“ ENVIRONMENTAL FLOWS- DETAILED ASSESSMENT OF THE RIVERS OF MAHANDI BASIN OF INDIA ”

A

DISSERTATION

Submitted in Partial Fulfilment of the Requirements for the Award of the Degree of

MASTER OF TECHNOLOGY

In

CIVIL ENGINEERING

With specialization in
WATER RESOURCES ENGINEERING

By
ANURAN BHATTACHARJEE

Under the supervision

Of

PROF. (Dr) RAMAKAR JHA

DEPARTMENT OF CIVIL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA-769008, INDIA
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NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA

CERTIFICATE

This is to certify that the Dissertation entitled "**ENVIRONMENT FLOWS-DETAILED ASSESSMENT OF THE RIVERS OF MAHANDI BASIN OF INDIA** " submitted by **ANURAN BHATTACHARJEE** to the **National Institute of Technology, Rourkela**, in partial fulfilment of the requirements for the award of **Master of Technology** in **Civil Engineering** with specialization in **Water Resources Engineering** is a record of bona fide research work carried out by him under my supervision and guidance during the academic session 2013-2014.

To the best of my knowledge, the results contained in this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

DATE: **SUPERVISOR**

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PARTICULAR	DESCRIPTION
EF	Environmental Flow
IRBM	Integrated River Basin Management
UN	United Nations
IFA	Instream flow assessment
BBM	Building Block method
CWC	Central Water Commission
MRB	Mahanadi River Basin
WQAA	Water quality assessment authority
MAF	Mean Annual Flow
RVA	Range of Variability Analysis
IHA	Indicators of hydrologic Alterations
EFC	Environmental Flow component
FDC	Flow Duration Curve
EMC	Environmental Management class
EWR	Environmental water requirement
SD	Standard deviation

ABSTRACT

Environmental flow (EF) is referred as the amount of water regarded as sufficient for shielding or maintaining the construction & function of an ecosystem and its dependent species. River systems attain zero flow due to construction of water Retaining Structures, Hydropower generating Structures, construction of bridges etc. which possess a tremendous and huge threat to the environment, ecology & aquatic life of the river systems. Thus, Environment Flow assessment is done in order to analyse and infer the natural flow regime of the river which is required to be in existence for the sustainability of the ecosystem.

In the present work, we are going to assess the Environmental Flow of the Mahanadi River Basin based on the Tennant method, RVA (Range of Variability Analysis), Flow Duration curve (FDC) & Flow Indices method (i.e 7Q10, 7Q2 etc), FDC shift and Spatial Interpolation method (applied on FDC). Tennant (or Montana) method utilizes a percentage of the average annual Flow (MAF) for two separate six month periods to classify the various circumstances of flow, whereas RVA uses IHA (Indicators of hydrologic Alterations) applications, to determine low flow, high flow, maximum high flow etc. Flow Indices (Q95, Q90 etc.) and the 7Q10, 7Q2 methods are computed with which the different low discharges are determined for the eight stations covering the whole Mahanadi river basin. Environmental Management classes are categorised here such that by shifting the FDC for each and every station, the flow can be analysed from the extreme modified (very poor) flow to the high flow. Spatial Interpolation method using the Flow-Duration curve computes the discharge of the destination station using the value of the source station. The Low discharge and the High discharge for the eight individual stations are computed for the various seasons to maintain an unrestricted flow over the entire river basin, ensuring that the balance of the river ecosystem is highly maintained. Our main focus is to maintain the Environmental Flow with a very small percentage of mean annual flow, which would serve our each and every purpose, ranging from aquatic life to the water quality of the river.

Keywords: EF, Tennant, RVA, FDC, 7Q10, 7Q2, 7Q5, 7Q20, 7Q50, EMC, Spatial Interpolation.

CHAPTER-01
INTRODUCTION

1.1 THE CONCEPT AND ITS RATIONALE

Water is a very weighty term since it's an integral part of an ecosystem, both in qualitative and quantitative terms. Diminished magnitude of water and deteriorated water value both have grave destructive influences on ecosystems. The environment has a natural self-purifying capacity and are flexible to water shortages. But when these are exceeded, inhabitants are affected, ecological systems are hampered, bio-diversity is lost, aquatic life is damaged. The river system is one of the primary natural ecosystems and has a deep-rooted relationship with the human beings. During the precedent centuries, the world-wide human population had increased exponentially resulting in six-fold increase of the area of the irrigated land and eight-fold increase of the quantity of water drawn from the freshwater ecosystem. In today's date, the modern governance of the river basins has made a tangible shift towards "Integrated River Basin Management (IRBM)"—a tactic that looks at both water and land management to ensure that the river systems can be developed and augment its uses in a sustainable manner. A vital part of this approach is the assessment and preservation of Environmental Flows – 'sufficient water to uphold the integrity and functioning of aquatic ecosystems and the allied socio-economic and cultural functions' (UN, 2005). Freshwater systems are domicile to 40% of all fish species in less than 0.01% of the world's total surface water, and when water-associated amphibians, reptiles and mammals are included to the fish totals, they collectively account for as much as one third of global vertebrate biodiversity (O'Keeffe and Le Quesne, 2009). During recent decades, scientists have amassed considerable evidence that a river's flow regime – its variable pattern of high and low flows throughout the year, as well as variation across many years – exerts great influence on river ecosystems. It has been observed that if there is an environmental flow in a river basin, then that river basin has very high socio-economic values and that also with no revenue losses. Each component of a flow regime – ranging from low flows to floods – plays an important role in shaping a river ecosystem. The science of environmental, or in-stream, flow assessments (EFAs or IFAs) has progressed over the last five decades, as a means to facilitate restrain, and conceivably to some extent annul, this degradation. Most major manoeuvring of flow regimes are linked to in-channel large dams. Fabricated to store water, mainly during the wet season, and transport it either downstream or offstream as entailed, dams have the potential to broadly amend natural patterns of river flow. In extreme cases, river flow can be changed from perennial to seasonal, or *vice versa*, small and medium-sized floods can be absolutely utilized by the dam, and seasonal reversal of downstream flow regimes can transpire as stored flood water is discharged during the dry season. Some of them most appropriate definitions given by various sources are provided below:

E-Flows as the water regime provided within a river, wetland or coastal zone to maintain ecosystems and their benefits where there are competing water uses and where flows are regulated (IUCN, 2003).

Environmental flows describe the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well being that depend on these ecosystems (10th International River Symposium, Brisbane, 2007).

Human interference in the natural ecosystem, have played a crucial role in the change of morphology, ecological water balance, climate change, modification in land use pattern, deficiency of commercial fisheries in many estuaries and costal regions. Environmental flows are exceptionally crucial to shield and maintain the environment, ecology, river morphology, aquatic life, pollution and water relocation among surface water and Ground water. Looking at the river basin features (land use, soil consistency, geography), rainfall type, availability of ground water, population, industrialization, water contamination from non-point sources as well as point sources, requirement and demand of water for religious and irrigation purposes, expenditure of water conservation for various purposes, proper methodologies should be applied for the computation for the computation of the EF. The in-stream water at any position on the stream may have to meet at least some in part some of the downstream demands. These demands generally includes: aquatic ecology, drinking and domestic requirements of the riparian communities, River morphology and the characteristics of its basin at certain points, cultural and religious requirements, agricultural uses and the need of downstream political units. In actuality, EF are one such observable fact which needs immediate attention by the policy makers and the planners. In the developing countries where human population are growing very fast, they are very much relying on the limited water resources and often on a range of other river resources as well.

1.2 AIM AND OBJECTIVE

The aim of the present work is to assess the environmental flow (EF) required for the eight stations, covering the entire Mahanadi river basin, analysing it with the different state-of-the-art methods and hence applying the best-fit, to determine the quantity of flow required for various season.

The objectives are:

i) The study of the EF concept used in the global context and the time-series analysis of the Hydrological data of the river systems for and also for the different extreme conditions (both for monsoon and non-monsoon).

ii) To reassess existing methods for computation of EF and evaluate their validity.

iii) Analysis of the EF using different techniques and their comparison to determine the best-fit method, which can be used for different purpose in MRB and hence suggest the best management practices for maintaining EF of MRB.

1.3 THESIS OUTLINE

Chapter 1 introduces with the concept of the environmental flows, its justification for practicing in the river system and the objectives of the dissertation.

Chapter 2 deals with the previous research works on the hydrological models of the EF flow, IFA and also with the assessment of the river water quality.

Chapter 3 gives a vivid description on the geographical location of the river basin, its characteristics and the description of the gauge stations. This chapter also deals with the hydrological data and the time-series analysis of the observed discharge data for the eight stations.

Chapter 4 focuses on the description of the different methodologies which are to be used for the analysis of the EF.

Chapter 5 incorporate the results obtained from the present research work and also the discussion related to the analysis.

Chapter 6 deals with the summary and conclusion achieved, the best management practices so that EF is maintained for the entire MRB and with the references preferred.

CHAPTER-02
LITERATURE REVIEW

In this present chapter, literature study has been done for a range of aspect of the present work, including hydrological index methods, holistic methods and Detailed Desktop analysis for the assessment of EF.

2.1 HYDROLOGICAL INDEX APPROACHES

Tenant method, considered as one of the oldest and ancestral method, classified under the hydrological index methods, was applied on a typical river basin **(Singh *et al.*, 1974)** to determine the environmental flow.

(Brismar, 2002) has compared the desired and the undesired effects of the large dams projects, in which the river services are used as the service providers and the environmental flow is determined for both the upstream and the downstream part of the dam.

The emerging trends and the global perspective of the EF is studied and lucid description of the different methods using which analysis of EF is possible, are clearly stated **(Tharme, 2003).**

Low flows are predicted at ungauged catchments, various low flow regionalisations have been developed using multiple regression techniques in this report. **(Pyrce, 2004)** applied in-stream flow methods for the computation of the base flow. Basically, this report deals with the Hydrological low flow indices and their uses.

(Smakhtin *et al.*, 2005) established the hydrological reference condition by reconstructing the unregulated flow regime and assessment of the land-use changes and water-resources development in the Walawe river basin for the previous 40 years. The environmentally acceptable flow regime is quantified.

(Blake, 2006) modelled flow data (hydrology based) are used for the assessment of the EF of the Nam Songkhram river basin, Thailand.

The report examines the emerging trends in environmental flow work in India and reviews desktop methods of environmental flow assessment, developed and used for preliminary planning purposes elsewhere**. (Smakhtin *et al.*, 2006)** used the method, which is based on the use of a flow duration curve – a cumulative distribution function of monthly flow time series and the results are interpreted in both forms- FDC and monthly flow time series.

The PHD dissertation **(Korsgaard, 2006)** computed and framed a new approach, which is used for determining Environmental flow in the Integrated water resources management using the linking flows and the services values.

This study comprises synopsis of methods for flow evaluation, examples of realistic applications and opting the accurate method. **(Freitas, 2008)**. The anticipated outcomes are understood, such as what is an environmental flow assessment, at what time to use and why, recognize the dissimilarities amid the four classes of environmental flow evaluation methodologies with benefits and drawbacks of each method by a genuine example application and to opt the right system.

(Jha et al., 2008) had critically evaluated the applicability of existing approaches, provided values of environmental design flows at different locations of Brahmani and Baitarani River systems, India and had suggested a suitable scientific technique, which can be applied for the assessment of EF.

This paper reviews the estimation methods developed and used in India for low-flow, long-term mean flow and flood characteristics. In this work **(Jha *et al.,* 2008)**, flood estimation characteristics and long-term mean annual flow using regression relationships with catchment parameters are computed.

To empathize and foretell the probable upshot of climatic alterations on the water resources and stream flow, it is obligatory to recognize the nonlinearity and complications of the relation between the climate and the land surface, and to judge the dependence of the scale on which these relations are examined. Based on the Indian climate situation **(Sharma *et al.,*2008)** potrays the total procedure for assessing low flows under various climatic circumstances using low flow duration and low flow frequency in Brahmani River Basin of India.

Dependable estimation of low-flows for rivers is crucial for the appropriate development and design of water resources assignments and this paper investigates a variety of low-flow measures/indices, their function and evaluation techniques presently in effect in Ireland and somewhere else in the world. **(Mandal et al., 2009)** has developed an uncomplicated regression basis simplified model for the flow-duration curves (FDC) for Irish rivers, which can be used for forecasting FDC for several ungauged catchment from the recognized catchment physiographic and climatological features.

A pragmatic approach is used **(McCartney *et al.,* 2013)** here for quantifying the flow regulating functions of floodplains, headwater wetlands and miombo forests in the basin. The method exploits the monitored streamflow records and flow duration curves to develop a simulated time series of flow in the dearth of the ecosystem. This is then compared with an observed time series to assess the impact of the ecosystem on the flow regime.

2.2 HOLISTIC APPROACHES

In South Africa, for determining the Instream flow of a regulated river basin, **(King *et al.*, 2000)** applied BBM method on the river basin, which included both the hydrological and also the hydraulics part of the river system. The ecology of the river basin is also taken into account such as the aquatic life and marine ecosystems, a sophisticated and well refined method developed in a workshop.

Holistic methodologies which included the hydrological data, hydraulics data of the river, biological data for marine life, geomorphologic characteristics (sediment transport) and water quality parameters were taken **(Arthington *et al.*, 2004)** for the study of a South African river.

An impact of the suspended sediments loadings on the EF of the Mara river, Kenya is analysed. **(Kiragu *et al.*, 2007)** had used the geomorphologic characteristics of the river basin and the flow is observed such that the sediments are hindering the flow, making the water quality highly turbid.

The BBM is fundamentally an elaborative tactic designed to erect a flow regime for upholding a river in a prefixed condition **(King *et al.*, 2008)**. The BBM has adjunctly provided the thrust for the fruition of numerous alternative holistic environmental flow methodologies, significantly the Downstream Response to Imposed Flow Transformations (DRIFT) methodology. The DRIFT methodology is a network and situation-based approach designed for applying in cooperating, and including a stout socioeconomic factor, weighy when computing subsistence use of river supplies by riparian peoples.

The explicit intention of this testimony are comprehending environmental flows both by water resources practitioners and by environmental connoisseur. **(Hirji *et al.*, 2009)** had portrayed lessons from experience in executing environmental flows by the bank and develop a rational framework to sustain more effectual amalgamation of environmental flow.

2.3 DETAILED DEKSTOP ANALYSIS

This contemporary study carried out by **(Kumara *et al.*, 2010)** by using equally desktop analysis and field examination dealing with two modules for the assessment of the environmental flows in Bhadra River, Karnataka, India. The two elements are Biophysical evaluation and Socio-economic review. Biophysical assessment furnishes the physical eminence of the river flow over a phase. The intention of Socio-economic assessment is to forecast how the inhabitants have been distressed by the stipulated river transformation.

(Jha, 2010) had applied different methods to match which serves the best purpose for maintaining the ecological balance of a typical river basin of India. Distinctive methods such as RVA, FDC, sediment yield, aquatic life etc. are considered, and the volume of water required to maintain EF for the five gauged stations are computed.

In this study, **(Shiau et al., 2004)** estimated the prediversion flows and ascertained the riverine management in terms targets in terms of 32 hydrological parameters known as the IHA (Indicators of hydrological alterations). This study targets to make the postdiversion flows attain the intended ranges at the similar frequency as that which in the prediversion flow regime.

CHAPTER-03
THE STUDY AREA
AND THE ESTIMATION SITES

To begin analysis for the computation of EF for any river basin, the pre-requisite are the discharge/flow data of that particular river/stream. Depending upon the full availability of the data, the number of sites can be determined. River Mahanadi of India has been opt for the study and the details of the study area are depicted hereinafter. This chapter begins with the narration of the study area chased by the selection of the sites, based on the available data.

3.1 PRIMARY DELINEATION OF THE MAHANADI RIVER BASIN

Mahanadi is a major river in central eastern India. The Mahanadi basin lies within geographical co-ordinates of $80^{0}30'$ to $86^{0}50'$ East longitudes and $19^{0}20'$ to $23^{0}35'$ North latitudes. The drainage area of the basin is of around 141,600 $km^2$and has a total course of 858 km. The river flows through the states of Chattisgarh and Orissa. Its farthest headwaters lie 6 km from Pharsiya village 442 m above sea level south of Nagiri town in Dhamtari district of Chattisgarh. The hills here are an extension of the Eastern ghats. Mahanadi river basin has a total of 6 dams- Dudhawa, Gangrel, Murrum silli, Hasdeo Bango, Tandula, Sondur reservoir, Sikasar dams- located in Chattisgarh, Hirakud dam (largest dam on Mahanadi river basin)- located in Orissa.

Hirakud dam was constructed in 1957 across Mahanadi near Sambalpur. It drains a total area of 83,400 km^2. It is accounted as the largest earthen dam in the globe measuring 24 km including dykes; having reservoirs stretched over 743 km^2 and live storage capacity of 5.37 x 109 cum. The downstream floods are moderated by the reservoir.

The soil types of the basin are red and yellow soils, laterite soils. The region of northern part as well as the Mahanadi and Tel sub-basin contains red soil which is obtained from Central Land Table. The river and Tel sub-basin are the largely thickly inhabited and agriculturally well-heeled part of the area with condensed settlements. The precipitation received by the basin is around 800 to over 1600 mm falls in the period from July to while during January to February, less than 50 mm precipitation is received. The annual rainfall of the Mahanadi catchment is about 141.7 cm.

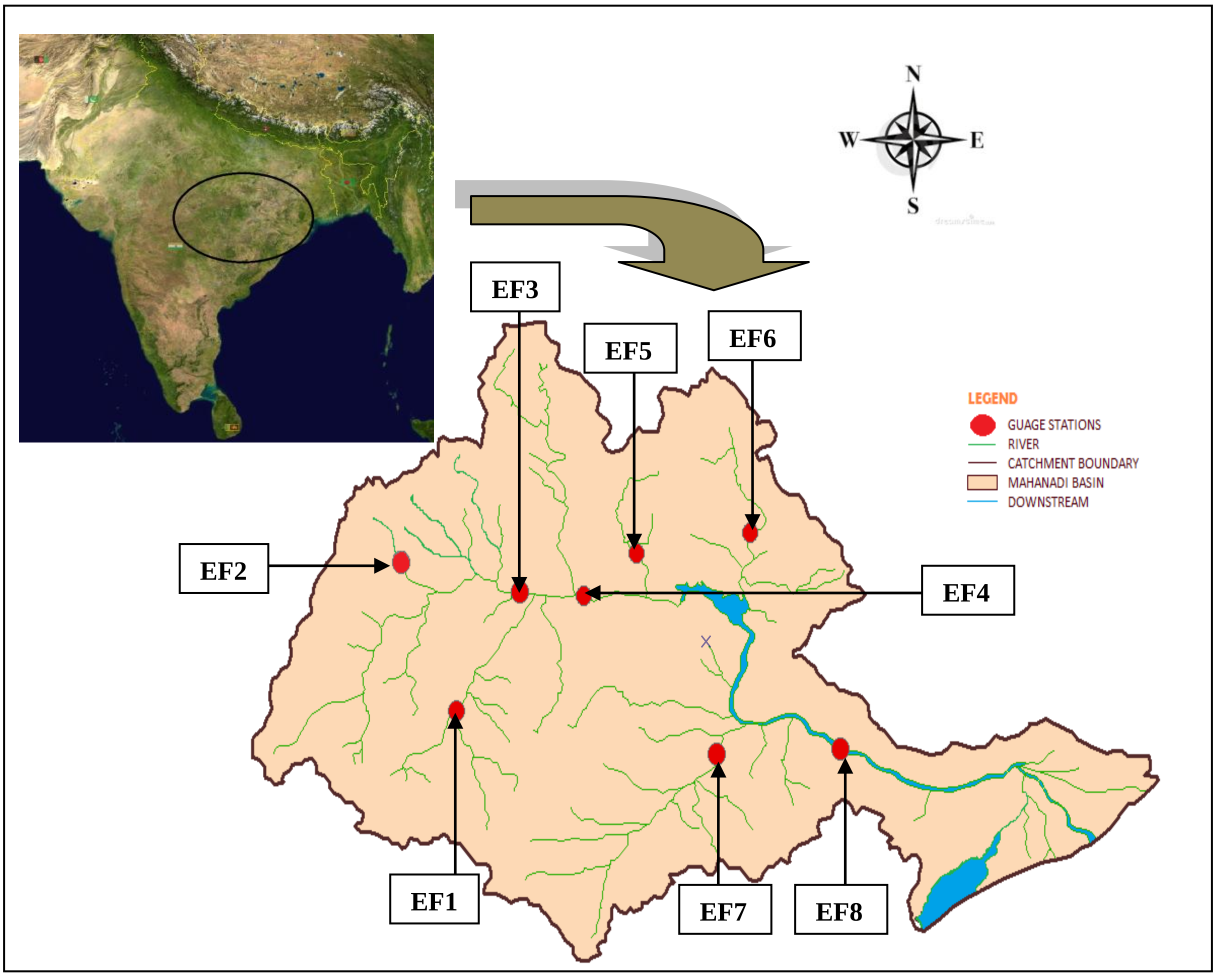


Fig 3.1: Location of Gauging sites in MRB

The geographical position of the catchment with respect to Bay of Bengal, where from most of the weather co-ordination start off influencing the meteorological and climatology of the catchment. The south-west monsoon plays a vital part by contributing 91% of annual rainfall during June to October. December is recognized as the driest month as it is contributing less than 10% of annual rainfall.

3.2 ESTIMATION OF THE SITES

The entire MRB have a total of 18 gauging stations of CWC, fourteen are located in Chattisgarh & four are in Orissa. After thoroughly scrutinizing the flow data, eight stations are selected for the analysis (Figure 3.1), covering the entire basin area, with seven stations having data for the 38 years (1978-2009) and one station data ranging from (1986-2009). The features of the sites along with the name, location, characteristics etc. are listed in the Table 1 below:

Station ID	**EF site name**	**River**	**Location**	**Average Annual Precipitation (cm)**	**Low discharge (cumec)**
EF1	Rajim	(Sondur + Pari + Mahanadi)	$20^0$57’N $81^0$52’E	96.44	0.02
EF2	Andhiyarkore	Seonath	21°90’N 81°50’E	80.29	0.11
EF3	Jondhra	Mahanadi	$21^0$43’N $82^0$20’E	95.06	0.43
EF4	Seorinarayan	Mahanadi	21°44'N 82°35'E	99.49	0.6
EF5	Kurubhata	Mahanadi	$22^0$00’N $83^0$55’E	100.33	0.09
EF6	Sundargarh	IB	22°07′N 84°02′E	111.01	0.37
EF7	Kantamal	Tel	$20^0$65’N $83^0$74’E	162.3	0.79
EF8	Tikarapara	Mahanadi	20°58’N 84°08’E	114.03	185

Table I: Description of selected gauging sites in MRB.

3.3 DATA COLLECTION AND TIME SERIES

The essential data required for design flow in MRB are virgin or naturalized historical flow records over the entire observed or simulated period of record. The natural flow variability is best described by daily discharge time series. After preliminary scrutiny based on data independency, data sufficiency and reliability, it was found that of only eight gauging sites could be used in the study. The locations and characterises of these selected EFs sites are summarized in Table I and shown in Figure 1. The mean flow for the period of record is calculated for the individual seven stations (1978-2010) expect seorinarayan (1986-2010) and Jondhra (1980-2010), hence we get the variation of mean daily discharges at the stations EF1, EF2, EF3, EF4, EF5, EF6, EF7 and EF8, which are shown below in the fig 2(a-h).

