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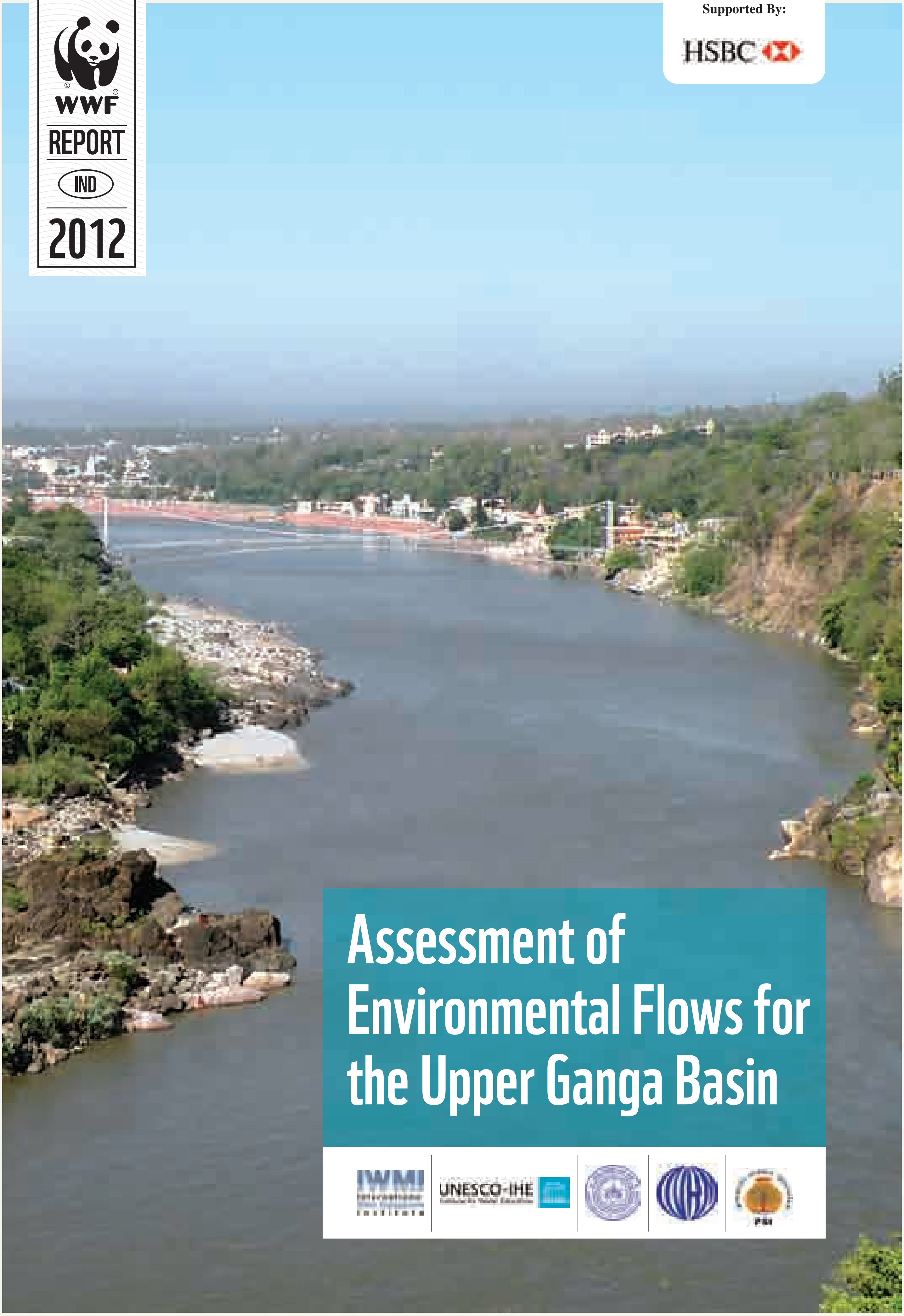

