

Impact of Provisioning of E-Flows on Energy Generation

at Some Major Hydro Electric Projects in
Alaknanda-Bhagirathi Basins

By



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1. Introduction

Harvesting hydropower potential is crucial for meeting the energy demands. It is equally, if not more, important to ensure that rivers continue to flow uninterruptedly for sustainable development. Rivers Alaknanda and Bhagirathi are major tributaries of river Ganga. Significant interventions have been done on these rivers to harness hydro power resulting in fragmentation of the rivers and subsequent alterations in the ecosystems.

Alaknanda river originates from Satopanth glacier and Bhagirath kharak Glacier while Bhagirathi river originates from Gangotri glacier. These rivers originate from the Gharwal Himalayas and flows in the territory of Uttarakhand state in India. The physiography of the region suggests that the paths of the flowing rivers have highly variable and steep slopes. The River Bhagirathi with a total length of 217 km up to Devprayag has an average slope of 12.5 m per km, whereas river Alaknanda has an average gradient of 15.5 m per km in her 224 km length up to Devprayag (AHEC, 2011).

At present five hydro electric projects (HEPs), above 25 MW, with installed capacity of 2194 MW have been completed and commissioned on the rivers Alaknanda and Bhagirathi. Maneri-Bhali I HEP (90 MW), Maneri-Bhali II HEP (304 MW), Tehri HEP (1000 MW) and Koteswar HEP (400 MW) are under operation on river Bhagirathi and Vishnuprayag HEP (400 MW) is under operation on river Alaknanda. To bridge the gap between power supply and demand, 53 new power projects are under construction or approved (given Environmental Clearances) with installed capacity of 7255.1 MW (IMG, 2013).

The flow regimes in the rivers Alaknanda and Bhagirathi have been significantly altered due to the construction of barrages and dams. The rivers have been split into many rivulets due to bypass of water through tunnel from barrage site to power house whereas the obstructions create reservoir at upstream side of dams/ barrages. The computation based on detailed reports of power projects shows that the affected stretches in main stem of the river caused by hydropower projects are 8% and 35% of the total length in river Alaknanda and Bhagirathi, respectively. These percentages will significantly increase if projects for which Environmental Clearances has been given are also included. Some of the projects (e.g. Srinagar project) are at very advance stage of construction.

A tradeoff between hydro electric power generation and maintenance of river ecosystems is warranted for sustainable growth. One of the essential conditions for the maintenance of the river ecosystems is to ensure a regime of flows (referred to as

Environmental Flows or simply E-Flows) that will not have significant adverse impact on the structure and functions of these systems. Thus it is necessary to evaluate the impact of provisioning for E-Flows on the estimated hydroelectric energy generation. It is to satisfy this end that the present study was undertaken on Alaknanda and Bhagirathi Basins.

2. Background

2.1. India: Power Scenario at a Glance

Today the electricity is needed by everyone. For any nation it is synonymous of development. According to Central Electricity Authority (GOI) the installed capacity of electricity in India is 225.14 GW as of May 2013. Non Renewable Power Plants comprise 70.16% of the installed capacity and rest 29.83% is of Renewable Capacity. In India the power generation is mainly from Thermal power. Other sources are Hydro power, Nuclear power, Wind power, Solar energy and Biomass energy. The installed capacity of Thermal Power in India, as of 31 May 2013, was 153.19 GW which is 68% of total installed capacity. The second largest source of power is Hydro power. The present installed capacity as of 31 May 2013 is approximately 39.62 GW which is 17.6% of total electricity generation in India (CEA, May, 2013). The estimated hydropower potential in India is 84 GW at 60% load factor.

2.2. Hydropower Potential in Uttarakhand State

Uttarakhand is blessed with hefty hydropower potential. A combination of various factors in Alaknanda and Bhagirathi basins provides a large number of sites for setting up hydropower projects to generate large quantity of electricity with relatively low investments. Some hydropower projects have already been commissioned and many more are either under construction or are planned. For this study hydropower projects with installed capacity exceeding 1 MW have been considered. Uttarakhand has a hydropower potential of the order of 20 GW against which only about 3164 MW has been harnessed (in operation). Hydropower projects under construction and development will add another 7712.5 MW of power to the existing capacity and if all the identified sites are made operational 9563.3 MW of additional power will be added.

2.3. Types of Hydropower Projects

Hydropower projects have been classified based on storage capacity, purpose (single and multipurpose), function (reversible and non-reversible), head (high and low) and size (large, small and micro).

2.3.1 Based on Storage Capacity

The major classification of hydropower projects is based on storage capacity. There are two types of hydropower projects designed, (a) run-of-the-river hydropower projects and, (b) storage based hydropower projects.

a) Run-of-the-River Projects: The run-of-the-river (ROR) projects draw the energy by utilizing the river water directly. In this type storage for short period like 4-6 hours is created and then sent to the power house through the tunnel. Sometimes direct river water goes through the tunnel without creating any storage, when the discharge in the river is greater than the design capacity of the power generating unit. This type is useful to fulfill base load. Figure 2.1 gives schematic representation of such type of projects while Plate 2.1 presents photograph of a typical project of this type.

The ROR project has significant daily, monthly, and seasonal variations. Transmission line from the powerhouse is connected to the nearest transmission system substation. The section of river between the diversion point and the tailrace tunnel coming out from powerhouse is called the 'diversion reach'. The large quantity of water is diverted from this section of river.

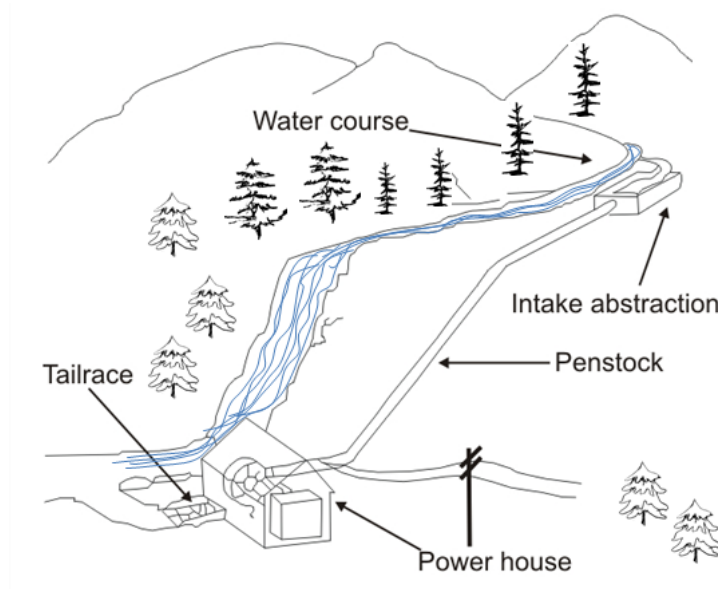


Figure 2.1: Schematic Representation of the Run-of-the-River Project

(Source: www.esru.strath.ac.uk/EandE/Web_sites/0910/Hydro/generation/gencph.html)



Plate 2.1: Photograph Showing Merging of Water Released after Power Generation with River Bhagirathi at Maneri-Bhali I HEP along with Power House and Transmission Lines

b) Reservoir based project: This type of project is proposed to reduce the variability of the river discharge. In this type a reservoir is created by constructing the large dam. The site is selected in a valley so that high head and storage can be obtained. Water flows through penstock at the dam to the turbines for power generation. This type of project is useful for managing peak loads. The excess flow of the river during monsoon would be stored in the reservoir to be released gradually during periods of lean flow. Naturally, the assured flow for hydropower generation is more certain for the storage schemes than the run-of- the river schemes. Figure 2.2 gives schematic representation of such type of projects while Plate 2.2 presents photograph of a typical project of this type.

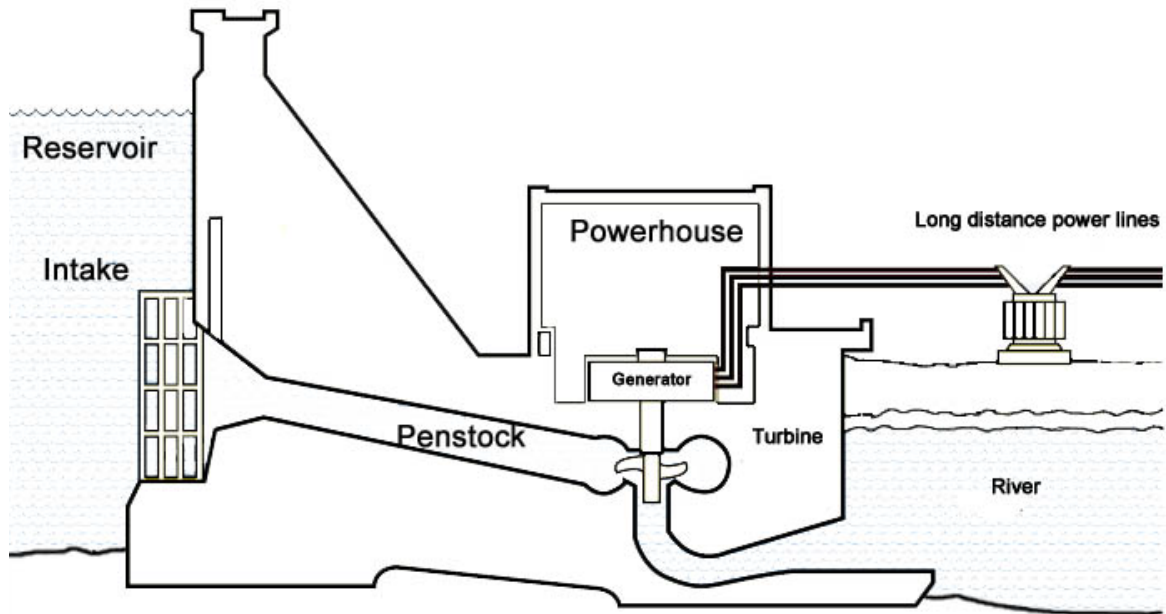


Figure 2.2: Schematic Representation of a Reservoir Type Project (Source- Tennessee Valley Authority)



Plate 2.2: Photograph Showing Downstream View of a Reservoir Based Project at Tehri at the Confluence of Rivers Bhagirathi and Bhilangana

2.3.2 Based on Purpose

Projects are also designed on the basis of their purpose. Some projects are only made for power generation while some are designed for irrigation, flood control as well. For example Tehri dam serves the purpose of irrigation, flood control and power generation whereas Maneri-Bhali II is designed only for power generation.

2.3.3 Based on Function

Projects based on function are categorized as reversible and non-reversible. The non-reversible projects are those in which the water from tailrace is released to the main course of river after power generation. In reversible types of projects water is pumped back to the reservoir in base load duration to generate power in peak load duration (refer Figure 2.3).

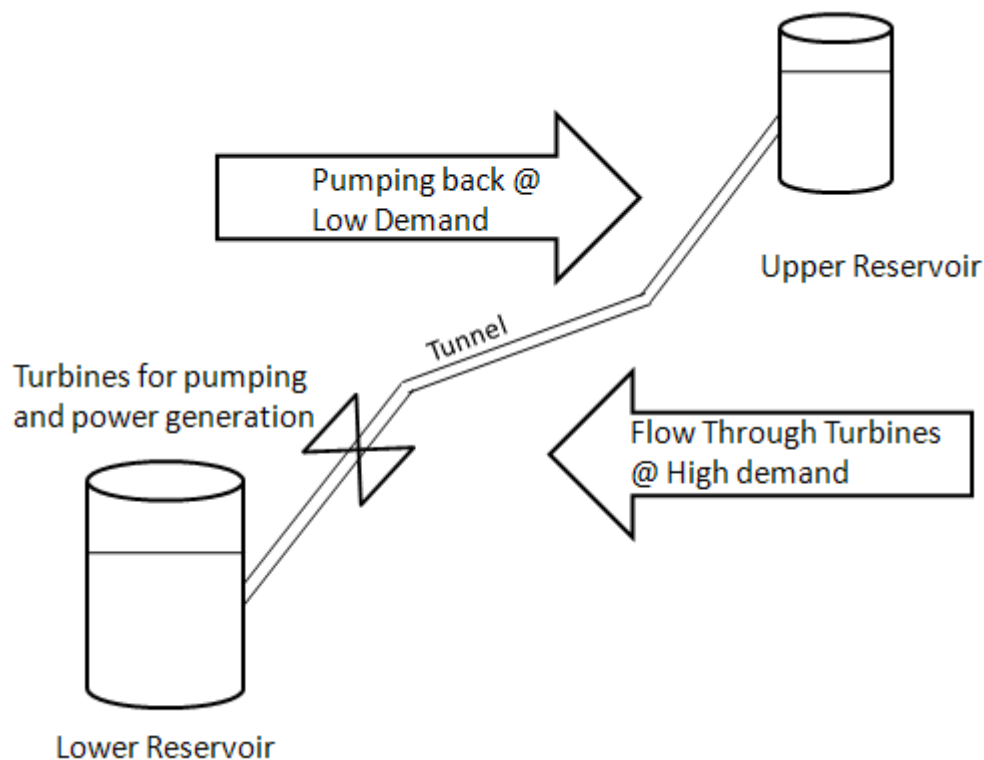


Figure 2.5: Pumped-Storage Hydroelectricity

During lean hours when excess electricity is available in the power grid, the water of the tail-water pond is pumped back into the head-water reservoir. The excess electricity in the grid is usually the generation of the thermal power plants which are in continuous running mode. However during night, since the demand of electricity becomes drastically low and the thermal power plants cannot switch off or start immediately, large amount of excess power is available at that time. It is efficient process and increases the efficiency of the project. This type is now introduced by Uttarakhand government in Tehri stage-2 HEP (1000 MW).

2.3.4 Based on Head

Based on head, the power project is classified into High head and Low head power projects. Projects from 3 m to 20 m come under low head projects. Low head projects are canal based projects and high head projects are tunnel based projects. Mostly run-of-the river schemes come under medium and high head projects (Singhal *et. al.*, 2010).

The major cost in the high head projects is of civil works while in the low head projects both civil works as well as mechanical equipments costs are significant because of high discharge (Singhal *et. al.*, 2010).

2.3.5 Based on Size

Based on size, the power projects are classified mainly in three types, a) large capacity, b) small capacity, and c) micro capacity. According to Department of Energy, India, the power project, with installed capacity, above 30 MW is large, between 100 KW to 30 MW is small and up to 30 KW is referred as micro power project. A micro power project can produce enough energy for a village.

2.4. Hydropower Potential

Electricity from water is usually referred to as Hydro-Power, where the term 'hydro' is the Greek word for water and hydropower is the energy contained in water. In hydropower generation the water is stored at upstream side of the river by providing dams and barrages. The barrages divert the water through tunnel and large turbines convert the kinetic energy of water into electrical energy. All that is required is a continuous inflow of water and a difference of height between the water level of the upstream intake of the power plant and its downstream outlet.

It is assumed that this energy is renewable and has no pollution. However recent researches report that hydropower projects contribute to greenhouse gas (GHG) emissions. All natural or manmade freshwater systems emit GHG due to decomposition of organic material (Cole *et. al.*, 2007).

In order to evaluate the power of flowing water, a uniform steady flow between two cross-sections of a river with H (meters) of difference in water surface elevation can be assumed. For a flow of Q (m^3/s), the power (P) can be expressed as

$$P = \eta \gamma Q \left(H + \frac{v_1^2 - v_2^2}{2g} \right) [Nm/s] \quad [Eq 2.1]$$

Where v_1 and v_2 are the mean velocities in the two sections and η is efficiency of the system. Neglecting the slight difference in the kinetic energy at the two sections, and assuming a value γ of 9810 N/m^2 , expression for power can be written as follows.

$$P = 9810 \cdot \eta \cdot Q \cdot H \text{ [Nm/s]} \text{ or } P = 9.81 \cdot \eta \cdot Q \cdot H \text{ [KW]} \quad [\text{Eq 2.2}]$$

Energy generated can be obtained as follows.

$$E = P \cdot \text{hours} \text{ [KWH]} \quad [\text{Eq 2.3}]$$

The Equation (2.1) gives the theoretical power of the selected river stretch at a specified discharge.

In order to evaluate the potential of power that may be generated by harnessing the drop in water levels in a river between two points, it is necessary to have knowledge of the hydrology or stream flow of the site, since that would be varying every day. Even the average monthly discharges over a year would vary. Similarly, these monthly averages would not be the same for consecutive years. Hence, in order to evaluate the hydropower potential of a site, the following criteria are considered:

1. Minimum potential power is based on the smallest runoff available in the stream at all times, days, months and years having duration of 100 percent. This value is usually of small interest,
2. Lower limits of power potential are computed using 90 % dependable flows,
3. Medium or average potential power generation is computed based on 50 % dependable flows.
4. Mean potential power results by evaluating the annual mean runoff.

2.4.1. Hydropower Potential of ROR Projects

The ROR projects are hydropower plants that make use of the stream flow as it comes without any storage being provided. ROR projects may also be provided with some storage to take care of the variation of flow in the river as for snow-melt Rivers emerging from the glaciers of Himalayas. Generally, these projects would be feasible only on such streams which have a minimum dry weather flow of such magnitude which makes it possible to generate electricity throughout the year. During lean hours of electricity demand, as in the night, some of the units may be closed and the water conserved in the storage space is utilized during peak hours for power generation. However, the potential of annual energy of such hydropower project is estimated on 90 % dependable year.

2.4.2. 90 % dependable year

To define this at least 20 consecutive years of flow data is necessary. A 90% dependable year is a year which has 90% exceedance probability in all years. The flow value in 90% dependable years has taken to calculate the design energy for a hydro-electric project. Water availability will be computed using 10 daily flows. Unrestricted energy generation of these hydrological years is arranged in descending order and exceedance probability computed. Based on the exceedance probability, 90% & 50% dependable years are identified. If discharge data for 'N' years is available, the 90% dependable year is defined as $(N+1)*0.9$ year in the table arranged in descending order. Power planning of the project is done on the basis of annual generation of 90% and 50% dependable years.

3. Literature Review

3.1 General

The present study was initiated to support decision making on hydro electric projects (HEP) in the Alaknanda and Bhagirathi Basin in the state of Uttarakhand. The major issue is to assess the viability of HEP while ensuring that river connectivity and flow regimes that allow rivers to carry out their various functions. The most critical step thus is to assess the appropriate flow regimes to serve various river functions. Such flow regimes are referred as Environmental Flows and hence the review of literature is focused on this subject.

3.2 Environmental Flow – The Concept and Its Rationale

Recognition of the escalating hydrological alterations of rivers on a global scale and resultant environmental degradation, has led to the establishment of the science of Environmental Flows (E-Flows) Assessment, whereby the quantity and quality of water required for ecosystem conservation and resources protection are determined. Several attempts have been made to define E-Flows in rivers.

The 3rd World Water Forum held at Kyoto in 2003 defined E-Flows as the provision of water within rivers and ground water systems to maintain downstream ecosystems and their benefits, where the river and underground system is subject to competitive uses and flow regulations. The E-Flows are thus considered as an amount of water that is kept flowing down a river in order to maintain the river in a desired environmental condition. All of the elements of a natural flow regime, including floods and droughts, are important in controlling the characteristics and natural communities in a river.

The IUCN (2003) defines “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”. The IUCN makes a clear conceptual distinction between the water needed to maintain the ecosystem in near pristine condition, and that which is eventually allocated to it, following a process of a holistic assessment for E-Flows.

Section 5.2.5 of National Environment Policy (2006) of India on ‘Freshwater Resources’ calls for promotion of ‘integrated approaches to management of river basins by the concerned river authorities, considering upstream and downstream inflows and withdrawals by season, interface between land and water, pollution loads and natural regeneration capacities, to ensure maintenance of adequate flows, in particular for maintenance of in-stream ecological values, and adherence to water quality standards throughout their course in all seasons’. This typically sets attributes for defining E-Flows.

Brisbane Declaration (2007) defines E-Flows as 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.

After critical study of various definitions of E-Flows, the consortia of 7 IITs for preparation of Ganga River Basin Management Plan (GRBMP) concludes that environmental flows refer to a regime of flows that mimics the natural pattern of a river’s flow, so that the river can perform its natural functions such as transporting water and solids from its catchment, formation of land, self-purification and sustenance of its myriad systems along with sustaining cultural, spiritual and livelihood activities of the people or associated population. Considering this following definition for E Flows is considered most appropriate and is being adopted.

"Environmental Flows are a regime of flow in a river or stream that describes the temporal and spatial variation in quantity and quality of water required for freshwater as well as estuarine systems to perform their natural ecological functions (including sediment transport) and support the spiritual, cultural and livelihood activities that depend on these ecosystems"

3.3 Overview of E-Flows Estimation Methods

From global experience, the assessment and establishment of E-Flows has significantly contributed to the management of natural resources in a judicious manner. O’Keeffe and Le Quesne (2009) have explained this phenomenon in detail. Some salient points are reproduced as follows for ready reference.

1. The characteristics and ecosystems of rivers are controlled in a very significant way by the flows. A good E-Flows regime mimics all flow variations that are needed to keep the river and all its aspects functioning in a desired condition.
2. E-Flows assessment is both a social and a scientific process. There is no one correct E-Flows regime for rivers – the answer will depend on what people want from a river.
3. E-Flows assessment is based on the assumption that there is some ‘spare’ water in rivers that can be used without unacceptably impacting on the ecosystem and societal services that the river provides.
4. E-Flows are not just about establishing a ‘minimum’ flow level for rivers; it actually considers all the elements of a natural flow regime, including floods, diurnal variations, and droughts, as they are important with respect to silt transport and in controlling the characteristics and natural communities of a river.
5. E-Flows don’t always require an increase from present flows. In some cases, e.g. where low season flows have been artificially increased by inter-basin transfers or releases from dams for hydropower, the E-Flows recommendations may be for lower flows.
6. E-Flows assessments are also very useful to know the environmental requirements before any development plans are made, so that these flows can be factored into the planning process at an early stage.

In order to reach a consensus about E-Flows, people need to have trade-off between river’s natural functions and river’s uses such as (i) growing more crops using its water, (ii) generate electricity, (iii) supply towns with water for domestic and municipal purposes, (iv) national/cultural heritage, e.g. river Ganga in India or river Thames in England. This guides in deciding the desired state of the river. In most cases people want to make use of the water and other resources of the river, so they do not want to keep it entirely natural. Also, in most cases (all cases hopefully) they do not want to turn it into a dry river bed or a drain for wastes. Thus the decision is to choose the state of the river somewhere between natural and completely ruined. This is the role of E-Flows assessment. Further, it is also aimed at keeping at least some of the natural flow patterns along the whole length of a river, so that the people, animals and plants downstream can continue to survive and use the river’s resources. This is essential for sustenance of the river itself as E-Flows are envisaged to sustain various river functions.

Acreman and Dunbar (2004) state that there is no simple figure which can be considered as E-Flows requirement for a river. It is actually related to number of factors: (i) size of the river, (ii) river's natural state, type or perceived sensitivity, and (iii) a combination of desired state of river and in practice, the uses to which it is put. They have classified the E-Flows settings into two distinct categories, where one of them is called the 'Objective Based Flow-Setting' and the other one is 'Scenario Based Flow-Setting'. Both these categories have merits and limitations. The answer to select the appropriate methodology lies in the requirements and aspirations of the people from their rivers. O Keeffe and Le Quesne (2009) also essentially advocate the same concept.