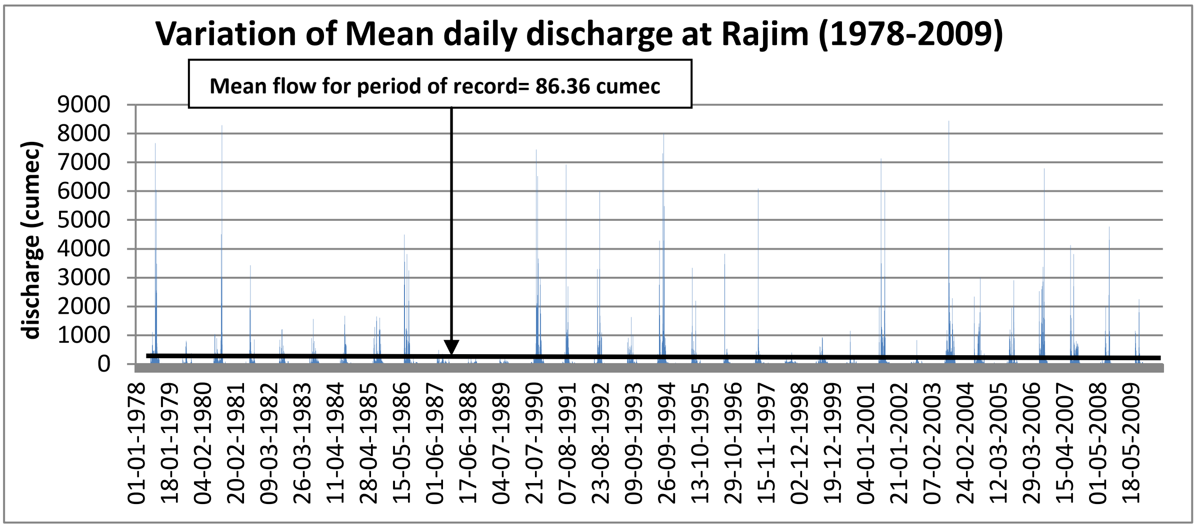


Figure 3.2 (a) Mean daily Flow at station EF1

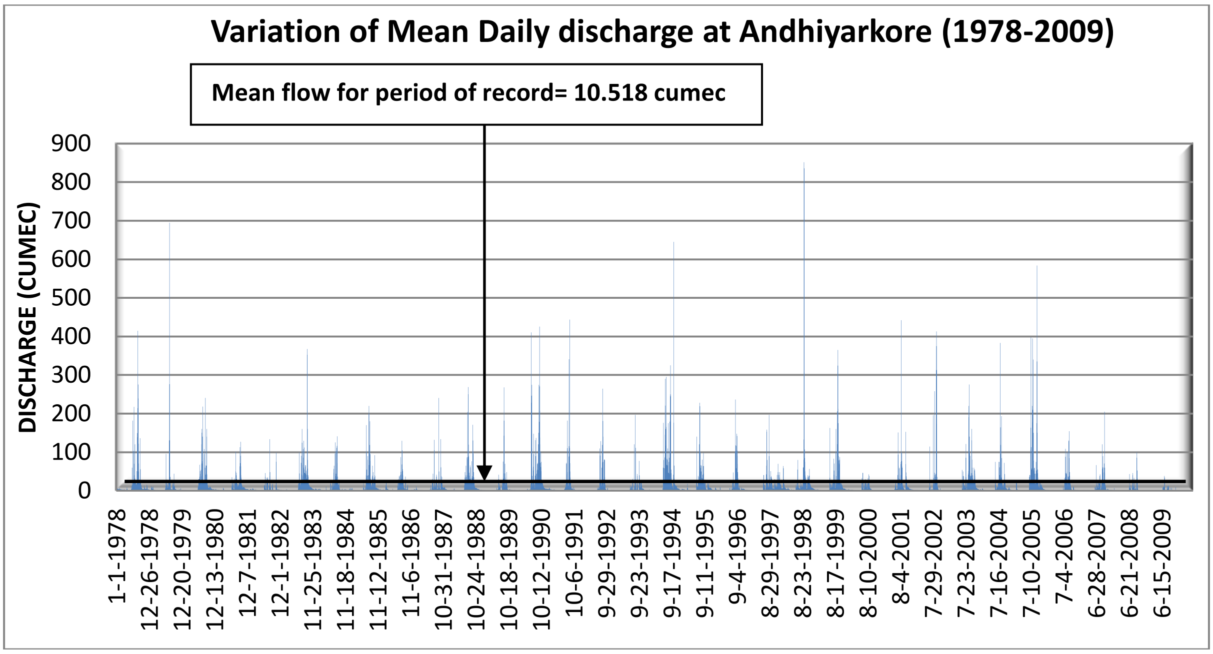


Figure 3.2 (b) Mean daily Flow at station EF2

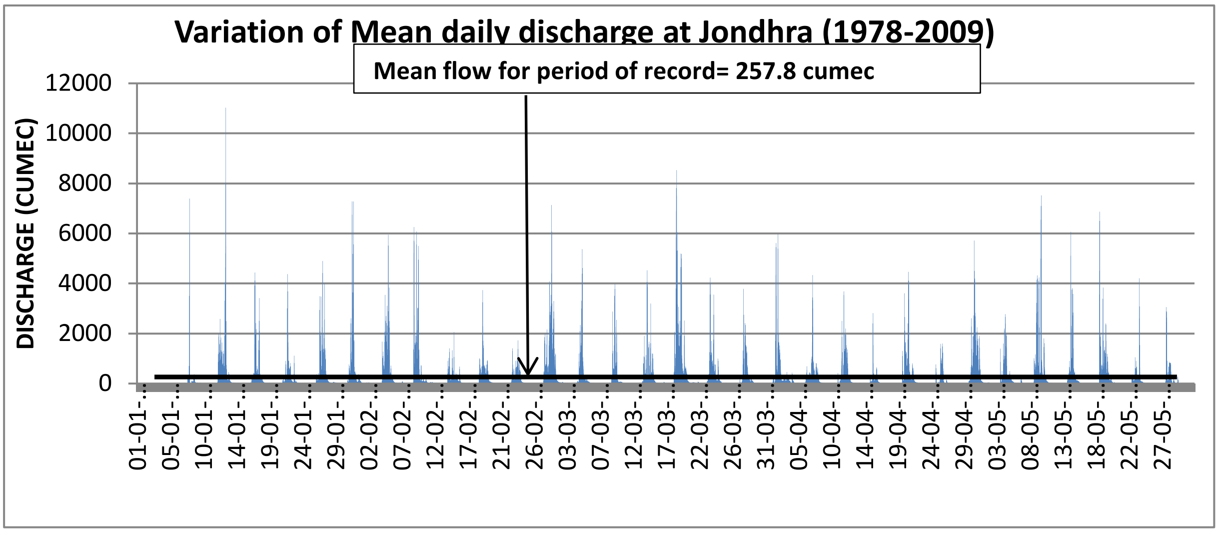


Figure 3.2 (c) Mean daily Flow at station EF3

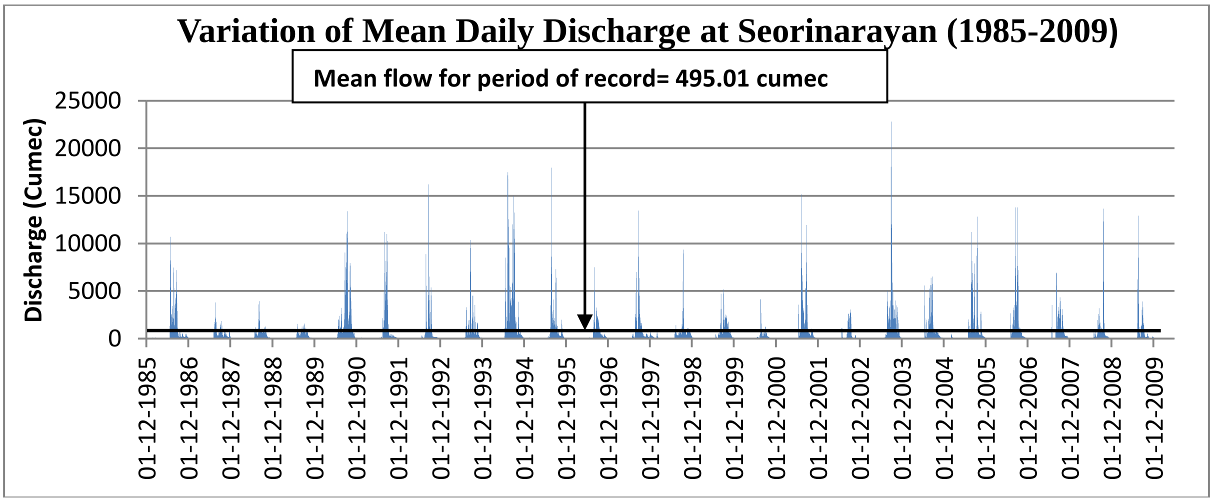


Figure 3.2 (d) Mean daily Flow at station EF4

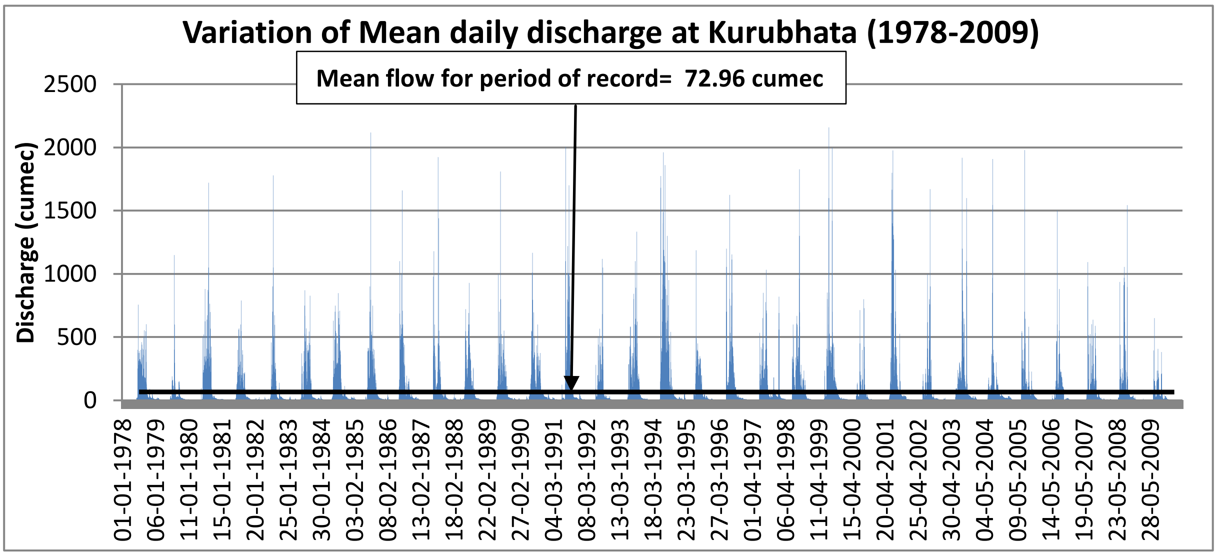


Figure 3.2 (e) Mean daily Flow at station EF5

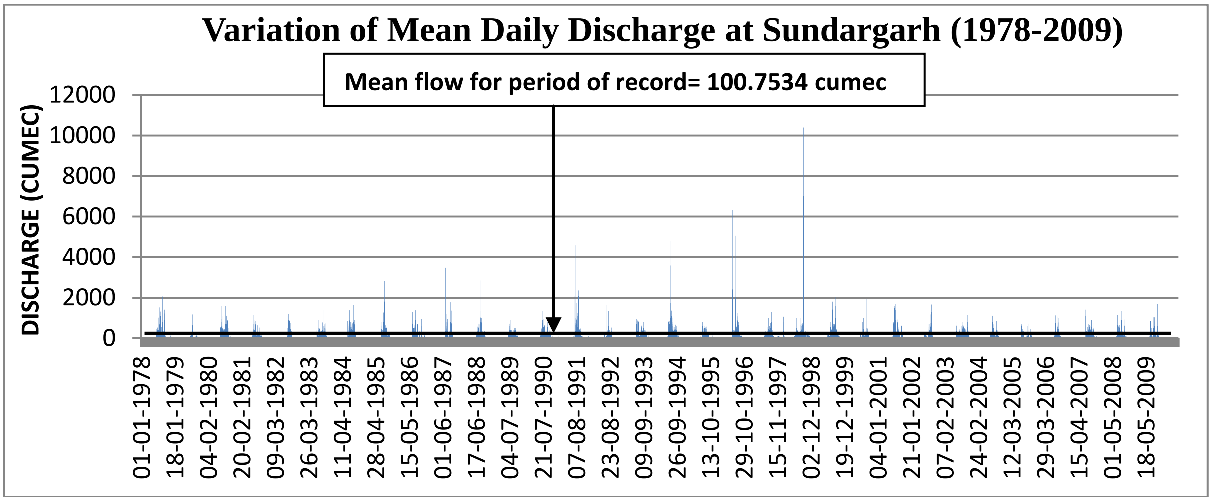


Figure 3.2 (f) Mean daily Flow at station EF6

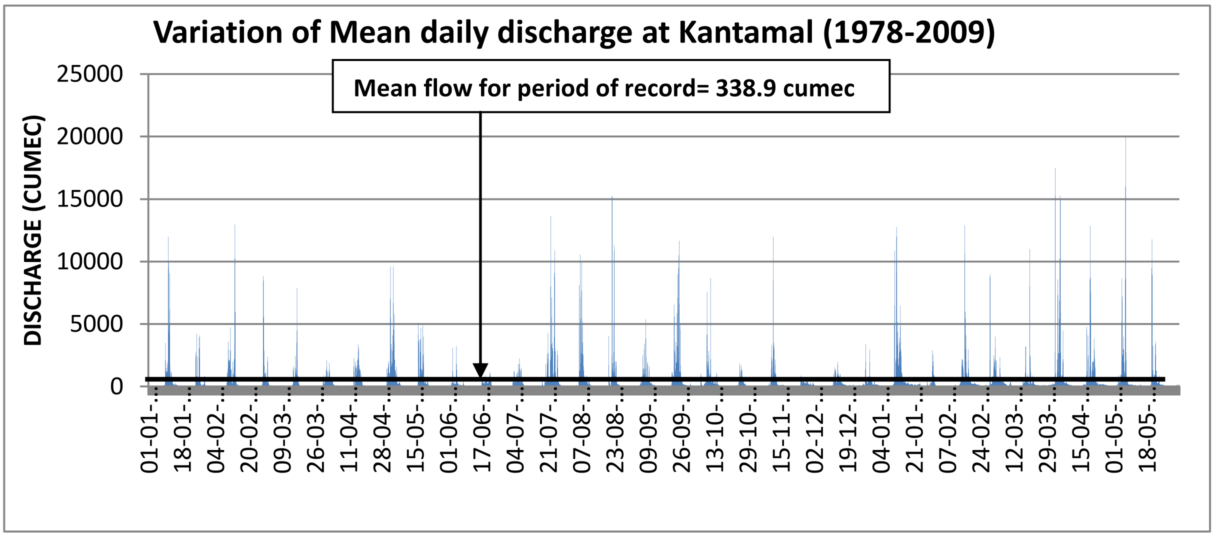


Figure 3.2 (g) Mean daily Flow at station EF7

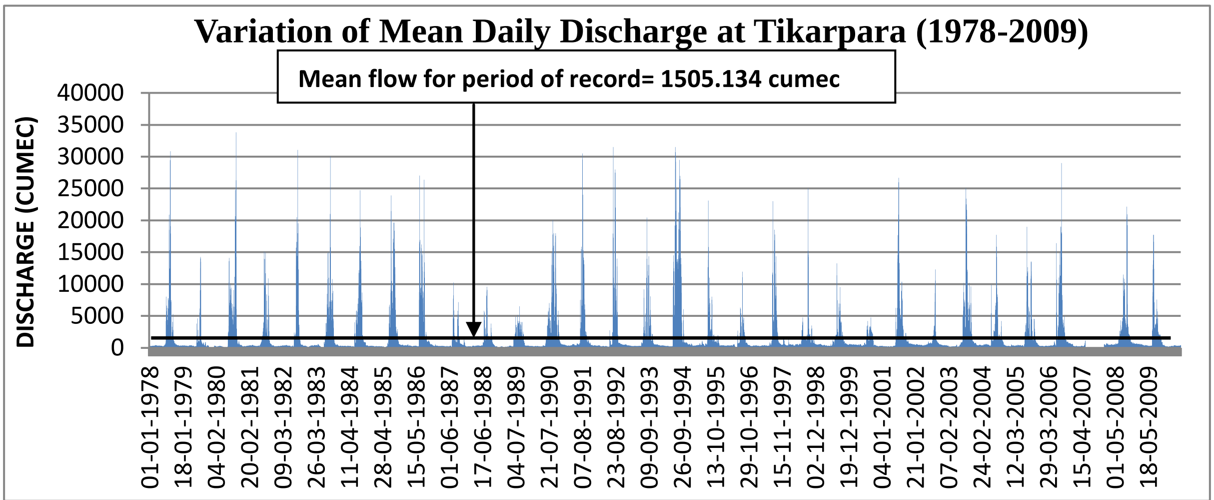


Figure 3.2 (h) Mean daily Flow at station EF8

Figure 3.2: Average Daily discharge for the Gauged sites for the period of record

The mean flow for the period of record for the total eight stations are shown in the above figure 2 (a-h). Considering fig. 2b, station EF2 is having the lowest mean discharge for the respective 38 years. If we see the table I, the respective station also receives the lowest average annual rainfall. Fig 2h shows the highest mean flow, since it's the downstream station of the Hirakud dam, having regulated flow. Station EF7 (Kantamal) have a high average annual precipitation contributing a part to its high mean discharge. Mean is calculated from the times series and standard deviation for each station is established by this relation.

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$

; where, σ = standard deviation; μ = mean of flow

x_i = daily flow; N= Number of days.

The mean, standard deviation and co-efficient of variance are established by the relation and the calculated values for the eight stations are enlisted in table II.

$$\textit{Coefficient of variance} = \frac{\textit{Standard deviation}}{\textit{Mean}}$$

STATION ID	MEAN	COEFF. OF VARIANCE	STANDARD DEVIATION
EF1	86.36	4.38	378.26
EF2	10.36	3.06	31.7
EF3	257.8	2.63	678.02
EF4	495	2.73	1351.35
EF5	72.96	2.29	167.08
EF6	99.41	2.69	267.42
EF7	338.9	2.98	1009.92
EF8	1457	2.13	3103.4

Table II: Mean, coefficient of variance and standard deviation for the eight stations

CHAPTER-04
METHODOLOGY

For the computation of EF of MRB, flow data of the sites are coordinated for the consecutive time periods. Several approaches are being harnessed and are stated in this chapter which are going to be applied in the present study.

4.1 TENNANT METHOD

This method was developed in 1976 and is the most common hydrological method applied worldwide and has been used by at least 25 countries in either the original form or the modified form (Tharme 2006). WQAA working group of India suggested it too. This method uses a percentage of mean annual flow (MAF) for two different six months periods to define the condition of the flow. Its main disadvantage is that the Mean Annual Runoff selected is just showing the flow of run-off in annual basis, but the variations of the flow aren't shown that are occurring throughout the year. The description of general condition of flow is given in the following table III.

DESDRIPTION OF GENERAL CONDITION OF FLOW	RECOMENDED FLOW REGIMES (% MAF) OCTOBER-MARCH	RECOMENDED FLOW REGIMES (% MAF) APRIL-SEPTEMBER
Flushing or Maximum	200%	200%
Optimum Range	60-100%	60-100%
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or Degrading	10%	30%
Poor or minimum	10%	10%
Severe Degradation	<10%	<10%

Source: Journal of Hydrological and Development, Ramakar Jha (Vol. 25, 2010)

Table III: Illustration of Montana (Tennant) method

4.2 RANGE OF VARIABILITY ANALYSIS

RVA developed by Ritcher at al. (1996,97), is aimed at providing a comprehensive statistical characterization of ecologically relevant features of the flow regime, recognizing the crucial role of hydrological variability in sustaining riverine ecosystems. It uses the hydrological Indices, termed IHA (Indicators of Hydrological Alterations). IHA consists of a total of 67 statistical parameters grouped in IHA-33 & EFC (Environmental Flow Components)-34 parameters. The IHA statistics are mainly grouped into five categories (magnitude, timing, frequency, duration & rate of change) & EFC are also grouped into five categories (low flows, extreme low flows, high flow pulses, small floods & large floods).

4.3 FLOW INDICES AND FLOW DURATION CURVE ANALYSIS

Flow duration curve known as FDC is a plot showing the percentage of time that flow in a stream is likely to equal or exceed some specified value of interest in abscissa and discharge in ordinate. The discharge may be daily, monthly, annual or entire period of record depending on our interest. In FDC flow records are analyzed over specified durations to produce flow duration curves which display the relationship between range of discharges and percentage of time that each of them is equalled or exceeded. FDC is a recipe for the sustainable management of water resources. The applications of FDC are diversified and are used for multipurpose programs: water resources management, public water supply, agriculture, fish farming, water quality, hydro-power and conventional power, navigation and ecosystem protection.

A flow duration curve is one of the most edifying method of demonstrating the entire range of river discharges, from low flows to flood events (Smakhtin, 2001). Its specified that the “design” low flow range of a flow duration curve is the 70%-99% range, or the Q70 to Q99 range (Smakhtin *et al.*, 2001). Q17, Q40, Q75, Q80, Q84, Q90, Q95, Q96, Q97, Q98 and Q99 are known as flow duration indices among which Q90 and Q95 are known as low flow indices. The percentile used as a flow index depends very much upon the type of river being studied. For perennial rivers, Q95 and Q90 are generally used. For semi-arid or polar regions, a larger percentage of zero values are often found in the recorded flow series.

4.3.1 7Q10: 7Q10 flow means 7 days average flow per 10 years period. 7Q10 flow is one of the most widely used (design or reference) instream flow methods and are used for regulation purposes ranging from

- To protect water quality protection from waste water discharges or waste water apportion and to prevent hostile biological influence on the receiving water.
- Stream design flow used to resolve waste load allocations to uphold the water quality.
- It also acts a general indicator of prevalent drought conditions, which generally envelop bulky areas.
- Determines the minimum stream flow necessary for the Habitat protection during drought condition and also serves as the chronic criteria for the aquatic life.
- It’s also used to compare the influence of the climate change and irrigation on low surface stream flows and also used as a local extinction flow.

However, the original use of 7Q10 is to normalize stream water quality from pollution.

4.3.2 7Q5: 7Q5 flow means 7days average flow per 5 years period. 7Q5 flow is generally referred as the critical low flow for low quality fishery waters (a stream catalogued for the beneficial use of warm water semi-permanent fish life propagation or warm water marginal fish life propagation).

4.3.3 7Q2: 7Q2 flow means 7 days average flow per 2 years period. 7Q2 flow is also usually referred as the most widely used designed low flow indices. It's used for the following purpose ranging from:

- Habitat maintenance flow and its sets a criteria for developing licence for waste load allocations.
- Some uses it as a specific design for Storm water holding facilities and also uses it as an In-stream Flow.

4.3.4 7Q20: 7Q20 is defined as the 7days average flow per 20 years period. 7Q20 is basically used as a system extinction flow, which causes noteworthy stress on the system. Its also used as an indicator of the minimum flow needed and serves as a limiting condition for sewage treatment and waste water disposal for a receiving water body. It plays a very crucial role in analysing summer design low flow for effluent wastewater discharge and drought flow periods and volumes. The 7Q20 is essentially a conservative approach to ensure that adequate stream-flow is accessible to assimilate/dilute point source discharges (Stainton, 2004).

4.3.5 7Q50: 7Q50 is describes as the 7days average flow per 50 years period. The range of flow which it gives is high compared to the other FDC's and hence it's used for flushing out the sediments and pollutants which can pose a severe threat to the ecological balance of the river system.

4.3.6 Q95: These are used as the low flow duration indices and are defined as the flow exceeded for 95% of the time. These are generally used for the following:

- Minimum flow to shield the ecosystem of the river.
- Minimum monthly specification for point discharges.

- Specifically used as the biological catalogue for the mean monthly flow.
- Used to sustain the natural monthly deviation and to regulate the EF rules.

4.3.7 Q90: These are defined as the flow exceeded for the 90% of the time and are also used as the commonly used low flow indices. They are generally used for the following purposes:

- Monthly value imparts unwavering and mean flow stipulations.
- Monthly value allots minimum flow for the aquatic environment.
- Used to scrutinize discharge-duration patterns of the small streams.
- Threshold for advising water managers for crucial stream flow levels.

The procedure followed to obtain the FDC of various return periods are as follows (Sugiyama *et al.*, 2003):

1. 7 day mean of each year calculated. The discharges of each year are arranged in the descending order and then ranked.

2. Calculate the plotting position with the following Weibull plotting formula, select the type probability paper to be used, and plot the data on the probability paper:

$$\boldsymbol{P = \frac{m}{n+1} * 100}$$

where P is the probability of all events less than or equal to a given discharge value, m is the rank of the event, and n is the number of events in the record.

3. FDC is obtained by plotting probability of exceedance in abscissa and discharge in ordinate.

4. Take the 95 percentile value from the FDC, rank in the ascending order and find the probability. Then plot the graph and obtain the best fit line. Similarly plot Q90, Q85....Q5.

5. Take 10 years simultaneous values for each plot from Q95, Q90, Q85.............Q10,Q5 for the difference of 5% probability. Plot 7Q10. Similarly plot 7Q2, 7Q5, 7Q20 and 7Q50.

4.4 EMC AND FDC SHIFT

EF are required to maintain the required amount of flow, hence its required to maintain an ecosystem which is classified into various classes/ segments , such that the various condition of the river can be described and analysed, hence can be upgraded to a better state, such that the required EF is maintained (Smakhtin & Anputhas, 2006). These division of the classes/segments are defined as the Environmental Management Class (for example Class A, Class B etc), illustrated in the table IV.