Assessment of Environmental Flows for the Upper Ganga Basin

IWMI International Water Management Institute

UNESCO-IHE Institute for Water Education

PSI

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Assessment of Environmental Flows for the Upper Ganga Basin

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Assessment of Environmental Flows for the Upper Ganga Basin

CONTENTS

ABBREVIATIONS

BBM	Building Block Methodology
CPCB	Central Pollution Control Board
CWC	Central Water Commission
DEM	Digital Elevation Model
EFA	Environmental Flows Assessment
EIA	Environmental Impact Assessment
EMC	Ecological Management Class
GAP	Ganga Action Plan
GEFC	Global Environmental Flow Calculator
GRBEMP	Ganga River Basin Environment Management Plan
IFIM	In stream Flow Incremental Methodology
IHA	Index/Indicators of Hydrologic Alteration
IIT	Indian Institute of Technology
INRM	Integrated Natural Resource Management
ITRC	Industrial Toxicology Research Institute (now called IITR-Indian Institute for Toxicological Institute)
IWMI	International Water Management Institute
IWRM	Integrated Water Resource Management
LISS	Linear Imaging Self Scanning
LU/LC	Land use/Land cover
MLIFR	Maintenance Low-flow Instream Flow Requirement
MoEF	Ministry of Environment and Forests
NGRBA	National Ganga River Basin Authority
NRCD	National River Conservation Directorate
NRSC	National Remote Sensing Centre
PSI	People's Science Institute
SIS	Social Importance and Sensitivity
SRTM	Shuttle Radar Topography Mission
SWAT	Soil and Water Assessment Tool
SWaRA	State Water Resources Agency
UNESCO-IHE	United Nations Educational, Scientific and Cultural Organisation-The Institute for Water Education
WWF-India	World Wide Fund for Nature

FOREWORD

Widely revered, rivers are an integral part of the Indian society and its culture. However, today as we witness the extensive degradation of our rivers, it is evident that this is just not an ecological problem but a larger societal problem – changes in land use, inefficient agriculture and irrigation practices, the growing urban and industrial water footprint and ever increasing energy demands have signifcantly altered the quantity and quality of water flowing in our rivers. Our lifelines are dying. These challenges multiply when we take the case of the Ganga. Although Ganga is considered sacred and revered by millions of Indians, it is amongst the top ten rivers at risk.

One of the key threats to the upper Ganga and other Himalayan rivers is water abstraction for hydropower, irrigation, urban and industrial needs. To address this, the concept of 'minimum flows' has recently been proposed and is being implemented in some river basins. However, this is still not based on a full understanding of the regime of flows needed in a river to maintain its ecological integrity as well as support human needs. It was this gap in a holistic approach to Environmental Flows (E-Flows) that led WWF-India to initiate a program to develop and test a methodology for determining E-Flows for the Ganga.

In 2008, a team from WWF, along with key partners and experts initiated the task of examining and adapting existing global E-Flows methodologies to develop an appropriate approach for a river as complex as the Ganga. This involved integrating various aspects of the river – social and livelihood needs, cultural and spiritual requirements, hydrology and hydraulics, geomorphology, water quality and biodiversity values. The approach to assess E-Flows for the Ganga was developed based on the Building Block Methodology which had to be adapted to include the unique cultural and spiritual values of the river. This report "Assessment of Environmental Flows for the Upper Ganga Basin" captures the journey, the outcomes and the lessons gathered over the last four years of this work.

We hope that this report will inspire and help different Union ministries including the Ministry of Environment & Forests and the Ministry of Water Resources, the State Governments, academics and civil society organizations, who wish to undertake E-Flows assessment in other river basins. As this was the first time that such a comprehensive E-Flows assessment has been undertaken in India, and as the team was working with data constraints, there will need to be constant updating as new knowledge, information and understanding on river basins emerges.

India will need to urgently work towards an implementable policy that retains adequate and good quality freshwater in its rivers. As the Government of India revisits its National Water Policy and the River Action Plans (including the Ganga Action Plan), this work could be a starting point for a new holistic policy, one which does not ignore ecological processes and biodiversity. If this becomes an integral part of India's water policy and management strategy, it can be hoped that rivers can still be brought back to life.