Objective Based Flow-Setting: In certain cases, people intend to have specific pre-defined ecological, economical and social objectives for the river. In such situations objective based flow setting can be adopted. For applying such an approach, the experts have to build a consensus on desired state of river. An example of such an application is from central valley of Senegal River basin, where the objective is to spare 50,000 hectares of floodplain for flood recession agriculture. As approximately, half the flooded area is cultivated, this equates to inundation of 1,00,000 hectares, which require around 7,500 MCM of water to be released from Manantali dam (Acreman, 2003). WWF-India's study on Assessment of E-Flows in the Upper Stretch of river Ganga also considered objective based flow-setting wherein the geomorphologic, ecological, socio-economic and cultural objectives of the river were first established by the expert groups and then river flow regime is established using hydraulic and hydrologic modeling to meet these objectives (WWF-India, 2011).

Scenario Based Flow-Setting: This is basically an alternative to the above one, where the water managers are able to understand and make decision on water allocations and scenarios for trade offs in managing and balancing the water demands/requirements. For instance – Under the Lesotho Highland Water Project, various scenarios of E-Flows releases from dams were considered. For each scenario, the impacts on the downstream river ecosystems and dependent livelihoods were determined (King *et al.*, 2003). These scenarios permitted the Lesotho government to assess the trade-offs presented by different E-Flows options.

3.4 Review of Various Methodologies Developed Across the World for Assessment of E-Flows

As stated earlier, E-Flows are required for (i) maintaining river regimes, (ii) self purification, (iii) maintaining aquatic biodiversity, (iv) groundwater recharge, (v) supporting livelihoods, and (vi) allowing the river to play its role in cultural and spiritual lives of people. In all contexts, determining E-Flows should be an adaptive

process, in which flows may be successively modified in the light of increased knowledge/information, changing priorities, and changes in infrastructure over time.

E-Flows assessment is thus a combination of scientific and social aspects. The scientists can do the best assessment of flow needs, but it won't be implemented unless people know why the flows should be left in the river, and think that it is important to do so. The E-Flows assessment was developed as an eco-hydrological process in the 1970's and 80's. There was a gradual realization in the 1980's that there needed to be a social component to the process – that the stakeholders needed to have a say in the uses and consequent condition of the resource (O'Keeffe, Le Quesne, 2009). But, it wasn't until the 1990's that there has been a full realization that E-Flows assessment is social process with an eco-hydrological process as an essential ingredient.

As the concept of E-Flows has evolved, there has been significant development of approaches to the assessment of E-Flows. There is no one correct E-Flows regime for rivers – the answer will depend on what people want from a river and not just about establishing a 'minimum' flow level for rivers. E-Flows assessments are not just useful on rivers for which the water resources have been developed – it's very useful to know the environmental requirements before any development infrastructure plans are made, so that these flows can be factored into the planning process at an early stage.

Assessment of E-Flows can be referred as to how much water can be withdrawn from the river without disturbing essential flow requirements of the river to an extent that, the specified and valued features of the river and its ecosystem are maintained and not depleted to significant level.

A global review of E-Flows Assessment methodologies by Tharme (2003) reveals that there are more than 200 methodologies, some are very quick modeling or extrapolation methods, requiring no or minimal extra work; others require years of fieldwork and specialists from a number of disciplines. Various E-Flows assessment methodologies can be broadly classified into four categories.

3.4.1 Hydrology-based

Hydrology based methods are confined to the use of existing, or modeled flow data, on the assumption that maintaining some percentage of the natural flow will provide for the environmental issues of interest.

Hydrology based methodologies constituted the highest proportion of the overall number of methodologies recorded with a total of over 60 different hydrological indices or techniques applied till date. Many of such methodologies have become obsolete over time, due to the fact that they are monotonous and there were no provision to integrate other associated aspects, for instance – the ecology, biodiversity, etc.

3.4.2 Hydraulic rating

These methods measure changes in the hydraulic habitat available (wetted-perimeter, depth, velocity, etc.) based on a single cross-section of the river that measures the shape of the channel. This cross-section is used as a surrogate for biological habitat, and allows for a rough assessment of changes to that habitat with changing flows.

Of the 23 hydraulic rating methodologies reported representing roughly 11% of the global total, most of them were developed to recommend in-stream flows for economically important salmonid fisheries in the United States during 1960s and 70s. These methodologies have been superseded by sophisticated habitat simulation and holistic methodologies in the recent years.

3.4.3 Habitat simulation

These are a development of the hydraulic rating methodologies. With these methods, multiple rated cross-sections are used in a hydraulic model to simulate the conditions in a river reach, again based on wetted perimeter, and average depth and velocity of flow. Habitat simulation methodologies ranked second (28%) only to hydrological methodologies at a global scale. There are about 60 such methodologies recorded throughout the world. These methodologies are more popular in the United States.

3.4.4 Holistic methodologies

These are based on the use of multiple specialists in different fields to provide a consensus view of the appropriate flows to meet a pre-defined set of environmental objectives, or to describe the consequences of different levels of modification to the flow regime. Most of these methods make use of (i) a hydrologist and a hydraulics engineer to provide the baseline data on flows and hydraulic conditions, (ii) freshwater biologists for fish, invertebrates, and riparian vegetation to characterize the requirements of the biotic communities, (iii) a geomorphologist to predict the changes in sediment transport and channel maintenance at different flows, (iv) a water quality specialist, and (v) a socio-economist.

Over the period of time, the primitive methodologies are being replaced by more comprehensive holistic methodologies in the UK, Australia and South Africa. While emphasizing the role of multi-disciplinary expert's team in assessment of E-Flows, Acreman and Dunbar (2004) pointed out that, in earlier days, the opinion of one

expert was used to assess E-Flows. However, a better alternative that has gradually replaced earlier methodologies is the use of a multi-disciplinary team, which comes out with E-Flows recommendations, after much needed deliberations and brainstorming. It is largely the holistic methodologies which provide the greater opportunity to have a multidisciplinary team of experts.

The choice of method from the list of various holistic methodologies depends on (a) the urgency of the problem, (b) resources available for the analysis, (c) the importance of the river, (d) difficulty of implementation, and (e) the complexity of the system.

Acreman and Dunbar (2004) state that no single methodology can be considered as the best and all the methods would benefit from further development and refinement. Moreover, the science of E-Flows is still young and much is still to be learnt.

Historically the United States has been at the forefront to develop experiment and exercise various methodologies for assessment of E-Flows. However, in the recent times, other countries like Australia, South Africa, China, England, New Zealand, Brazil, Japan, Portugal, Latin America, Czech Republic, etc. are also involved in E-Flows assessment and establishment.

A closer analysis of various methodologies for assessment of E-Flows suggests that the simpler and primitive methodologies including hydrology based, hydraulic rating and habitat simulation are getting outdated and various holistic methodologies are replacing them as a comprehensive tool for assessment of E-Flows. An investigation of the different methodologies involving a team of experts from various institutes/organizations and with variety of expertise conducted by WWF-India about three years back suggested that holistic methodologies are most suitable for the rivers like Ganga. Holistic methods are not only comprehensive, but also allow consideration of socio-economic and environmental aspects along with scientific and technical aspects.

3.5 Comparative Analysis of various Holistic Methodologies for Assessment of E-Flows

Arthington *et al.* (2004) have given detailed account of various holistic methodologies developed and being applied across the world. For sake of brevity, an attempt has been made to present a comparative analysis of various important holistic methodologies in Table 3.1. Much of the information given in Table 1 has been adopted from Arthington *et al.* (2004).

Table 3.1: Comparative Assessment of Various Holistic E Flow Estimation Methods

S No	Name of Methodology and its origin	Features and Strengths	Limitations
1	Expert Panel Assessment Method (EPAM) (Swales and Harris, 1995). First multidisciplinary panel based E-Flows Methodology developed and used by Department of Water Resources & Fisheries in New South Wales, Australia.	- Low resource intensive - Bottom-up, reconnaissance-level approach - Rapid, inexpensive and site-specific - Requires limited field data - Suitable for sites where dam releases are possible - Aim to address river ecosystem health - Relies on field based ecological interpretations	- Recommendations purely based on opinion of experts and no role of other stakeholders, mainly users - Focused on fish species - No explicit guidelines for application - Subjective scoring approach, so poor congruence in opinion of different panel experts
2	Scientific Panel Assessment Method (SPAM) (Thoms <i>et al.</i> 1996; Cottingham <i>et al.</i>, 2002) Developed during E-Flows assessment for Barwon-Darwin River system, Australia	- Bottom-up, mixed approach i.e. includes field and desktop - Evolved from EPAM as more sophisticated and transparent expert panel approach - Considers other biodiversity actors like – fish, trees, macrophytes, invertebrates and geo-morphology - Incorporates systemic hydro-logical variability and elements of ecosystem functioning - Includes stakeholders panel workshop - Moderately rapid, flexible and resource intensive - Simpler, less rigorous in compared to DRIFT and BBM	- appears limited to single application in Australia in its original form - Highly generalized approach - Requires significant modifications before adopting in other river basins
3	Habitat Analysis Method (Walter <i>et al.</i> 1994; Burgess and Vanderbyl 1996; Arthington, 1998) Developed by former Queensland's Dept. of Primary Industries and Water Resources (now called Department of Natural Resources [DNR]) in Australia, as part of water allocation and management planning initiative.	- Relatively rapid and inexpensive - Basin-wide reconnaissance method for determining preliminary E-Flows requirements at multiple points in catchment - Superior to simple hydrological methodologies - Bottom-up approach, field data requirement is limited or absent - Identifies generic aquatic habitat types existing in the catchment - Determines flow related ecological requirement of each habitat	- Inadequate for comprehensive E-Flows assessment - Little consideration of specific flow needs of individual ecological components - Requires standardization of process - Represents simplified version of holistic approach and largely superseded by Benchmarking Methodology

4	Benchmarking Methodology (Brizga <i>et al.</i> 2001, 2002) Developed in Queensland by local researchers and DNR in Australia, to provide a framework for assessing risk of environmental impacts due to water resources development at basin level	- Rigorous and comprehensive - Scenario based, top-down approach for application at basin level - Uses field and desktop data for multiple river sites - Assesses ecological conditions and trends - Includes formation of multi-disciplinary expert team and development of hydrological model for catchment - Defines link between flow regime components and ecological processes - Presents a comprehensive benchmarking process and transparent reporting system	- No explicit consideration of social aspects - Requires evaluation of several aspects including – (i) applicability and sensitivity of key flow statistics, (ii) degree to which benchmarks from other basins/ sites within basins are valid considering differences in river hydrology and biota - Doesn't provide the room to integrate other local significant aspects like cultural and spiritual ones
5	Environmental Flow Management Plan Method (FMP) (Muller 1997; DWAF 1999) Developed in South Africa by the Institute for Water Research, for use for intensively regulated river systems	- Simplified bottom-up approach - Applicable in highly regulated and managed river systems with considerable operational limitations - Workshop based - Multidisciplinary assessment including ecologists and system operators - Determines current ecological status and desired future state	- Limited scope for applicability as structure and procedures for application are not formalized and well documented - No provision of evaluation, so limited applicability - Not replicable as the methodology is marred with uncertainties
6	Downstream Response to Imposed Flow Transformations (DRIFT) (King <i>et al.</i> 2003; Arthington and Pusey, 2003) Developed in South Africa with inputs from Australian researchers as an interactive scenario based holistic methodology	- Rigorous, top-down, well-documented approach - Scenario based approach with interactive scenario development - Appropriate for comprehensive exercises for assessment of E-Flows - Mix of biophysical, economical and sociological approach - High potential for application in other aquatic ecosystems - Amendable to simplification for more rapid assessments	- Provides limited consideration for synergetic interactions among different ecosystem components - Requires significant documentation of generic procedures - Limited inclusion of flow indices describing system variability

7	Flow Restoration Methodology (FLOWRESM): (Arthington <i>et al.</i> 1999; Arthington <i>et al.</i> 2000) Developed in a study of the Brisbane river in Queen-sland, Australia.	- Suitable for river systems exhibiting a long history of flow regulations and requiring flow restoration - Preliminary bottom-up, field and desktop approach - Emphasize on identification of the essential features that need to be built back into the hydrological regime to shift the regulated system towards the pre-regulation state - More rigorous than expert panel methods - Include flexible top-down process for assessing ecological implications of alternate modified flow regimes	- Risk of inadvertent omissions of critical flow events - Requires significant documentation of generic procedures - Single application in Australia till date
8	Flow Events Method (FEM): (Stewardson and Cottingham, 2002) Developed in 'Australian Cooperative Research Centre for Catchment Hydrology' to provide state agencies with a standard approach	- Top-down method for regulated rivers - Based on empirical data and expert judgment - Integrates existing analytical techniques and expert opinion to identify vital aspects of flow regime - Assesses ecological impacts of changes in flow regimes - Specifies E-Flows rules and targets - Optimizes flow management rules to maximize ecological benefits within the constraints of existing WRD schemes	- Limited application in other river basins, so far applied in Australia only - No consideration of an associated expert panel
9	River Babingley (Wissey) Method: (Petts <i>et al.</i> 1999) Developed for application in groundwater dominated rivers in Anglian region of England	- Bottom-up field and desktop approach - Uses hydro-ecological, habitat and hydrological simulation tools to assist in identification of E-Flows - Allows for flexible examination of alternate E-Flows scenarios - Includes provision for both drought and wet year conditions - Considers biota	- loosely structured approach with limited explanation of procedures for integration of multidisciplinary inputs - Specific to base E-Flows dominated rivers - Requires further research in intricate basins - Wider application is very limited

10	Building Block Methodology (BBM) (King and Louw 1998; King <i>et al.</i> 2002) Developed in South Africa by local researchers through applications in numerous water resources development projects to address E-Flows requirements for entire riverine ecosystems under conditions of variable resources. Adapted for intermediate and comprehensive determinations of the ecological Reserves under the new South Africa Water law.	- Rigorous and extensively documented - Manual and case studies available - Perspective bottom-up approach with interactive scenario development - Takes account of number of sites within the critical stretch of the river - Well established socio-economic component - Flexible to accommodate other local aspects, like religious and spiritual requirements (hence applicable for Indian rivers) - Functions well in data-rich and data-poor situations - Multidisciplinary approach with continuous deliberations/ workshops among various experts - Designed to provide specific pre-defined river condition - High potential for application to other aquatic ecosystems - Links to external stakeholders and public participation processes - Less time and cost intensive in comparison to DRIFT methodology - Applicable to regulated and non-regulated river regimes - Globally, most frequently used methodology - Adopted as a standard methodology for South African Reserve determinations	- Moderate to highly resource intensive
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In the recent times, as the science of E-Flows has gained significant impetus, the viability and acceptability of various methodologies is being contested. Therefore, there has been changing pattern in the preferences for adoption of methodologies for E-Flows assessment. As a result of this, the researchers, practitioners, academicians and people from the civil society has apparent inclination towards various methodologies falling under the category of 'holistic' ones, for the simple reason that, the methodologies under this category have a comprehensive approach and takes into consideration various associated aspects of a river regime and not only the hydrology and hydraulics. In a nutshell, the process of development of various E-Flows assessment methodologies is an evolutionary one, where a specific methodology takes lesson from previous methodologies and in the process the methodology under consideration gets refined.

3.6 International Practices

The international practices like 10% method, France method and 75% of Q95 methods are majorly adopted schemes for rivers. According to the IMG Report (2013) the criteria selected by different courtiers are as follows

- a) In France, the Fresh Water Fishing Law (1984) stated that residue flows in bypassed section of river must be a minimum of 1/40 of the mean flow for existing schemes and 1/10 of the mean flow for new schemes.
- b) In U.K., the flow with 95% exceedance probability has been adopted to maintain the continuum of the rivers in 'Natural and Healthy Condition'.
- c) In USA the Tennant or Montana method is specified in which 10%, 30% and 60% of the mean flow are specified for the poor quality, moderate and excellent quality habitat, respectively.
- d) In South Africa, Hughes and Munster (2000) and Hughes and Hannart (2003) developed a method by using coefficient of variation of flows (CV) and base flow index (BFI). They defined a hydrological index which is a ratio of CV and BFI. To assess the E-Flows, a relationship between hydrological index and percentage of mean annual runoff (MAR) is used.

3.7 E-Flows in India

In India, the concept is very new and evolving. However, some agencies have attempted to assign some fraction of flows or some minimum flows as E-Flows. For example Himachal Pradesh State Environment Protection and Pollution Control Boards have fixed 15% of lean season flow as E-Flows. UJVNL, Uttarakhand has fixed the E-Flows as maximum of, either 10% of minimum discharge or 0.3 cumecs for Himalayan Rivers.

The Water Quality Assessment Authority (WQAA, 2007), GOI has used 'Modified Tennant Method' to assess E-Flows for Indian Rivers. The E-Flows for Himalayan river is 2.5% of the 75% dependable annual flow in the river in lean season and in monsoon season it is 250% of the 75% dependable flow in cumecs. For other than Himalayan rivers, the E-Flows is fixed at minimum flow of 10 daily flows with 99% exceedance probability of the measured flow. In case of non-availability of 10 daily flows the E-Flows would be 0.5% of the 75% dependable annual flow. The monsoon season E-Flows would be 600% of the 75% dependable annual flow in cumecs.

3.8 E-Flows in Ganga Basin

River Ganga was declared as National River of India in 2008. Various institutes and research organizations have been doing extensive work in Upper and Middle Ganga Basin to calculate the E-Flows because of the existing hydropower projects and many such projects are still in waiting to be established. Alternate Hydro Energy Centre

(AHEC, IIT Roorkee), World Wildlife Foundation (WWF), Wild Life Institute of India (WII) and Ganga River Basin Environment Management Plan (GRBEMP) by Consortium of seven IIT's has also conducted study on E-Flows in Upper Ganga Basin. The recommendations by various organizations/ groups are following.

3. 8.1 E-Flows by AHEC (2011), Roorkee

The method used by IIT-Roorkee is Desktop method, based on percentage of Mean Annual Flow (MAF). Data for 10 daily flows from HEPs and various religious places on Bhagirathi and Alaknanda River has been collected and analyzed using various methodologies, covering the area of impact assessment study to ensure environmental and social sustainability of developmental projects, geological study to avoid interference with springs and ground water, accumulation of sediment at upstream of project site, natural flow regime in diverted stretch of river due to ROR projects, hydro power related aspects, environment and biodiversity, religious and social aspects, monitoring and construction related aspects. The several methods used for computing environmental flows were:

(a) 10% method, (b) France method, (c) 75% of Q95, (d) EMC-HMD method

IIT-Roorkee recommended environment flows by EMC-HMD method for HEP's located at main stem of the river and 75% of Q95 method for tributaries.

3. 8.2 E-Flows by WWF (2012)

WWF adopted the Building Block Methodology for evaluation of E-Flows. They studied three specific sites, 1) Kaudiyala (near Rishikesh), 2) Kachlaghat and 3) Bithoor (near Kanpur). The recommendations of WWF, for various seasons, are based on the views of Smakhtin *et al*, (2007), which proposed E-Flows for the lower regions, where the fish requirements for water is very large and hydropower potential does not exist.

3. 8.3 E-Flows by WII (2012)

The WII Report, while using the data collected by IIT Roorkee, has specially focused on conservation of rare, endangered and threatened (RET) floral and faunal species and assessment of the cumulative impacts of hydropower projects in the two basins. It has suggested the E-Flows based on requirement of aquatic biodiversity, especially fish and recommended 21.5% of MSF of river if it falls in 'Mahseer Extract Zone' and 14.5% of MSF in 'No Fish Zone'. These recommendations should, therefore, be considered more appropriate for meeting the needs of the environment and ecology.

WII differed in two important respects with the suggestions made by IIT-Roorkee. First, WII recommended environmental flows based on Mean Seasonal Flows (MSF), while IIT-Roorkee recommendations were based on Mean Annual Flow (MAF). Second,

WII made distinction between two river domains: flows for 'fish zone' and 'no fish zone' and made special mention of flows which are necessary to see that two major varieties of fishes, namely, Mahseer and Snow Trout are protected, preserved, sustained, and developed.

3. 8.4 E-Flows by Consortium of 7 IITs

Consortium of 7 IITs has recommended BBM Method for assessment of E-Flows (IIT Report, 2011). The E-Flows of upper Ganga are being estimated on the basis of geomorphology and biodiversity. The criteria adapted is based on the depth of water required for maintenance of keystone species during lean season (low flows) and during wet season for breeding and enhancement of progeny (biological criteria) and water required for inundation of riparian vegetation (geomorphology criteria). The keystone species are identified on the basis of its importance in the defined stretch. The selected keystone species are Snow Trout (*Schizothorax richardsonii*) and Golden Mahseer (*Tor putitora*) in the stretch between Gangnani to Devprayag and Devprayag to Bhimgoda, respectively.

3.9 Concluding Remarks

The holistic approach is extensive approach and needs much data. The study by Consortium of 7 IITs is more scientific than previous studies and also encompasses the recommendations by AHEC (2011) and WII (2012). The present study being part of the larger study for preparing GRBEMP adopts and illustrates methodology adopted by the Consortium of 7 IITs for Alaknanda-Bhagirathi basins which are sub basins of the Ganga Basin.

4. Physiography and Hydrology of Bhagirathi - Alaknanda Basin

4.1 Physiography of Bhagirathi Basin

The Bhagirathi basin is located in Uttarakhand State and has a total catchment area 8847 km². The Bhagirathi has three sub-basins, namely, Bhagirathi, Bhilangana and Asiganga river sub-basin.

Bhagirathi is a Himalayan river arising at Gomukh (3892 m) from the Gangotri glacier. The Gangotri glacier is bound between 30°43'22"-30°55'49"N and 79°04'41"-79°16'34"E, which is about 30.2 km in length and its width varies from 0.5 km to 2.5 km (Area 258.56 km²). Bhagirathi River flows for 217 kilometers till it reaches Devprayag

(475 m) where it merges with the Alaknanda River. Downstream of Devprayag confluence, the combined river is known as Ganga.

The bed slope is very steep in the upper stretch. At some places it is of the order of 50.0 m per km. The slope between Gomukh (3892 m) to Harsil (2620 m) is of 30.3 m per km in 42 km stretch. It decreases to 20.0 m per km in its stretch from Loharinag (2147.5 m) to Tehri (755 m). The elevation ranges from 3200 m to 480 m in this 217 km stretch and has an average gradient of 1.25%. On an average for any Run-of-the-River hydropower project, the power station has to be built about 8 km far from the barrage to get a net head of 100 m. Initially Bhagirathi flow small streams loaded with debris up to Gangotri (3048 m), due to recession of glaciers. Further downstream of Gangotri 'U' shaped valley of glacial origin is seen at the higher elevation and the river has cut a narrow 'V' shaped fluvial valley at the lower elevation up to Kharali.

4.1.1 Tributaries

The major tributaries of river Bhagirathi are Bhilangana and Asiganga. Asiganga joins Bhagirathi river at 5 km upstream (1120 m) of Uttarkashi from west direction.