EMC	**Ecological description**	**Management Perspective**	**Default FDC Shift limits**
A: Natural	Pristine condition or minor modification of in-stream and riparian habitat	Protected rivers and basins. Reserves and national parks. No new water projects (dams, diversions, etc.) allowed	Lateral shift of a reference FDC one percentage point to the left along the time axis from the original FDC position.
B: Slightly Modified	Largely intact biodiversity and habitats despite water resources development and/or basin modifications	Water supply schemes or irrigation development present and/or allowed	Lateral shift of a reference FDC one percentage point to the left along the time axis from the position of the FDC for A Class.
C: Moderately Modified	The habitats and dynamics of the biota have been disturbed, but basic ecosystem functions are still intact. Some sensitive species are lost and/or reduced in extent. Alien species present	Multiple disturbances associated with the need for socio-economic development, e.g., dams, diversions, habitat modification and reduced water quality	Lateral shift of a reference FDC one percentage point to the left along the time axis from the position of the FDC for B Class
D: Largely Modified	Large changes in natural habitat, biota and basic ecosystem functions have occurred. A clearly lower than expected species richness. Much lowered presence of intolerant species. Alien	Significant and clearly visible disturbances associated with basin and water resources development, including dams, diversions, transfers, habitat modification and water	Lateral shift of a reference FDC one percentage point to the left along the time axis from the position of the FDC for C Class

	species prevail.	quality degradation	
E: Seriously Modified	Habitat diversity and availability have declined. A strikingly lower than expected species richness. Only tolerant species remain. Indigenous species can no longer breed. Alien species have invaded the ecosystem.	High human population density and extensive water resources exploitation	Lateral shift of a reference FDC one percentage point to the left along the time axis from the position of the FDC for D Class
F: critically Modified	Modifications have reached a critical level and ecosystem has been completely modified with almost total loss of natural habitat and biota.	This status is not acceptable from the management perspective. Management interventions are necessary to restore flow pattern.	Lateral shift of a reference FDC one percentage point to the left along the time axis from the position of the FDC for E Class

Source: Research Report 107, V. Smakhtin and M.Anputhas (2006)

Table IV: Environmental Management Classes (EMC) and default limits for FDC shift.

4.5 SPATIAL INTERPOLATION METHOD

The core principle in this technique is that flows happening concurrently at sites in rationally close proximity to each other correspond to analogous percentage points on their respective FDCs. The site at which the stream flow series is generated is known as the destination sites and the site where the time series is available, is referred as the source sites. In this framework, the intended (destination) FDC is the one representing the EF series to be generated, for the destination site, while having the source FDC and time series for the reference flow regime. For computing monthly discharge, the procedure deals with the following steps: a) spot out the percentage point position of the source site's flow b) reads the monthly flow value for the corresponding percentage point from the intended FDC and c) generate the time series plot of the destination site. This method is very useful, if we are having the standardized FDC curve for some particular site and wants to generate EF for that site.

CHAPTER-05
RESULTS AND DISCUSSION

In this present chapter, the flow data of the MRB are to be analysed using various state-of-the art approaches. The approach which would suggest minimum flow besides serving all the other purposes that would be considered as the role model of this dissertation.

5.1 TENNANT METHOD (*APPROACH 1*)

Using the Tennant (or Montana) method (1976), percentage of the MAF (mean annual flow) for two different six months periods were computed to define conditions of flow, regarding "Insream Flow regimes for fish, wildlife, recreation and related environmental resources" are shown in Table V. This table is useful for the water resources managers and planners for allocating water for Flushing out the sediments deposits to maintain the Morphology of the river system and to keep it in good health. The lower values for the four stations (considering both upstream and downstream) indicates the poor/ severe degradation of the health, water quality and ecology of the river system. Flushing, optimum range and outstanding flows as prescribed by Tennant is useful for flushing out the pollutants and sediments, which pollutes the river system and due to the sediment deposition, the flow might be hindered which would lead to the disturbance of the ecological balance of the basin. Excellent and good flows are considered as the flows which would keep the ecosystem function normally and very little modification is required. Minimum (poor) flow is referred as the lowest class below which there would be severe degradation of the basin, hampering the total ecosystem.

Narrative condition of general condition of flow (%)	% of MAF in cumec for NON-MONSOON.								% of MAF in cumec for MONSOON							
	EF1	**EF2**	**EF3**	**EF4**	**EF5**	**EF6**	**EF7**	**EF8**	**EF1**	**EF2**	**EF3**	**EF4**	**EF5**	**EF6**	**EF7**	**EF8**
Flushing or maximum (200%)	172.72	20.72	515.6	990.2	145.9	198.8	677.8	2914	172.72	20.72	515.6	990.2	145.9	198.8	677.8	2914
Optimum range (60-100%)	51.8 - 86.36	6.22 - 10.36	154.7 - 257.8	297.1 - 495.1	43.78 - 72.96	59.65 - 99.41	203.4 - 338.9	874.2 - 1457	51.8 - 86.36	6.22 - 10.36	154.7 - 257.8	297.1 - 495.1	43.78 - 72.96	59.65 - 99.41	203.4 - 338.9	874.2 - 1457
Outstanding (40/60%)	34.5	4.14	103.12	198.04	29.2	39.8	135.6	582.8	51.8	6.22	154.7	297.1	43.78	59.65	203.4	874.2
Excellent (30/50%)	25.91	3.11	77.34	148.5	21.89	29.8	101.7	437.1	43.2	5.18	128.9	247.6	36.5	49.7	169.5	728.5
Good (20/40%)	17.3	2.1	51.6	99.02	14.6	19.9	67.78	291.4	34.5	4.14	103.12	198.04	29.2	39.8	135.6	582.8
Fair or degrading (10/30%)	**8.63**	**1.03**	**25.7**	**49.5**	**7.3**	**9.94**	**33.89**	**145.7**	**25.91**	**3.11**	**77.34**	**148.5**	**21.89**	**29.8**	**101.7**	**437.1**
Poor or minimum (10%)	**8.63**	**1.03**	**25.7**	**49.5**	**7.3**	**9.94**	**33.89**	**145.7**	**8.63**	**1.03**	**25.7**	**49.5**	**7.3**	**9.94**	**33.89**	**145.7**
Severe degradation <10%	<8.63	<1.03	<25.7	<49.5	<7.3	<9.94	<33.89	<145.7	<8.63	<1.03	<25.7	<49.5	<7.3	<9.94	<33.89	<145.7

Table V: Results of Tennant method in MRB

In this work, focus is mainly emphasised on the low and the optimum flow required. Table V provides a chart for the eight stations classifying the flow into various categories. Good flow isn't practically applicable all the time. Fair flow need to be maintained, if not possible then minimum flow (10%) should be positively maintained for the total catchment in order to sustain the ecological conditions.

5.2 RANGE OF VARIABILITY ANALYSIS (*APPROACH 2*)

Range of Variability analysis (RVA) is a detailed desktop analytical approach. The variation of the flow is analysed for different seasons over a series of years. In this work, we will be dealing with the variation of the minimum flow and the extreme low flow. IHA (Indicators of Hydrologic alterations) calculates for five different types of EFCs (Environmental Flow Components)- low flows, extreme low flows, high flow pulses, small floods & large floods. During Drought periods, rivers drop down to very low levels that can be stressful for aquatic and riparian ecosystems. Here, extreme low flow is taken as the 10% of the total flow for a year, which is refereed as the standard index. Extreme low flow can be varied to 15-20% of the total flow, depending upon the condition of the basin on which it is applied. EF8 is ignored since it's the regulated flow (downstream side of the Hirakud dam. The results obtained for extremely low flow peaks, duration, frequency, zero flow, comparison of 1-day, 3-day, 7-day, 30-day and 90-days minimum flow are given below

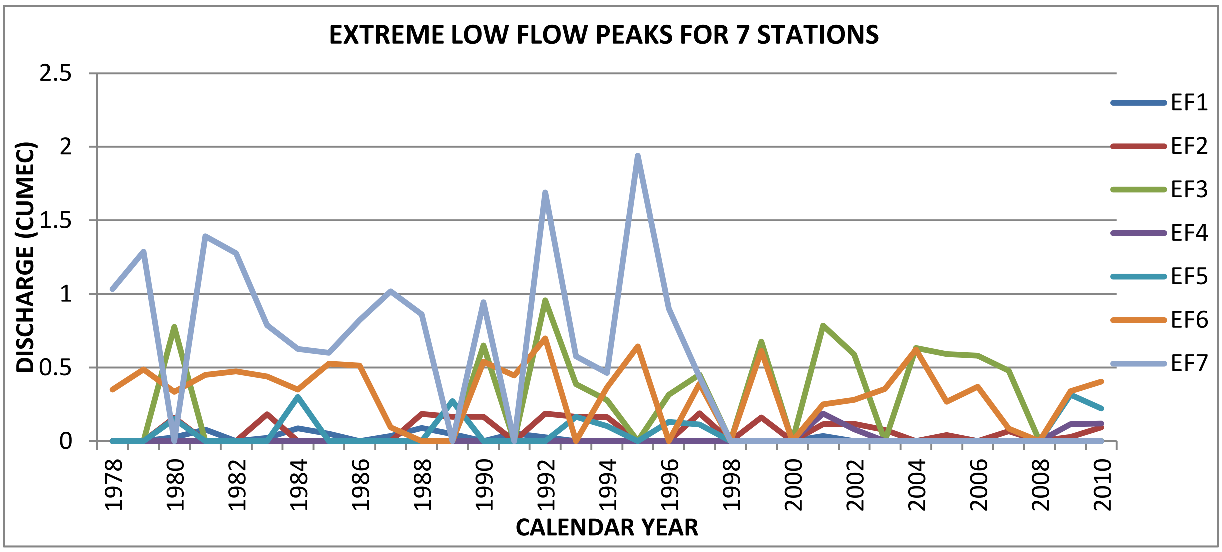


Figure 5.1: Comparison of Extreme Low flow Peaks

Fig. 5.1 shows that the peak of the extreme low flow of EF7 is high up to the year 1997 and after that it subsequently decreases. EF6 can be seen the second highest to be after EF7. The rest of the stations seem to be near to zero except EF3 and EF5.

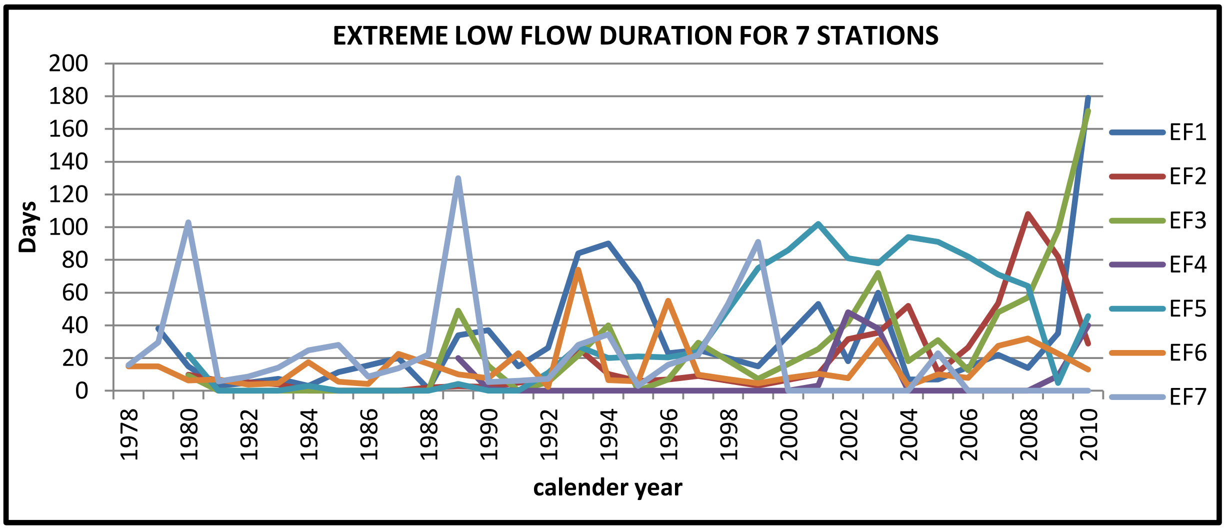


Figure 5.2: Comparison of Extreme Low flow Durations

EF1 and EF3 show the highest duration of extreme low flow followed by EF2. Duration of EF5 had increased consecutively after 1996 and simultaneously EF7 had zero extreme low flow after 1999. 2010 being a drought year, EF1 and EF3 shows a sharp increase.

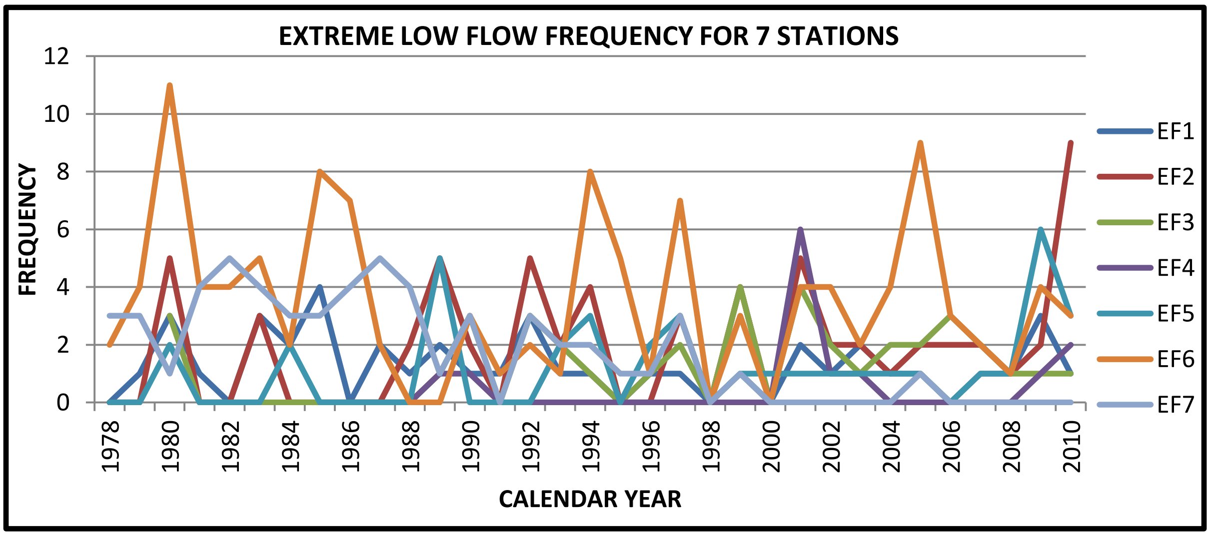


Figure 5.3: Comparison of Extreme Low flow Frequency

EF6 exhibits the highest low flow frequency than the other stations. EF2 extreme low flow frequency has sharply increased in 2010 as a result of the drought, hitting Orissa. EF7 has the least frequency after year 1998, owning to the construction of the dam. In the year 2000-01, EF4, EF2 and EF3 were also affected by the drought, where EF1, EF5 and EF7 were unaffected.

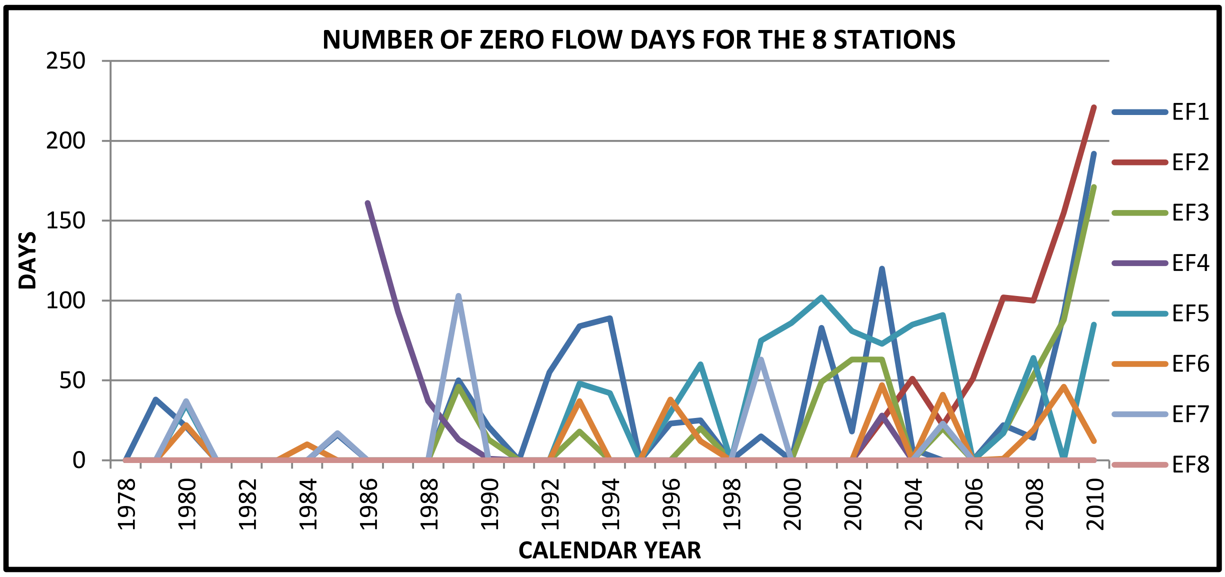


Figure 5.4: Comparison of the number of zero flow days

EF4 had a steep declination and from 1990 it had no zero days flow, owing to the opening of the Bango dam. EF5, EF6 & EF7 is showing a series of undulations over the record of years while EF8 has zero number of zero days flow (downstream of Hirakud dam and is completely regulated). 2010 indexed as the drought year, stations EF1, EF2 and EF3 shows the maximum number of zero days flow which shows that flow is stagnant for more than half of the year and also having minimal precipitation throughout the year.

7-day minimum flow is defined as the 7-days moving average of the minimum flow for a particular site. Similarly, 1-day, 3-day and 30-days minimum flow are defined as the 1-day, 3-days and 30-days moving average of the minimum flows. 1-day minimum flow is generally not considered as the water from the various parts of the catchment (time of concentration) to reach that particular site might be more than one day, so 3-days and 7-days are considered as the standardized index for analyzing the minimum flow.

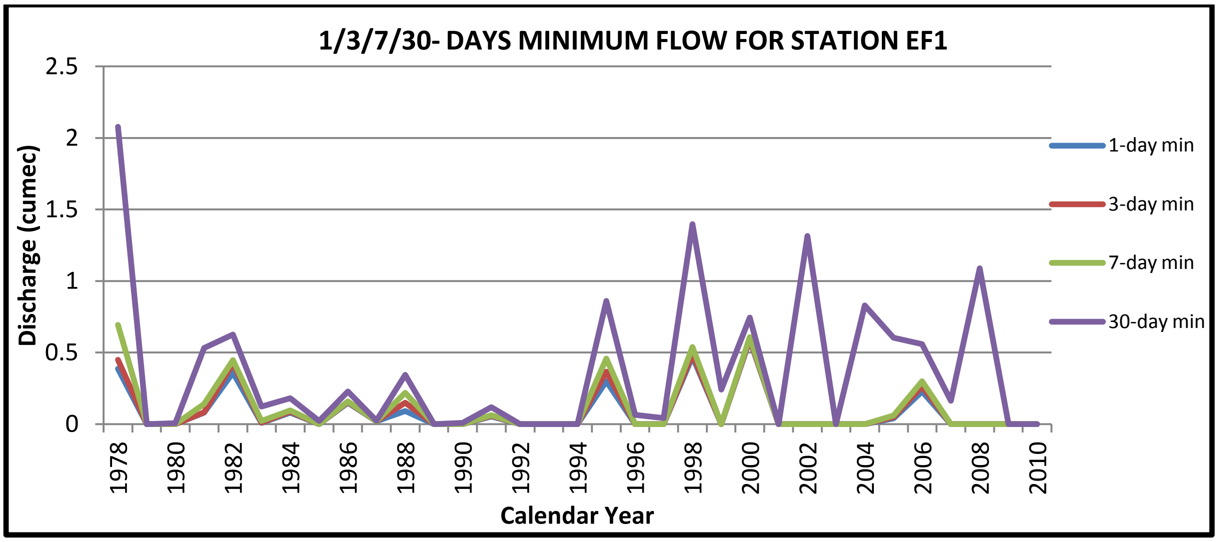


Figure 5.5: Comparison of the 1/3/7/30-days minimum flow for EF1

The station shows that the trend of the minimum flow in 1978 was approximately higher than the rest of the years. 1987, 1992-93 and 2010 was a drought year having zero minimum flow (extreme low flow).

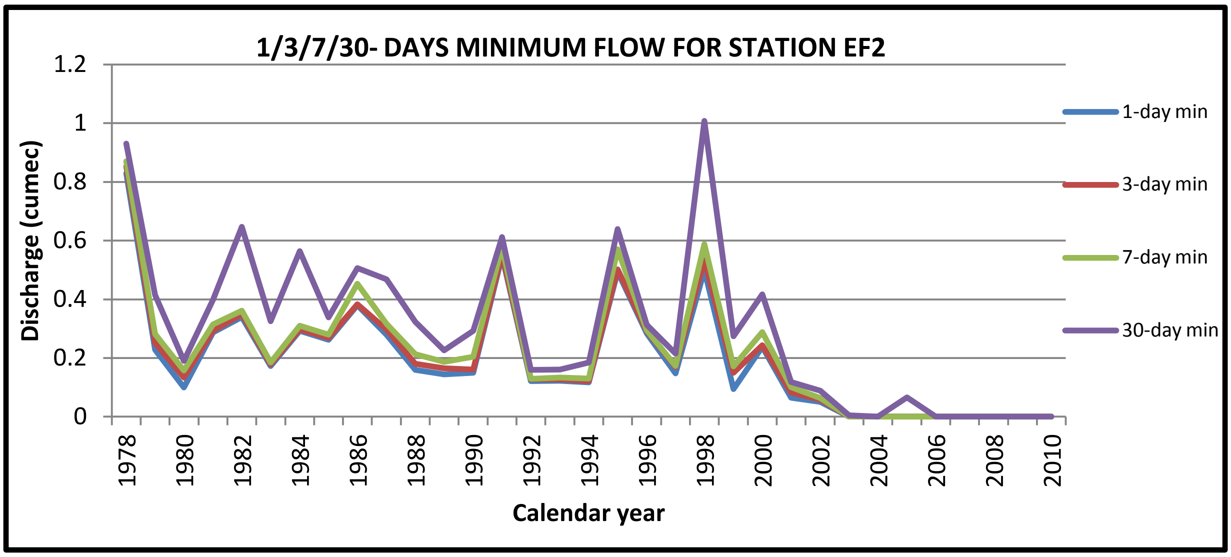


Figure 5.6: Comparison of the 1/3/7/30-days minimum flow for EF2

EF2 shows that this station was not affected by the drought years 1983, 1987, 1992 2000 except 2008 and 2010. Minimum flow had gone down to zero discharge from 2003 to 2010 and the extreme low flow had taken its toll.

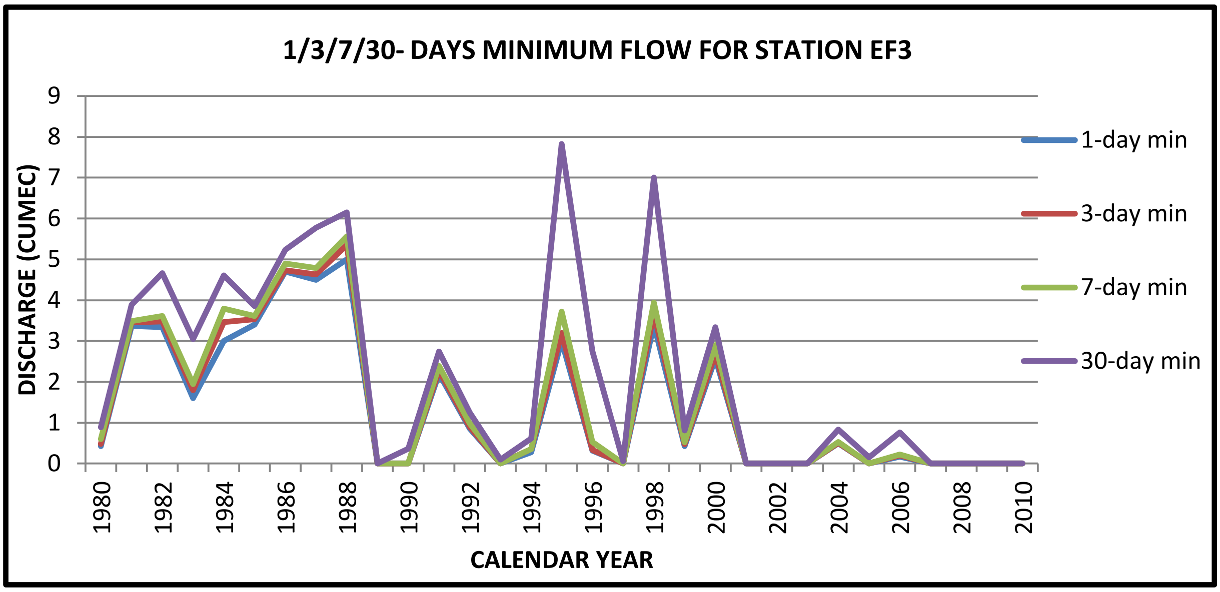


Figure 5.7: Comparison of the 1/3/7/30-days minimum flow for EF3

The trend shows that from 2001, EF3 shows zero discharge. EF3 was affected in the drought years 1992-93, 2001-02 and 2010. In future, the flow should be increased such that the site shouldn't be categorized as the extreme low flow.