RAVI SINGH
Secretary General and CEO
WWF-India

Photo Credit: Amrit Pal Singh

Clasping hands in prayer, a *sadhu* (holyman) begins his day by taking a dip, and worshipping the Ganga

EXECUTIVE SUMMARY

BACKGROUND

Ecosystem integrity as well as the goods and services offered by the rivers in India are getting adversely affected by changes in quantity, quality and flow regimes. Growing water abstractions for agriculture, domestic, industrial and energy use are leaving many rivers running dry, while others are becoming severely polluted.

The mighty Ganga is no exception. During its 2,525 km journey from Gangotri to Ganga Sagar, there are complex, nested sets of challenges that threaten the very existence of the holy river revered by millions of Indians. In the upper Himalayan reaches, the flow in the river is vulnerable to water abstractions by hydropower projects, both existing and proposed. From the time the river enters the plains, abstractions for agriculture, urban and industrial uses leave the river lean and polluted. As the river's dynamics have been altered by diversions and inefficient use, the freshwater flow has reduced, leading to a reduction in the river's assimilative capacity. As the river makes its way to the sea, and more pollution is added to the lean flows, the stress on the Ganga increases. Climate change is adding another set of complexities to the problems of the Ganga and to the hundreds of millions of people who depend on the river and its basin.

GROWING CONCERN

Awareness of these complexities led WWF-India to initiate its Living Ganga Programme (LGP) in 2007 to develop a comprehensive framework for the sustainable management of water and energy in the Ganga basin in the face of climate change. One of the key challenges for the LGP, was to understand the issue of flows – in other words, how much water does the river need to sustain its social, cultural and ecological functions, and how can this be determined?

Globally, there is a realisation and acknowledgement that managing flows can give a fresh lease of life to dying rivers. Environmental Flows (E-Flows) are increasingly recognised as a key to the maintenance of ecological integrity of the rivers, their associated ecosystems, and the goods and services provided by them. The underlying principle that drove the work on E-Flows under the LGP is that the E-Flows are multidimensional, and their assessment is both a social and technical process, with social choices at its core. Social, as it depends on what the society wants a river to do for them – to support culture and spirituality or livelihoods or biodiversity or all the above functions and more. Technical, because it requires a range of specialist investigations into past, present, and desired future river functioning to provide the data that will inform and support these choices.

ADDRESSING THE PROBLEM

It was this realisation that prompted WWF to bring together civil society groups, National and international experts (hydrologists, geomorphologists, ecologists, hydraulics engineers, water chemists and sociologists) and Government departments to sit together, deliberate, and select an appropriate methodology for the assessment of E-Flows. This was the most challenging task faced by WWF and its partners, who were clear that any methodology selected should respect the uniqueness of the Ganga and its various dimensions (including its socio-cultural importance).

The Building Block Methodology (BBM), a relatively simple and robust method which has been used for E-Flows assessment in rivers in many different parts of the world was ultimately selected. The choice was driven by its flexibility, applicability and reliability under different levels of data and information availability (Chapters 1 and 2).

THE PROCESS

In order to characterise the river in its different reaches, homogenous zones were defined, based mainly on the changing gradient and consequent geomorphological conditions overlain by the changing land uses and river developments (Chapter 3). A sampling site was identified within each zone: Kaudiyala (representing Zone 1 from Gangotri to Rishikesh), Kachla Ghat (representing Zone 3 from Narora to Farrukhabad) and Bithoor (representing Zone 4 from Kannauj to Kanpur). Zone 2, from upstream of Garhmukteshwer to Narora, was selected as a reference zone, where the relatively unaffected conditions could be used as a bench-mark to assess the state of the other three zones.

Besides undertaking technical evaluations to determine the flow requirements to maintain the river in a desired future state according to specific objectives for each component, the groups also carried out interviews with diverse stakeholders to capture their needs and aspirations in terms of their livelihoods and spiritual/cultural well being (Chapter 4).