Bhilangana River originates from Khatling glacier (3950 m) in South of Gomukh and joins the river Bhagirathi at Tehri from east direction. Tehri dam is built on the confluence of river Bhagirathi and Bhilangana.

Table 4.1: Some Relevant Information on Rivers in Bhagirathi Basin

River	Length* (km)	Elevation (m) at		Average Gradient (%)
		Origin	Confluence	
Bhagirathi	217	3200	480	1.25
Bhagirathi-Asiganga	83.5	3200	1120	2.49
Bhagirathi-Bhilangana	91	1120	610	0.56
Bhagirathi-Devprayag	42.5	610	480	0.31
Asiganga	20.5	2440	1120	6.44
Bhilangana	109	3000	670	2.14
Balganga	37	1730	814	2.48

*Upper Reaches of River have not been accounted (Source: Wildlife Institute of India, 2012)

4.1.2 Glaciers

Bhagirathi river basin is not a single valley glacier. It is a combination of several other glaciers that are fed to it and form a huge mass of ice. The glacierized area of Bhagirathi basin is 285.56 km² (Naithani *et al.*, 2001) and the total volume is 39.18 km³ (Kaul, 1999).

The Gangotri system is a cluster of glaciers comprising the main Gangotri glacier (length 30.2 km, width 0.20-2.35 km, area 86.32 km²) as the trunk part of the system. The major glaciers of the system are Raktvarn (55.30 km²), Chaturangi (67.70 km²),

Kirti (33.14 km²), Swachaud (16.71 km²), Ghanohim (12.97 km²), and few others (13 km²). Depth of the glacier is about 200 m and the elevation varies from 4000-7000 m.

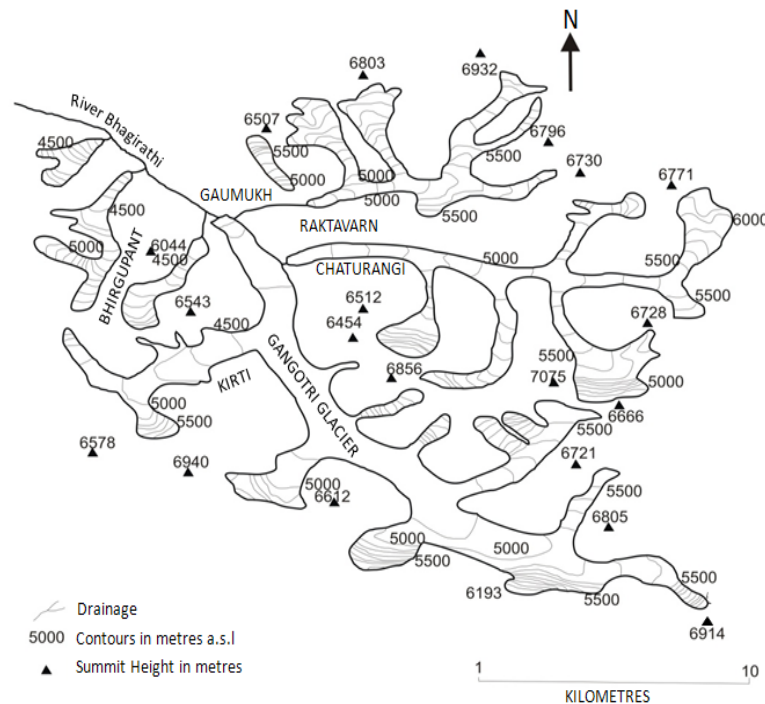


Figure 4.1: Schematic Representation of Glaciers in Bhagirathi Basin
(Source: Sharma and Owen, 1996)

4.1.3 Climate, Temperature and Rainfall

The Bhagirathi river basin experiences strong climatic seasonal variations, which is clearly reflected in the monthly variation of stream flows. The average daily maximum and minimum temperatures are observed to be 14.7°C and 4.1°C respectively, whereas average mean temperature is 9.4°C. All calculation has been done on the basis of data provided by IMD, Pune (duration 1980-2006).

A meteorological site has been installed at Bhojwasa by National Institute of Hydrology, Roorkee, which is just about 3 km downstream from Gomukh. The data for that station is presented in Table 4.2 for the years 2000-2003.

Table 4.2: Typical Weather Parameters of Bhagirathi Basin*

Parameter	May	June	July	August	September	October
Mean Temperature, °C	8.8	10.3	11.7	10.8	8.0	5.4
Mean Maximum Temperature, °C	15.4	15.6	16.2	15.0	13.2	12.4
Mean Minimum Temperature °C	2.3	5.0	7.0	6.5	2.9	-1.5
Relative Humidity, %	69	83	88	89	78	67
Sunshine, h/d	7.2	5.4	4.7	4.0	5.2	6.8

*Based on Observations at Bhojwasa Meteorological Site of NIH during 2000-2003

Note: All parameters are Monthly Averages

The basic pattern of Indian climate is governed by summer and winter monsoon systems of Asia. The winter rains are brought by the Western disturbances and the summer rains by the summer monsoon winds. For all the seasonal regularity of monsoon winds and rainfall, local climates (over much of the area) are quite variable. Sometimes, the rains may come at the expected time or rainfall over an entire monsoon season may be considerably diminished. In contrast, there will be time when the rainfall is unusually heavy, often leading to disastrous floods. In the interior region of catchment, rainfall is very low. Annual rainfall is about 1500-2000 mm (AHEC, 2011).

4.1.4 Catchment Areas

The catchment areas at various CWC stations of Bhagirathi and Hydro-electric Project Site of the Basin are given in Table 4.3.

Table 4.3: Catchment Area for Some Select Sites on Bhagirathi River

Location	Catchment Area, km ²
Uttarkashi*	4400
Maneri Bhali I Hydro Electric Project	4024
Maneri Bhali II Hydro Electric Project	4416
Tehri Hydro Electric Project	7511
Tehri/ Zero point*	7287
Koteshwar Hydro Electric Project	7691
Devprayag A1*	7813
Devprayag Z9*	19600

*CWC Monitoring Sites

4.2 Physiography of the Alaknanda Basin

The Alaknanda basin is in the eastern part of the Garhwal Himalayas and lies between 30°0'0"N-31°0'0"N and 78°45'0"E - 80°0'0"E in Uttarakhand State. The catchment area of the basin is about 10882 km². The basin is subdivided into Alaknanda, Mandakini, Nandakini, Pinder, Dhauliganga and Birahiganga. The main river Alaknanda runs a total 224 km distance before its confluence with Bhagirathi at Devprayag (472 m). The major feed in these rivers is due to glaciers. The total catchment area of rivers Alaknanda & Bhagirathi at Devprayag is 19600 km².

4.2.1 Tributaries

The Saraswati River, which originates from the Tara glacier, is the major left bank tributary of the Alaknanda River in its headwater region. Most part of the Saraswati river catchment, upstream of the confluence of Arwa nala (4016 m), is covered with snow. Glaciers and avalanches descend up to the river bed in this stretch. Downstream of Mana, Rishiganga, Dhauliganga, Nandakini, Birahiganga, Mandakini, and Pinder are important tributaries of the Alaknanda River.

Table 4.4: Some Relevant Information on Rivers in Alaknanda Basin

River	Length* (km)	Elevation (m) at		Average Gradient (%)
		Origin	Confluence	
Alaknanda	224	4016	480	1.58 %
Alaknanda-Dhauliganga	47	4016	1446	5.47 %
Alaknanda-Pinder	60	1446	795	1.09 %
Alaknanda-Devprayag	109	795	480	0.29 %
Dhauliganga	50	2880	1446	2.87 %
Rishiganga	38.5	4000	1900	5.45 %
Birahiganga	29.5	2160	994	3.95 %
Nandakini	44.5	2200	880	2.97 %
Pinder	114	2200	775	1.25 %
Mandakini	81	3562	640	3.61 %

*Upper Reaches of River have not been accounted (Source: Wildlife Institute of India, 2012)

4.2.2 Glaciers

The major glaciers present in the catchment are Khular Bank, Khuliagarvia Gal, Anadeb Gal, Dakhshini Nakthoni Gal, Uttar Nakthoni Gal, Paschimi Kamet Glacier, Dakhshini Chamrao Glacier, Uttar Chamrao Glacier, Balbala Bank, Tara Bank, Arwa bank, Kalandani Bank, Vidum Bank and Bhagnyu Bank.

4.2.3 Climate, Temperature and Rainfall

Based on geographic and physiographic factors, there are five climatic zones in the Himalayas as affected by altitude. These are, Warm Tropical (800m), Warm subtropical (800-1200m), Cool Temperate (1200-2400m), Alpine (2400-3600m) and Arctic (3600m and above). While these are only broad zones, there are many local variations as a result of variable precipitation, temperature, wind patterns, humidity, radiation, etc. The climate in Alaknanda basin varies from sub-tropical to alpine. The altitude varies from 442 m at Devprayag to 7120 m at Trishul. The latitudinal variation and distance from sea does not affect the climate.

Temperature varies from season to season and from valley regions to highly elevated regions as highest temperature is recorded in Srinagar in the month of June (30°C) and lowest in Tungnath in the month of January (0.5°C).

Table 4.5: Mean Monthly Temperature in the Alaknanda Basin

Location	Altitude (m)	Mean Monthly Temperature (°C)											
		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Srinagar	550	14	18	20	25	25	30	29	28	25	27	17	15
Mastura	1800	4	6	12	14	15	20	20	18	17	14	8	4
Joshimath	1875	2	3	7	11	14	17	18	17	16	10	7	4
Tungnath	3600	0.5	1	3	6	7	12	12	11	5	4	2	1

Sources of data: HAPPRC Srinagar Garhwal, Uttarakhand

There is a great variation in rainfall, mainly because of topographical variation. The break of monsoon is quite indefinite but it frequently breaks in mid June. The major portion of rainfall is received in July and August. The monsoon ends in mid of September and November is the driest month in this basin. The mean annual rainfall reduces from 2000 mm to 250 mm as altitude rises from 1000 m to 4000 m in the Alaknanda basin. After 4000 m the snowfall feed the glaciers round the year. In Joshimath, about 64% of the total rainfall is during the monsoon period (June-Sept), amounting to 714.4 mm. The rainfall during the monsoon period at Badrinath amounts to 470 mm.

Rainfall, across five stations of the basin (Table 5.6) located at different altitudes, was found maximum at Okhimath (199.4 cm) followed by Karanprayag (147.1 cm), while lowest rainfall was recorded in Srinagar (92.5 cm). This data reveals that higher the altitude, higher the rainfall and vice-versa.

4.2.4 Catchment Areas

The catchment area of various CWC stations and Hydroelectric Project (HEPs) sites of Alaknanda Basin are given in Table 5.7.

Table 4.6: Rainfall in the Alaknanda Basin

Station	Altitude (m)	Annual Rainfall (cm)	Seasonal Rainfall (%)			
			Winter	Pre-Monsoon	Monsoon	Post-Monsoon
Srinagar	550	92.5	16.0	17.7	58.8	8.5
Karanprayag	883	147.1	10.5	13.4	15.9	10.2
Okhimath	1578	199.4	8.8	11.3	71.3	8.6
Pauri	1630	130.3	14.8	14.7	61.5	9.0
Joshimath	1875	107.5	15.4	10.3	53.1	12.2

Source: Forest Working Plan, Nainital Working Circle

Table 4.7: Catchment Area for Some Select Sites on Alaknanda River

Location	Catchment Area, km ²
Badrinath*	1285
Joshimath*	4508
Karanprayag*	2294
Chandrapuri*	1297
Rudraprayag A5*	1644
Rudraprayag G5*	10675
Srinagar*	11332
Alaknanda Hydro Electric Project	1016

Vishnuprayag Hydro Electric Project	1130
Vishnugad Pipalkoti Hydro Electric Project	4672
Tapovan Vishnugad Hydro Electric Project	3100
Srinagar Hydro Electric Project	11110

*CWC Monitoring Sites

4.3 Hydrology of Alaknanda-Bhagirathi Basin based on Flow Data

Central Water Commission (CWC) has established 11 sites for measurement of river flow in the Alaknanda-Bhagirathi catchment. All sites are Gauge-Discharge sites except Srinagar CWC station which is only a Gauge site. Discharge data for about 30 years is available at most of these sites. The oldest major Hydro-electric Project is Maneri-Bhali I (90 MW, commissioned in 1984) and Vishnuprayag (400 MW, commissioned in 2006) in Bhagirathi and Alaknanda Basin respectively. The flow at most sites is regulated because of dams/ barrages; hence to describe hydrology of the basin, natural (virgin) flow data is required. The flow during, 1972-1982 is taken as virgin flow for all sites in Bhagirathi Basin and 1977-2004 for Alaknanda Basin. Figure 4.2 shows the Alaknanda-Bhagirathi basin in Uttarakhand State and Figure 4.3 shows the CWC observation and hydroelectric project sites in the basin.

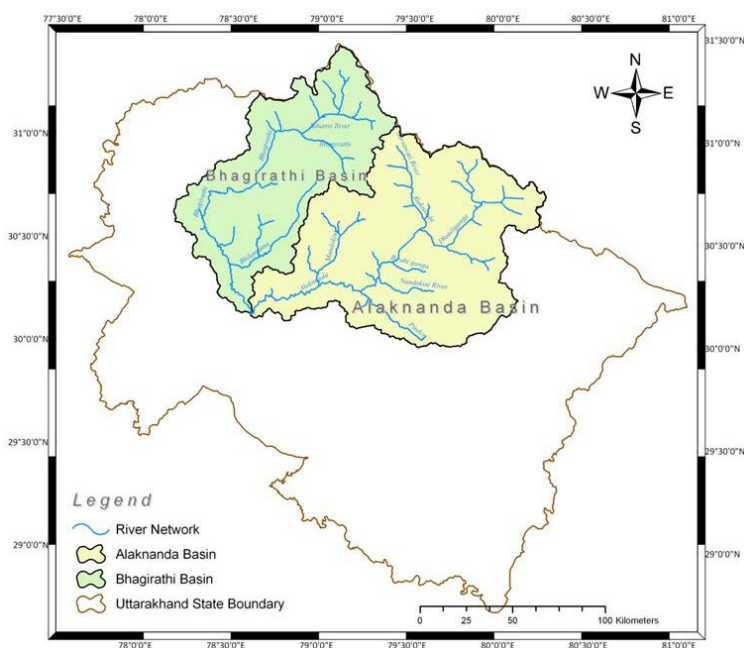


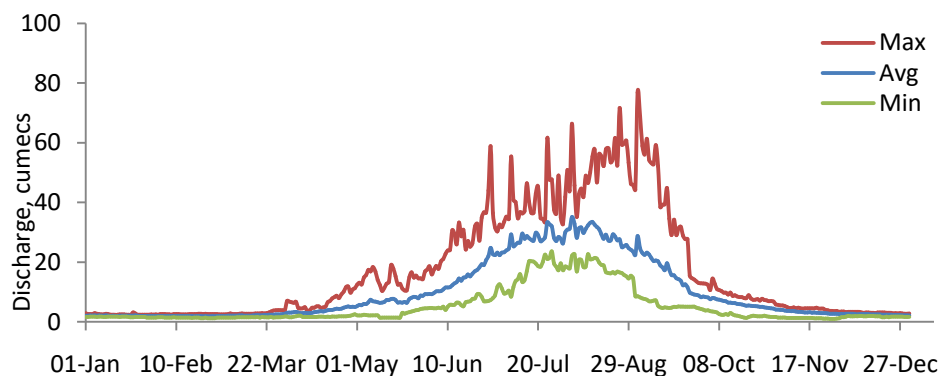
Figure 4.2: Schematic Representation of Alaknanda-Bhagirathi Basin within the Boundaries of Uttarakhand State



Figure 4.3: Schematic Representation of CWC Observation Stations and Hydro Electric Project (Operating and Under Construction) Sites in Alaknanda-Bhagirathi Basin

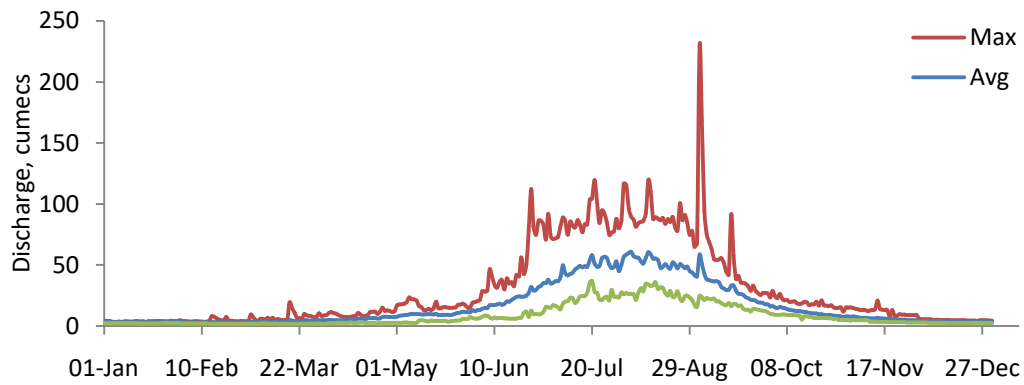
4.3.1 Hydrograph and Flow duration curve at CWC sites

The x-axis represents the date and y-axis represents the normalized discharge value. The average daily hydrograph is a hydrograph of average discharge for a particular day in 10 years. For example, the average of all 1st January discharge data, in 10 years (Bhagirathi)/ 27 years (Alaknanda), is the average daily discharge in the hydrograph. Hydrograph corresponding to maximum and minimum daily flows are drawn similarly by taking maximum and minimum values during the period 1972-1982 and 1977-2004 for rivers Bhagirathi and Alaknanda respectively. To draw Flow duration curve normalized data of 10 years for Bhagirathi basin and 27 years for Alaknanda basin has been used. The x-axis represents Exceedance Probability and y-axis represents normalized discharge in cumecs. The plot is log-linear plot.



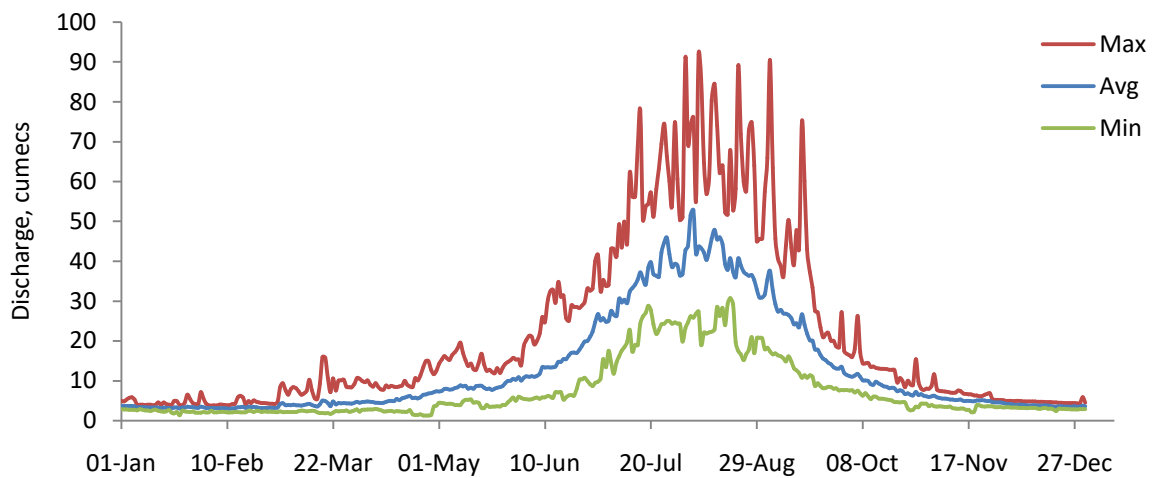
Note: Discharge values have been normalized

Figure 4.4: Representation of Hydrograph Generated based on Daily Discharge Measurements by CWC during the period 1972-1982 at Uttarkashi Observation Station



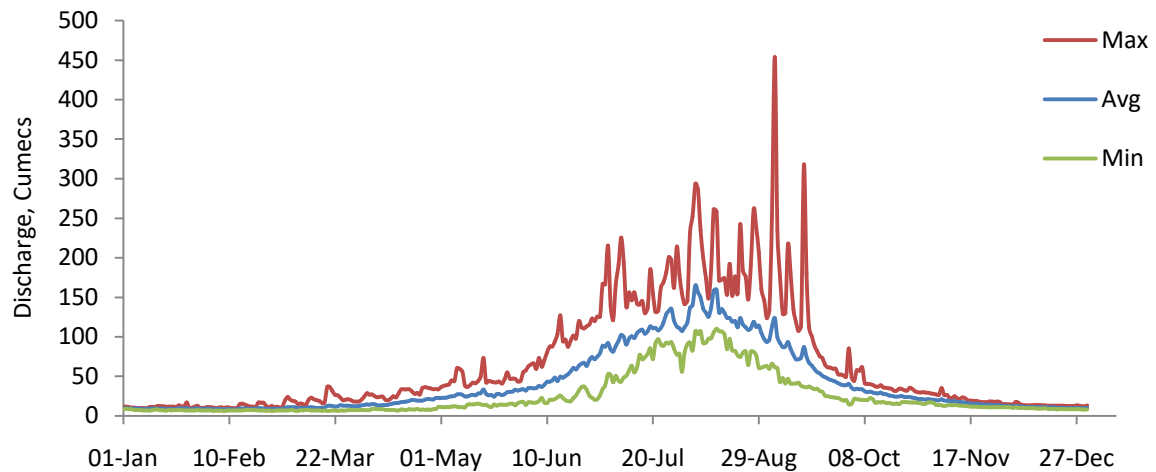
Note: Discharge values have been normalized

Figure 4.5: Representation of Hydrograph Generated based on Daily Discharge Measurements by CWC during the period 1972-1982 at Tehri Observation Station



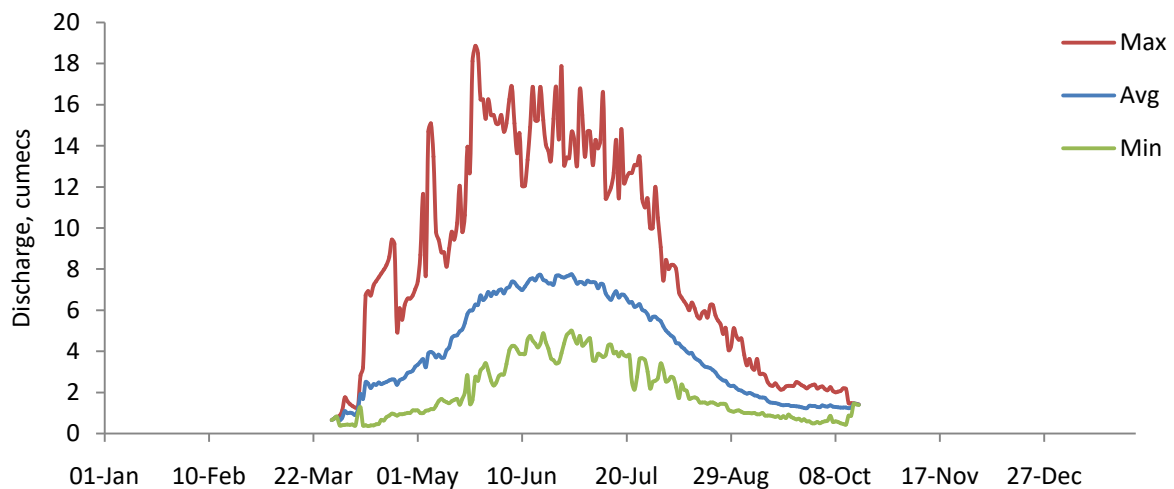
Note: Discharge values have been normalized