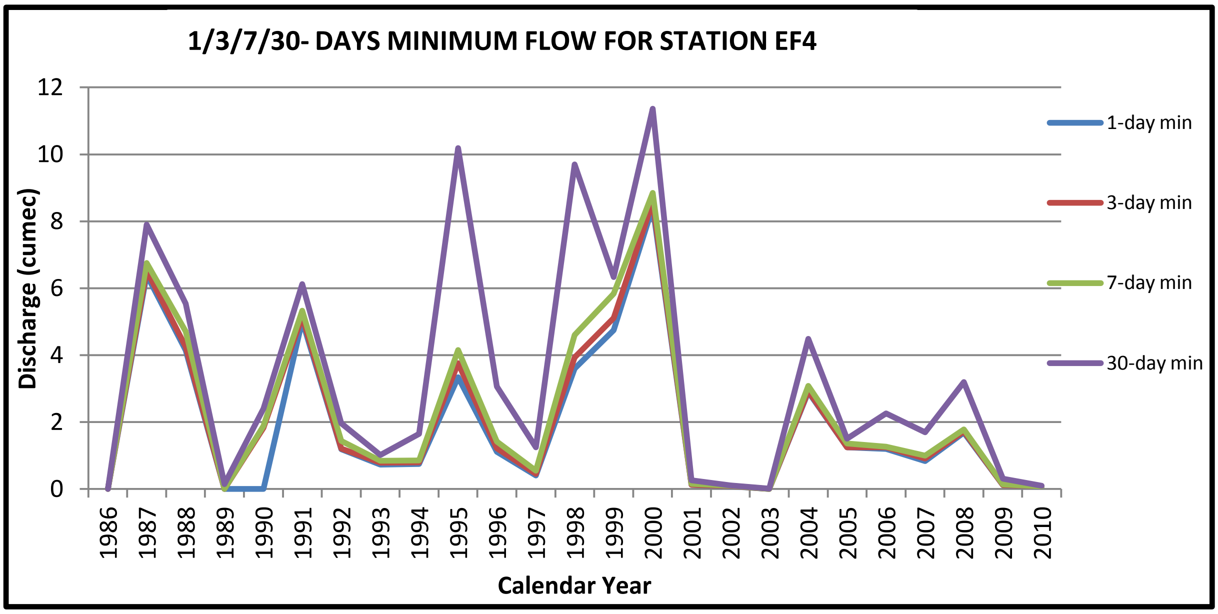


Figure 5.8: Comparison of the 1/3/7/30-days minimum flow for EF4

Fig.5.8 illustrates that the station EF4 suffered zero minimum flow during the year 2001-03 and also during 2010. In 1999-2000 the discharge was high with respect to other years, due to the devastating cyclone hitting the basin.

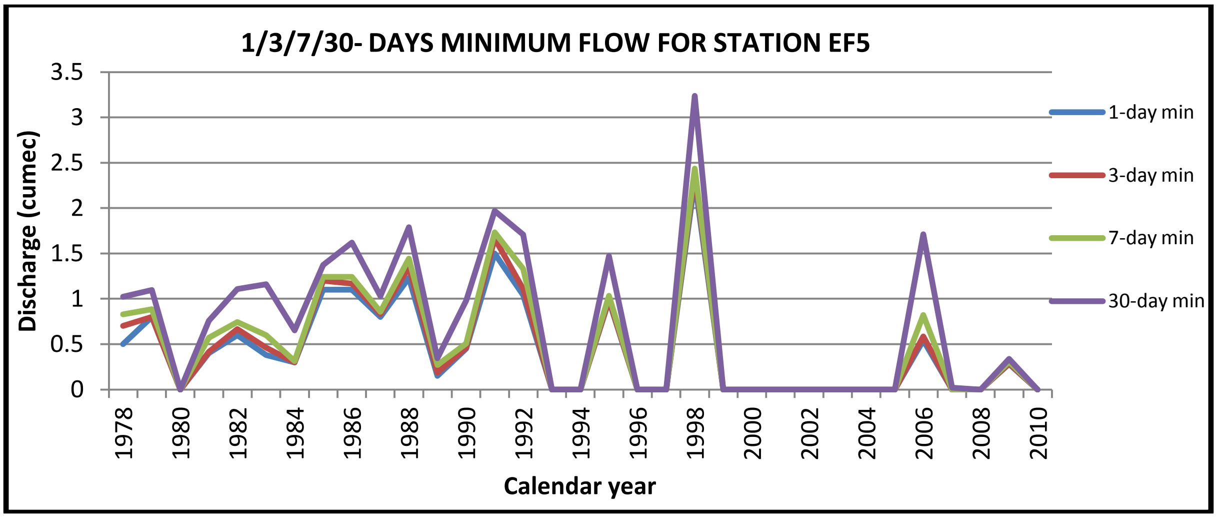


Figure 5.9: Comparison of the 1/3/7/30-days minimum flow for EF5

Figure 5.9 depicts that EF5 has zero minimum flow for the consecutive years 2000-05, 1993, 1997 and 2007-08. The trend shows that the minimum flow has decreased consecutively, with two or three years profiling a high peak some times.

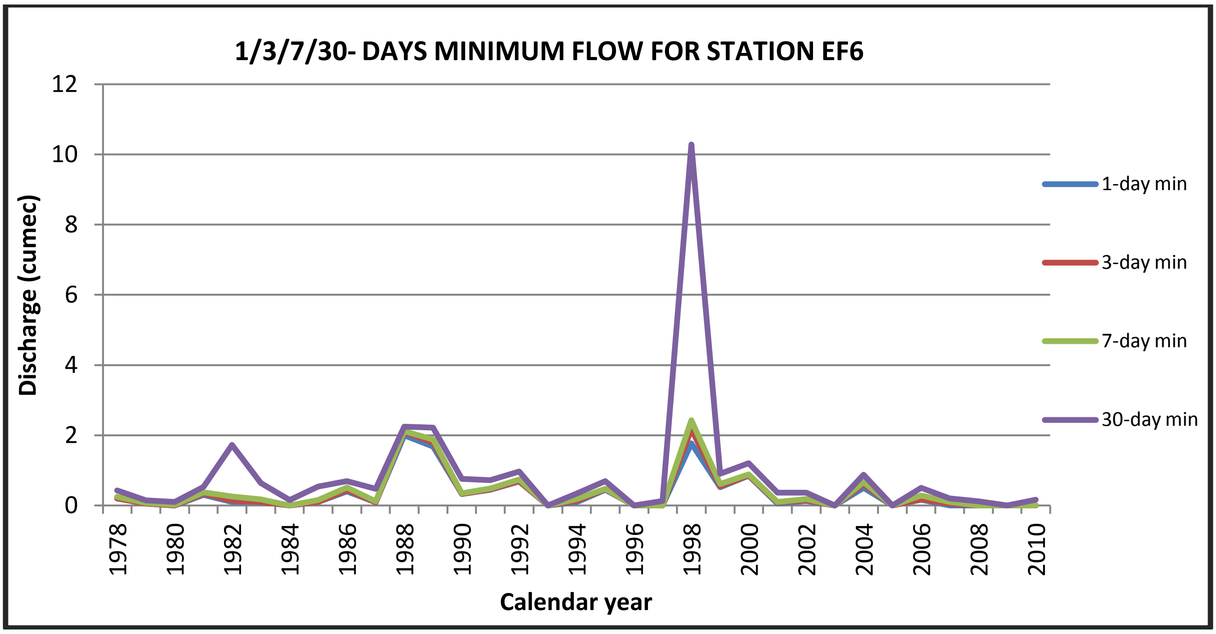


Figure 5.10: Comparison of the 1/3/7/30-days minimum flow for EF6

The trend of the graph (fig. 5.10) portraying EF6 shows that the tendency is almost same, there is no major variation of the flow except the year 1999(flood). 1987, 1992 and 2010 were the drought years, classifying EF6 having extreme low flow for the particular years.

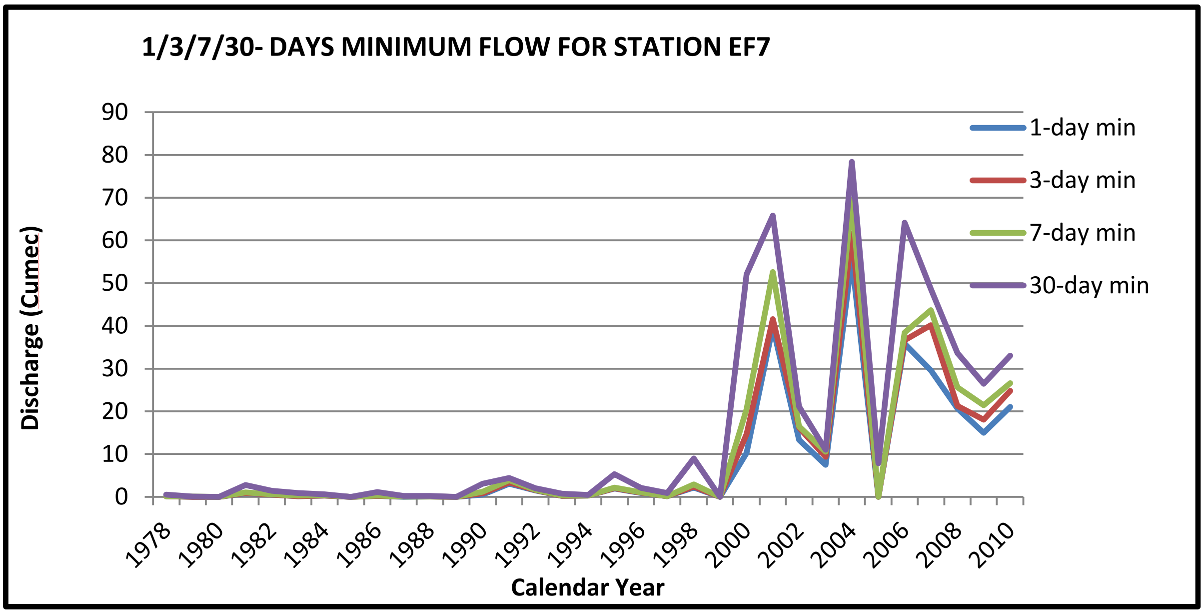


Figure 5.11: Comparison of the 1/3/7/30-days minimum flow for EF7

Station EF7 shows that after the year 1998, the amount of minimum flow increases. Past records says that in the year 1998, there was an opening of the dam (irrigation and generating hydro-power), making the flow of EF7 regulated, thereby abolishing extreme low flow.

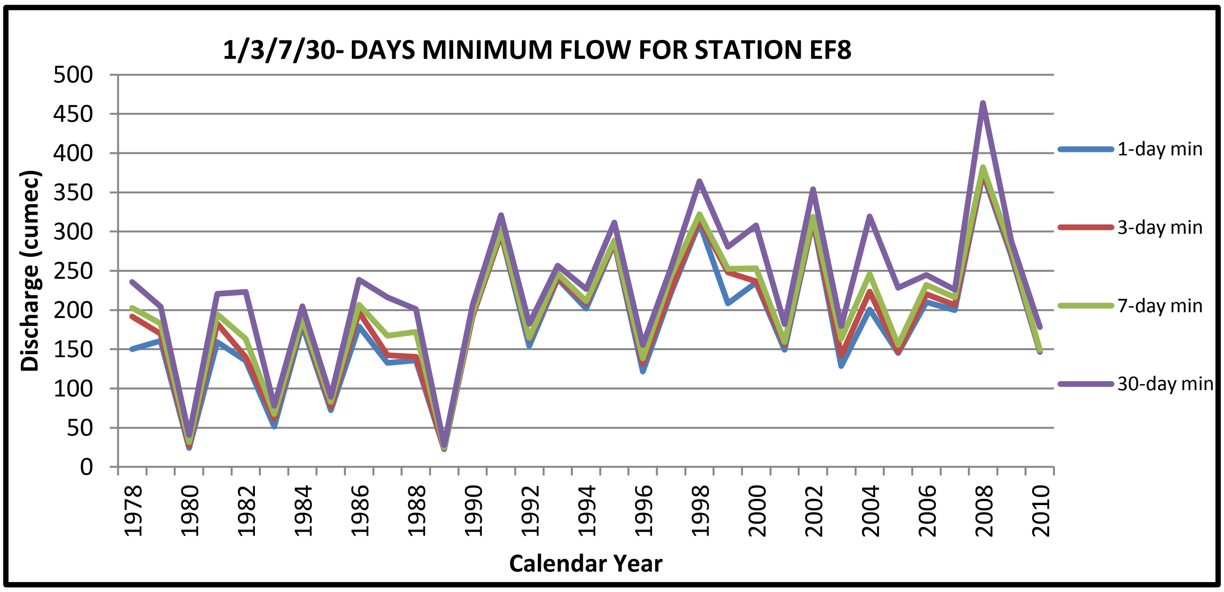


Figure 5.12: Comparison of the 1/3/7/30-days minimum flow for EF8

EF8 is the downstream station of the Hirakud dam, hence it's completely a regulated flow. Table II indicates that its mean discharge is very high and so the minimum flow. It shows a downfall in the drought years 1983, 1989 and 2010.

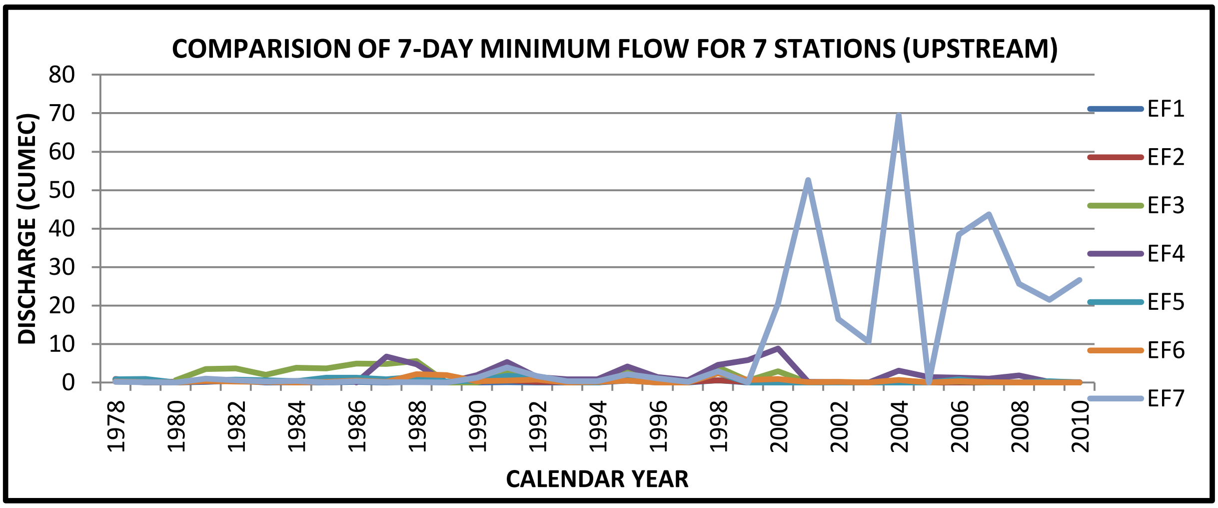


Figure 5.13: Comparison of the 7-day minimum flow for 7 Stations

Considering figure 5.13, 7-day minimum flow is taken as the most ideal record for the minimal flow analysis. EF7 is showing the highest variation, whereas all the other stations except EF4 and to some extent EF3 are more or less same and tends to be zero. If we consider the early part of the record for EF7, it shows that the flow tends to be zero, but it shows a sharp increase after the year 1999. The daily flow discharge (m^3/s) required for the eight stations are obtained and quoted in table VI below:

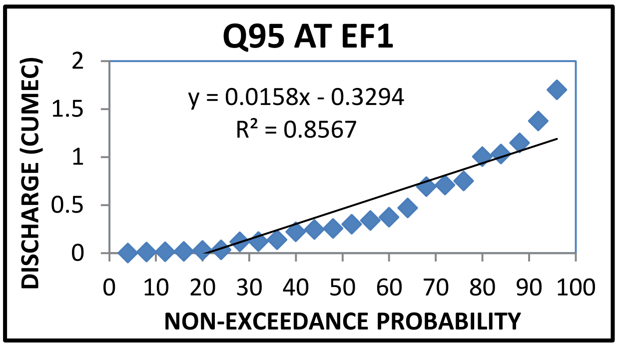
STATION ID	EXTREME LOW FLOW (cumec)	1-DAY MINIMUM (cumec)	3-DAYS MINIMUM (cumec)	7-DAYS MINIMUM (cumec)	30-DAYS MINIMUM (cumec)
EF1	0.03	0.09	0.11	0.12	0.41
EF2	0.12	0.19	0.21	0.23	0.31
EF3	0.43	1.39	1.47	1.56	2.15
EF4	0.07	1.93	2.08	2.25	3.3
EF5	0.1	0.44	0.47	0.52	0.71
EF6	0.37	0.33	0.36	0.41	0.86
EF7	0.79	7.92	9.04	10.36	14.48
EF8	174.56	182.17	190.77	200.08	227.62

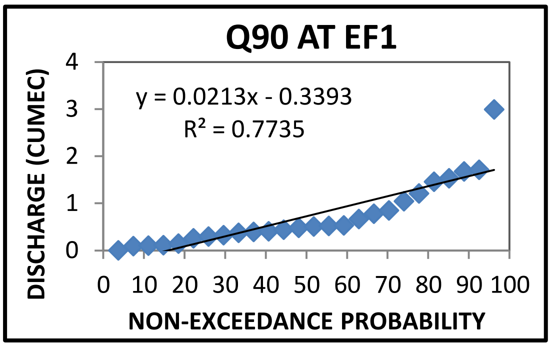
Table VI: Computation of RVA method in MRB

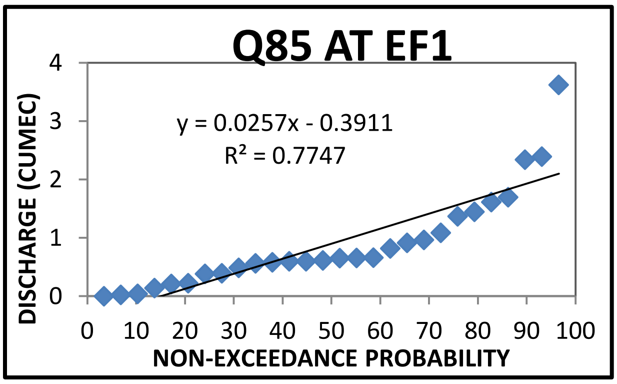
Table VI illustrates the daily flow discharge (m^3/s) for the eight stations, stating the extreme low flow, 1-day, 3-days, 7-days and 30-days minimum flow. EF8 is regulated hence much stress isn't given. Table V states the values for the eight stations using the Tenant method and the values computed using the tenant method is very high which is practically impossible to maintain throughout the season. RVA satisfies the criteria for maintaining EF with low values which are practically feasible for most of the stations.

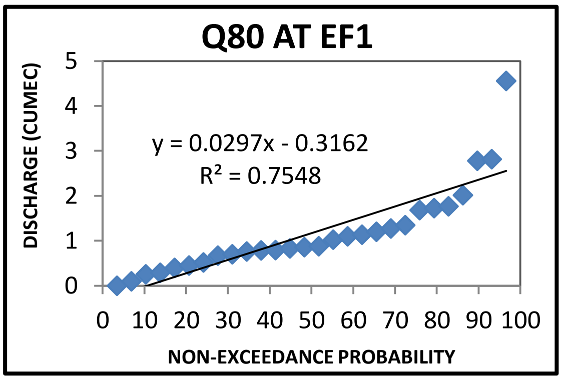
5.3 FDC AND FLOW DURATION INDICES (*APPROACH 3*)

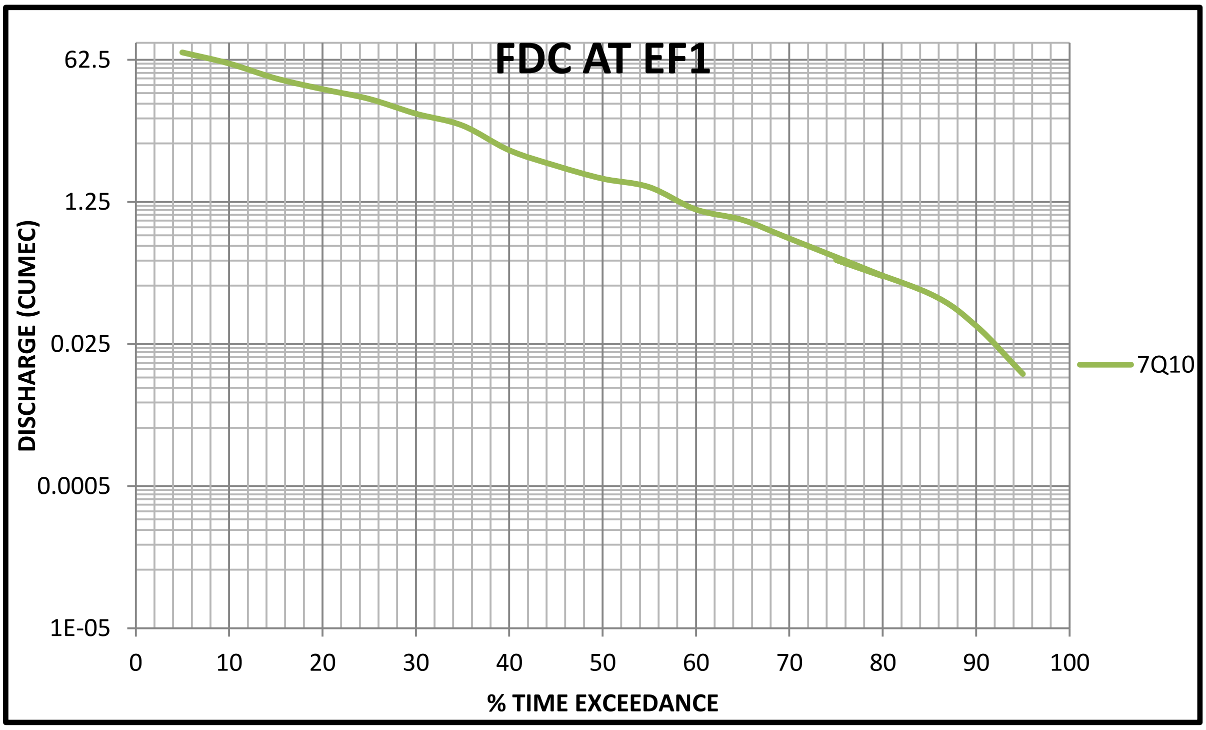
The data of 24 years starting from 1978 to 2009 is used to determine the minimum flow. The low flow duration indices Q95, Q90, Q85 and Q80 are plotted for all the required eight stations and the regression equations are found out for the individual flow indices. Comparison of all the 7 year average flow's FDC for the return periods 2, 5, 10, 20 and 50 years are done for all the required stations.











