then the available releases will be sufficient for diverting water in link canal for providing annual irrigation in new command of link canal lying in Mahananda basin.

While diverting Kosi water in non monsoon season under Sapt Kosi high dam scenario, the same canal section will be sufficient for diversion, and no modification will be required.

The existing non-monsoon flow is intact from any diversion in both cases either diverting Kosi water in monsoon months in present scenario or diverting annually on receipt of the releases from sapt Kosi high dam.

The link canal will not have any adverse impact on Indo-Bangladesh agreement on Ganga water because:

In pre Sapt Kosi high dam, the diversion of Kosi water is limited upto monsoon inflows only and no lean season flow is proposed to be diverted

In post Sapt Kosi high dam scenario, the contribution of Kosi water to river Ganga in lean season will be more even after annually diversion in link canal for irrigation in new command in Mahananda basin.

The link project envisages diversion of Kosi water for providing irrigation Mahananda basin and does not utilizing any waters of Mahananda. Therefore, there is no any adverse impact on the bilateral agreement signed between Govt. of Bihar and Govt. of West Bengal on Mahananda water also.