Figure 4.6: Representation of Hydrograph Generated based on Daily Discharge Measurements by CWC during the period 1972-1982 at Devprayag A1 Observation Station



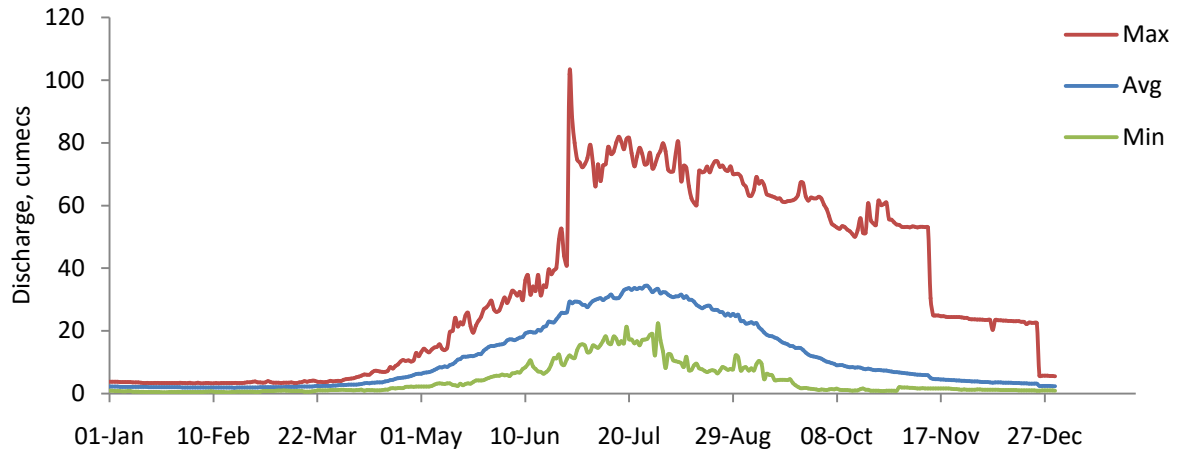
Note: Discharge values have been normalized

Figure 4.7: Representation of Hydrograph Generated based on Daily Discharge Measurements by CWC during the period 1972-1982 at Devprayag Z9 Observation Station



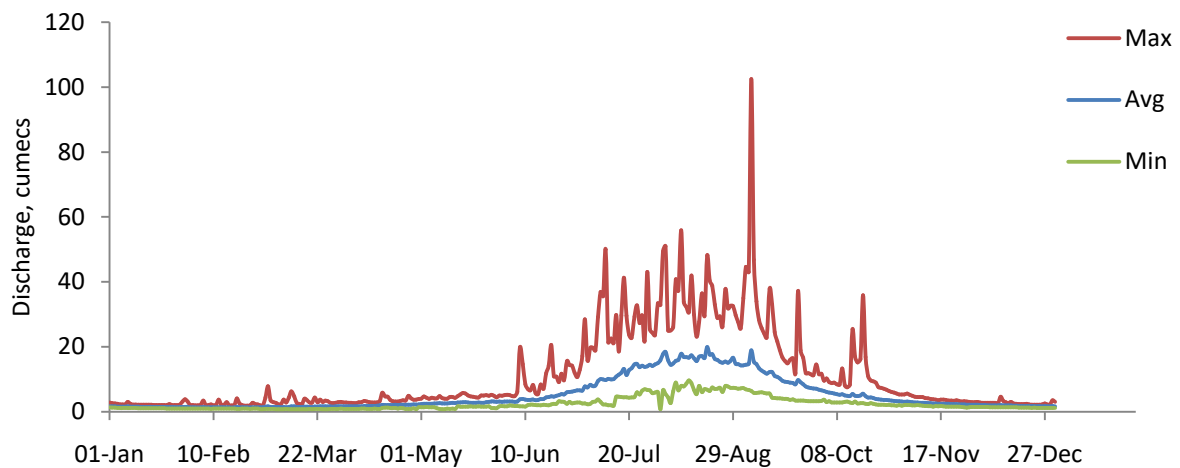
Note: Discharge values have been normalized; Flow at Badrinath is seasonal. Only summer period has flow, in winter there is no flow because of snow

Figure 4.8: Representation of Hydrograph Generated based on Daily Discharge Measurements by CWC during the period 1977-2004 at Badrinath Observation Station



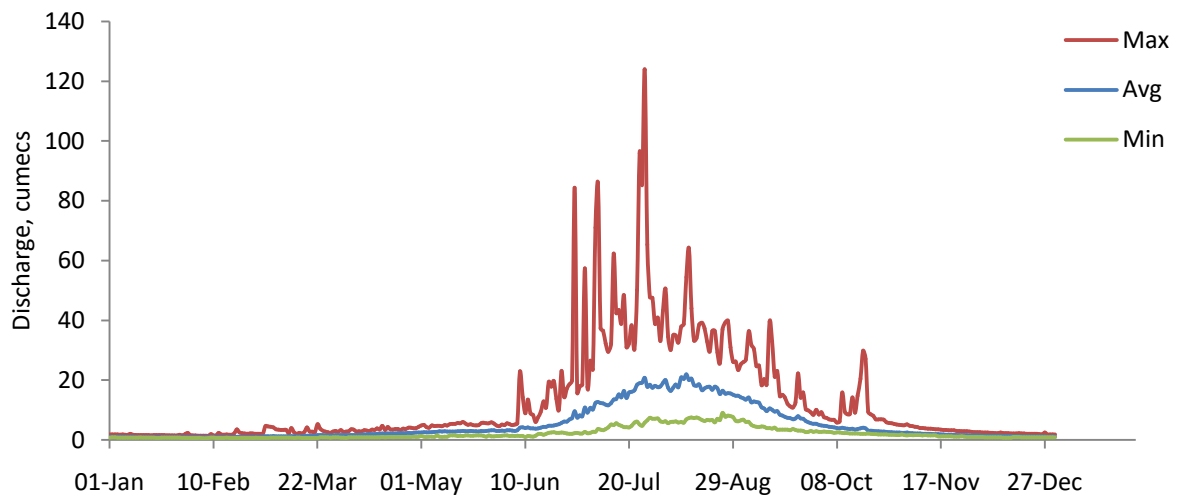
Note: Discharge values have been normalized

Figure 4.9: Representation of Hydrograph Generated based on Daily Discharge Measurements by CWC during the period 1977-2004 at Joshimath Observation Station



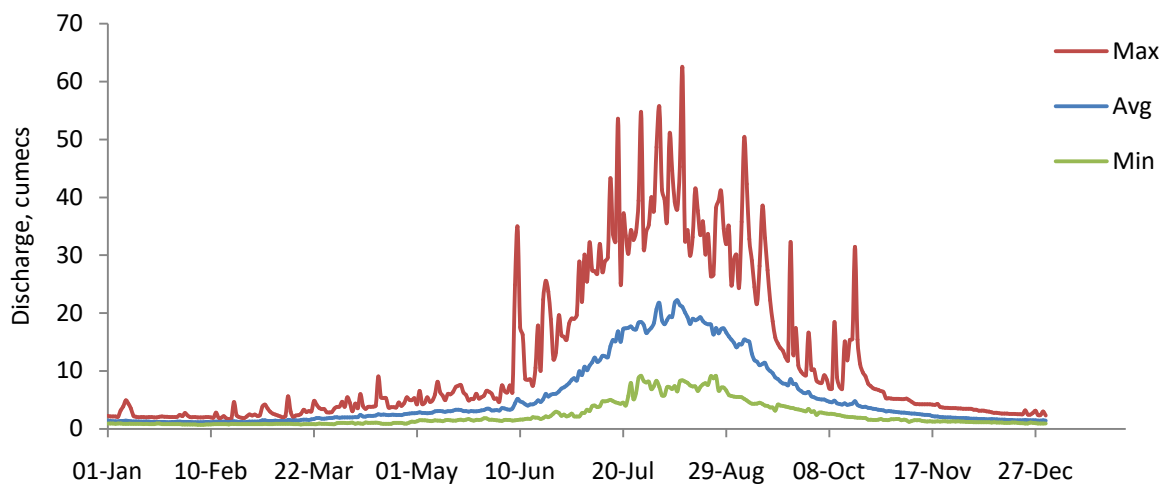
Note: Discharge values have been normalized

Figure 4.10: Representation of Hydrograph Generated based on Daily Discharge Measurements by CWC during the period 1977-2004 at Karanprayag Observation Station



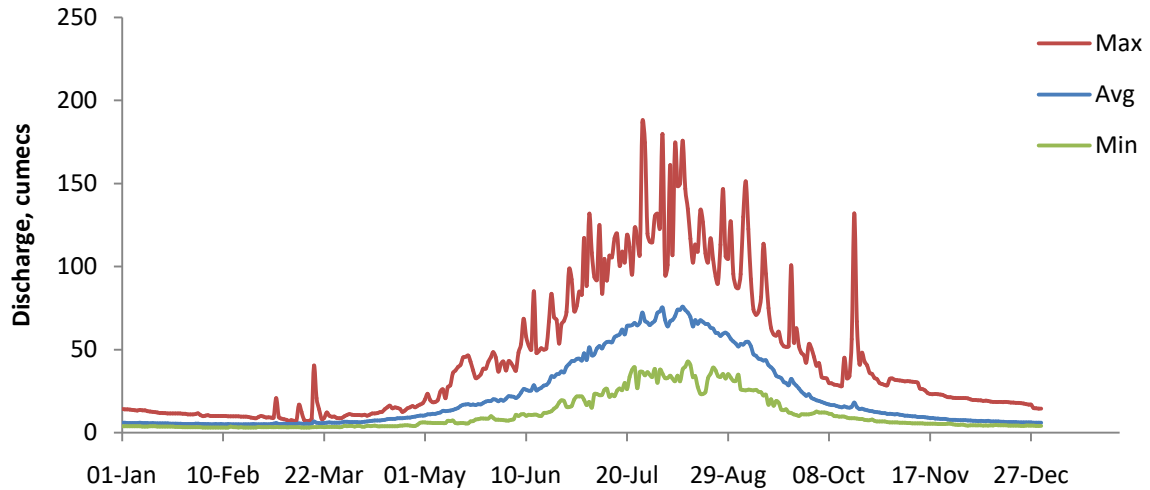
Note: Discharge values have been normalized

Figure 4.11: Representation of Hydrograph Generated based on Daily Discharge Measurements by CWC during the period 1977-2004 at Chandrapuri Observation Station



Note: Discharge values have been normalized

Figure 4.12: Representation of Hydrograph Generated based on Daily Discharge Measurements by CWC during the period 1977-2004 at Rudraprayag A5 Observation Station



Note: Discharge values have been normalized

Figure 4.13: Representation of Hydrograph Generated based on Daily Discharge Measurements by CWC during the period 1977-2004 at Rudraprayag G5 Observation Station

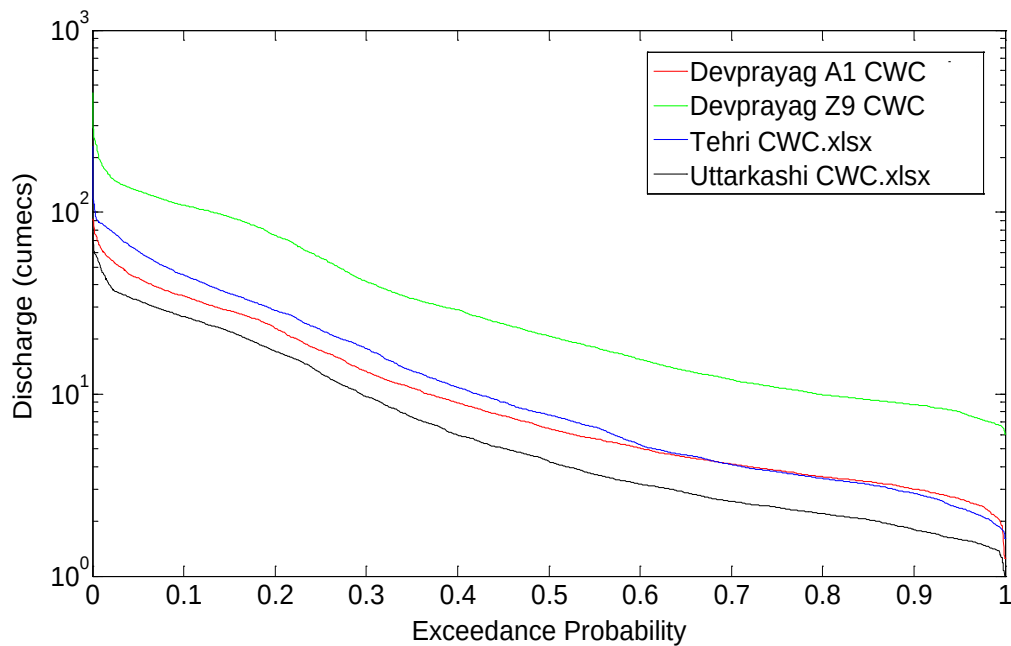


Figure 4.14: Flow Duration Curves based on Daily Discharge Measurements by CWC during the period 1972-1982 at Various Observation Stations in Bhagirathi Basin

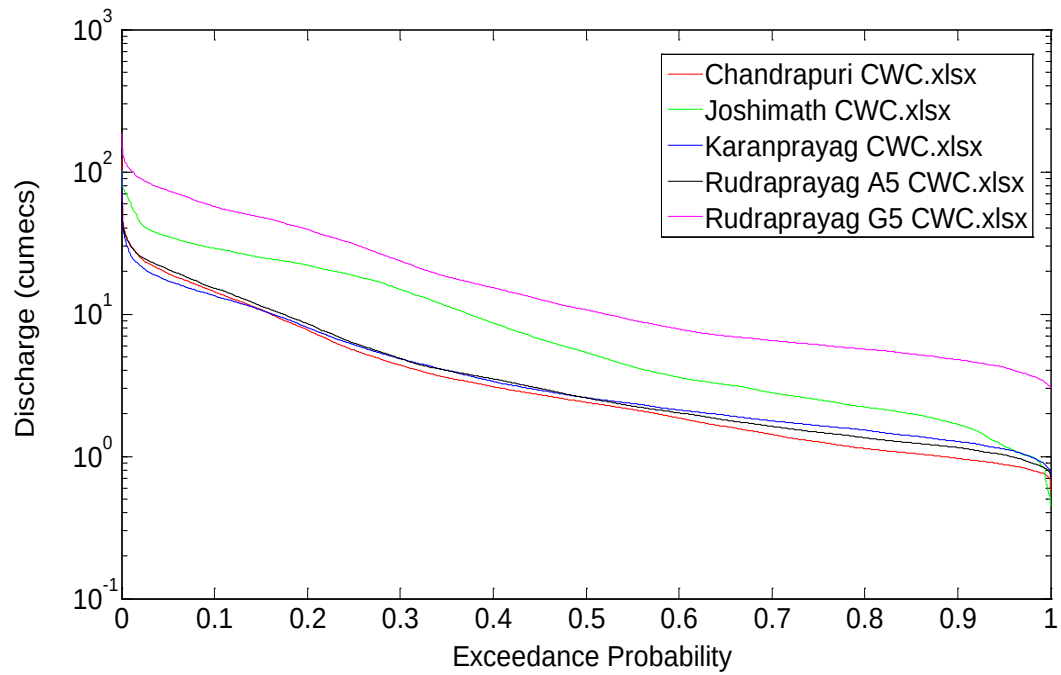


Figure 4.15: Flow Duration Curves based on Daily Discharge Measurements by CWC during the period 1977-2004 at Various Observation Stations in Alaknanda Basin

4.3.2 Available Flows and 90% dependable flow at CWC sites

Bhagirathi-Alaknanda basin has 11 CWC observation stations. Salient Features of CWC Observation Stations on Alaknanda River (1977-2004) and Bhagirathi River (1972-1982) are presented in Table 5.8

Table 4.8: Salient Features of CWC Observation Stations on Bhagirathi River (1972-1982) and Alaknanda River (1977-2004)

S No	Name of Gauge-Discharge Station	River	Total Length of All Streams (km)	Catchment Area (km ²)	Range of Measured Daily Discharges (cumecs)	Standard Deviation in Measured Daily Discharges (cumecs)	50% Dependable Flow (cumecs)	90% Dependable Flow (cumecs)
1	Uttarkashi	Bhagirathi	328	4400	16 to 1228	174.2	68.58	28.87
2	Zero Point/ Tehri	Bhagirathi	121.3	7287	26 to 3670	319.6	123	45.54
3	Devprayag-A1	Bhagirathi	569.0	7813	20 to 1470	227.1	103.88	48.02
4	Devprayag-Z9	Ganga	1389.3	19600	96 to 7259	704.3	333.87	140.1
5	Badrinath	Alaknanda	51.9	1285	5.75 to 302	46.7	79.13	25.25
6	Joshimath	Alaknanda	211.8	4508	7.3 to 1630	202.91	86.5 (327.94)*	26.93 (86.53)*
7	Karanprayag	Pinder	154.2	2294	12 to 1640	93.78	41.30	20.36
8	Chandrapuri	Mandakini	65.5	1297	9.3 to 1981	109.35	38.46	15.49
9	Rudraprayag-A5	Mandakini	108.9	1644	11.5 to 998	106.96	41.34	18.49
10	Rudraprayag-G5	Alaknanda	638.4	10675	49 to 2987	381.62	171.5	76.4

**Based on Only Summer Season Observation*

4.3.3 Hydrograph and Flow duration curve at HEP sites

The direct measurements of flow data are not available at hydroelectric project sites. The nearest CWC observation station is used to get the flow data.

The methodology of routing is mainly based on rainfall data and catchment area. But in the Alaknanda-Bhagirathi basin only 2-3 rain gauge sites are established, and the data gathered at these stations is also not accessible. Hence to obtain flows at hydro project site drainage area ratio method has been used (AHEC, 2011).

Drainage area ratio method

The standard drainage area ratio method is the most straight-forward technique used for transferring stream flow from gauged sites to ungauged sites (Smakhtin & Masse, 2000). A catchment area ratio between 0.5-1.5 refers linear catchment ratio and method proposed by Stedinger *et al.* (1993) is used. Higher catchment ratios are referred as nonlinear catchment ratio and the method proposed by Mohamoud & Parmar (2006) is adopted. The standard method is based on the assumption that the ratio of stream flows of the gauged and the ungauged sites are equal to the ratios of their catchment areas. The nonlinear catchment area ratio methods are not based on the linearity assumption and are intended to address some limitations of the standard method. The catchment area ratio equations are written as follows.

$$Q_u = Q_g (A_u/A_g) \quad [\text{Eq 4.1}]$$

$$Q_u = Q_g \{\tan (A_u/A_g)\} \quad [\text{Eq 4.2}]$$

$$Q_u = Q_g \{\arctan (A_u/A_g)\} \quad [\text{Eq 4.3}]$$

Q_u = Discharge at Ungauged site; A_u = Catchment Area at Ungauged site

Q_g = Discharge at gauged site; A_g = Catchment Area at gauged site

Equation (4.1) is for linear catchment ratio and Equations (4.2) and (4.3) are for non-linear catchment ratio.

Based on the physiography and FDC of the basin it can be assumed that the surface-subsurface interaction in this zone is negligible. So estimation of the flow data for hydro project site can be done using following protocol.

- a) Compute the catchment area ratio of the nearest CWC site and hydro project site
- b) Multiply the flow data of CWC site to the catchment area ratio

Comparison of Badrinath CWC Station and Vishnuprayag HEP Site: The nearest CWC site of Vishnuprayag HEP is the Joshimath CWC after the Badrinath CWC site (the flow at Badrinath CWC station is measured only in summer duration, and hence the flow data of Joshimath CWC station is used. The ratio of catchment area of both sites is 0.25. Hence following expression has been used.

$$Q_u = Q_g \{\arctan (A_u/A_g)\};$$

Q_u = Discharge at Ungauged site (Vishnuprayag HEP);
 A_u = Catchment Area at Ungauged site (Vishnuprayag HEP);
 Q_g = Discharge at gauged site (Joshimath CWC);
 A_g = Catchment Area at gauged site (Joshimath CWC)

A comparison is also made between Flow Duration Curve of Badrinath CWC and Vishnuprayag HEP. The FDC of Vishnuprayag shows the same pattern as for Badrinath CWC. Hydrographs and flow duration curves obtained using protocol described above for various major hydro electric project sites in the Alaknanda-Bhagirathi basin are presented in following figures.