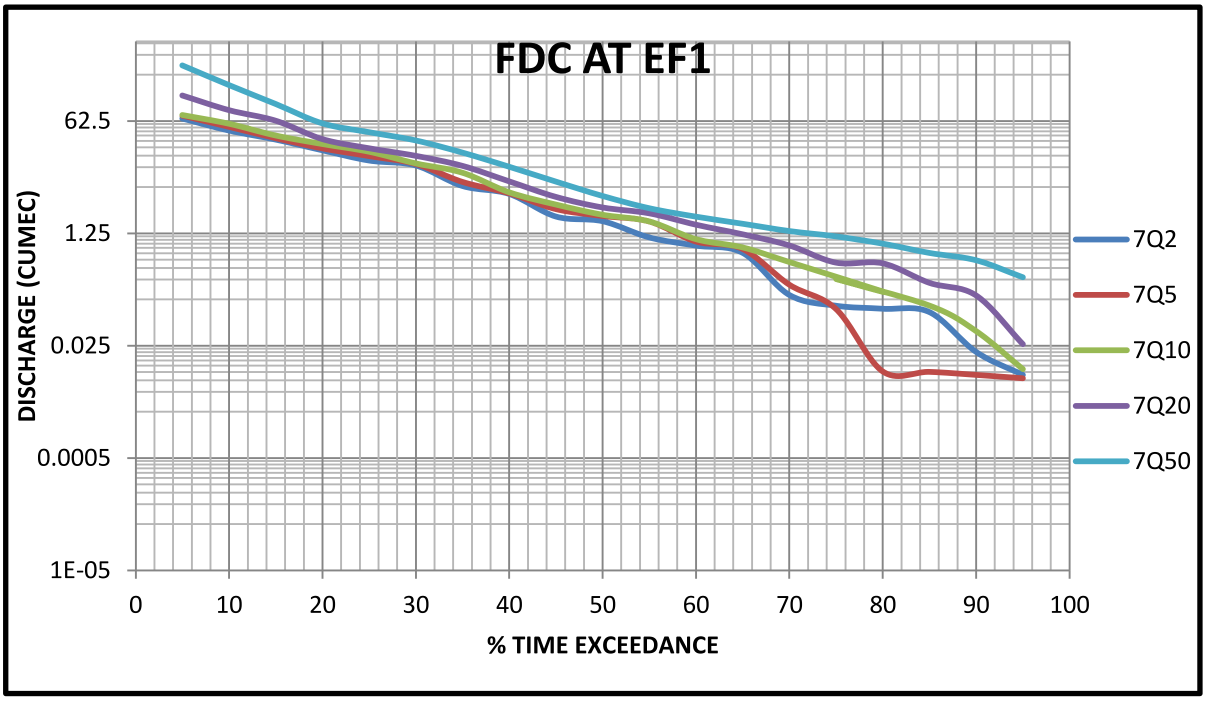
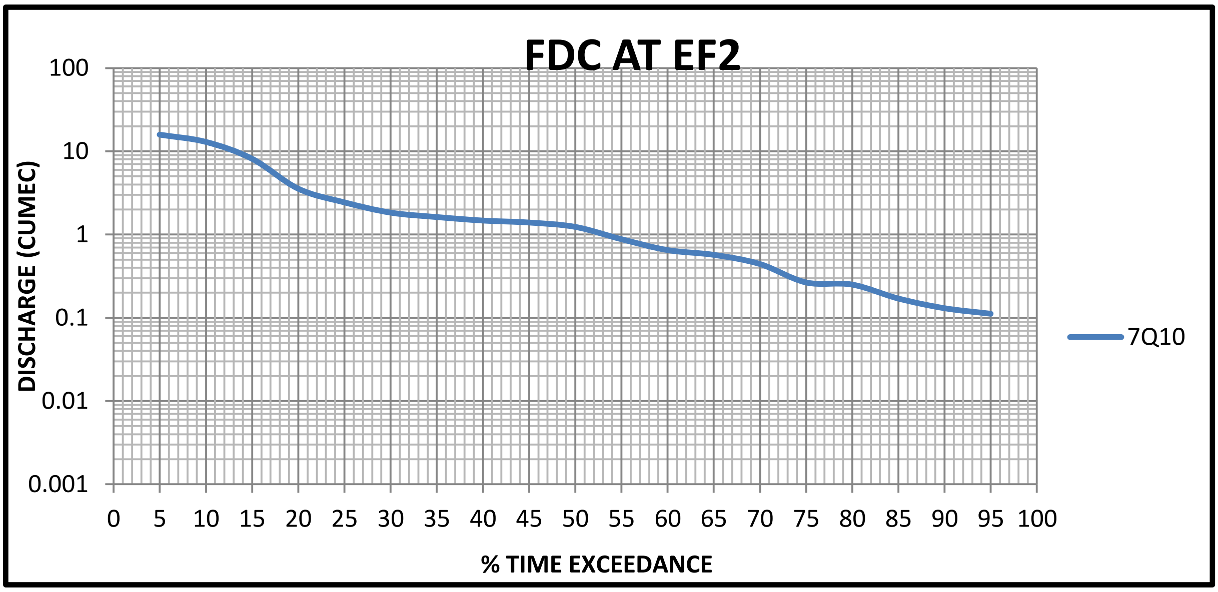


Figure 5.14: Figures showing Q95, Q90, Q85, Q80, 7Q10 and comparison of FDC's-EF1

During the non-monsoon season, EF1 have tremendous low flow affecting the flora and fauna of the region. If we consider the minimum flow from the graph, it is seen that the values for the 95th and 90th percentile are 0.011 cumec and 0.041 cumec.



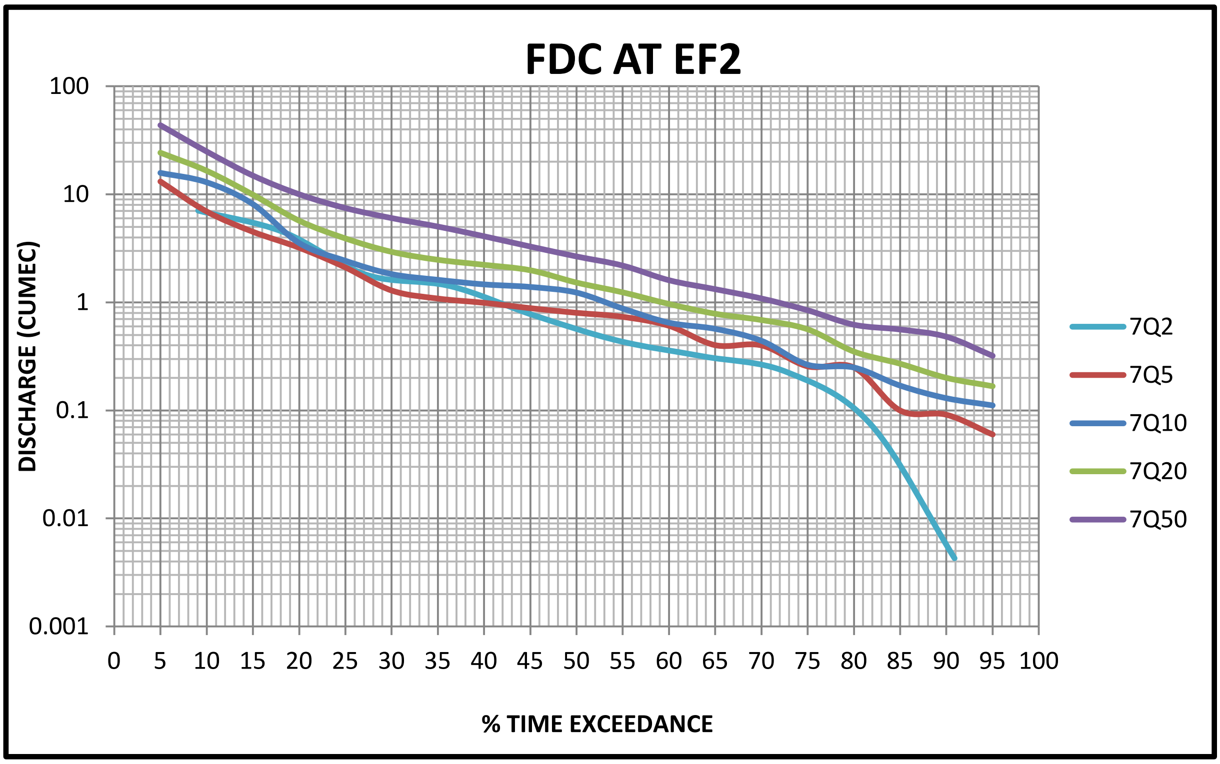
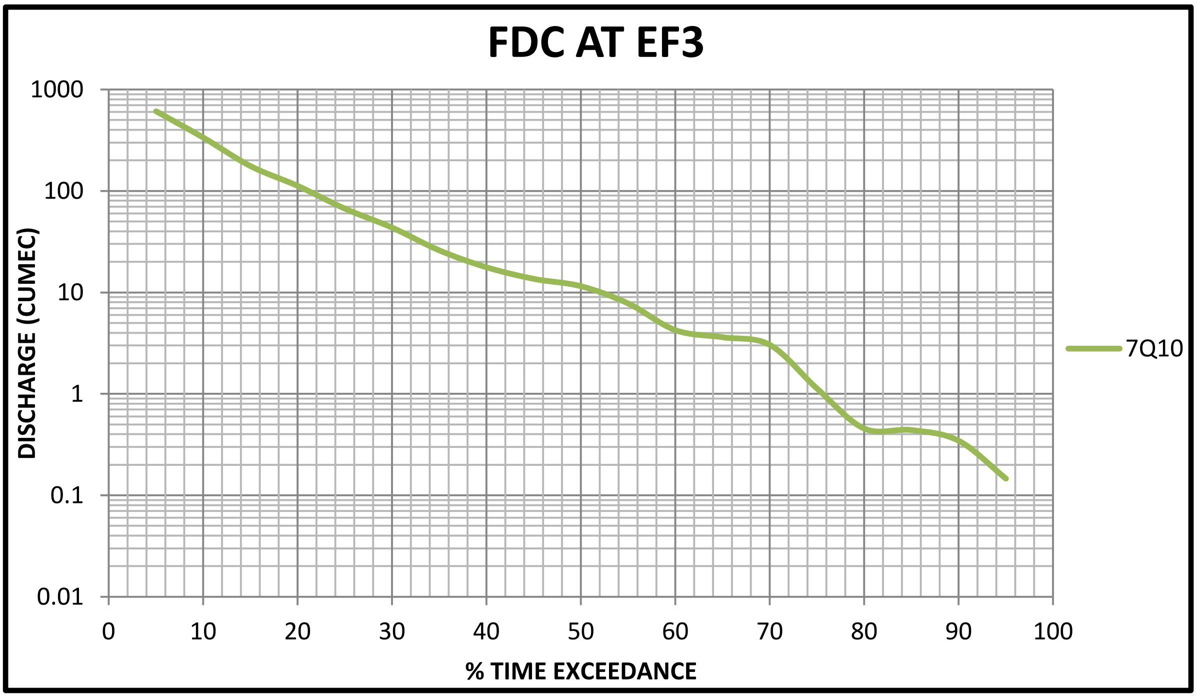


Figure 5.15: Figures showing 7Q10 and comparison of FDC's for EF2

At the 43th percentile, 7Q2 and 7Q5 interchanges their position. From 5th- 43th percentile, 7Q5 was moving downward than 7Q2. It might be happening due to that 2-days cumulative discharge is higher than the 5-days discharge. It might be the case that the precipitation is higher for the two days time whereas for the average of the five days time, it might be smaller. Hence giving to the high discharge for 7Q2.



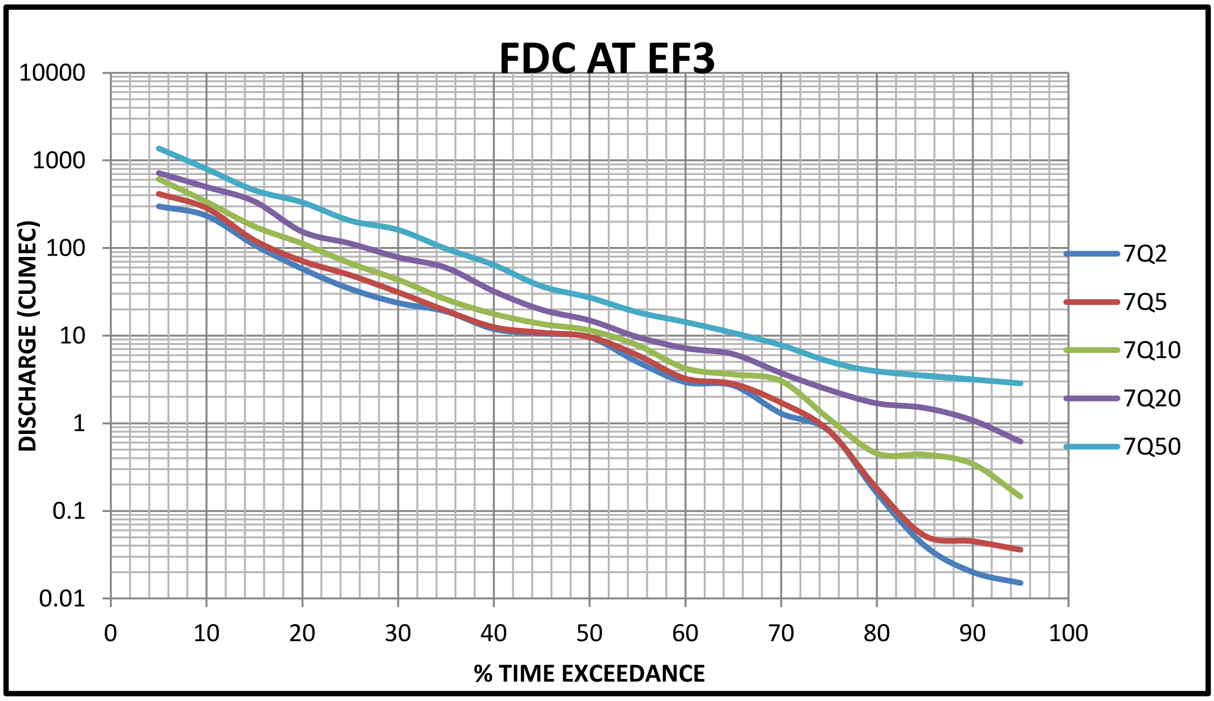
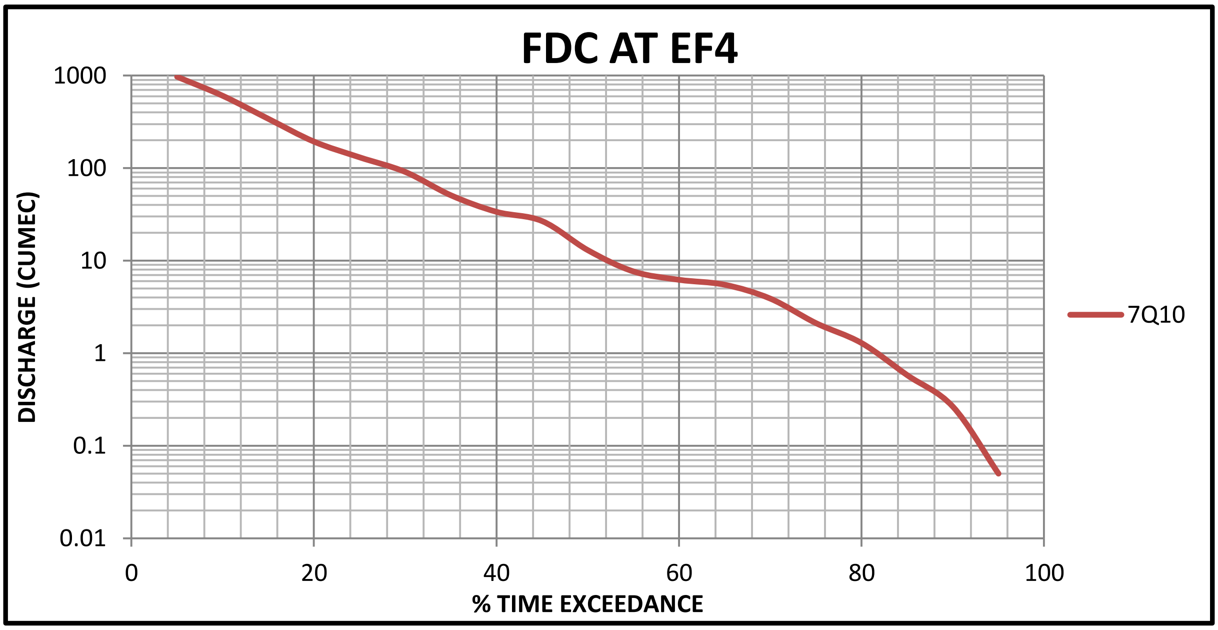


Figure 5.16: Figures showing 7Q10 and comparison of FDC's for EF3

The above figure 5.16 shows that 7Q2 and 7Q5 are very much close to each other in the total series. After 75th percentile all the FDC's moves apart, 7Q2 and 7Q5 gives very small values for the range 80th- 95th percentile.



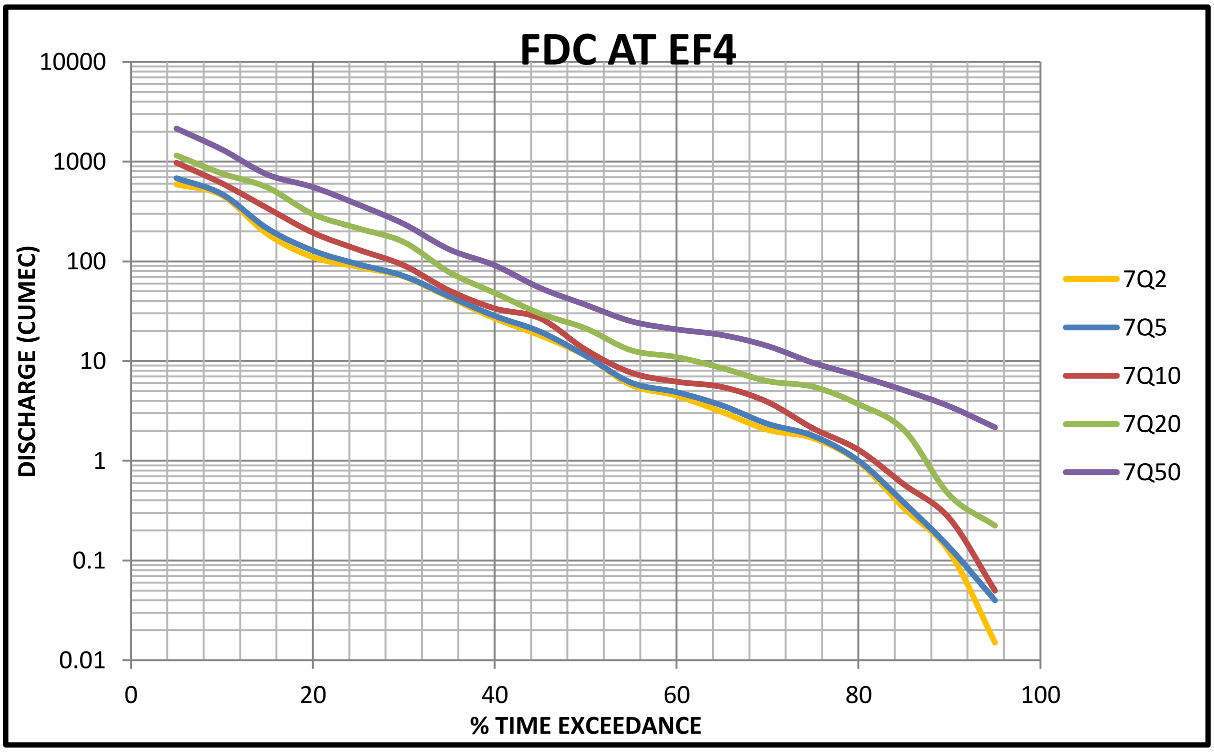
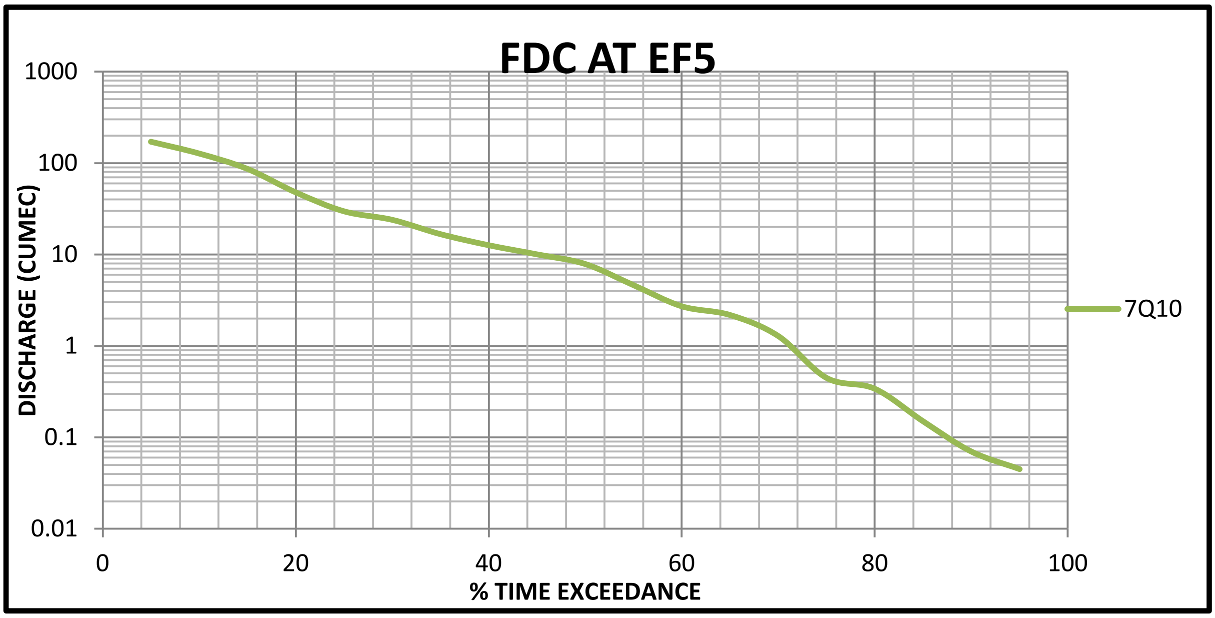


Figure 5.17: Figures showing 7Q10 and comparison of FDC's for EF4

In the figure 5.17, 7Q2 and 7Q5 almost gives the same values, except for the 95th percentile where it shoots down below.