Then, using a consultative process, each working group (which were setup to take care of each of the components of the study) came up with estimates for appropriate flow regimes to meet the specific objectives and requirements of all species, components and processes in the river during different seasons.

- **The hydrology group** summarised the natural flow regime at each site, illustrating intra-annual and inter-annual flow variability, and flow conditions throughout a "normal" year and a “drought” year. The driest month (January) and wettest month (August) were identified.
- **The hydraulics group** presented and explained the surveyed cross-sections, which illustrated the relationships between river depth, width and flow velocity for any discharge.
- **The fluvial geomorphology group** concentrated on the flow velocities and depths required to move, sort and deposit different sizes of sediment, so as to maintain or restore channel size and other important channel features (such as multiple channels and bars).
- **The biodiversity group** concentrated on the habitat characteristics required for important flow-dependent species such as the river dolphin, selected fish species, macro-invertebrates and floodplain vegetation. These characteristics included the depth, flow velocity, river width, and substrate types required for different parts of their lifecycle.
- **The livelihood group** focused on depth, water quality and river width required to maintain certain livelihood activities (such as ferrying or rafting).
- **The spiritual/cultural group** had to ascertain the depth and water quality issues that would affect religious and cultural activities (such as ritual bathing).

- **The water quality group** responded to the recommendations of the other groups, estimating the effects that the recommended flows would have in mitigating pollution or other water quality issues.

Each group worked out flow motivations corresponding to the following three scenarios:
- Flows for maintenance years (normal years, neither too wet nor too dry)
- Flows for drought years
- Flood flows for both maintenance and drought years

For river Ganga, it has been estimated that the Maintenance Flows would be equaled or exceeded 70 years out of 100. However flows would be lower for 30 years out of 100 or in other words, 70% probability on the flow duration curve. Drought flows are the lowest that would still provide some habitat and survival conditions (i.e. fish would survive but may not breed that year). So, for long-term E-Flows, the water volume required would be at maintenance recommendations or higher for 70% of the time, and between drought and maintenance for 30% of the time.

The recommended flows were based on the flow indicators chosen by each working group (Chapter 5).

RECOMMENDED FLOWS

The recommended flows at each site are expressed as a percentage of the natural Mean Annual Runoff (MAR) in table 1 below. E-Flows are actually a *pattern* of flows. In addition to annual MAR percentages, the monthly and seasonal flow requirements, depicted on the figures (Figures 1 to 6), should be noted.

Table 1: Recommended flows expressed as % of the natural Mean Annual Runoff at each site.

Name of site	Maintenance flows as % of MAR	Drought Year flows as % of MAR
Kaudiyala	72%	44%
Kachla	45%	18%
Bithoor	47%	14%

Figures 1 to 6 summarise the recommended monthly flows for each site during maintenance (normal) years, and during drought years. These are the flows which the specialist groups decided would meet all the objectives.

The monthly flows depicted in these figures are extrapolated from the flows recommended by the specialist groups for the wettest and driest months of the drought and maintenance years. They were calculated by the Hydrology group, to mimic the natural seasonal flow patterns in each zone.

Figure 1: Recommended E-Flows requirement for maintenance years for the Kaudiyala site in Zone 1