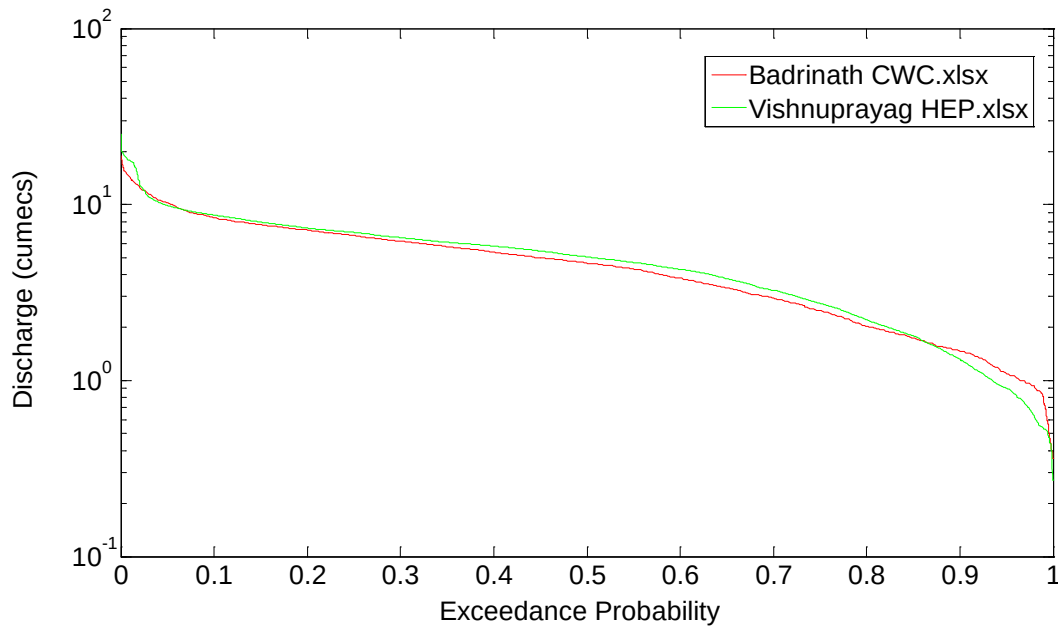


Figure 4.16: A Comparison of Normalized Flow Duration Curve Between Observed Flows at Badrinath CWC Station and Vishnuprayag Hydro Electric Project Site

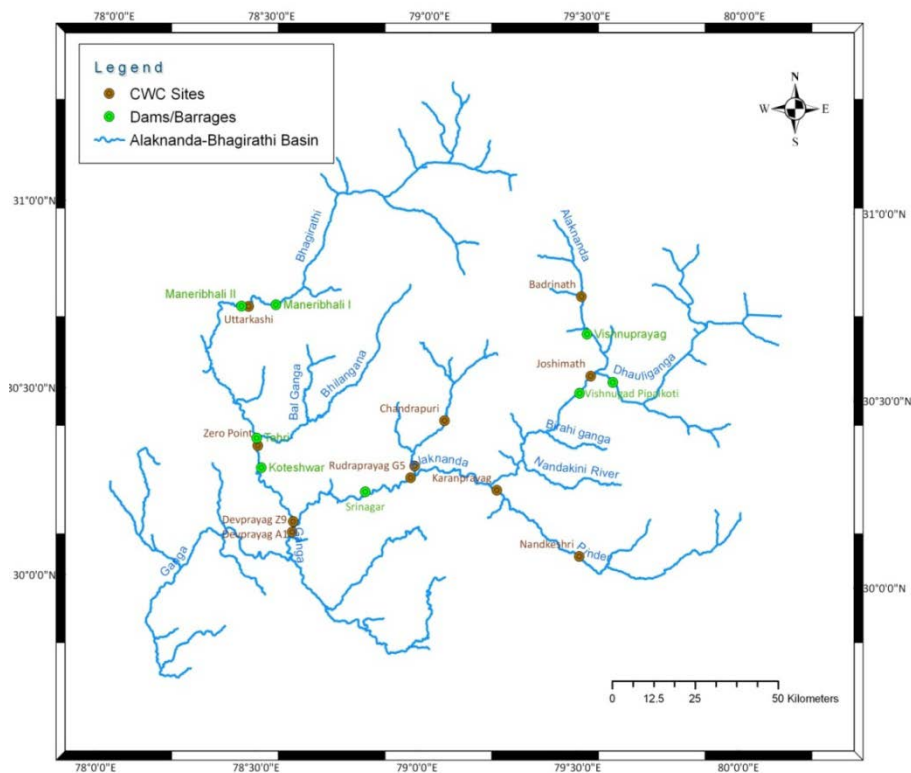
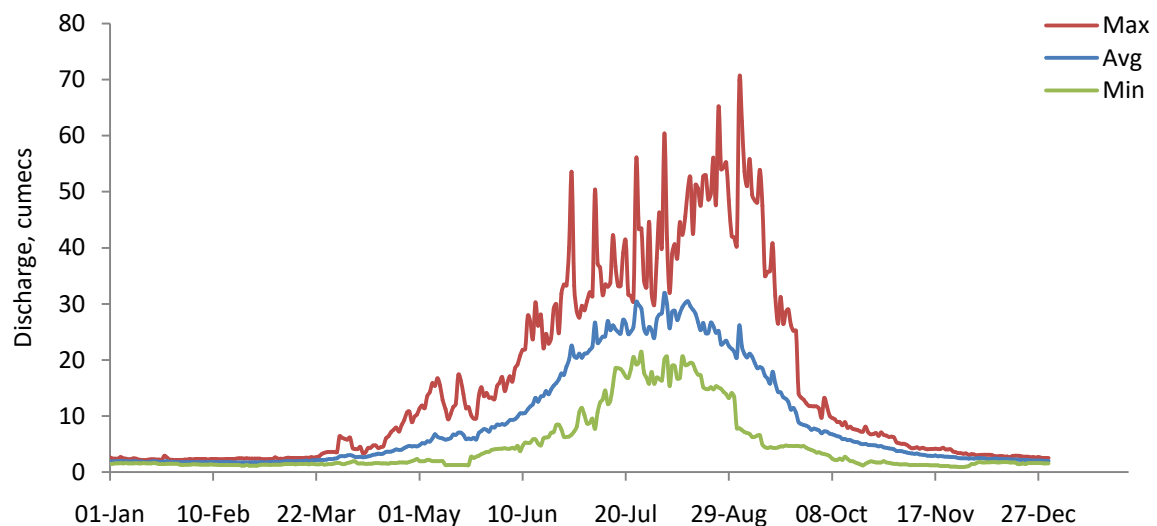
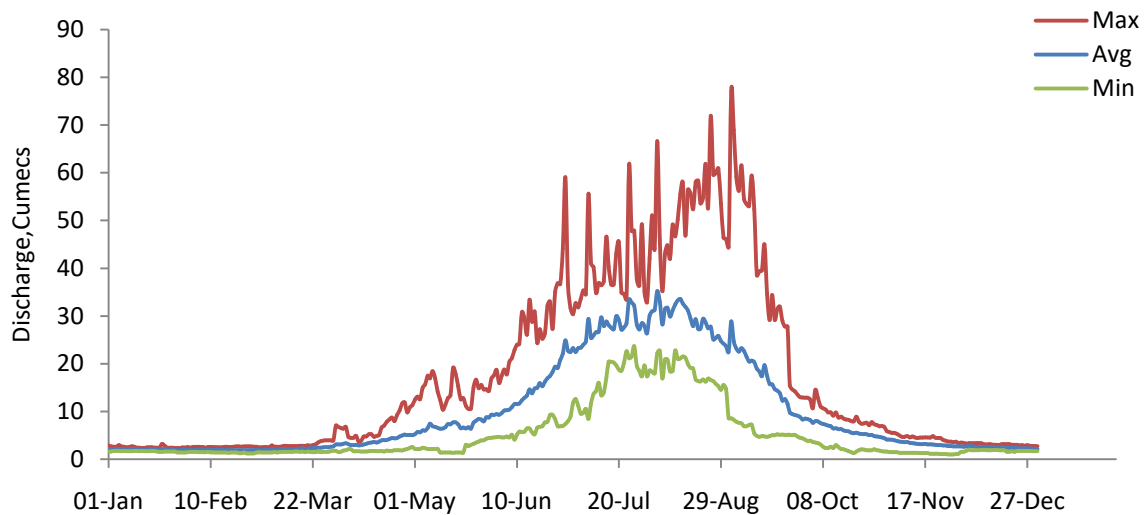


Figure 4.17: Representation of Stream Network, CWC Observation Stations and Hydro Electric Power Project (Under Operations and Construction) Sites in the Alaknanda and Bhagirathi Basins



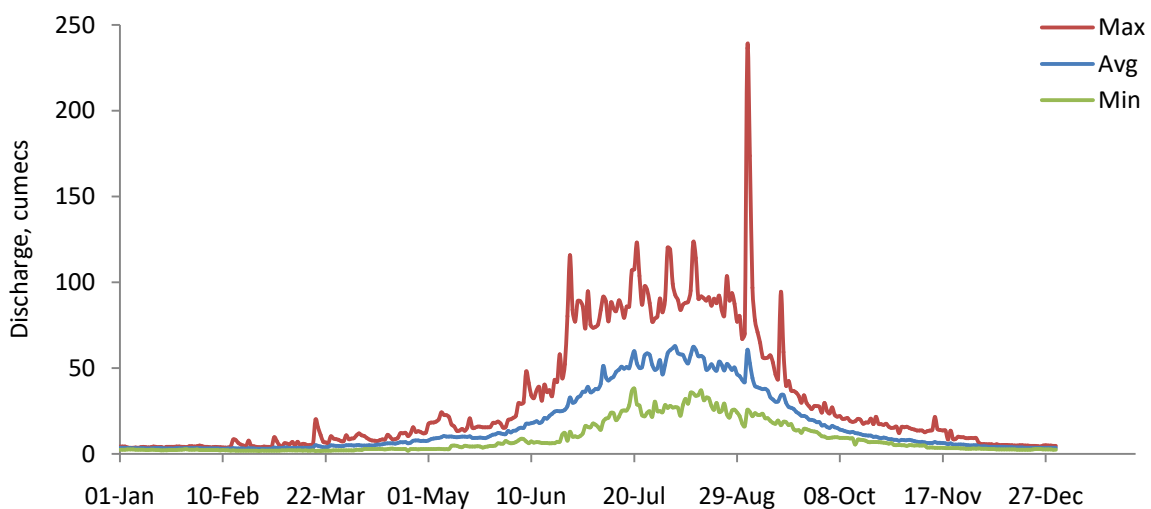
Note: Discharge values have been normalized; this hydrograph is derived using the hydrograph for the nearest CWC observation site (refer Figure 5.4) and routing using proportionate catchment area.

Figure 4.18: Representation of Hydrograph Generated at Maneribhali I Hydro Electric Project Site



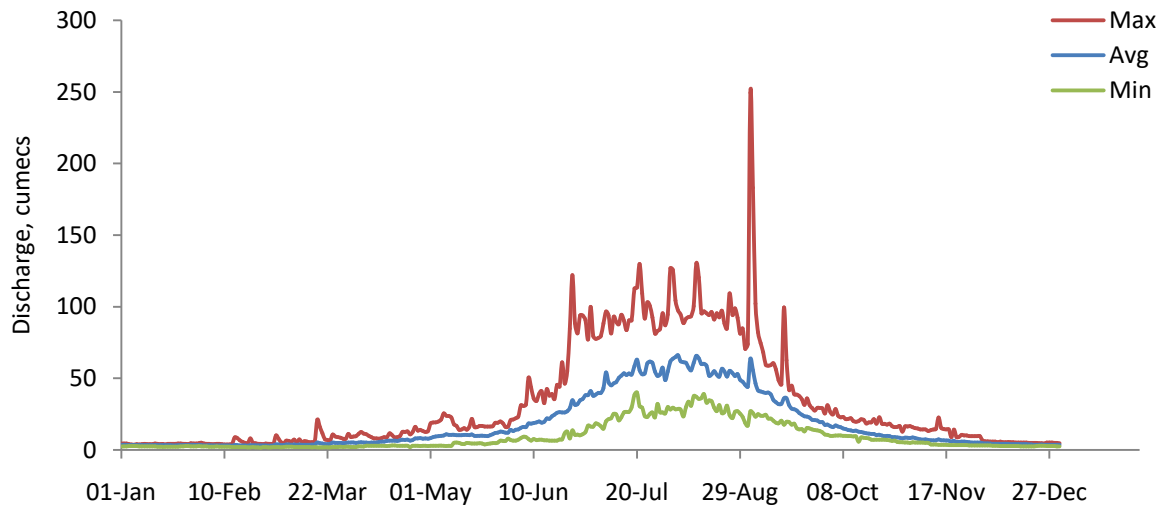
Note: Discharge values have been normalized; this hydrograph is derived using the hydrograph for the nearest CWC observation site (refer Figure 5.4) and routing using proportionate catchment area.

Figure 4.19: Representation of Hydrograph Generated at Maneribhali II Hydro Electric Project Site



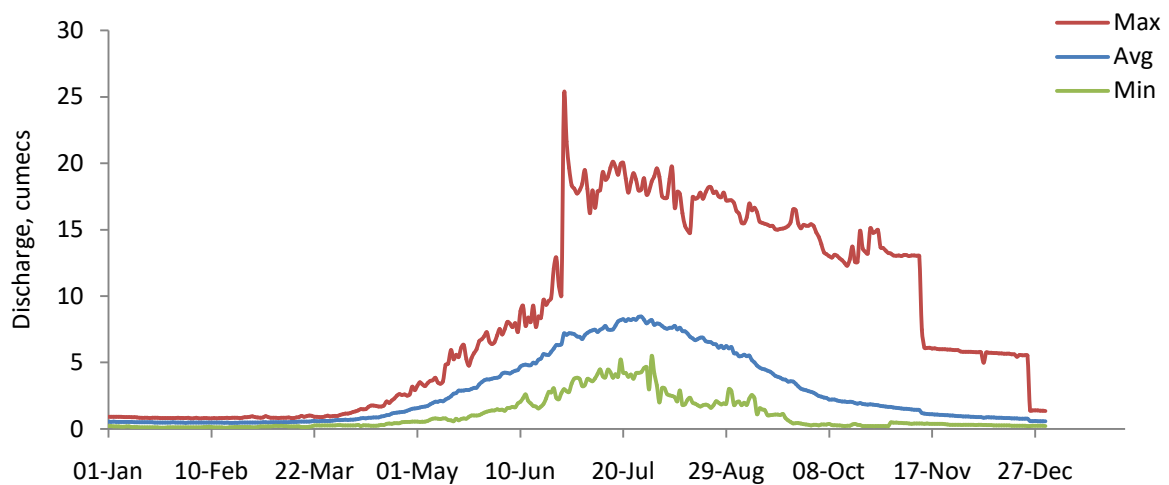
Note: Discharge values have been normalized; this hydrograph is derived using the hydrograph for the nearest CWC observation site (refer Figure 5.5) and routing using proportionate catchment area.

Figure 4.20: Representation of Hydrograph Generated at Tehri Hydro Electric Project Site



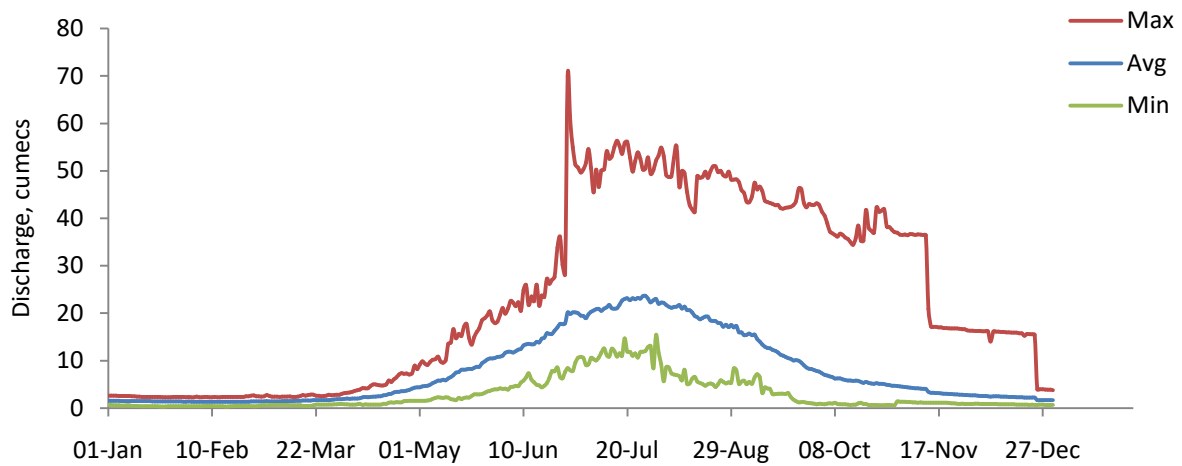
Note: Discharge values have been normalized; this hydrograph is derived using the hydrograph for the nearest CWC observation site (refer Figure 5.5) and routing using proportionate catchment area.

Figure 4.21: Representation of Hydrograph Generated at Koteswar Hydro Electric Project Site



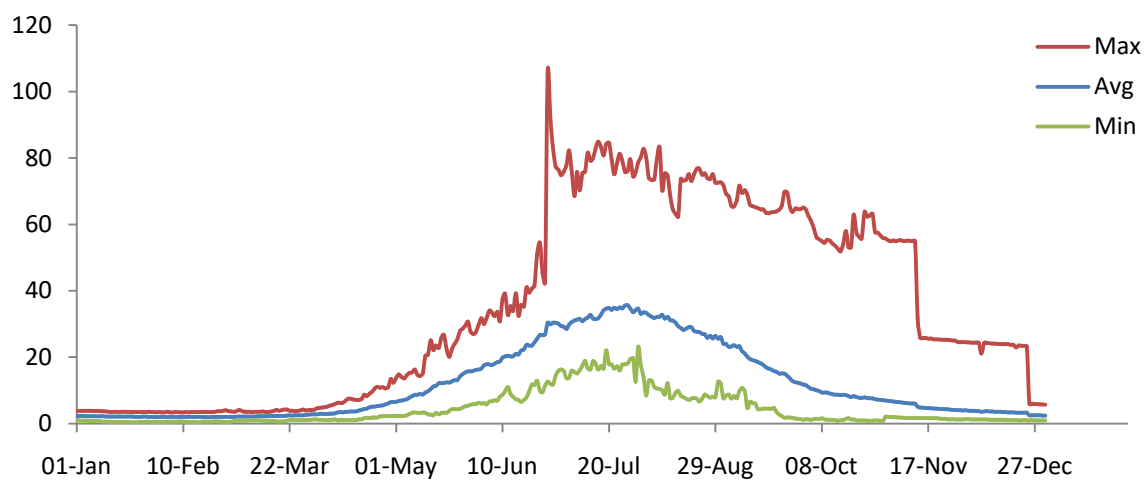
Note: Discharge values have been normalized; this hydrograph is derived using the hydrograph for the nearest CWC observation site (refer Figure 5.9) and routing using proportionate catchment area.

Figure 4.22: Representation of Hydrograph Generated at Vishnuprayag Hydro Electric Project Site



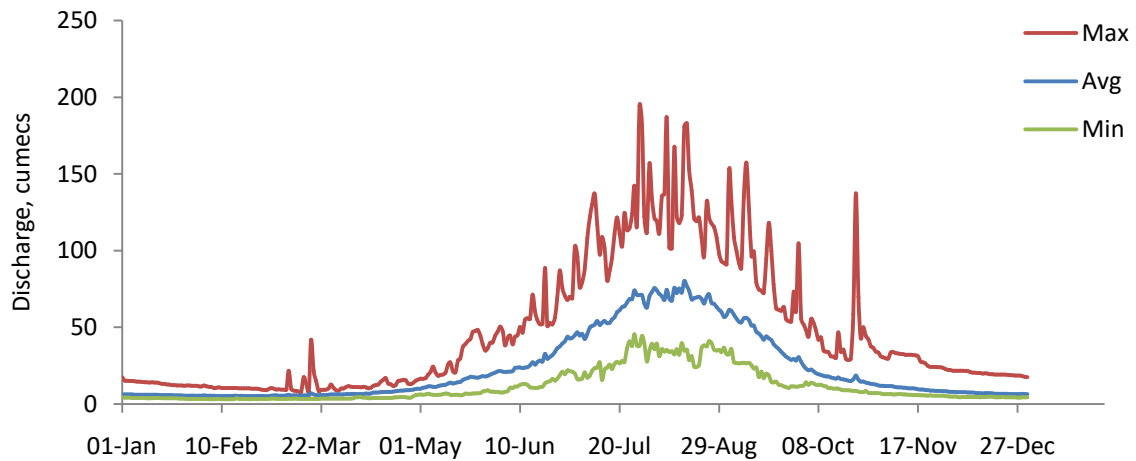
Note: Discharge values have been normalized; this hydrograph is derived using the hydrograph for the nearest CWC observation site (refer Figure 5.9) and routing using proportionate catchment area.

Figure 4.23: Representation of Hydrograph Generated at Tapovan Vishnugad Hydro Electric Project Site



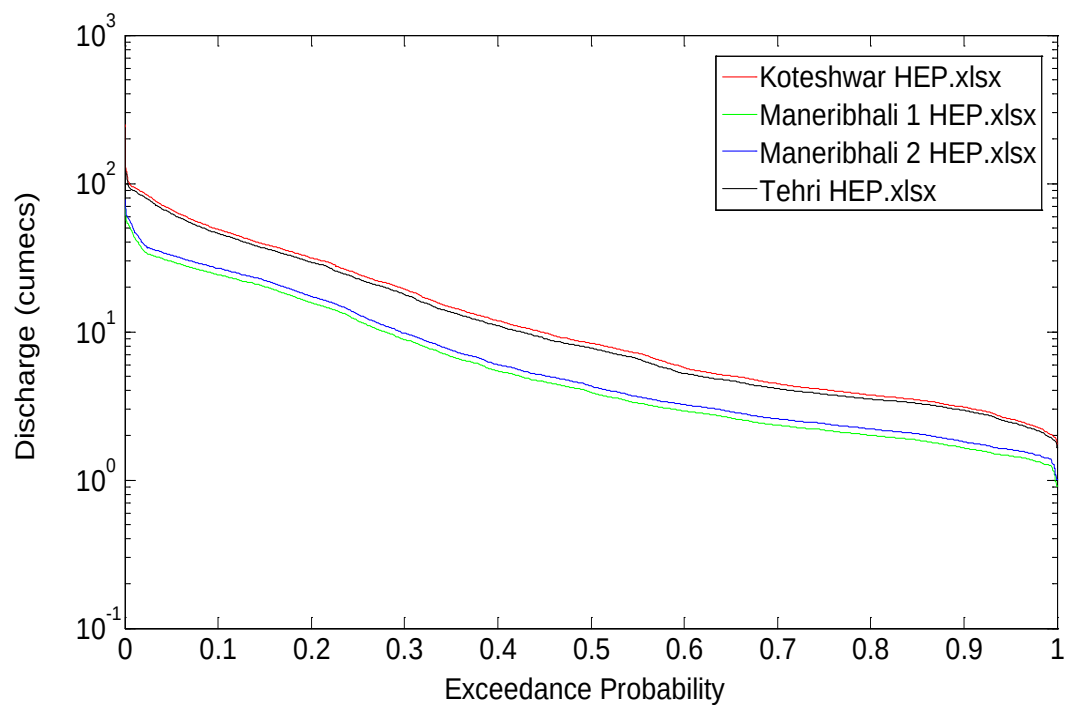
Note: Discharge values have been normalized; this hydrograph is derived using the hydrograph for the nearest CWC observation site (refer Figure 5.9) and routing using proportionate catchment area.

Figure 4.24: Representation of Hydrograph Generated at Vishnugad Pipalkoti Hydro Electric Project Site



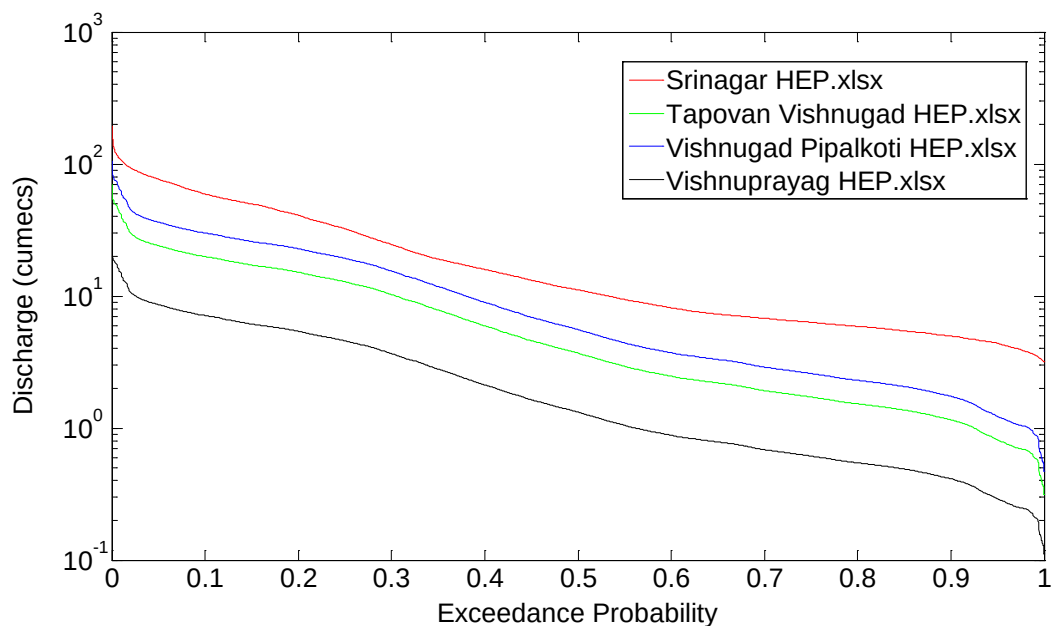
Note: Discharge values have been normalized; the hydrograph is derived using the hydrograph for the nearest CWC observation site (refer Figure 5.13) and routing using proportionate catchment area.