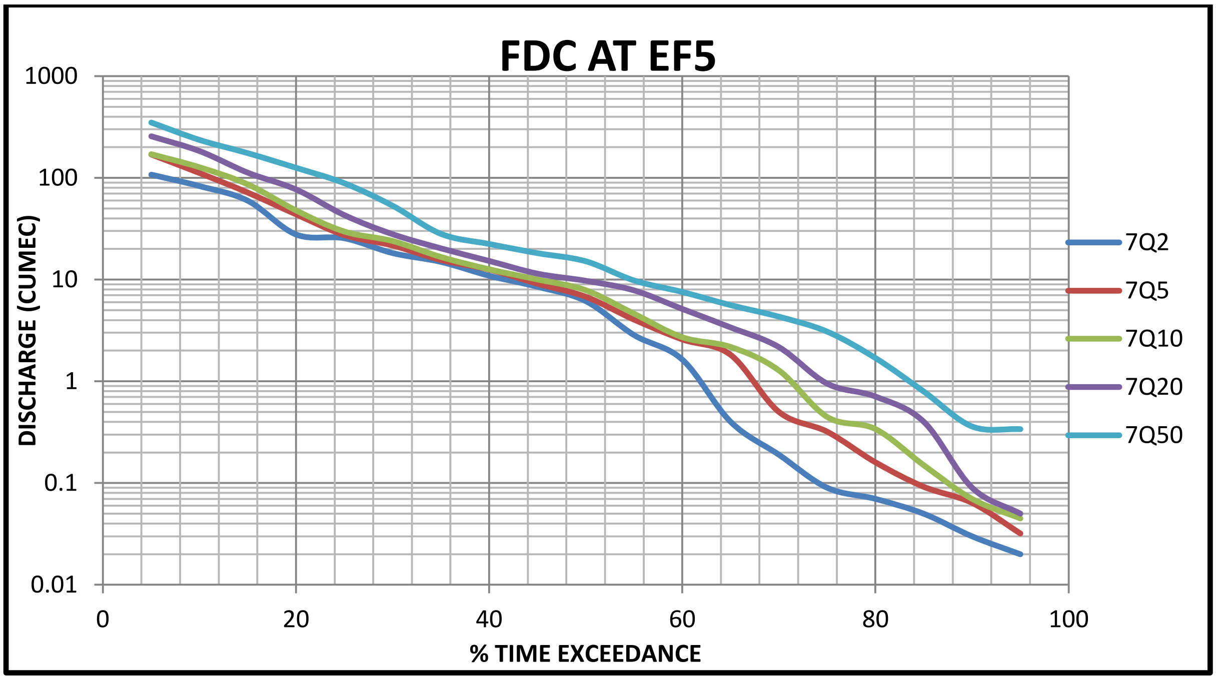
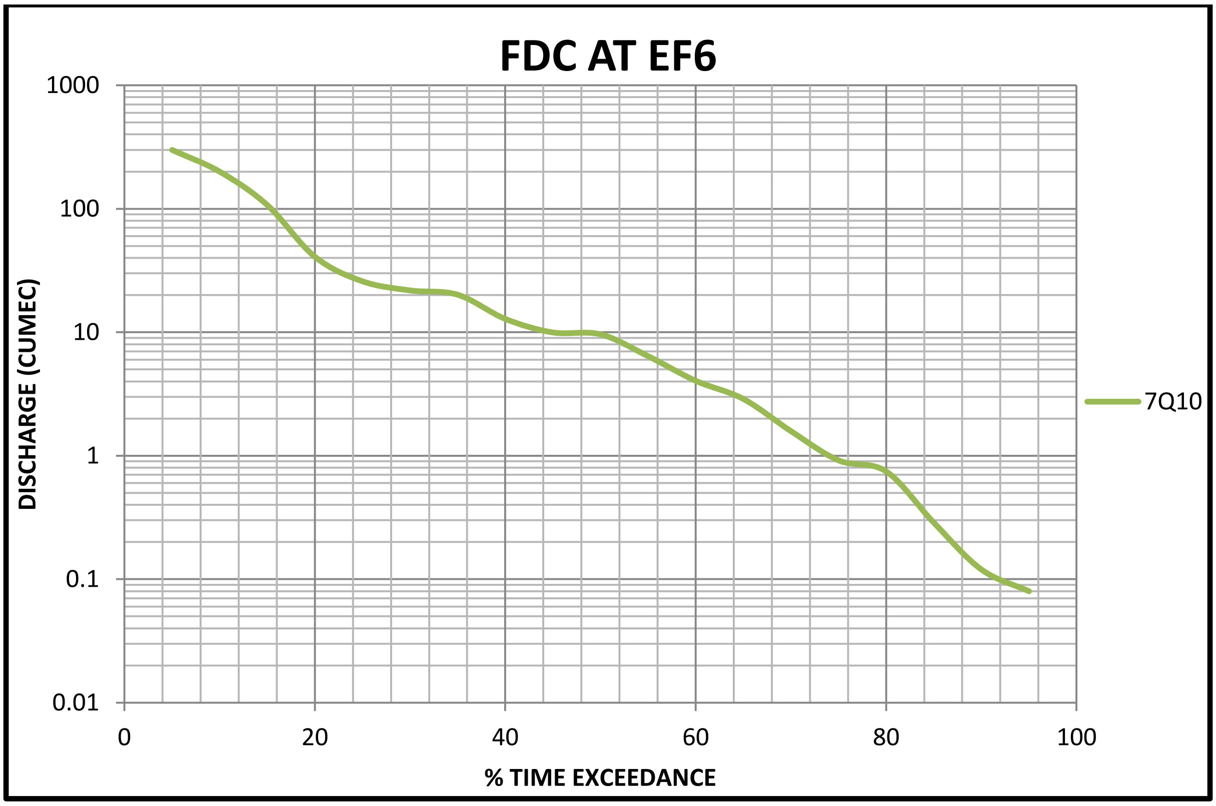


Figure 5.18: Figures showing 7Q10 and comparison of FDC's for EF5

Figure 5.18 shows that after 60th percentile, the FDC's bifurcates from each other, thereby showing there are variations for the low percentiles for all the graphs in the series. However at the 95th percentile, 7Q20 and 7Q10 tends to give almost the same value.



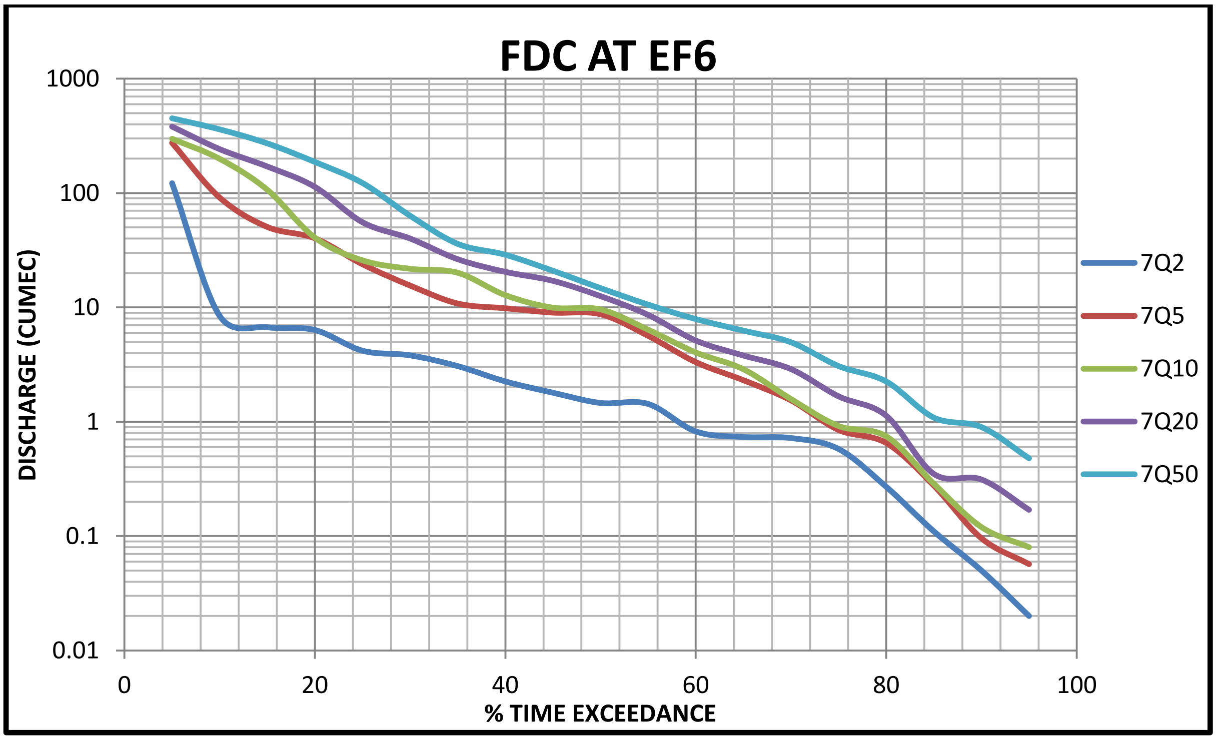
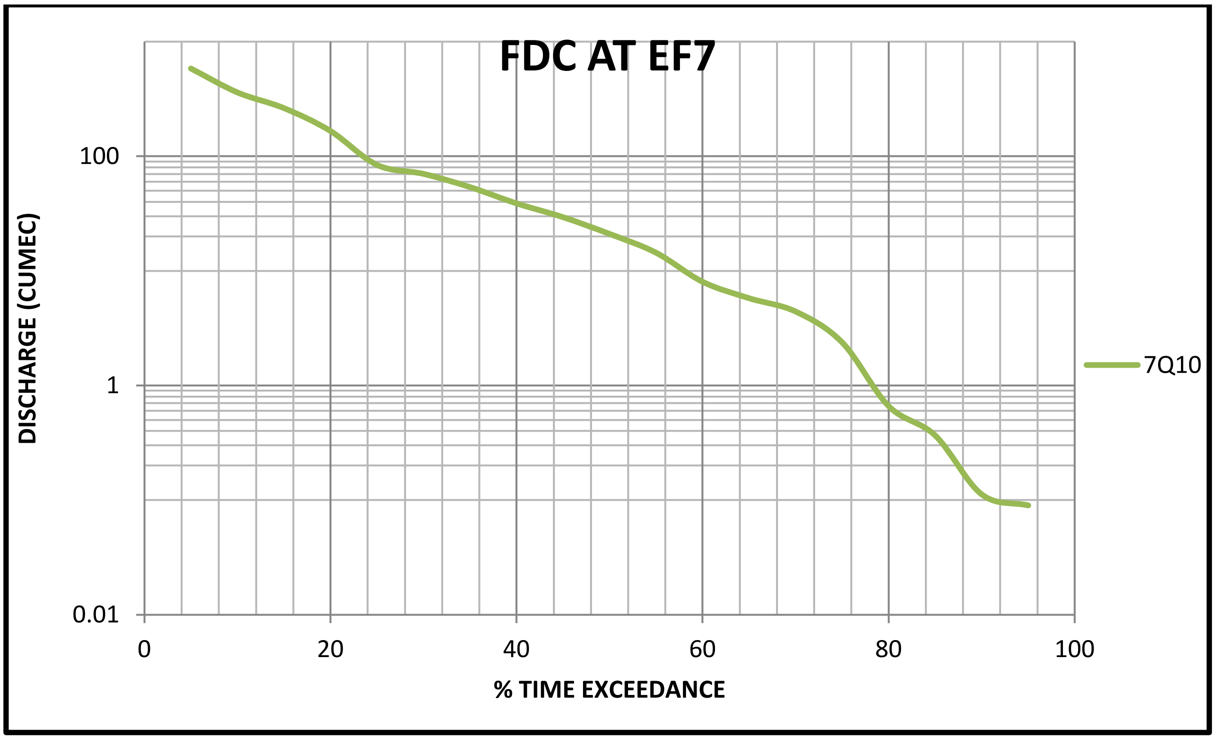


Figure 5.19: Figures showing 7Q10 and comparison of FDC's for EF6

Figure 5.19 shows that the 7Q2 shows a very low flow and very low flow values for every 5th percentile compared to 7Q5. 7Q10 and 7Q5 doesn't show much variation and almost gives nearby values for some distinct points.



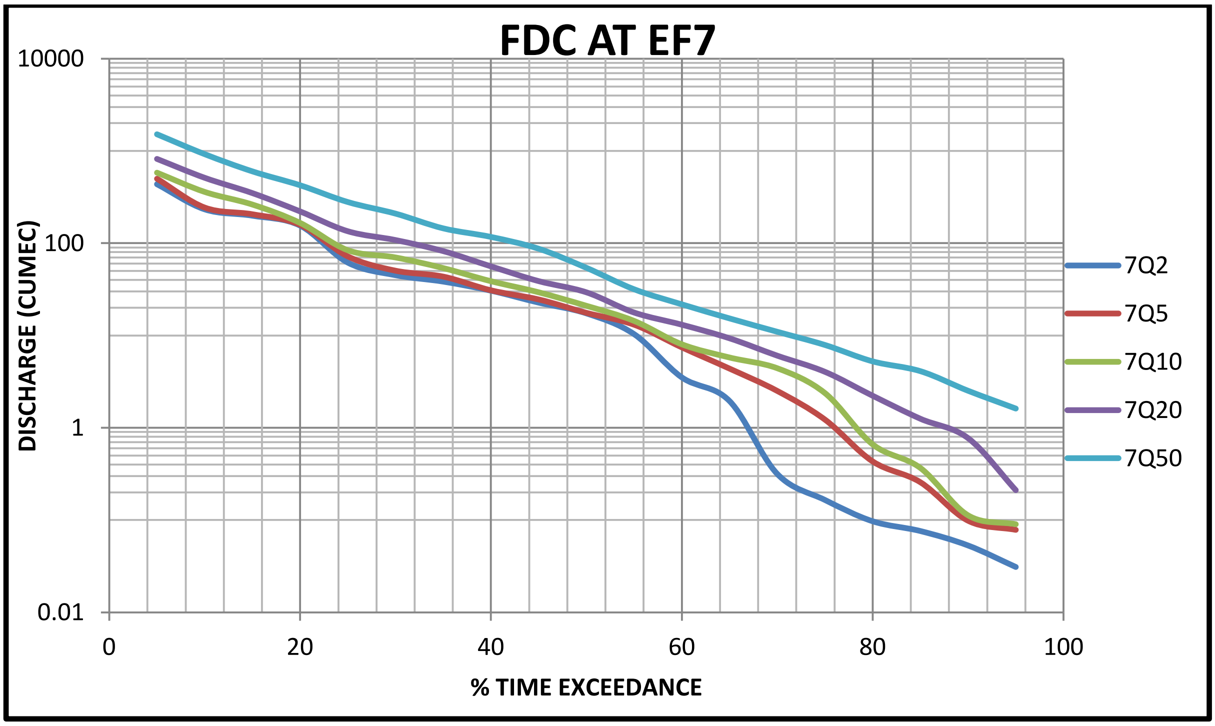
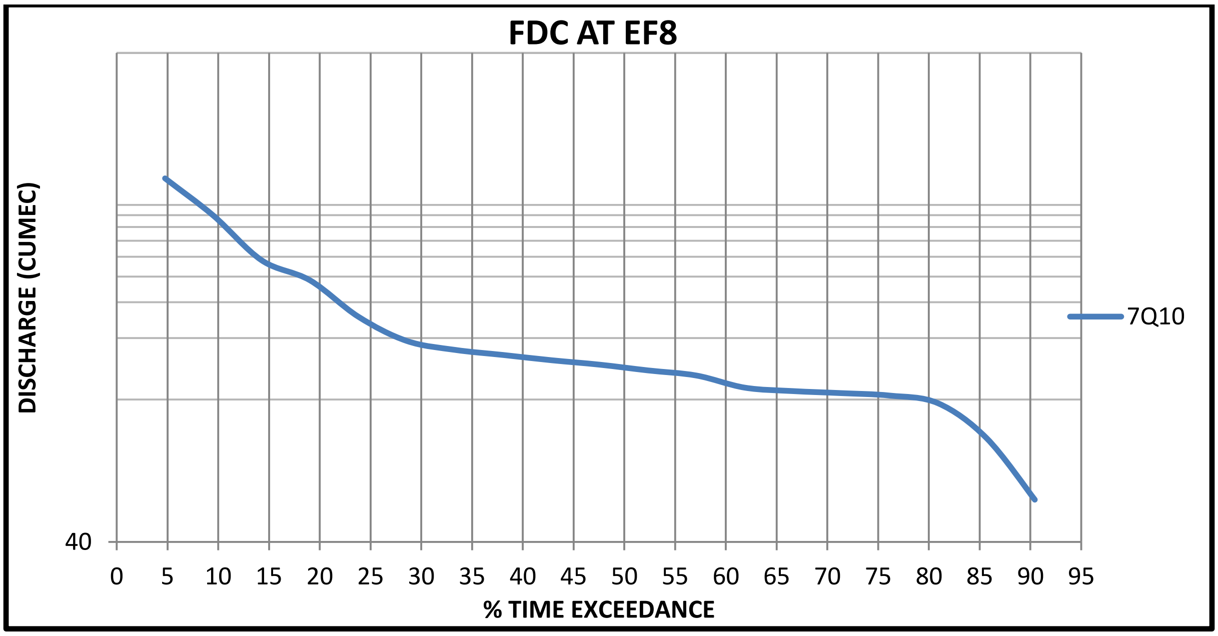


Figure 5.20: Figures showing 7Q10 and comparison of FDC's for EF7

7Q2 shows a large bifurcation from the 55th percentile and it goes downward as shown in the figure 5.20. 7Q2 and 7Q5 were more or less giving values with little variations from 5th – 55th percentile range.



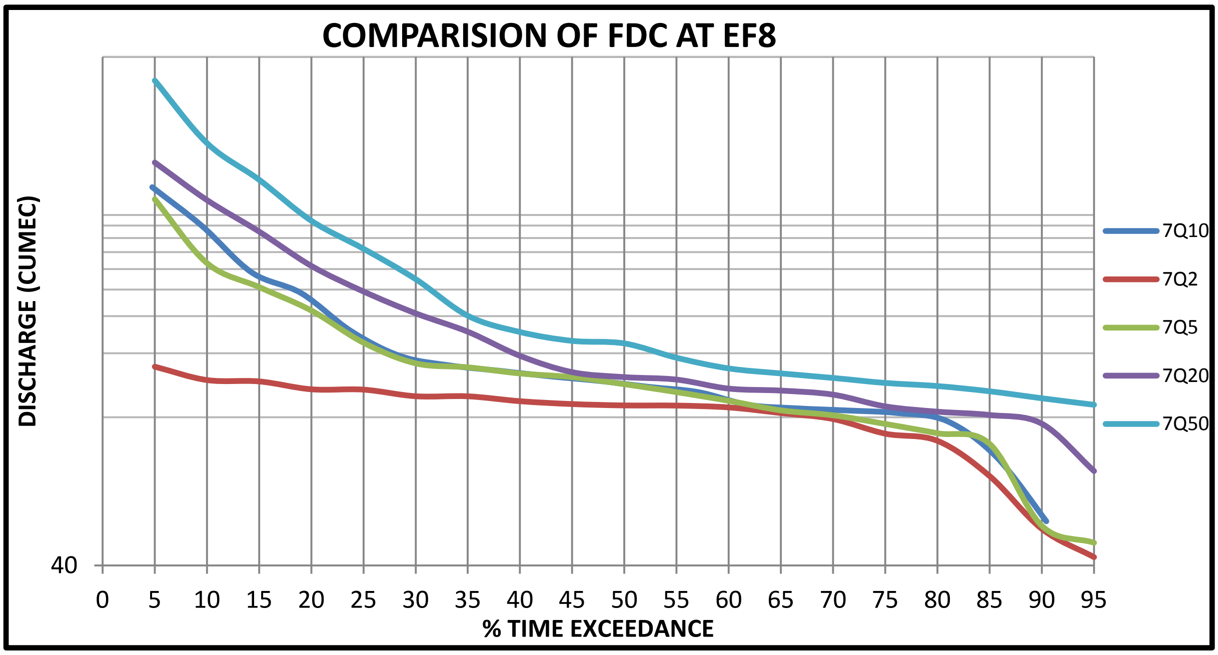


Figure 5.21: Figures showing 7Q10 and comparison of FDC's for EF8

From the above figures 5.14-5.21, it can be seen that the 7Q2 and 7Q5 FDC's give very low flows, which can't sustain all the normal functions of the river basin. In some cases, like figure-5.14 & 5.15, it can be seen that the both FDC's 7Q2 and 7Q5 interchanges their position, which isn't possible theoretically. 7Q20 and 7Q50 gives reasonably high flows, which is not possible for the water managers to maintain every time. Hence, 7Q10 emerges as the best-fit curve among all of the FDC's and further analysis is carried out with 7Q10.

5.4 EMC AND FDC SHIFT (*APPROACH 4*)

In this following approach, station with the largely wavering flow regimes and relatively having the steeply sloping curves, have the lowest MAF in all the classes, whereas the stations with more or less constant flow regimes and having gentle slopes, have the highest MAF in all the classes.