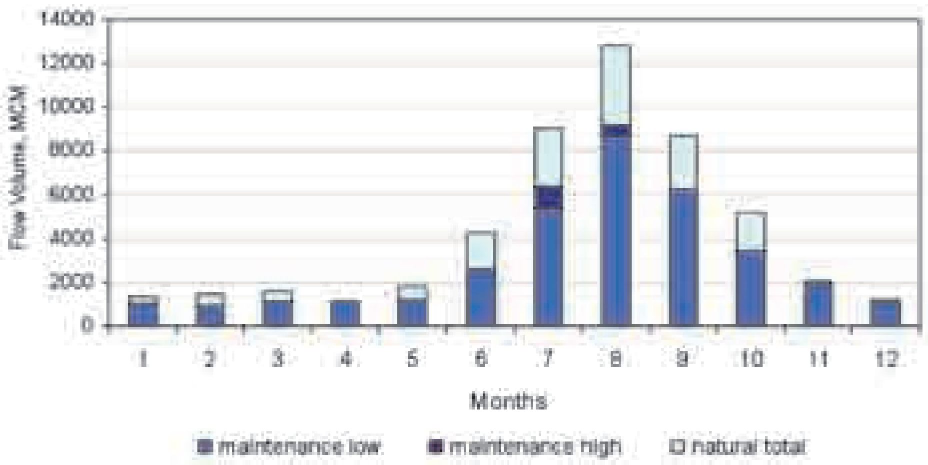
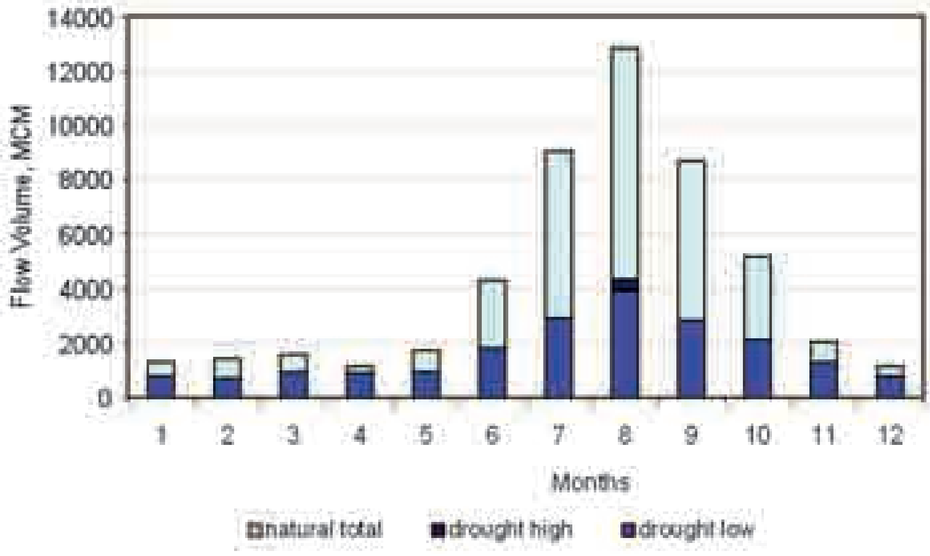


Figure 2: Recommended E-Flows requirement for drought years for the Kaudiyala site