Figure 4.25: Representation of Hydrograph Generated at Srinagar Hydro Electric Project Site



Note: Discharge values have been normalized; this Flow Duration Curve is derived using the Flow Duration Curve for the nearest CWC observation site (refer Figure 5.14) and routing using proportionate catchment area.

Figure 4.26: Flow Duration Curve at Various Hydroelectric Project Sites in Bhagirathi Basin



Note: Discharge values have been normalized; this Flow Duration Curve is derived using the Flow Duration Curve for the nearest CWC observation site (refer Figure 5.15) and routing using proportionate catchment area.

Figure 4.27: Flow Duration Curve at Various Hydroelectric Project Sites in Alaknanda Basin

4.3.4 Available Flows and 90% dependable flow at HEP sites

In Alaknanda-Bhagirathi basin 70 hydroelectric power projects are operating or under construction. Out of them, 8 major projects are listed in Table 4.9.

Table 4.9: Salient Features of Sites of Hydro Electric Power Projects (Operating and Under Construction) on Bhagirathi River and Alaknanda River

S No	Hydro Electric Project (HEP) at	Nearest CWC Observation Sites Selected for Routing	Catchment Area (km ²)	Ratio of Catchment Area up to CWC Observation Site to Catchment Area up to HEP Site	Range of Measured Daily Discharges (cumecs)	Standard Deviation in Measured Daily Discharges (cumecs)	50% Dependable Flow (cumecs)	90% Dependable Flow (cumecs)
1	Maneri Bhali I	Uttarkashi	4024	0.91	14 to 1117	159	62.62	26.32
2	Maneri Bhali II	Uttarkashi	4416	1.004	16 to 1233	175	69.1	29.04
3	Tehri	Tehri	7511	1.03	26 to 3782	329	123.98	47.35
4	Koteshwar	Tehri	7691	1.055	27 to 3991	349	133.8	49.54
5	Vishnuprayag	Joshimath	1130	0.25	1.8 to 400	49	21.24	6.61
6	Tapovan Vishnugad	Joshimath	3100	0.687	5 to 1121	139	59.49	18.51
7	Vishnugad Pipalkoti	Joshimath	4672	1.03	7.5 to 1689	210	89.65	27.9
8	Srinagar	Rudraprayag G5	11110	1.04	50 to 3108	397	178.48	79.65

4.4 Concluding Remarks

4.4.1 Assessment of River flows of Bhagirathi River based on FDCs

1. Flow Duration Curves of all sites on Bhagirathi River basin have steep slopes which show highly variable flow in river. The major contribution is due to direct runoff. The FDC's have steep slope at the left segment which implies that the river carries a large volume of water in short period or flood season.
2. At Tehri and Devprayag A1 sites the FDC has steep slope near the right end which implies that in the lean season, the flow falls rapidly.
3. At Uttarkashi and Devprayag Z9 the perennial storage is significant as revealed by steep slope at lower end.
4. The catchment area (CA) of two sub-basins should be in proportion to their flows. Values reported in Table 5.10 suggest that the ratio of CA of Uttarkashi and Tehri are not equal to the 50% or 90% dependable flow's ratio respectively. It suggests that there is significant water loss or flows are regulated due to dam/ barrage. The ratio of CA of Devprayag A1 and Devprayag Z9 is almost equal to the 50% or 90% dependable flow's ratio respectively. It also helps in estimating the tributaries contribution in the main course of the river.

Table 4.10: Relative Catchment Areas and Dependable Flows (50 and 90 %) between Two Observation Sites of CWC

CWC Observation Sites	Ratio of Catchment Area	Ratio of 50% Dependable Flow	Ratio of 90% Dependable Flow
Uttarkashi Versus Zero Point/Tehri	0.58	0.31	0.10
Devprayag A1 Versus Devprayag Z9	0.39	0.31	0.30

5. Just downstream of the confluence of Bhagirathi with Bhilangana, the contribution of Bhilangana River is 1/3rd of that in Bhagirathi.

4.4.2 Assessment of River flows of Alaknanda River based on FDCs

1. FDC at Badrinath has mild slopes that show that the river flows have low variability. The major contribution to the flows comes from snow melting.
2. At all sites the river is flashy as revealed by steep slope at upper end.
3. At all sites river has perennial storage as indicated by mild slope at lower end.
4. Comparison of Badrinath and Joshimath is made for same duration as the flow data of Badrinath site is only for the summer period. Comparison of FDC at Badrinath and Joshimath suggests that at 50% exceedance probability, the flows at Badrinath and Joshimath are 79.13 327.94 cumecs respectively. It means that the contribution of Dhauliganga River is 253.18 cumecs which is 0.7 times of total flow.

5. By comparing flows of Rudraprayag G5 and Rudraprayag A5 site, it was found that the contribution of Mandakini River is 0.25 times of total flow after confluence.
6. A comparison of flows of sites Devprayag Z9 and Rudraprayag G5 show that the contribution in Ganga from Alaknanda is twice that from Bhagirathi.
7. From above appraisal the assumption of negligible or very less interaction between surface-subsurface water appears to be valid.

4.4.3 Assessment of River flows and E-Flows based on Hydrographs and Statistics

1. The hydrographs based on CWC data reveals that the peak flow shifts from March-April to June-July, as we move from higher elevation to lower elevation. It indicates that in upper reaches the flow comes from ice melting. The flow rises as the melting rises. The contribution from rainfall is much less than the ice melting.
2. The study of slope at various stretches and 90% dependable flows at CWC sites in Bhagirathi basin indicate that there are various stretches at which the HEPs which are under construction are not beneficial.

5. Provision of E-Flows for Hydro Electric Project Site

5.1 E-Flows by Holistic Approach

To evaluate E-Flows for hydroelectric projects site, we are adopting GRBEMP methodology. This methodology is based on holistic approach. The E-Flows for Upper Ganga basin assessment is based on Hydrology, Geomorphology and Biodiversity, which automatically satisfies requirements, like socio-economic aspects, cultural aspects etc.

5.2 Hydrology, Biodiversity and Geomorphology Data

IIT Kanpur team provided the requisite data for Upper Ganga basin. They selected some E-Flows site on Alaknanda-Bhagirathi basin and surveyed for parameters like cross-section, geomorphologic attributes and biological-ecological profiles at E-Flows sites. The cross-section survey at Dharasu D/S, Rudraprayag (near Rudraprayag G5 CWC site), Devprayag (near Devprayag A1 CWC site) and Devprayag D/S (near Devprayag Z9 CWC site) has been completed. The CWC monitoring stations at Rudraprayag and Devprayag D/S are also chosen as E-flows sites.

5.3 Methodology developed by IIT Kanpur

5.3.1 Stage-Discharge Relationship at E-Flows site

The CWC data at Uttarkashi and Devprayag A1 are used to determine the stage discharge relationship at the E-flow sites Dharasu D/S and Devprayag, respectively. Here, we are using Manning's equation to get stage-discharge relationship at E-Flows sites.

5.3.2 Geomorphologic Attributes and Biological-Ecological Profiles

The requisite data for E-Flows sites is provided by IIT Kanpur Team. To fulfil the aspects for E-Flows sites, the recommendations are separated out for E-Flows site in two sections, Pool section and Riffle section.

a) Pool section: The various depths defined by IIT Kanpur are:

D1- Depth of water required during lean period (Nov to June) .The level was defined as 2 meter water depth at the pool location.

D2- Depth of water required for initial development of juveniles of keystone species. The level was defined as 0.2 meter water level on the banks.

D3- Depth of water required for spawning of keystone species. The level was defined as 0.5 meter water level at the banks.

D4- Depth of water required for inundation of some riparian vegetation for 10-15 days in a year. The level may be variable depending on the inundation of riparian vegetation.

b) Riffle section: The various depth are defined by IIT Kanpur as:

D1- Depth of water required during lean period (Nov to June). The level was defined as 0.5 meter water depth at the riffle location.

D4- Depth of water required for inundation of riparian vegetation (July-Sept). The level may be variable depending on the inundation of riparian vegetation.

5.4 E-Flows at Dharasu

Dharasu site is at Riffle section. E-Flows for various months is listed below in Table 5.1

Table 5.1: Provisioning Environmental Flows at Dharasu site

Months	Flow corresponding D1 depth	Flow corresponding D2 depth	Flow corresponding D3 depth	Flow corresponding D4 depth	Volume MCM
Jan	17.35	-	-		46.47
Feb	17.35	-	-		41.97
Mar	17.35	-	-		46.47
Apr	17.35	-	-		44.97
May	17.35	-	-		46.47
Jun	34.67	-	-		89.87
Jul	34.67	-	-	587.23	283.83
Aug	34.67	-	-	587.23	379.31
Sep	34.67	-	-	587.23	280.83
Oct	34.67	-	-		92.87
Nov	17.34	-	-		44.97
Dec	17.34	-	-		46.47

*The flow values for D1, D2, D3 and D4 are in cumecs; - The values of D2 and D3 are not applicable as it is a riffle section.

5.5 E-Flows at Rudraprayag D/S

Rudraprayag site is at Riffle section. E-Flows for various months is listed below in table 5.2

Table 5.2: Provisioning Environmental Flows at Rudraprayag site

Months	Flow corresponding D1 depth	Flow corresponding D2 depth	Flow corresponding D3 depth	Flow corresponding D4 depth	Volume MCM
Jan	60.74	-	-		162.69
Feb	60.74	-	-		146.95
Mar	60.74	-	-		162.69
Apr	60.74	-	-		157.44
May	60.74	-	-		162.69
Jun	96.84	-	-		251.02
Jul	96.84	-	-	1284.4	669.81
Aug	96.84	-	-	1284.4	875.02
Sep	96.84	-	-	1284.4	661.44
Oct	96.84	-	-		259.39
Nov	60.74	-	-		157.44
Dec	60.74	-	-		162.69

*The flow values for D1, D2, D3 and D4 are in cumecs; - The values of D2 and D3 are not applicable as it is a riffle section.

5.5 Concluding Remarks

- 1) The E-Flows calculated for these sites, represents the E-Flows for a river stretch. Hence, the E-Flows for these sites are taken as E-Flows for hydroelectric project sites.
- 2) The E-Flows calculated for Dharasu is used in assessment of Maneri-Bhali I, Maneri-Bhali II, Tehri and Koteswar HEPs, as they are located in the river stretch.
- 3) The E-Flows calculated for Rudraprayag D/S is used in assessment of Srinagar HEPs, as it is located in that river stretch.
- 4) For Vishnuprayag, Vishnugad Pipalkoti and Tapovan Vishnugad HEPs, we didn't assess the hydropower generation with provision of E-Flows, as the E-Flows for river stretch is not defined at that location.

6. Design Energy: A Methodology based on 90% Dependable Monthly Flow

6.1 Design Energy

Design energy, for a hydropower project, is the energy generation on installed capacity of the power project, without any restriction.

10-daily unrestricted energy generation in 90% dependable year is restricted to 95% of the installed capacity of the power house. The total of these 10-daily restricted energies for the year gives the annual design energy generation (CEA, 2012).

6.2 Methodology

6.2.1 Methodology by CEA

Central Electricity Authority, GOI has issued the guidelines for power generation in hydroelectric projects.

A hydro-electric project is designed on the basis of dependable yearly flow. To define the dependable year, data of at least 20 consecutive years is required. Following procedure is used to determine 90% dependable year.

- Calculate the Annual Flow Volume of all 'N' years; where N= no. of years
- Arrange the N yearly flow volumes in descending order ;
- Calculate $(N+1)*0.9$ rounded off to the next higher integer;

The year corresponding to the above integer value is the 90% dependable year, i.e. the flow volume for that year gives the 90% dependable annual flow. The 10 daily flow values of that year are used for energy calculation, which is called Design energy.

6.2.2 Methodology based on 90% Dependable Monthly Flow

In this regard, we did a comparative study, which is different in procedure to find out 90% dependable year. The step by step procedure is:

- a) Collect daily flow data of at least 20 consecutive years
- b) Separate data by month e.g. separate January data of all 20 years and collate.
- c) Draw flow duration curve for each month
- d) By using FDC, find out 90% dependable flow for each month
- e) Calculate energy on the basis of 90% dependable monthly flow

And summation of monthly energy is the yearly design energy.

The details and calculation by the two methods of the hydropower projects are given in Appendix I and Appendix II, respectively.

6.3 Results

A comparison has been made between the two procedures, by calculating energies for eight hydroelectric projects, which is tabulated below-

Table 6.1: A comparison on Design Energy using different methodologies at various Hydro Electric Projects

HEP	Design Energy for 90% Dependable Year, GWH	Design Energy for 90% Dependable Month, GWH	Design Energy as per IMG Report for 90% Dependable Year, GWH
Maneri-Bhali I ^{*+}	594	538	412
Maneri-Bhali II ^{*+}	1323	1265	1497
Tehri ⁺	3228	2044	Not calculated
Koteshwar ⁺	1391	871	Not calculated
Vishnuprayag ^{*+}	1358	1438	2087
Tapovan Vishnugad [*]	1938	2008	2649
Vishnugad Pipalkoti	1721	1526	1859
Srinagar ⁺	1187	1070	1403

* Run-of-the-river projects; ⁺ Commissioned projects

6.4 Conclusions

1. Design energy, by 90% dependable year, estimates more than 90% dependable month except Vishnuprayag and Tapovan Vishnugad HEP.
2. Difference of estimated design energies, for Run-of-the-river projects, is less than those for the storage projects.
3. The IMG report estimates energy for Vishnuprayag and Tapovan Vishnugad much higher than the design energy based on 90% dependable year and it is much lower for Maneri-Bhali I (It is to be noted that the Design energy by IMG, is also based on 90% dependable year). It is also noted, that the IMG report followed the “90% dependable year” method but, its design energy vary from our calculation, done by the same method, for all projects.
4. All projects, except Maneri-Bhali I, were commissioned in recent 3-4 years, and are in transition phase. So, comparison of average energy generation is of not much significance. The energy generation data for Maneri-Bhali I, provided by UJVNL, reveals that the average energy generation, for last 10 years is 468 MW, which is closer to the design energy calculated by “90% dependable months” method, than the design energy calculated by “90% dependable year” method.

7. Potential Hydro Electric Power Without and With Provision of E-Flows

7.1 Hydropower Generation

At present five hydropower projects are in operation at Bhagirathi-Alaknanda basin. The hydropower calculation is based on virgin flow data. The virgin flow data from 1972 to 1982 and from 1977 to 2004 are provided by IIT Kanpur, for Bhagirathi and Alaknanda basin, respectively.

7.1.1 Calculation Procedure

- Calculate power, from daily flow data (obtained from routing) by using the formula-
 $\text{Power} = \text{Water Density} * \text{Net Head} * \text{Discharge} * 9.81 * \text{Efficiency}$
Where, Power is in watt; water density in kg/m^3 ; net head of hydroelectric project in meter; discharge at barrage site in m^3/s
- Maximum running hours of HEP is calculated by dividing the daily discharge from unit design discharge
- Calculate average of energy generation and running hours on daily basis
- Calculate monthly energy generation
- Calculate energy generation with E-Flows using above mentioned procedure up to (d) after deducting the E-Flows from daily flow

7.2 Maneri-Bhali I HEP

7.2.1 Energy Generation Hydrographs

A comparison between energy generation hydrographs and running hour hydrograph, on average daily basis without and with E-Flows is shown in Figure 7.1.

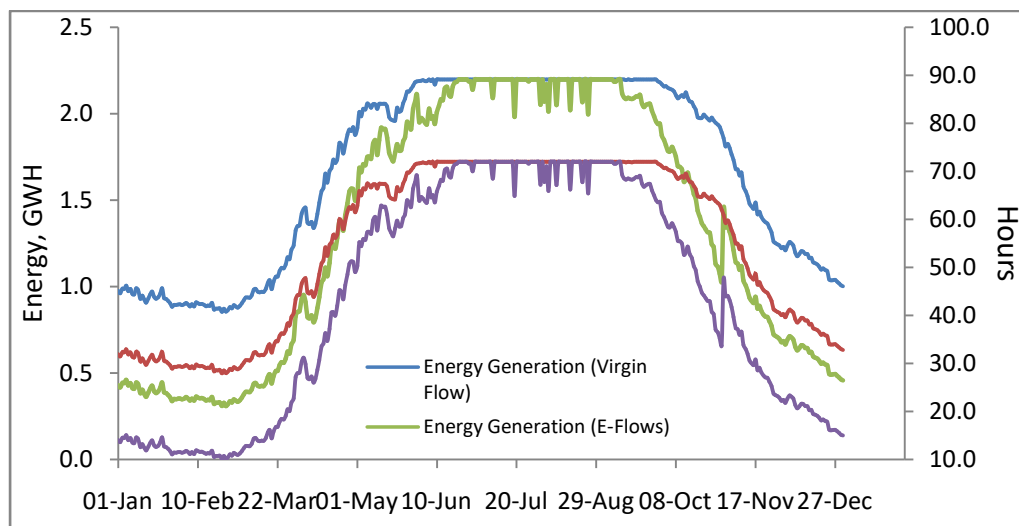


Figure 7.1: Daily Variation in Potential Hydro Electric Power Generation without and with Provision of Environmental Flows (E-Flows) at Maneri-Bhali I Hydro Electric Project

7.2.2 Monthly Energy Generation

Monthly average energy generation without and with E-Flows is shown in Figure 7.2 and monthlies percentage reduction is shown in Table 7.1, below.

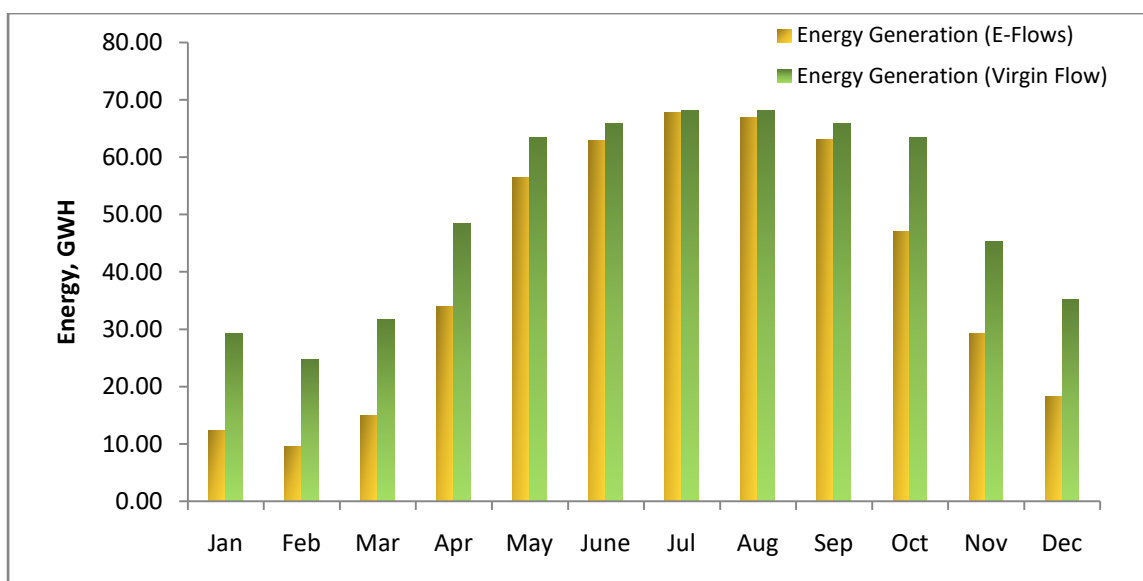


Figure 7.2: Monthly Variation in Potential Hydro Electric Power Generation without and with Provision of Environmental Flows (E-Flows) at Maneri Bhali I Hydro Electric Project

Table 7.1: Impact of Provisioning Environmental Flows on Energy Generation at Maneri Bhali I Hydro Electric Project

Month	% Reduction	Month	% Reduction in
January	57.6	July	0.5
February	61.5	August	1.7
March	53.0	September	4.4
April	29.9	October	26.0
May	11.0	November	35.1
June	4.6	December	48.0
Average Annual Reduction in Energy Production		27.8 %	

7.3 Maneri-Bhali II HEP

7.3.1 Energy Generation Hydrographs

A comparison between energy generation hydrographs and running hour hydrograph, on average daily basis without and with E-Flows is shown in Figure 7.3.

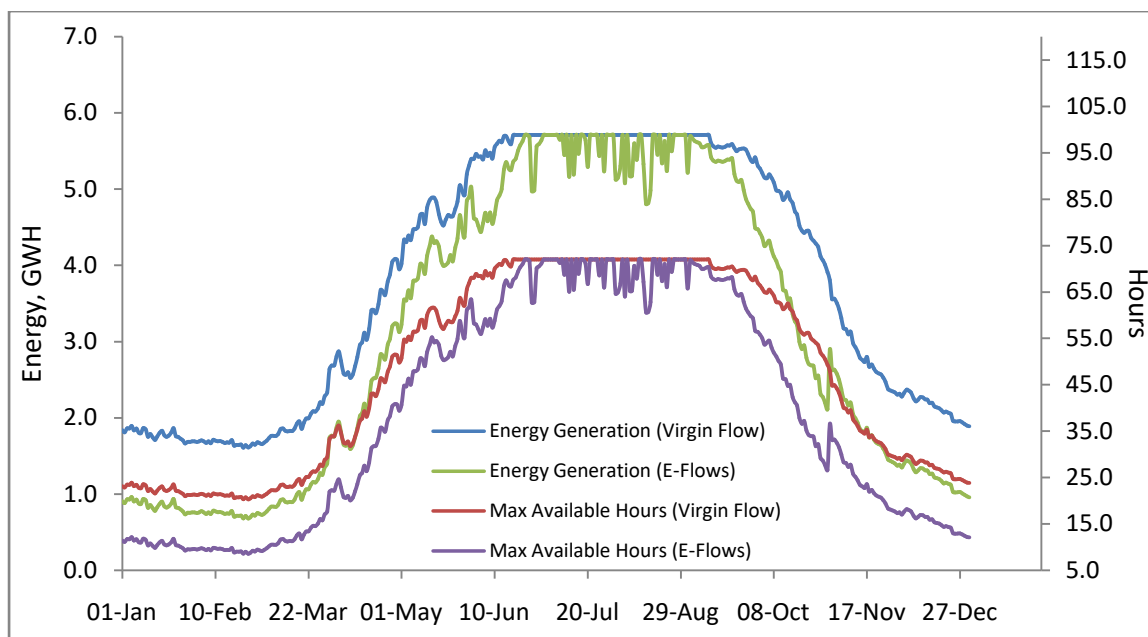


Figure 7.3: Daily Variation in Potential Hydro Electric Power Generation without and with Provision of Environmental Flows (E-Flows) at Maneri-Bhali II Hydro Electric Project

7.2.2 Monthly Energy Generation

Monthly average energy generation without and with E-Flows is shown in Figure 7.4 and monthlies percentage reduction is shown in Table 7.2, below.