A) EMC AT EF1

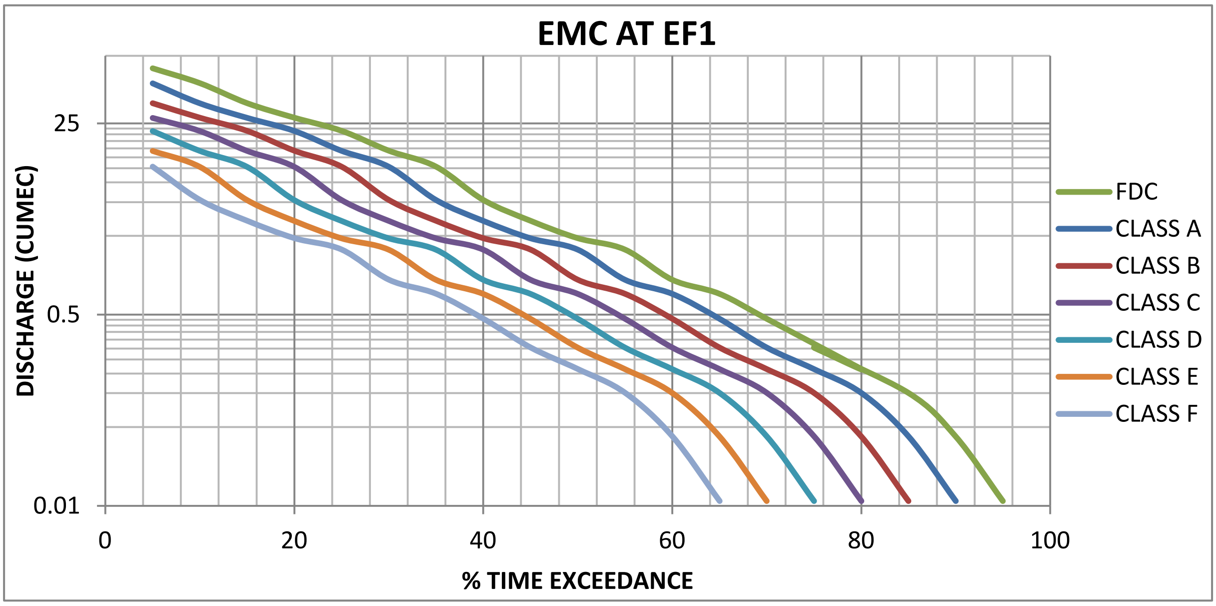


Figure 5.22: EMC at station EF1

B) EMC AT EF2

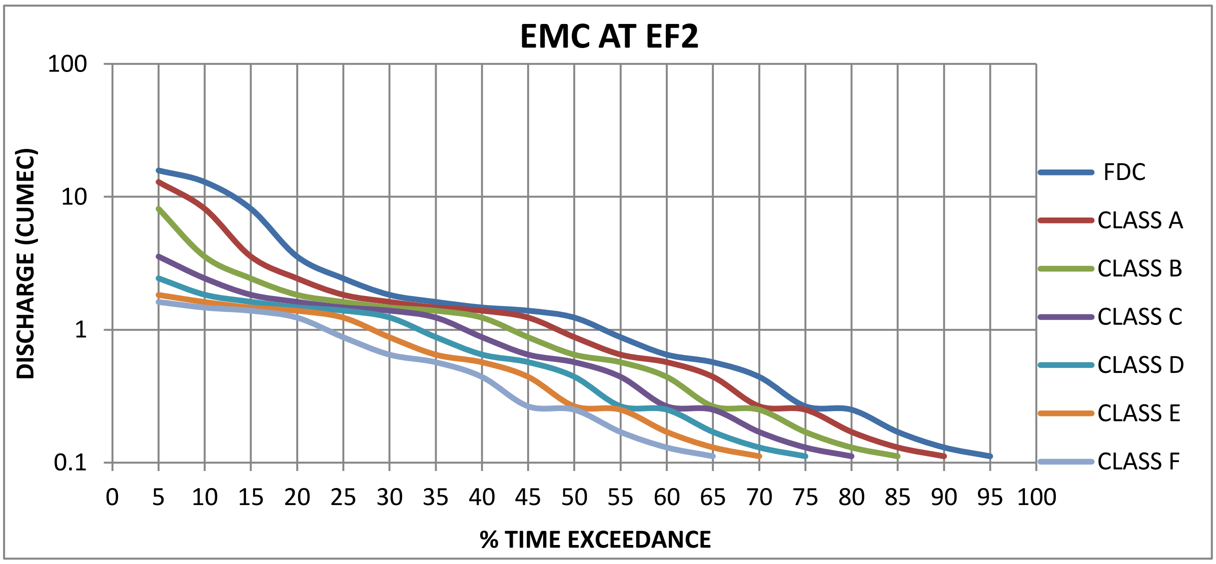


Figure 5.23: EMC at station EF2

C) EMC AT EF3

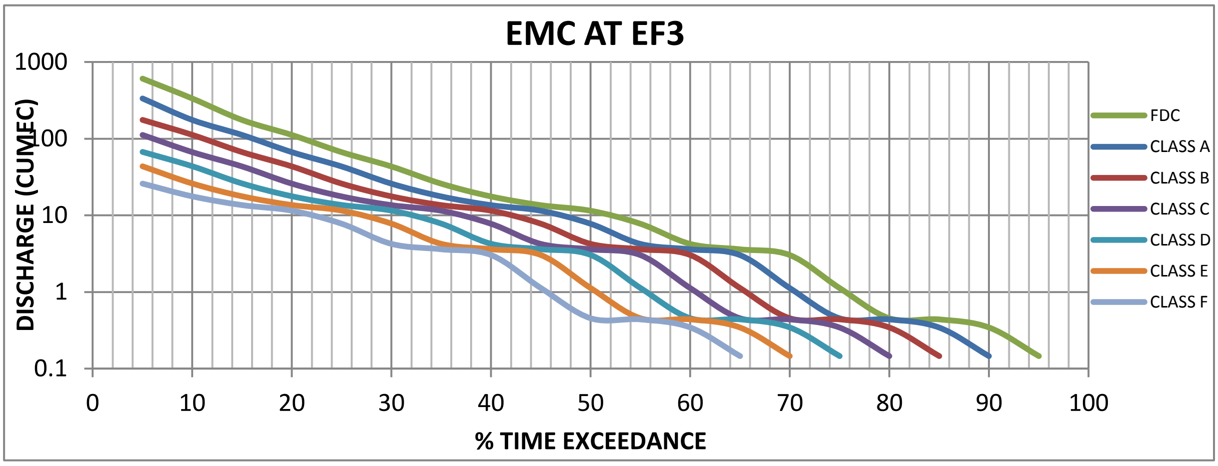


Figure 5.24: EMC at station EF3

D) EMC AT EF4

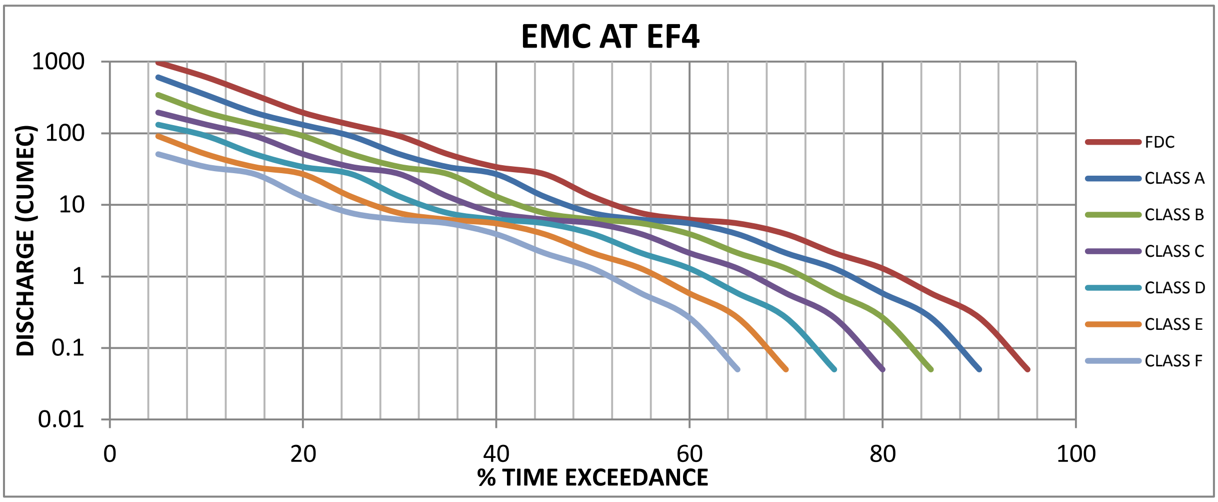


Figure 5.25: EMC at station EF4

E) EMC AT EF5

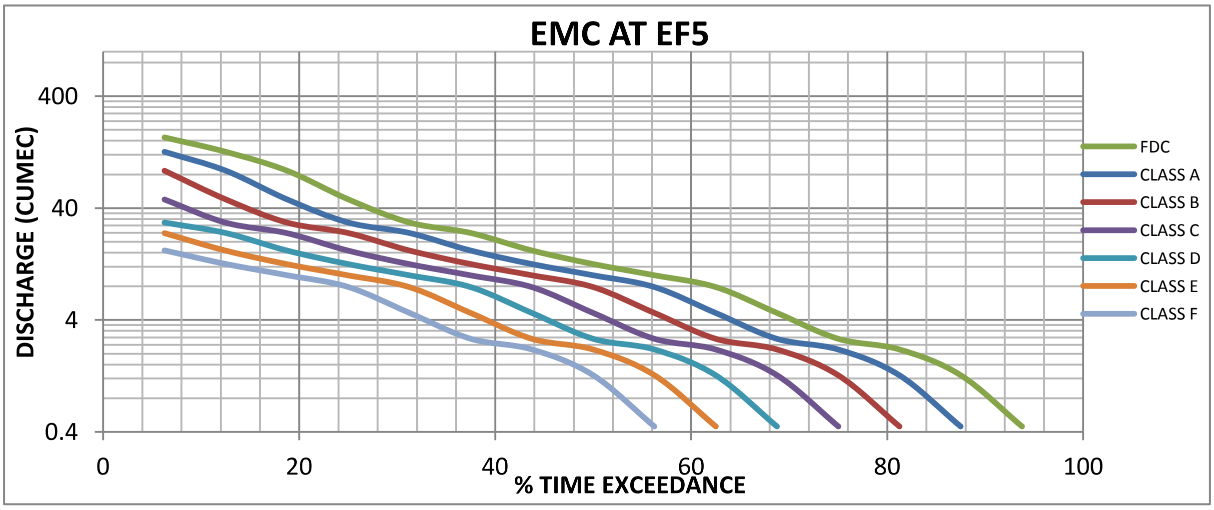


Figure 5.26: EMC at station EF5

F) EMC AT EF6

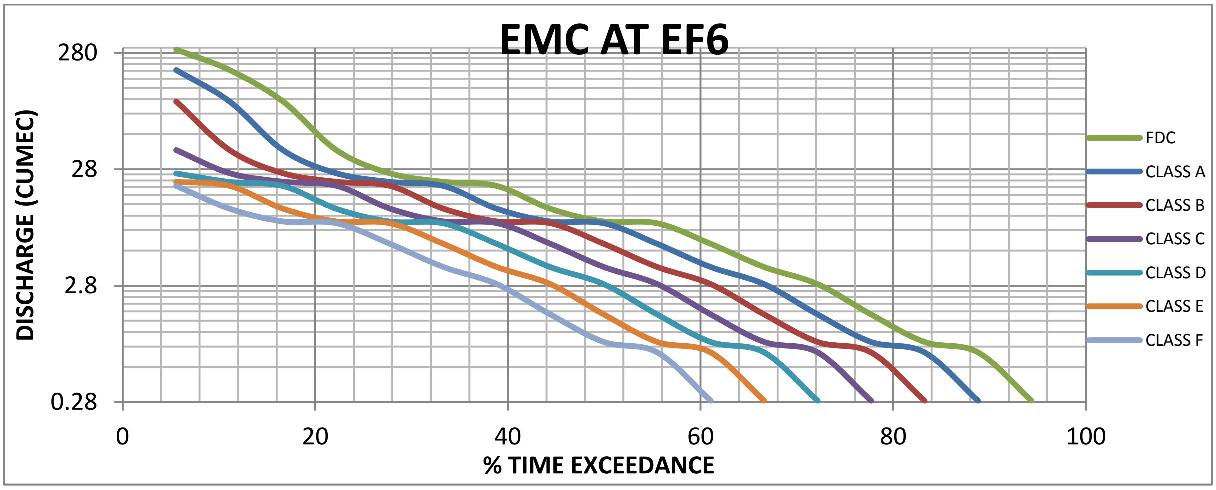


Figure 5.27: EMC at station EF6

G) EMC AT EF7

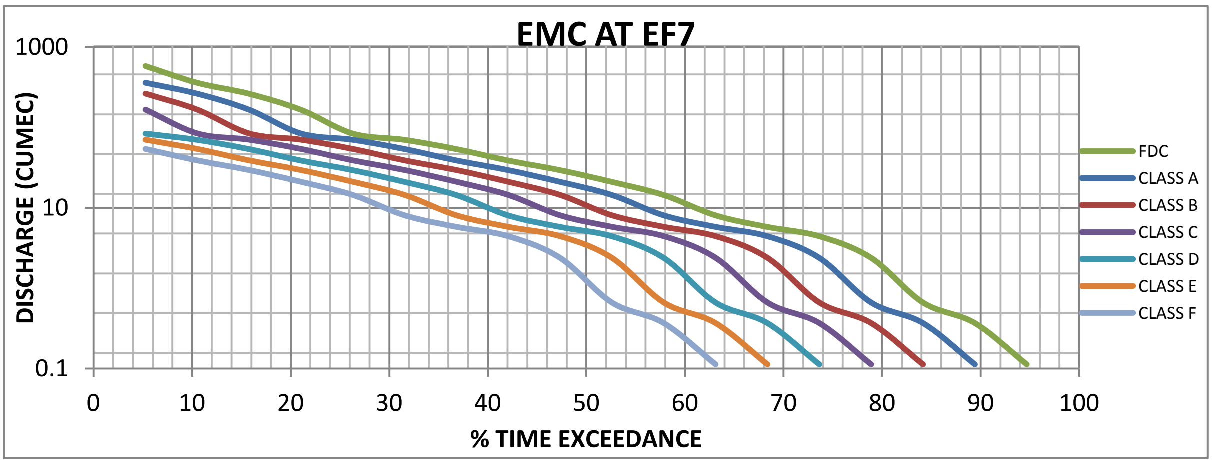


Figure 5.28: EMC at station EF7

H) EMC AT EF8

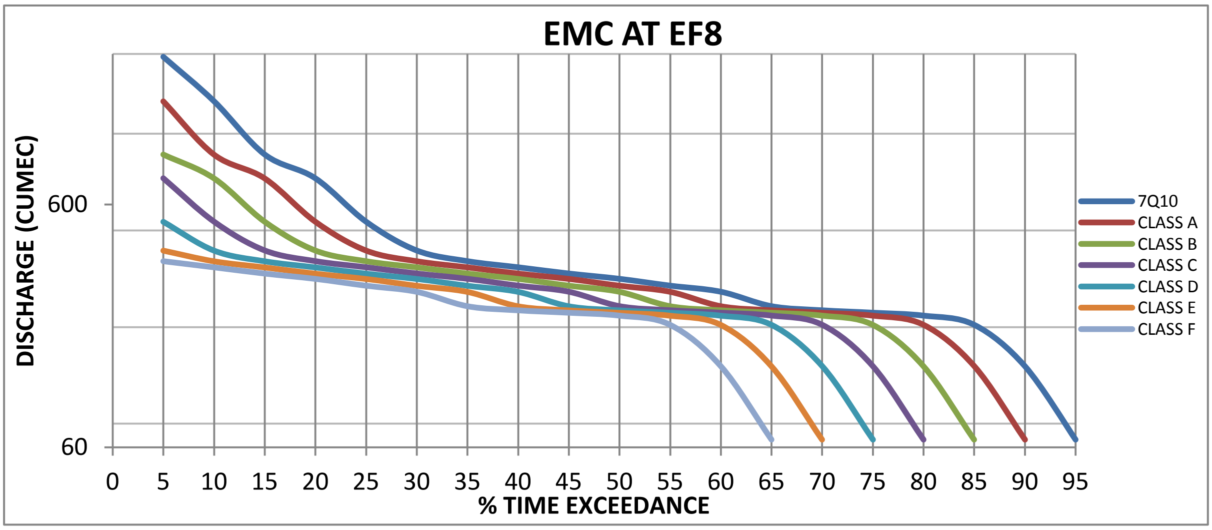


Figure 5.29: EMC at station EF8

The various classification of the EMC are shown in the figure 5.22-5.29 for the various EF stations. On characteristic feature of the estimated EF from the EMC is that the higher the flow variability of a site of the basin, the more steep the slope of the FDC is and vice-versa. The division (classes) of the FDC denotes that the part of variability of flow is lost. It explains that the identical flow will be occurring less repeatedly. Class E and F define if the system is largely or critically modified. If the present flow of the site is analysed, the site can be immediately grouped in the particular environmental class comparing it with the natural FDC. Figure 5.22 and 5.29 shows EF1 and EF8 have a steep slope and hence it shows high flow variability. This EMC method helps us to analyse the flow during the drought season, when the natural FDC can't be applied. An example of the drought year 2008-09 is taken for the station EF2 and compare with this method to observe that which FDC (EMC) generated would serve the purpose.

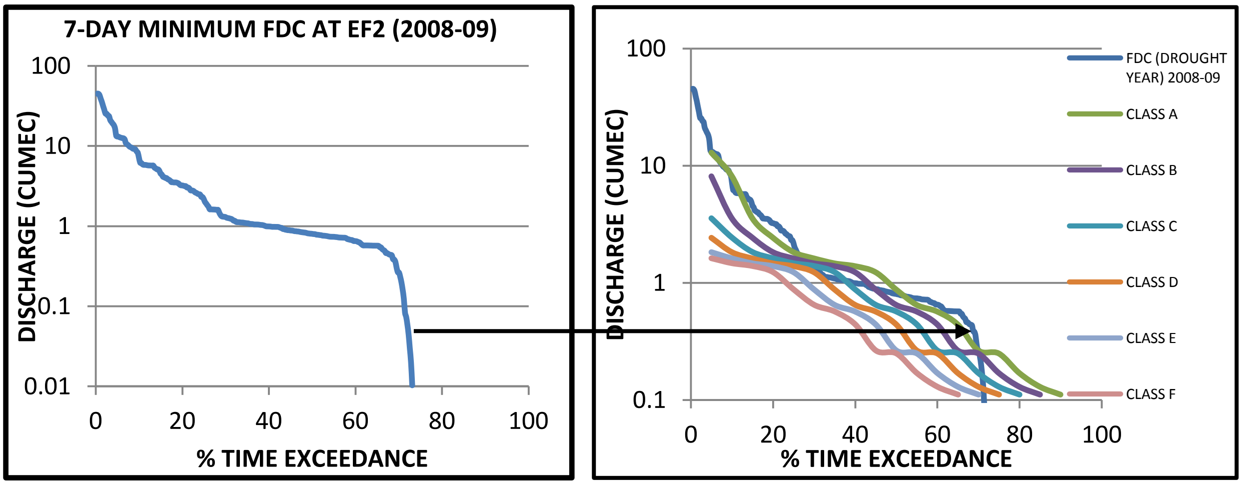


Figure 5.30: Fitting of Drought year FDC of station EF2 to fit the EMC

The above FDC of drought year 2008-09 shows that in the EMC graph, it technically fits in the class D. At 25 percentile, FDC (2008-09) touches class D and then goes up touching class A, but at 70th percentile it shoots down again fitting class D.

5.5 SPATIAL INTERPOLATION METHOD (*APPROACH 5*)

In this method, the drought years for the specific stations are analysed and verified with regression technique. The RVA analysis computing the minimum flow clearly indicates the drift in the flow subjecting to near about zero discharge in some cases is due to the drought season. This method compares the flow values of a particular year with the mean of some preceding years, to analyse if that year was a wet year or a drought year, to cross-check our result and increase the efficiency of our analysis.

Another important characteristics of this method is its used to determine monthly time series of a station (targeted) from a source station. The practice is to relocate the stream flow time series from the position where the data sets are existing, to the targeted site

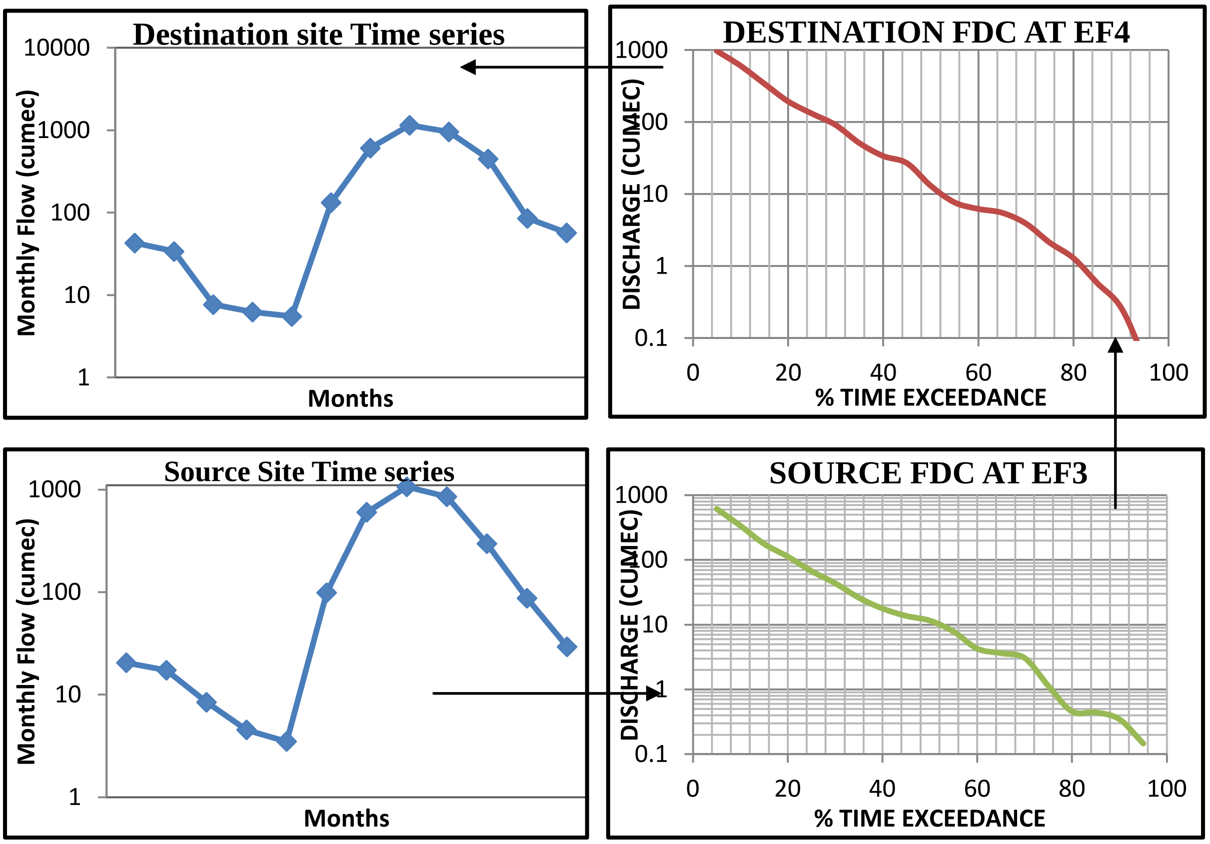


Figure 5.31: Illustration of spatial Interpolation procedure to generate a complete a monthly time series for the destination site EF4

The above figure 5.31 generates the monthly time series for the destination site. For this analysis, only EF3 and EF4 are found suitable for the advantageous location (Figure 3.1). EF4 is the station downstream of EF3, hence it's possible to generate a time series graph of EF4. This method is suitable when the FDC is readily available for the destination station. The different flow values of station EF3 are read and hereafter plotted and compared with the FDC of EF3 (source site). The value of EF3 FDC is then matched with the FDC of EF4 and hence the monthly time series for the targeted station is generated.

Anomalies are incorporated in this spatial interpolation method to analyse a particular year as a wet year or a dry year. A scattered graph is plotted with the observed discharge versus the mean discharge. 2002-03 was a dry year and the discharge values are taken for comparison with the standard mean discharges of the 30 years. If the trend line tends to shift towards the compared discharge (y-axis), then it's a dry year, otherwise it's a wet year.

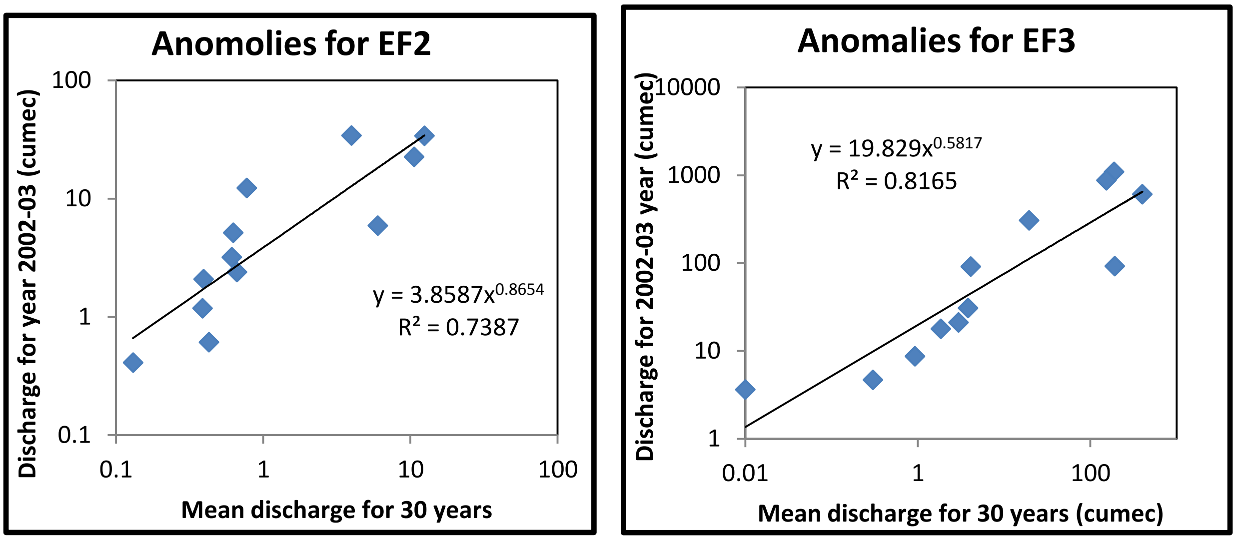


Figure 5.32: Anomalies for EF2 and EF3- analysis of the dry year 2003-03

Both the stations EF2 and EF3 in the figure 5.32 shows that the trend line for the year 2002-03 tends to be more inclined to the y-axis, hence confirming that 2002-03 was a wet year. This is technically similar to **Mean** $\mp$ **SD** i.e Mean (discharge) + SD= Wet year and Mean (discharge) – SD= Dry Year.

CHAPTER-06
CONCLUSION

6.1 CONCLUDING REMARKS

The decided researched area is Mahanadi river basin, which is a basically a rain-fed river with a total of eight gauge stations, covering the entire area of the basin. Five methods are used for the computation of the EF requirements: Tenant, RVA, FDC and low flow duration indices, EMC and FDC shift and spatial interpolation method. The concluding report from the various methods is given below:

❖ Time series plot shows that the observed discharge for the seven stations for 30 years (except Tikarpara- EF8) apart from the monsoon season, is very low.

❖ Tennant method doesn’t give the practical values for both the fair and the minimum flow values for the eight stations. It’s just suitable for the policy makers.

❖ RVA method computes the flow values for various parameters where 7-day minimum plays the best fit role giving 0.12, 0.23, 1.56, 2.25, 0.52, 0.41, 10.36 and 200.08 (m^3/s) for stations EF1, EF2, EF3, EF4, EF5, EF6, EF7 and EF8 simultaneously.

❖ FDC and low flow duration indices suggest that for depicting the low flow, Q95 is the best low flow duration indices which can be used for MRB basin. FDC generated for the eight stations suggests that 7Q10 is the best-fit-curve for the entire basin and serves all the purposes whereas 7Q2, 7Q5 and 7Q20 can be solely applied where the main purpose is habitat maintenance, fisheries and flow limiting condition.

❖ EMC and FDC shift classifies the FDC to be applied for the dry year or wet year, when the basin flow needs to be modified. It’s categorised into six classes. 2008-09 was a drought year and the FDC generated matched with that of the Class D FDC of station EF2.

- Spatial Interpolation method generates the required monthly time series for the station EF4 from the station EF3 with the standardized curve 7Q10 and anomalies for dry year (2002-03) for both the stations EF2 and EF3 are analysed.

Hence from the above research arena, it can be concluded that the 7Q10 (FDC) evolves as the best-fit method for the determination of the EF of the basin. It gives a range of values which satisfies different purpose of the EF of the basin (such as ecological balance, marine ecosystem, flushing away sediments, maintaining riparian habitat etc).

6.2 BEST MANAGEMENT PRACTICES FOR MAINTAINING EF

- Planning is considered as the foundation of environmental watering practise. Water management plan is considered as the main driver action, which guide every policy makers.
- Recognization of the asset and its priority is one of the most important aspect in the field of maintain EF. The important characteristics and the features of the study areas should be studied thoroughly.
- Water revival (savings) is an important infrastructure development and should be well-emphasised and developed to put a step towards an integrated EF management.
- Optimal consumption of small environmental water allotments is a huge step for the drought management.
- State-of-the art methods and tools should be used for computation of EF (for eg. RS, GIS etc.) and continuous monitoring of the river basin should be done.
- Community engagement is an important aspect and environmental policy makers should deal with these efficiently, as public consultancy is very useful.
- Adaptive management should be taken into consideration as to how the riparian environment is effectively managed.

- ❖ Incorporating new knowledge and the water managers should be daily updated about the environmental flow. Quality assessment should be done with the latest technologies and techniques available universally.
- ❖ In many cases it has been seen that the illegal structures and water theft is very common and these prevent the natural regulation of the river. Hence for effective management, illegal structures and various mischievous pilfering should be stopped and uprooted from the grass root level.

6.2 FUTURE SCOPE OF THE STUDY

- MRB is a very big catchment and all the eight gauging stations are either situated near some major cities, where the population is very high and the water requirements are mostly fed directly from the river or near mining areas and major industries, where the pollutants are directly discharged into the river, making the river contaminated if sufficient flow isn't there. High flow pulses can be generated using the tenant method or using the spatial interpolation method for these mining and industrial areas to flush out the pollutants and sediments if they are blocking the flow, endangering the ecological system of the area.
- The outcome of the analysis is very good. These methods can be applied for the different basins across the universe and is independent of the catchment area, with proper amendments of the input parameters. All the five methods are equally flexible and can operate accordingly with the availability of discharge data for different basins.