***Note**: For Figure-1 and 2, current flow data was not available.*

Figure 3: Recommended E-Flows requirement for maintenance years for Kachla Ghat

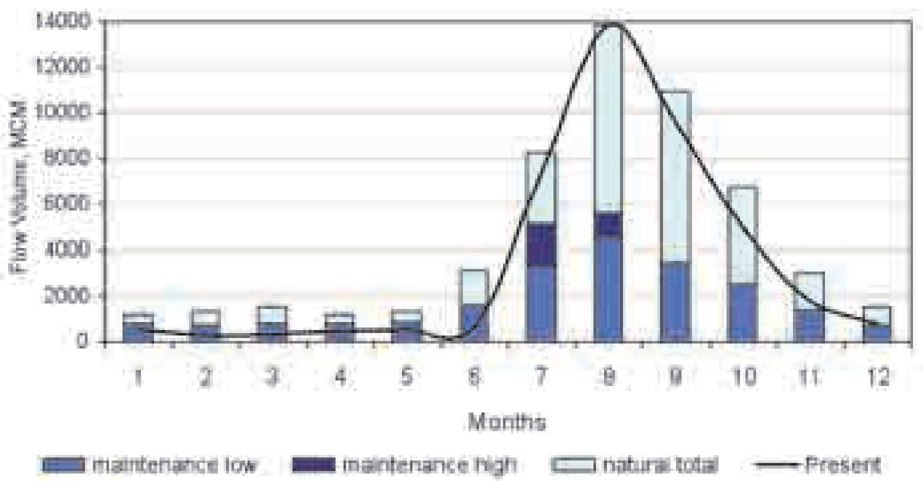


Figure 4: Recommended E-Flows requirement for drought years for Kachla Ghat

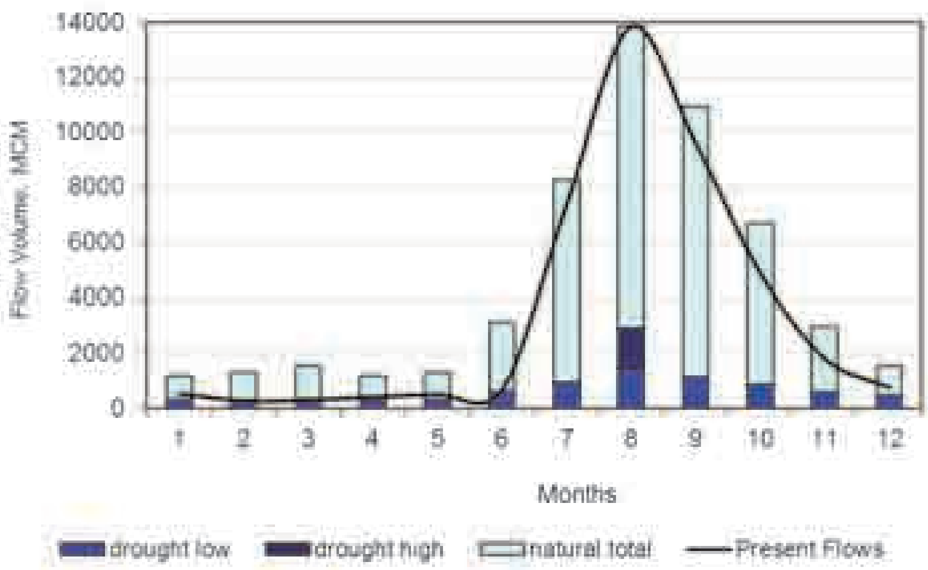


Figure 5: Recommended E-Flows requirement for maintenance years for the Bithoor site

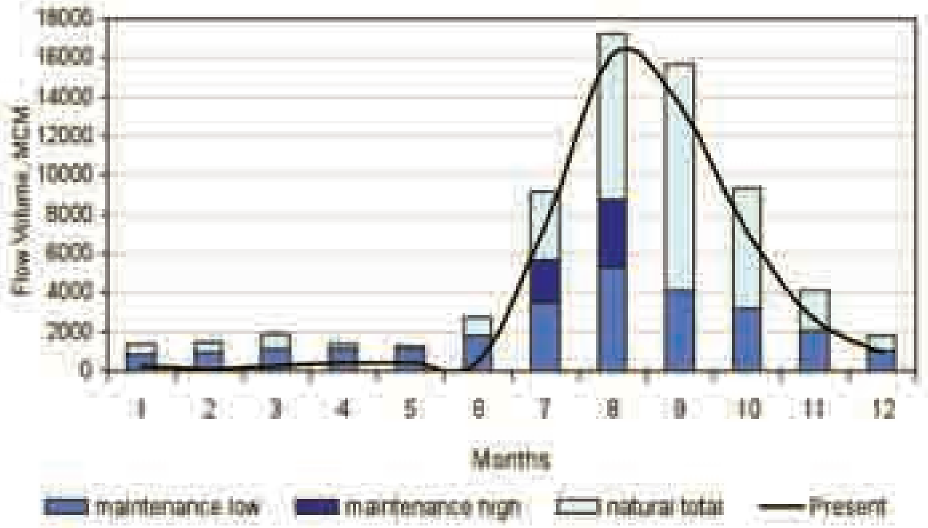
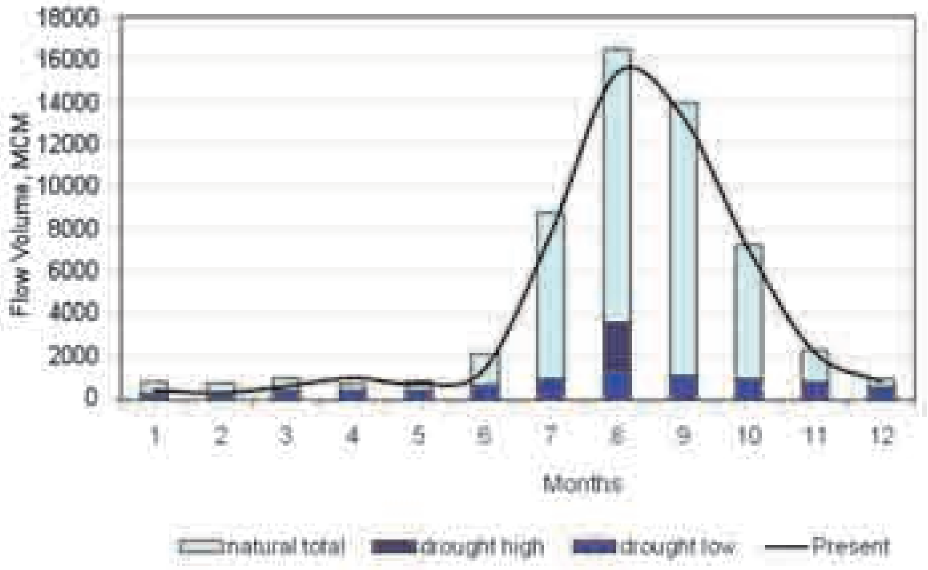