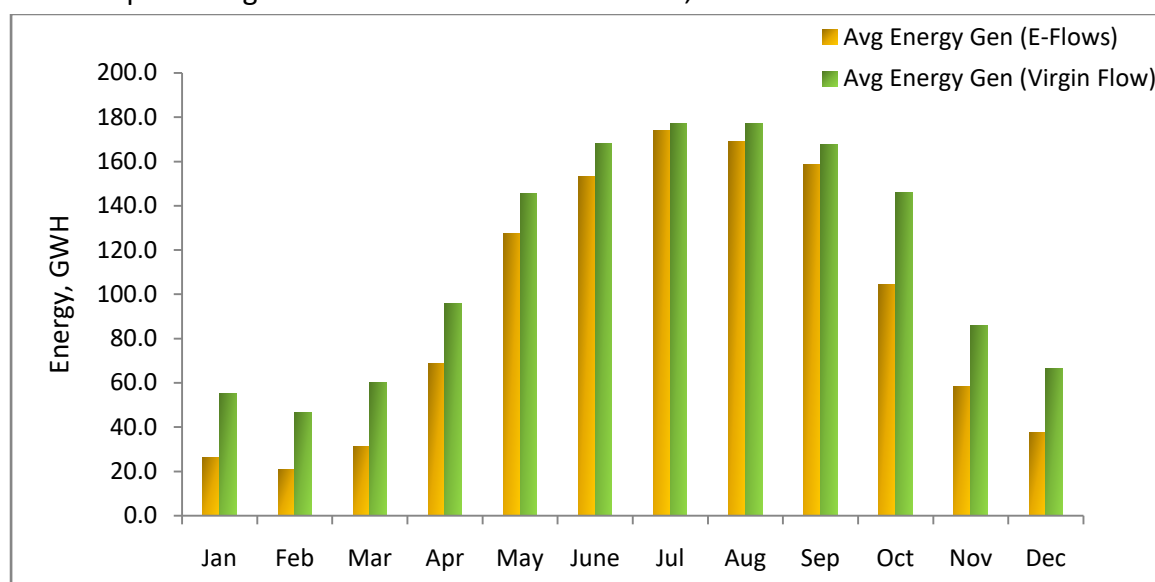


Figure 7.4: Monthly Variation in Potential Hydro Electric Power Generation without and with Provision of Environmental Flows (E-Flows) at Maneri-Bhali II Hydro Electric Project

Table 7.2: Impact of Provisioning Environmental Flows on Energy Generation at Maneri-Bhali II Hydro Electric Project

Month	% Reduction	Month	% Reduction in
January	52.2	July	1.6
February	55.7	August	4.5
March	48.0	September	5.3
April	28.1	October	28.4
May	12.4	November	32.4
June	9.0	December	43.5
Average Annual Reduction in Energy Production		26.8 %	

7.4 Tehri HEP

7.4.1 Energy Generation Hydrographs

A comparison between energy generation hydrographs and running hour hydrograph, on average daily basis without and with E-Flows is shown in Figure 7.5.

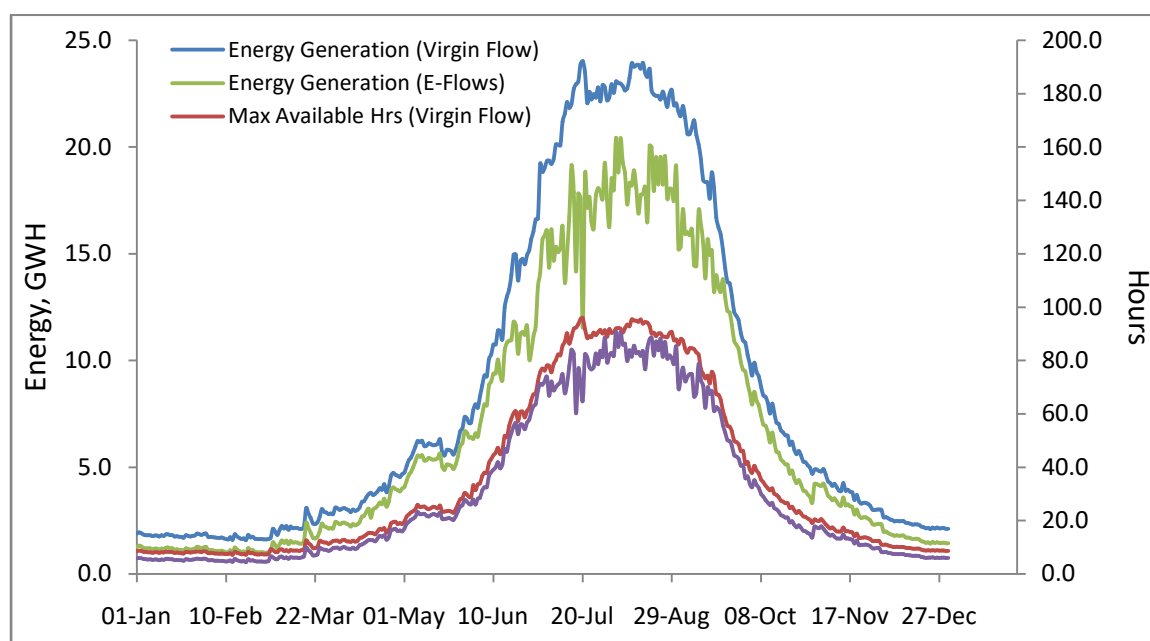


Figure 7.5: Daily Variation in Potential Hydro Electric Power Generation without and with Provision of Environmental Flows (E-Flows) at Tehri Hydro Electric Project

7.2.2 Monthly Energy Generation

Monthly average energy generation without and with E-Flows is shown in Figure 7.2 and monthlies percentage reduction is shown in Table 7.1, below.

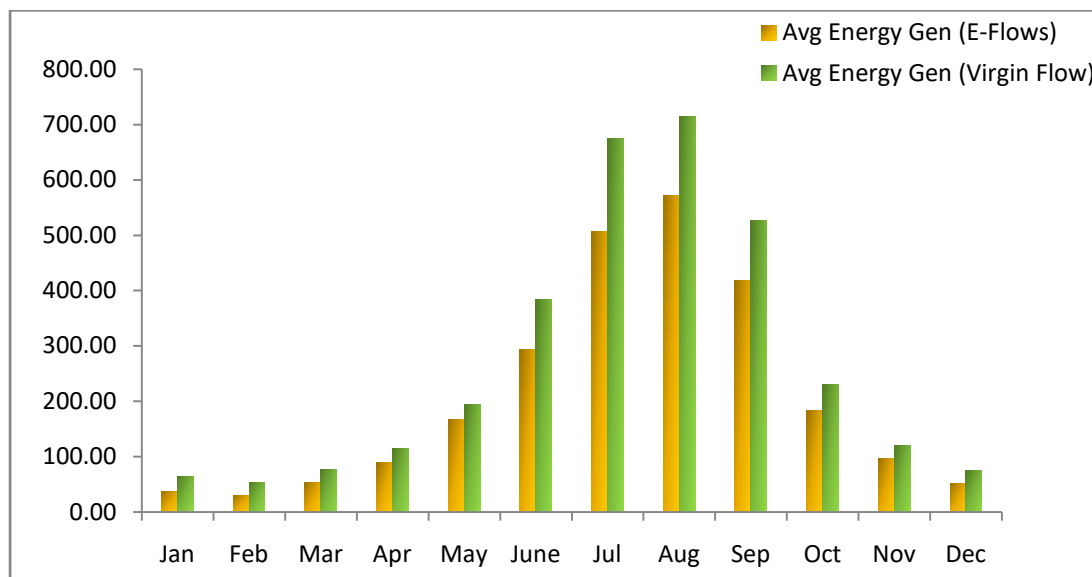


Figure 7.6: Monthly Variation in Potential Hydro Electric Power Generation without and with Provision of Environmental Flows (E-Flows) at Tehri Hydro Electric Project

Table 7.3: Impact of Provisioning Environmental Flows on Energy Generation at Tehri Hydro Electric Project

Month	% Reduction	Month	% Reduction in
January	42.0	July	24.9
February	44.0	August	20.0
March	31.7	September	20.6
April	21.5	October	20.3
May	14.2	November	19.6
June	23.6	December	30.8
Average Annual Reduction in Energy Production		26.1 %	

7.5 Koteshwar HEP

7.5.1 Energy Generation Hydrographs

A comparison between energy generation hydrographs and running hour hydrograph, on average daily basis without and with E-Flows is shown in Figure 7.7.

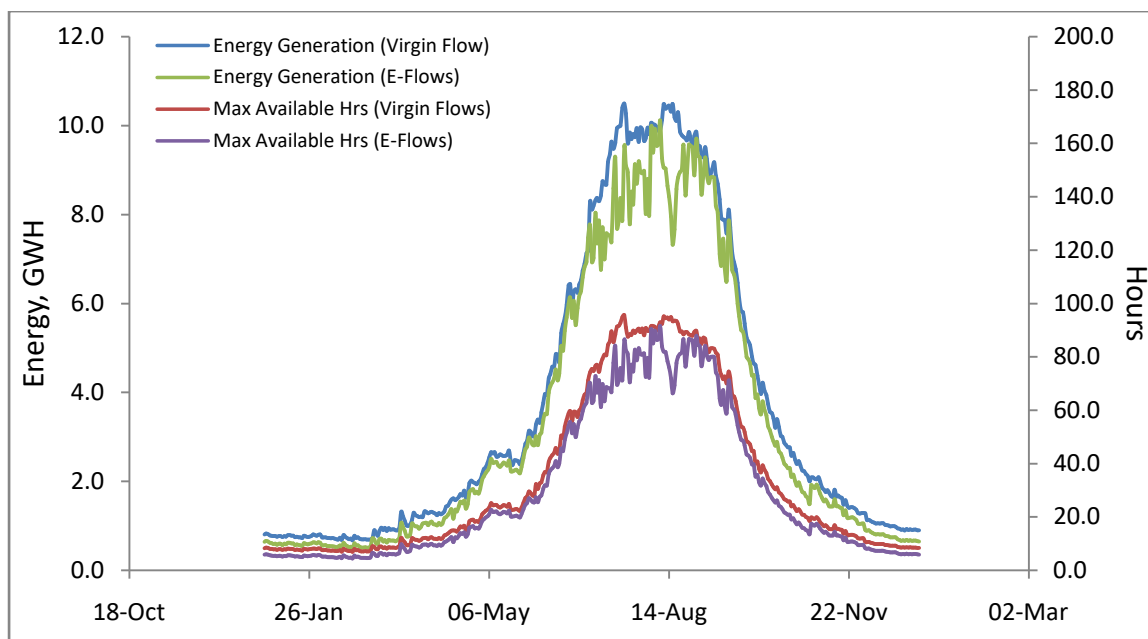


Figure 7.7: Daily Variation in Potential Hydro Electric Power Generation without and with Provision of Environmental Flows (E-Flows) at Koteswar Hydro Electric Project

7.2.2 Monthly Energy Generation

Monthly average energy generation without and with E-Flows is shown in Figure 7.2 and monthlies percentage reduction is shown in Table 7.1, below.

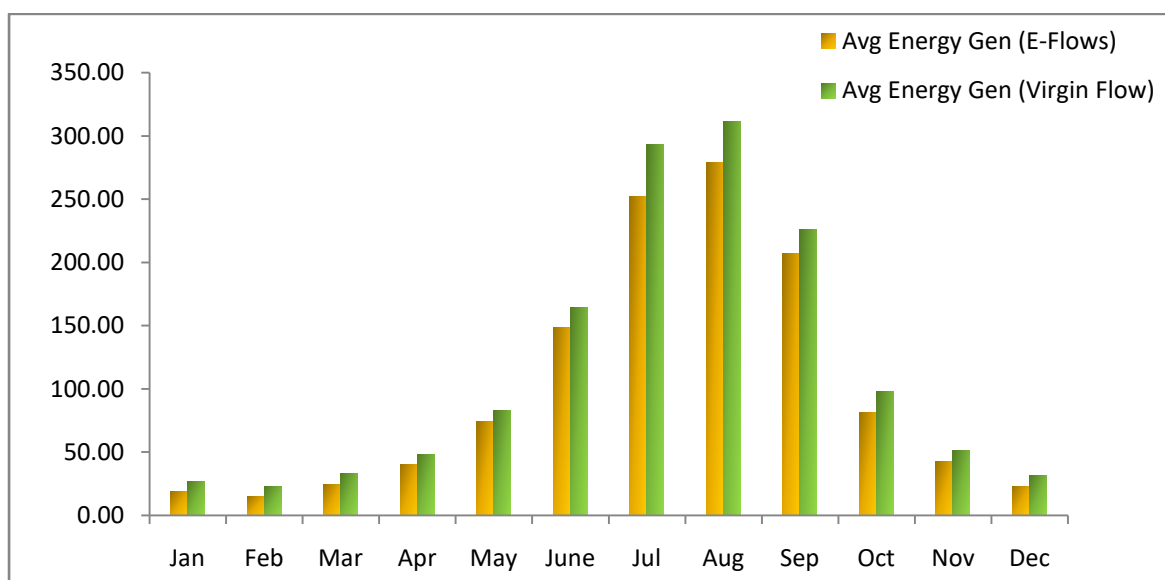


Figure 7.8: Monthly Variation in Potential Hydro Electric Power Generation without and with Provision of Environmental Flows (E-Flows) at Koteswar Hydro Electric Project

Table 7.4: Impact of Provisioning Environmental Flows on Energy Generation at Koteswar Hydro Electric Project

Month	% Reduction	Month	% Reduction
January	31.4	July	14.0
February	33.6	August	10.5
March	25.7	September	8.3
April	17.4	October	17.3
May	10.3	November	16.1
June	9.6	December	26.8
Average Annual Reduction in Energy Production		18.4 %	

7.6 Srinagar HEP

7.6.1 Energy Generation Hydrographs

A comparison between energy generation hydrographs and running hour hydrograph, on average daily basis without and with E-Flows is shown in Figure 7.9.

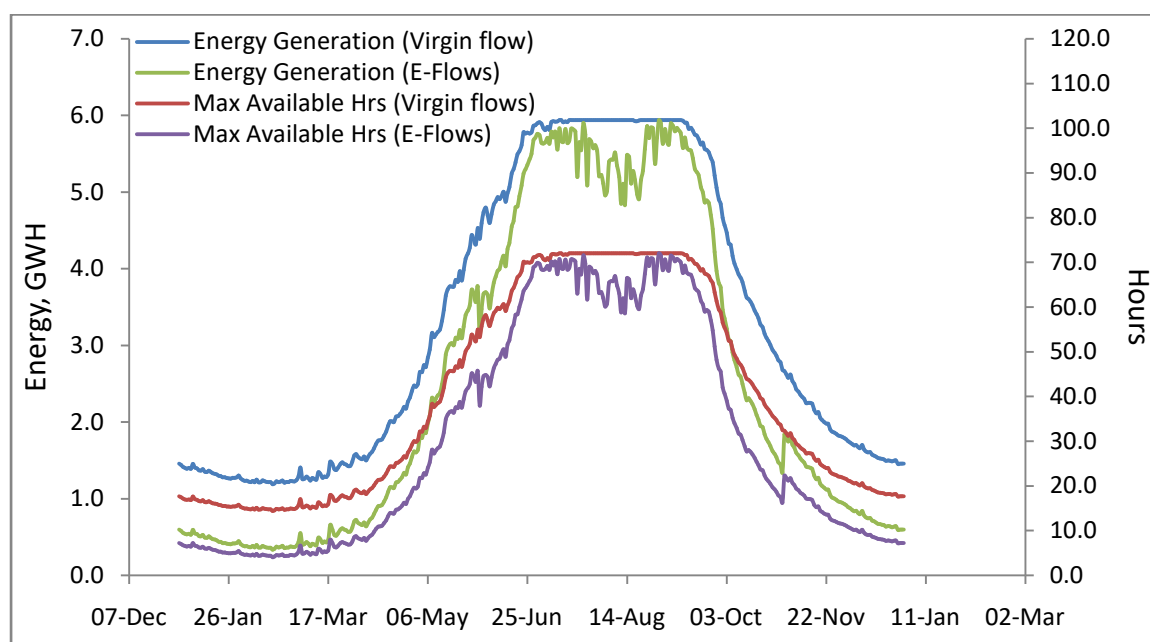


Figure 7.9: Daily Variation in Potential Hydro Electric Power Generation without and with Provision of Environmental Flows (E-Flows) at Srinagar Hydro Electric Project

7.2.2 Monthly Energy Generation

Monthly average energy generation without and with E-Flows is shown in Figure 7.2 and monthlies percentage reduction is shown in Table 7.1, below.

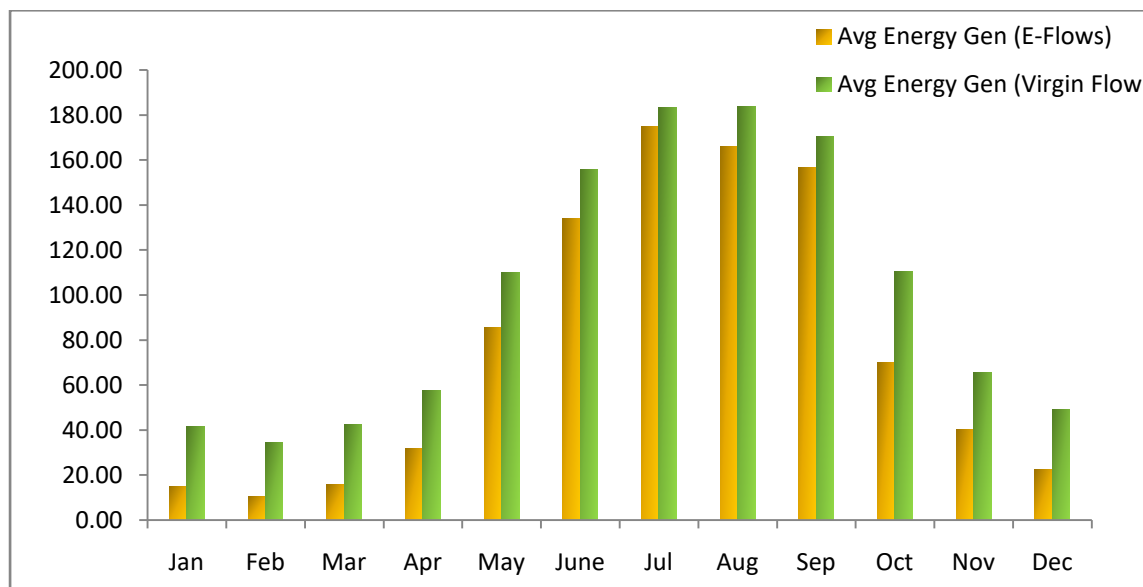


Figure 7.10: Monthly Variation in Potential Hydro Electric Power Generation without and with Provision of Environmental Flows (E-Flows) at Srinagar Hydro Electric Project

Table 7.5: Impact of Provisioning Environmental Flows on Energy Generation at Srinagar Hydro Electric Project

Month	% Reduction	Month	% Reduction in
January	63.7	July	4.6
February	69.6	August	9.8
March	62.4	September	8.2
April	44.9	October	36.5
May	22.3	November	38.6
June	14.0	December	54.0
Average Annual Reduction in Energy Production		35.7 %	

7.7 Reduction in Energy generation

Providing E-Flows at barrage/ dams reduces the intake of water and generation of hydropower. Various power projects, as a result of reduced by some percentage annual energy generation is listed below in Table 7.6

Table 7.6: Impact of Provisioning Environmental Flows on Energy Generation at Various Hydro Electric Projects in Bhagirathi-Alaknanda Basins

HEP	Potential Annual Average Energy Generation without Provision of E-Flows, GWH	Potential Annual Average Energy Generation with Provision of E-Flows, GWH	% Reduction
Maneri Bhali I*	609.86	482.77	20.84
Maneri Bhali II*	1391.62	1129.96	18.80
Tehri	3228.11	2497.80	22.62
Koteshwar	1391.16	1207.54	13.20
Srinagar	1204.85	922.96	23.39

* Run-of-the-river project

7.8 Conclusions

- 1) The power generation hydrograph rises from February and attains its peaks in June-July as flow in the June-July is highest.
- 1) Average annual reduction in energy production ranges between 18% and 36%. The maximum reduction occurs at Srinagar HEP and minimum at Koteshwar HEP.
- 2) There is no correlation found between percentage reduction and installed capacity of the projects or type of the projects.
- 3) The overall percentage reduction is 20.24% due to these hydro projects, in the Alaknanda-Bhagirathi basin.
- 4) In lean period the power generation reduces more than monsoon season as availability of water in the monsoon season.
- 5) The highest percentage reduction in energy production has been found for the months of January-February for all projects and is in the range of 33-70%.
- 6) The minimum percentage reduction in energy production has been found for the months July, September and October for all projects and is below 10%.

7.9 Recommendations

- 1) The power generation is reduced by the order of 1/5th of the total generation. Hence, the energy requirement should be fulfilled by other renewable resources.
- 2) The power projects should be planned in such a way that the E-Flows requirement is fulfilled.
- 3) The study of assessment of hydropower without and with E-Flows is based only on flow data and rainfall-temperature data is not used in calculation. Hence, it would be remarkable if more meteorological stations are positioned in the Alaknanda-Bhagirathi basin.
- 4) After analyses of UJVNL data, we concluded that because of high silt load the RoR projects remain closed, mostly during Monsoon period. A proper analysis should be done, so that partial power generation, without affecting dam/ barrage components, can be made possible, as well as peak flows for E-Flows are also provided in the river.