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APPENDIX

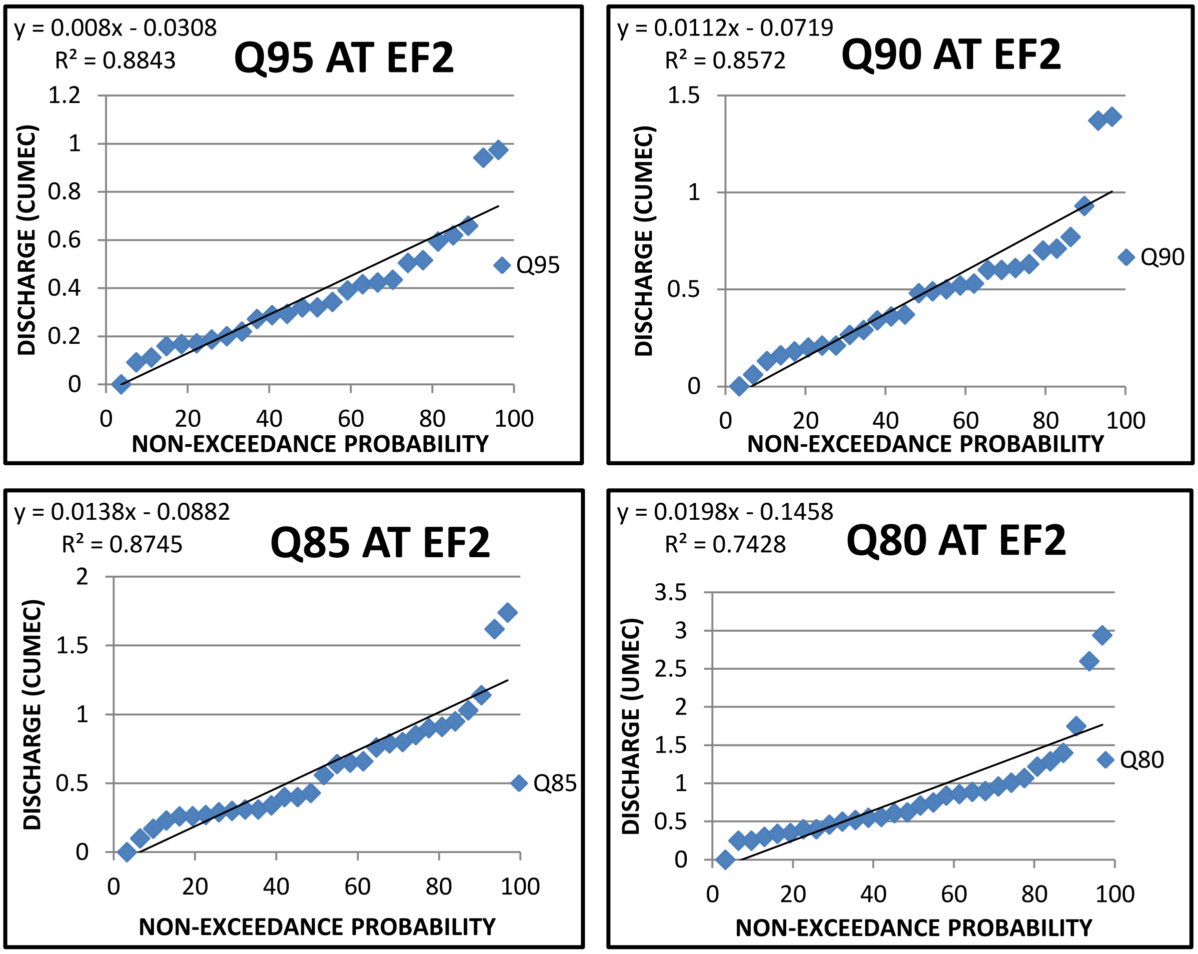
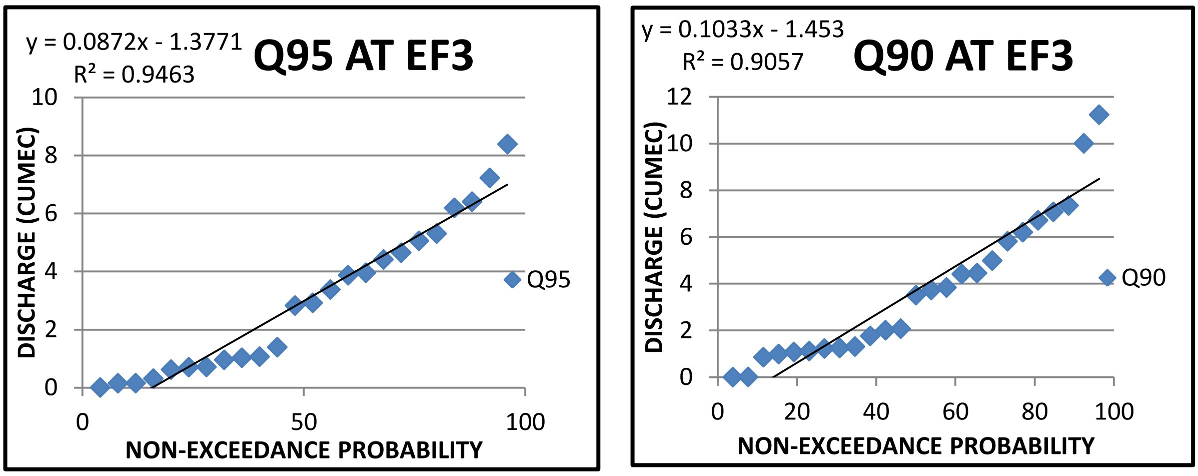


Figure (i): Figures Q95, Q90, Q85 & Q80 low flow indices for EF2



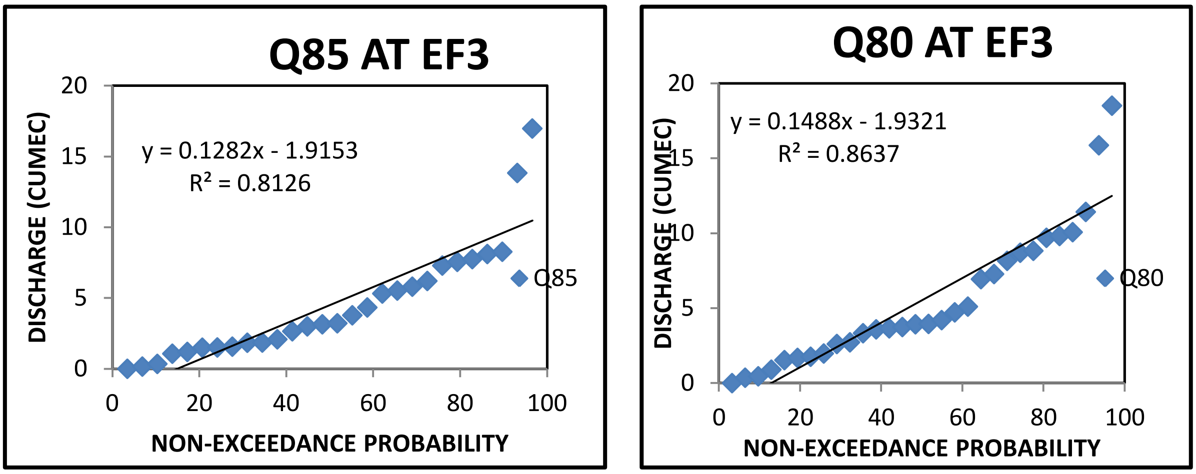


Figure (ii): Figures Q95, Q90, Q85 & Q80 low flow indices for EF3

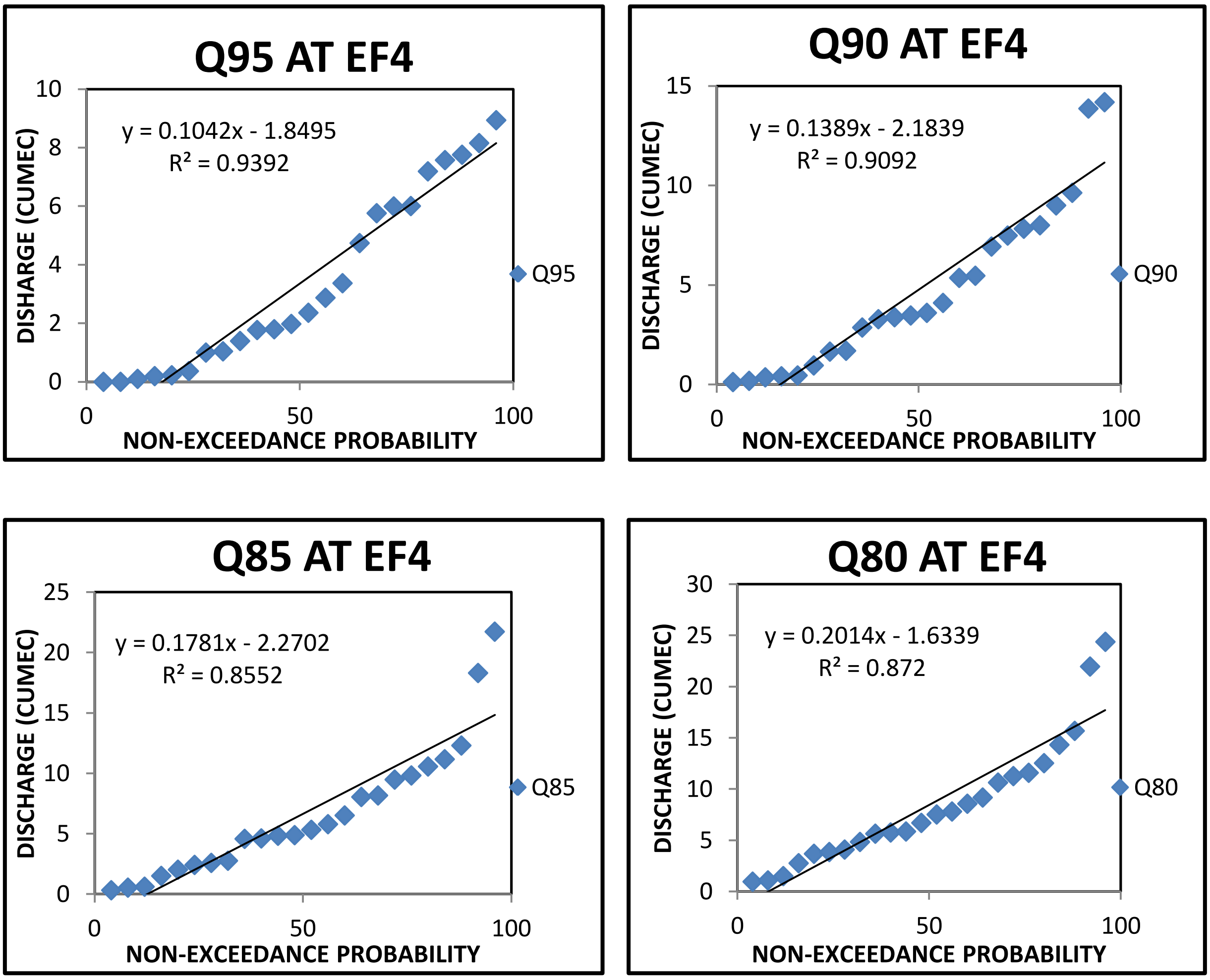


Figure (iii): Figures Q95, Q90, Q85 & Q80 low flow indices for EF4

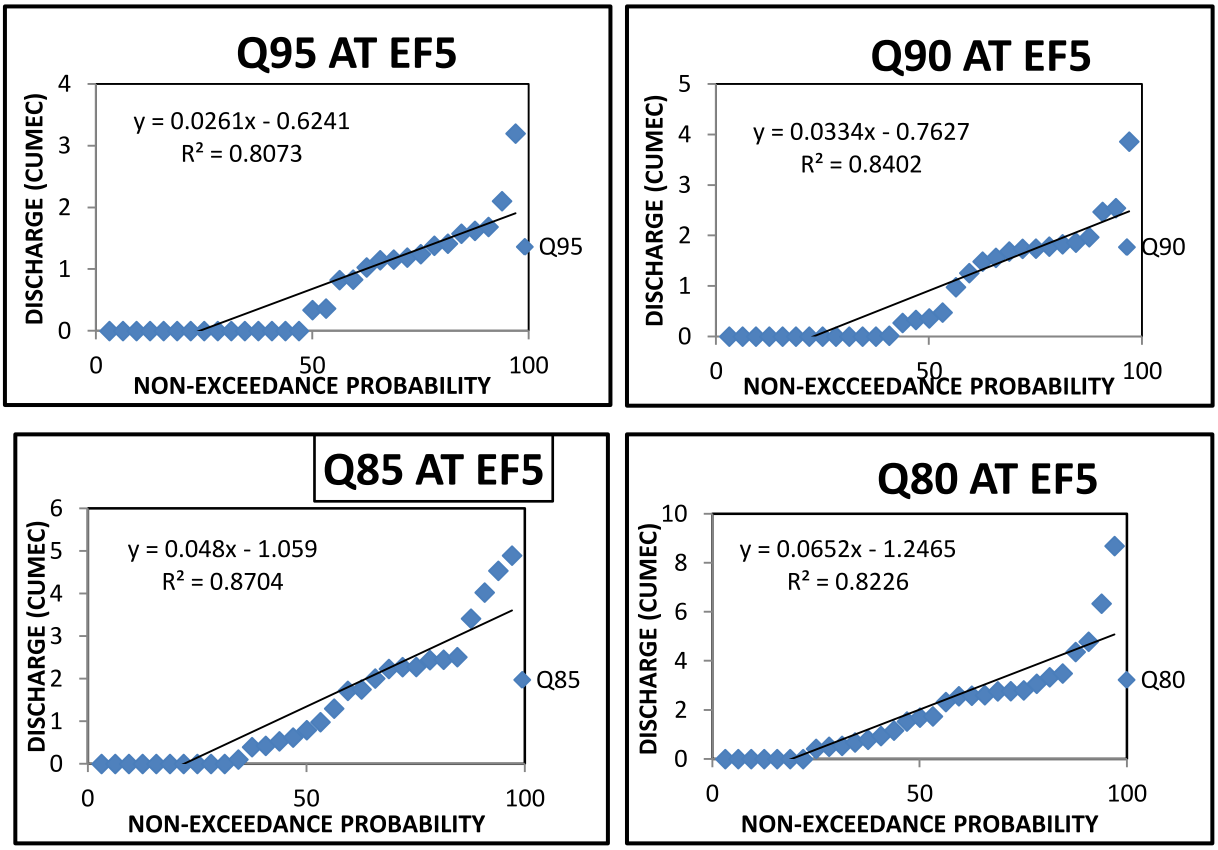


Figure (iv): Figures Q95, Q90, Q85 & Q80 low flow indices for EF5

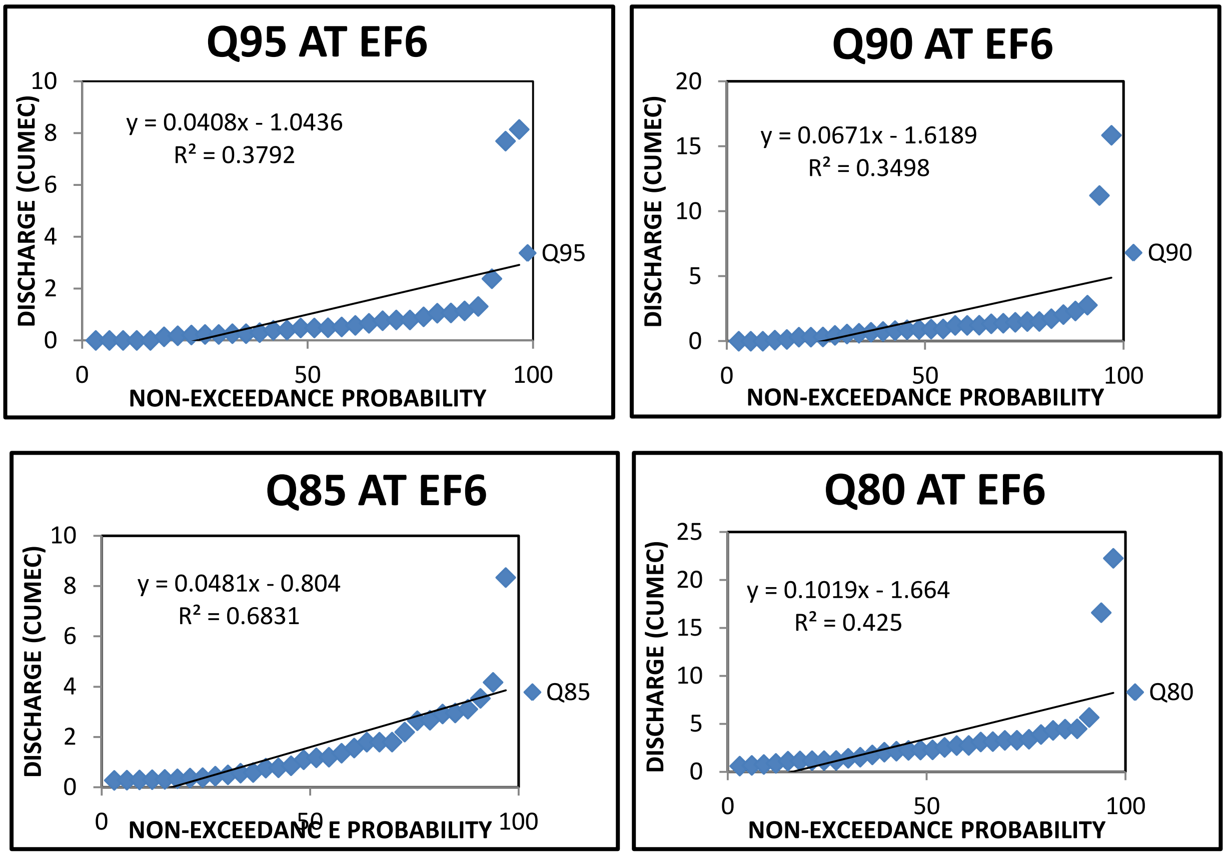


Figure (v): Figures Q95, Q90, Q85 & Q80 low flow indices for EF6

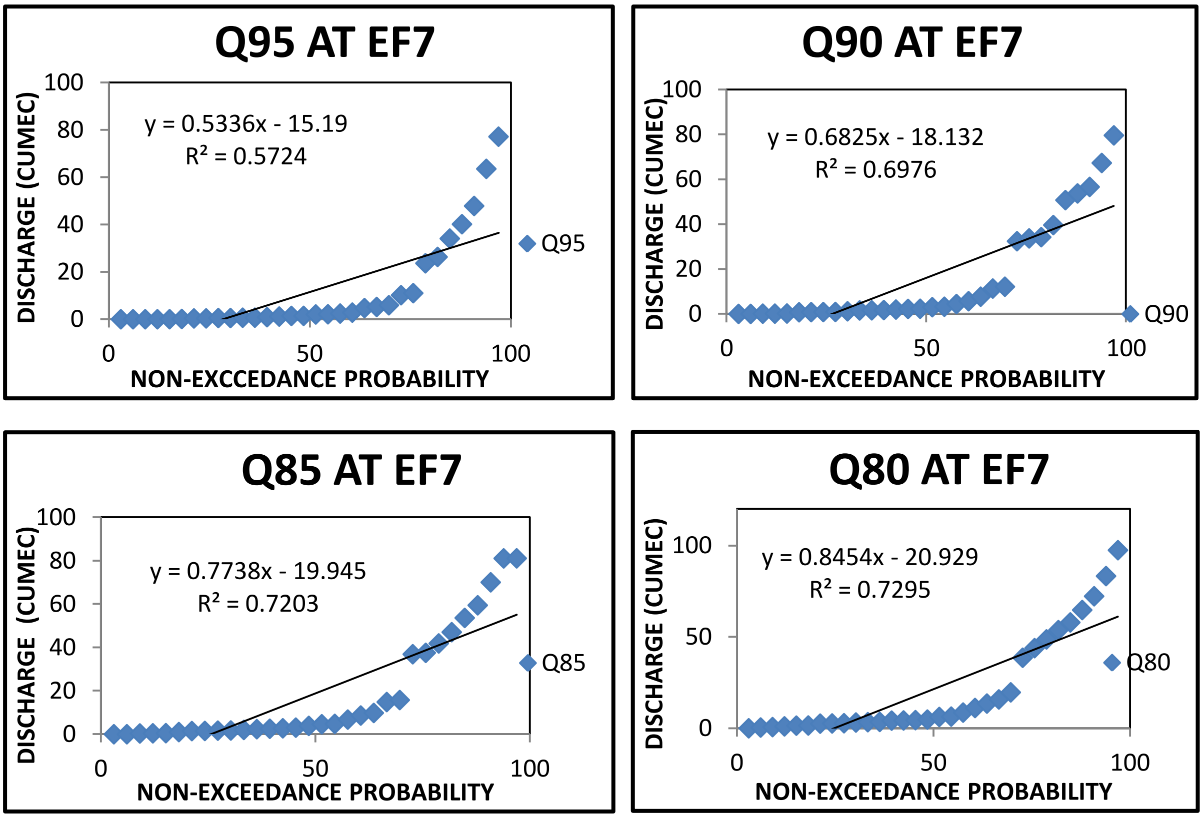


Figure (vi): Figures showing Q95, Q90, Q85 & Q80 low flow indices for EF7

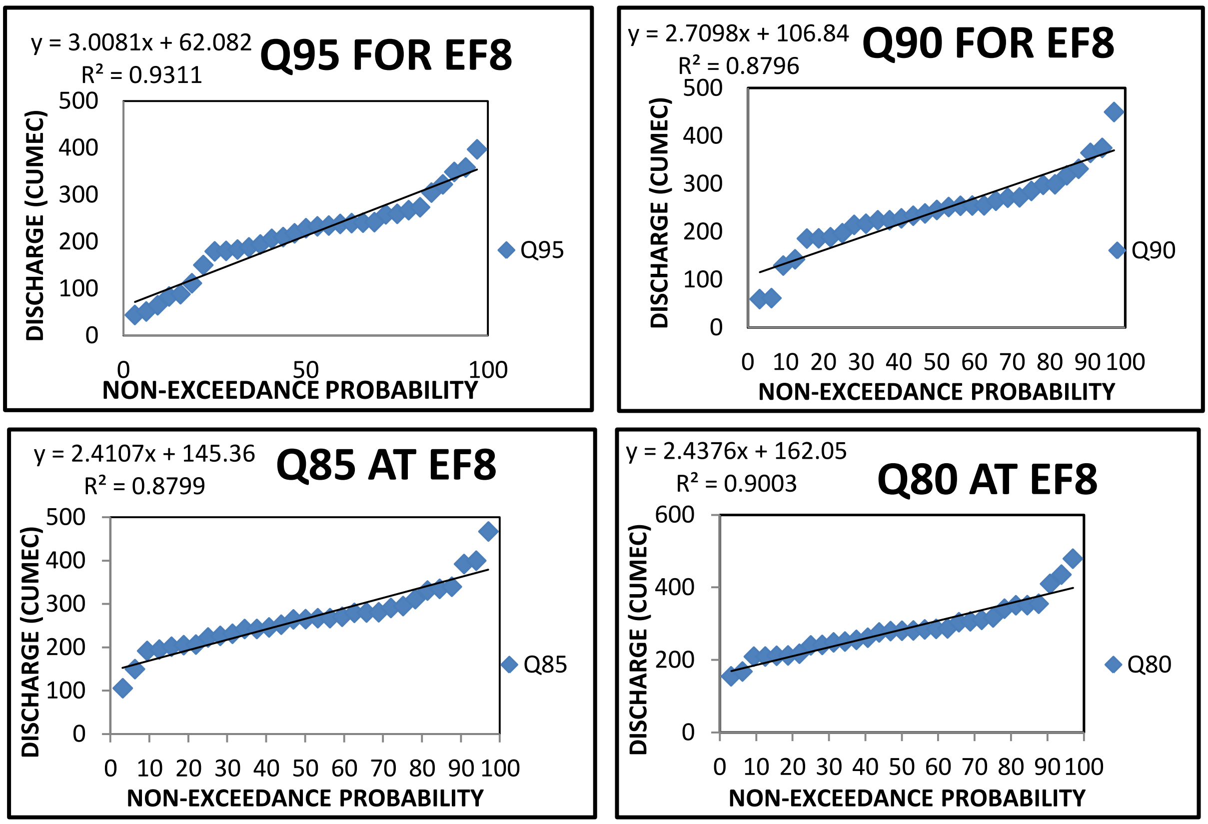


Figure (vii): Figures showing Q95, Q90, Q85 & Q80 low flow indices for EF7