Appendix I

Details of Hydro Electric Projects

AI.1 Maneri-Bhali I HEP

Project detail

- Name of the River - Bhagirathi
- Coordinates of Barrage site - 30°44'25.09"N, 78°31'44.01"E
- Coordinates of Power House - 30°43'37.51"N, 78°26'42.56"E
- Installed capacity - 90 MW
- No. of units - 3
- Design Discharge for 1 unit - 23.80 cumecs
- Net Head - 147.5 m
- Calculated Power for 1 unit - 31.68 MW
- Efficiency - 92%

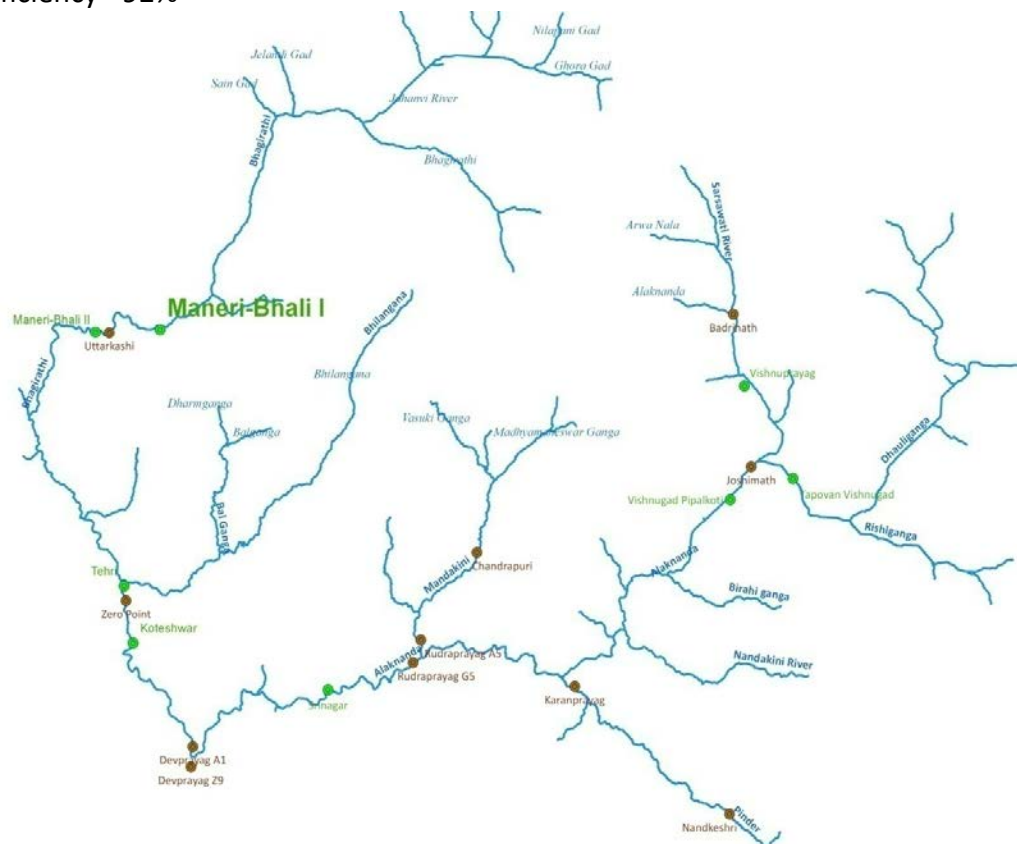


Figure AI.1: Stream Network of Alaknanda-Bhagirathi Basin Indicating Location of Maneri-Bhali I Hydro Electric Project Site

Maneri-Bhali II HEP

Project detail

- Name of the River - Bhagirathi
- Coordinates of Barrage site - 30°43'46.35"N, 78°25'25.35"E
- Coordinates of Power House - 30°36'27.95"N, 78°19'8.42"E
- Installed capacity - 304 MW
- No. of units - 4

- Design Discharge for 1 unit - 35.50 cumecs
- Net Head - 247.6 m
- Calculated Power for 1 unit - 79.33 MW
- Efficiency - 92%

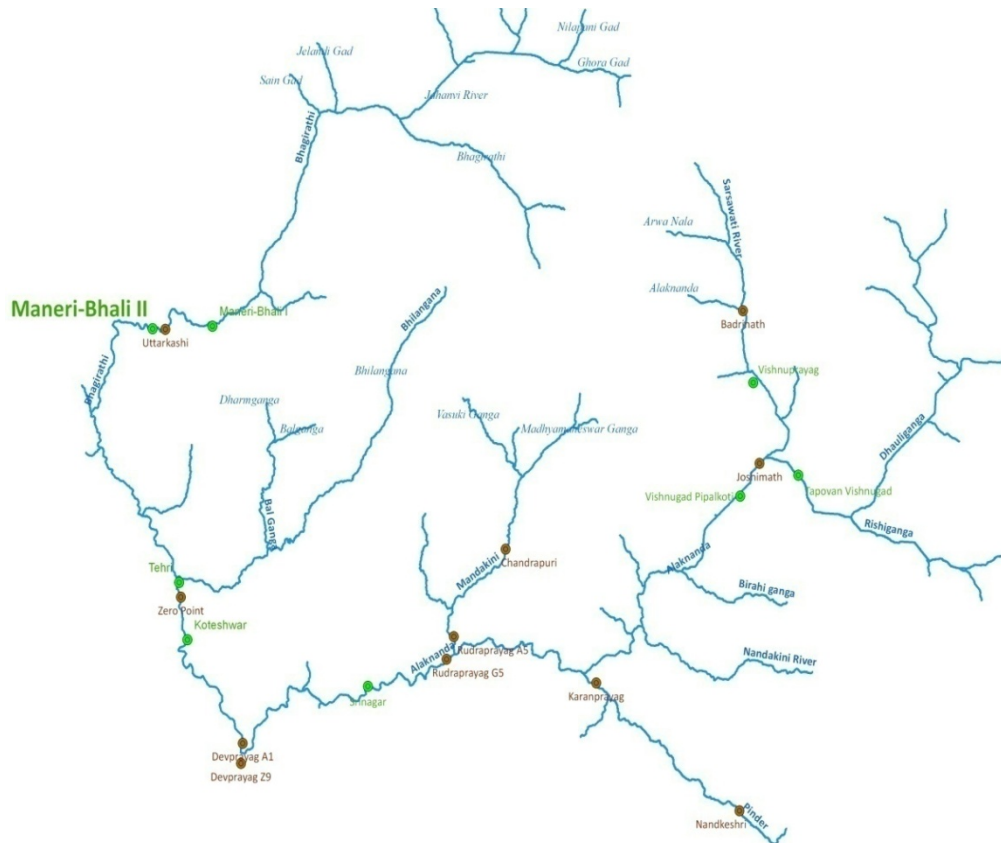


Figure AI.2: Stream Network of Alaknanda-Bhagirathi Basin Indicating Location of Maneri-Bhali II Hydro Electric Project Site

Tehri HEP

Project detail

- Name of the River - Bhagirathi
- Coordinates of Dam Site - 30°22'39.58"N, 78°28'49.75"E
- Installed capacity - 1000 MW
- No. of units - 4
- Design Discharge for 1 unit - 154 cumecs
- Net Head* - 185 m
- Calculated Power for 1 unit - 251.54 MW
- Efficiency - 90%

*For calculation it is assumed that Net Head is not varying.

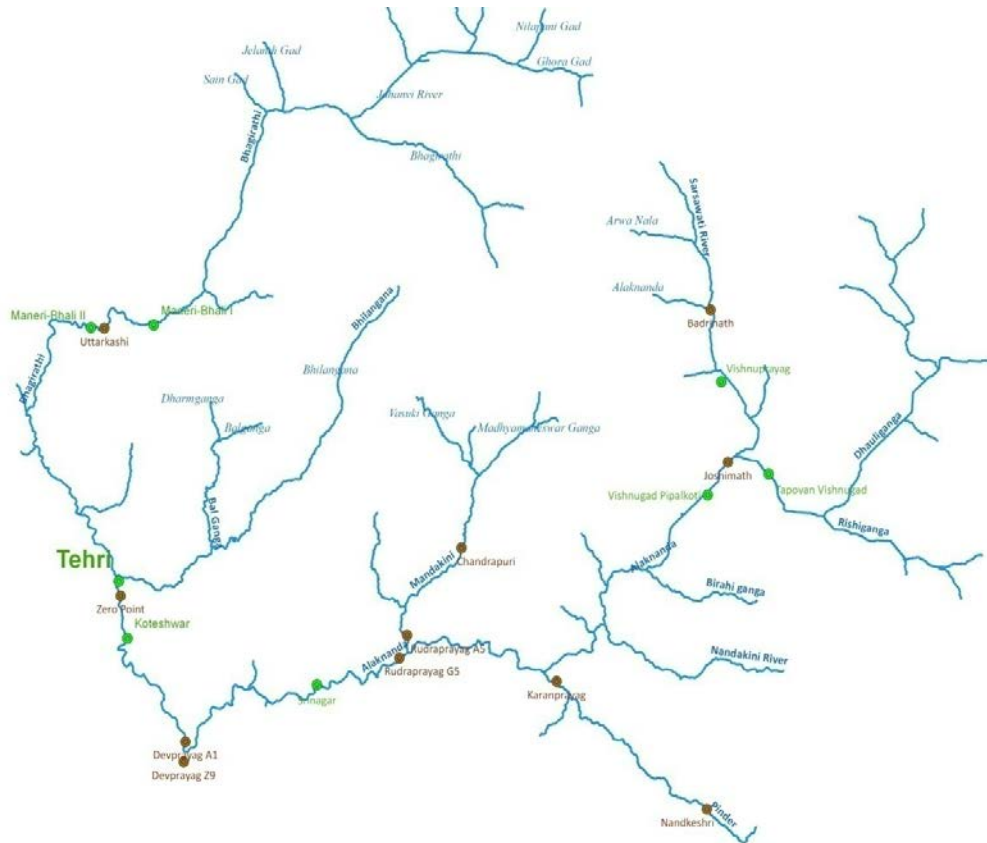


Figure AI.3: Stream Network of Alaknanda-Bhagirathi Basin Indicating Location of Tehri Hydro Electric Project Site

Koteswar HEP

Project detail

- Name of the River - Bhagirathi
- Coordinates of Dam Site - 30°15'43.40"N, 78°29'39.39"E
- Installed capacity - 400 MW
- No. of units - 4
- Design Discharge for 1 unit - 167.50 cumecs
- Net Head* - 74.70 m
- Calculated Power for 1 unit - 110.47 MW
- Efficiency - 90%

*For calculation it is assumed that Net Head is not varying.

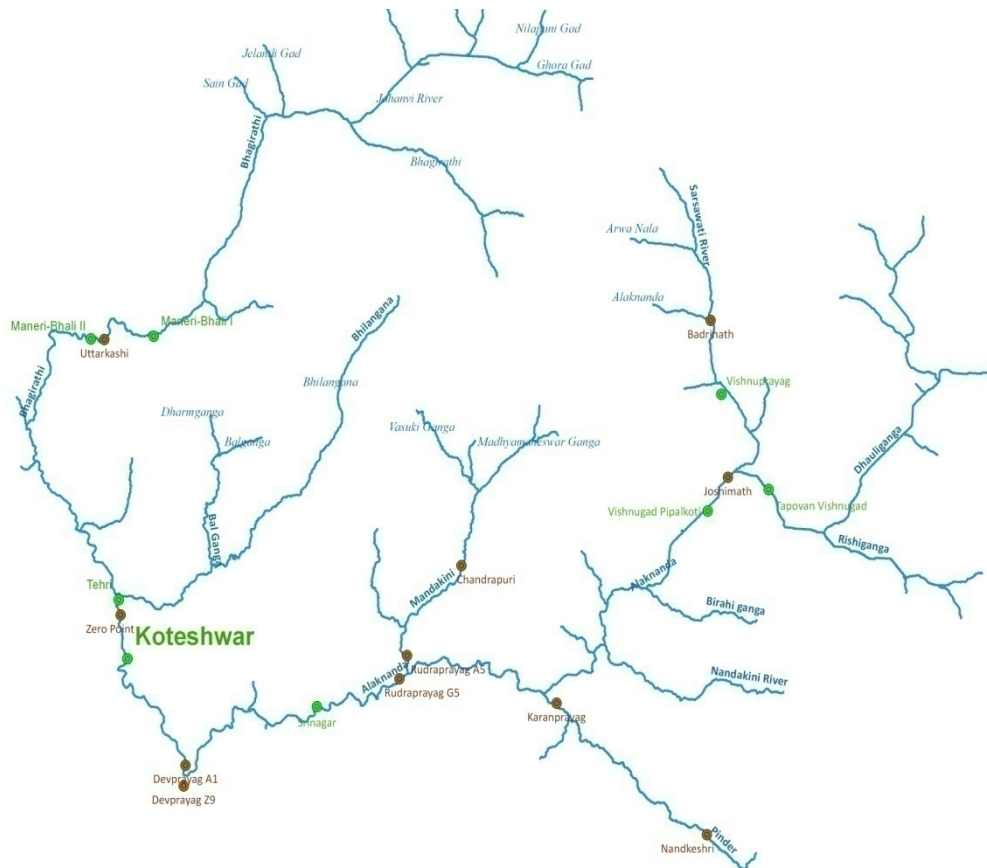


Figure AI.4: Stream Network of Alaknanda-Bhagirathi Basin Indicating Location of Koteswar Hydro Electric Project Site

Vishnuprayag HEP

Project detail

- Name of the River - Alaknanda
- Coordinates of Barrage Site - 30°40'22.12"N, 79°30'48.01"E
- Coordinates of Power House - 30°34'1.27"N, 79°32'49.10"E
- Installed capacity - 400 MW
- No. of units - 4
- Design Discharge for 1 unit – 12.5 cumecs
- Net Head - 915 m
- Calculated Power for 1 unit – 100.98 MW
- Efficiency - 92%

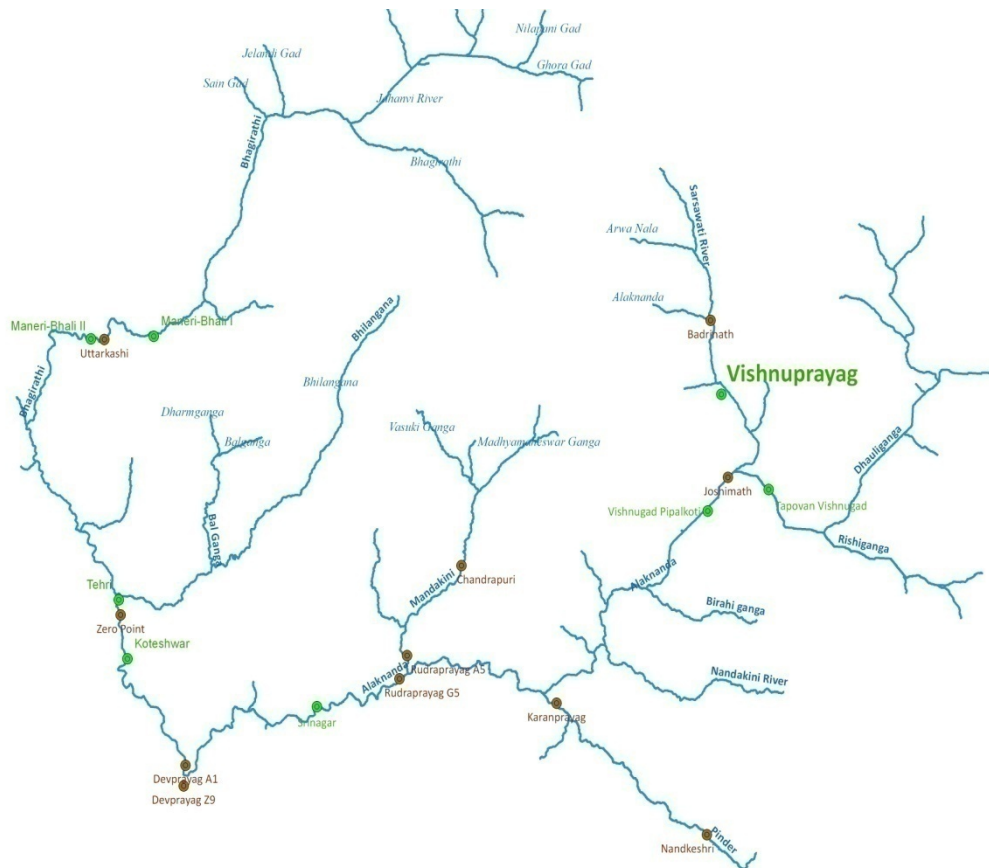


Figure AI.5: Stream Network of Alaknanda-Bhagirathi Basin Indicating Location of Vishnuprayag Hydro Electric Project Site

Tapovan Vishnugad

Project detail

- Name of the River - Dhauliganga
- Coordinates of Barrage Site - 30°29'30"N, 79°37'30"E
- Installed capacity - 520 MW
- No. of units - 4
- Design Discharge for 1 unit – 30.5 cumecs
- Net Head - 483 m
- Calculated Power for 1 unit – 130.26 MW
- Efficiency - 92%

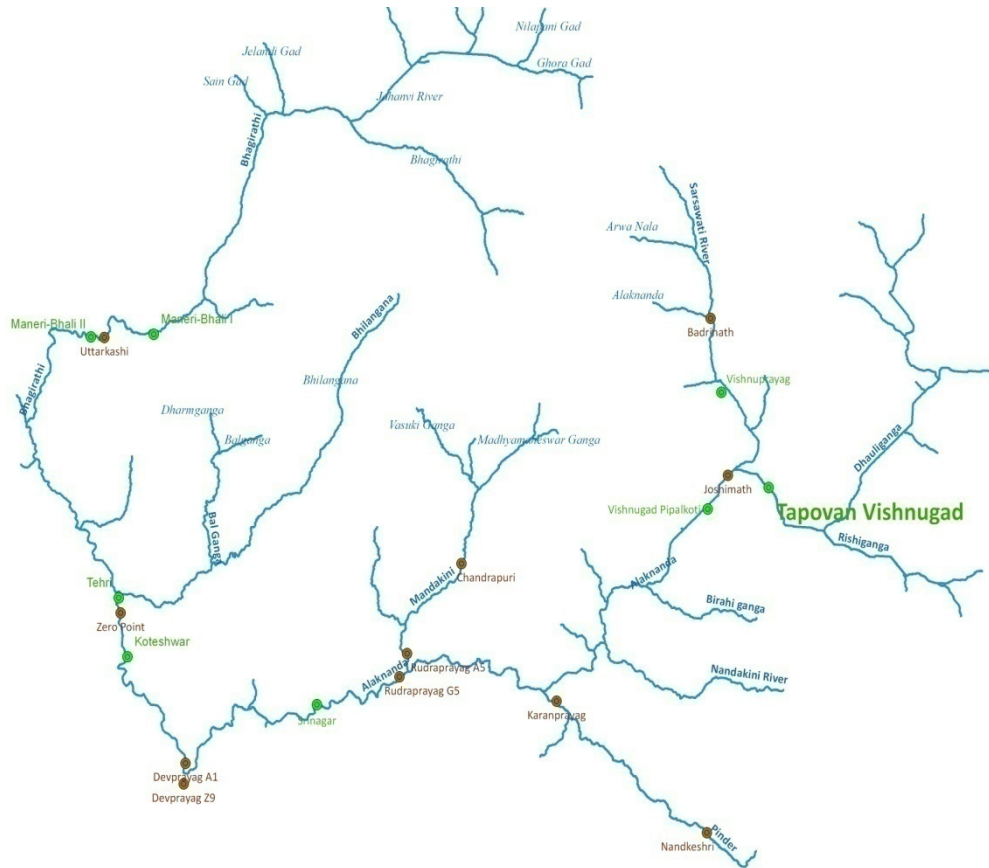


Figure AI.6: Stream Network of Alaknanda-Bhagirathi Basin Indicating Location of Tapovan Vishnugad Hydro Electric Project Site

Vishnugad Pipalkoti HEP

Project detail

- Name of the River - Alaknanda
- Coordinates of Barrage Site - 30°30'50"N, 79°29'30"E
- Coordinates of Power House - 30°25'31"N, 79°24'56"E
- Installed capacity - 444 MW
- No. of units - 4
- Design Discharge for 1 unit - 56 cumecs
- Net Head - 220.08 m
- Calculated Power for 1 unit - 111 MW
- Efficiency - 92%

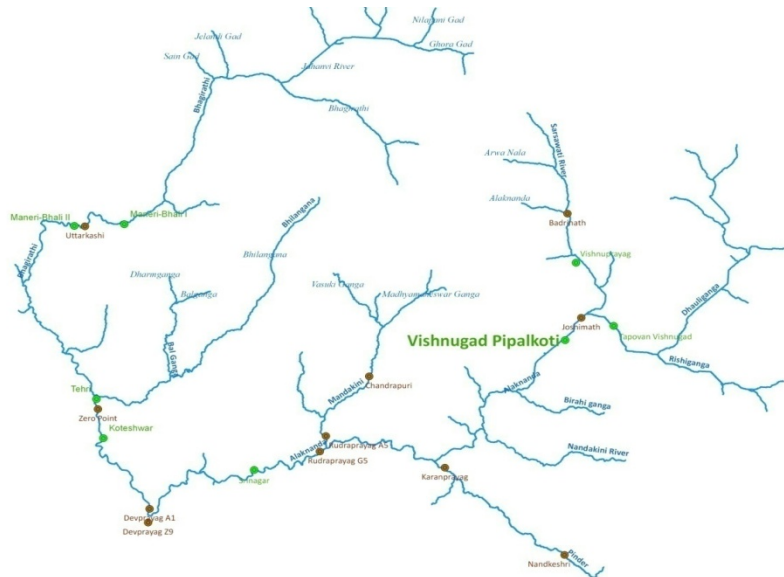


Figure AI.7: Stream Network of Alaknanda-Bhagirathi Basin Indicating Location of Vishnugad Pipalkoti Electric Project Site

Srinagar HEP

Project detail

- Name of the River - Alaknanda
- Coordinates - 30°14'26.51"N, 78°49'29.41"E
- Installed capacity - 330 MW
- No. of units - 4
- Design Discharge for 1 unit - 140 cumecs
- Net Head - 65.97 m
- Calculated Power for 1 unit - 82.45 MW
- Efficiency - 92%

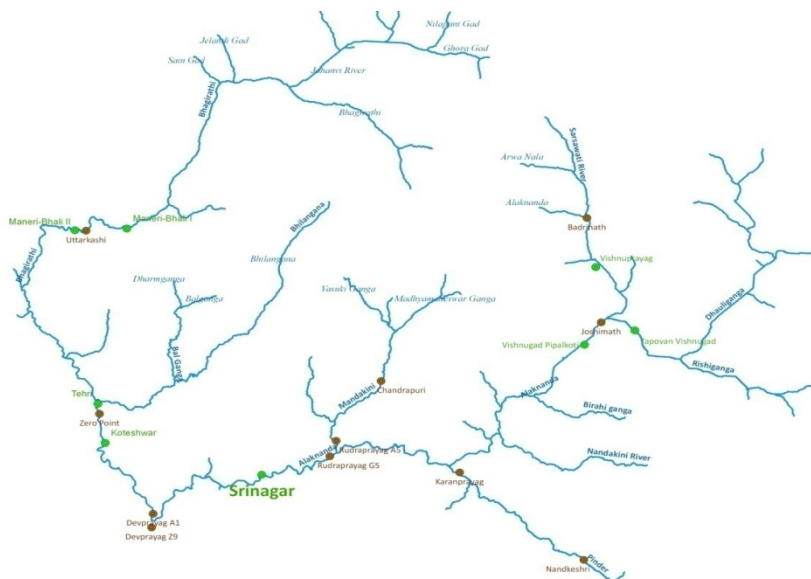


Figure AI.8: Stream Network of Alaknanda-Bhagirathi Basin Indicating Location of Srinagar Hydro Electric Project Site

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