Figure 6: Recommended E-Flows requirement for drought years for the Bithoor site



Chapter 5 provides a more detailed explanation of the assessment and extrapolation of the recommended E-Flows.

CONFIDENCE

The values arrived at are only indicative, as they were based on simulated data (in the absence of access to observed flow data). These could be refined with the availability of more credible and long term real time data. However, as this report will show, the lack of access to hydrological data does not need to prevent the development of a credible methodology for assessment of E-Flows. It is also important to recognise the fact that assessment and implementation of E-Flows is an adaptive process, in which flows may be successively modified in the light of increased knowledge, changing priorities, and changes in infrastructure over time.

WAY FORWARD

This preliminary assessment of the E-Flows requirements for the Upper Ganga from Gangotri to Kanpur has contributed much to the building of capacity and awareness raising amongst experts and organisations who will now be able to undertake Environmental Flows Assessments (EFAs) for other Indian rivers. (Chapter 6). It has also significantly enhanced the knowledge base for the Upper Ganga.

This study was the first attempt to develop a holistic methodology for assessment of E-Flows relevant to the upper Ganga. For this, the BBM was adapted to capture cultural and spiritual dimensions. It did not, however, address the much more difficult question of how these E-Flows can be maintained or restored in the river, or make any attempt to evaluate the costs and benefits of implementing E-Flows.

Two issues remain: Finding the water required to achieve the desired future state, and the practical implementation of the recommended E-Flows. The provision of E-Flows will require either rationalisation and improved efficiency of existing uses, or provision of additional storage to intercept monsoon flows for allocation during the dry season: complex and costly solutions, with their own social and environmental costs.

Two principles should be borne in mind:

- Implementation may be phased and gradual: E-Flows provide a balance between the use and protection of the natural resource. Just as the degradation of rivers is usually a gradual process, an incremental process of E-Flows implementation and evaluation can be followed.
- The results of implementation may emerge slowly: Whilst the costs and benefits of consumptive water use are usually quite simple to calculate in the short-term, the costs and benefits of restoring E-Flows are often long-term, and complicated to quantify.

There is a need to develop successful examples of implementation of E-Flows in Indian rivers. A small-scale pilot implementation in a tributary sub-basin would demonstrate the benefits of E-Flows, complement and support such efforts on the river Ganga, and promote the sustainable development of India's water resources as a whole.

It is hoped that this work will inspire the different Union ministries including the MoEF and MoWR, the State Governments, academics, and civil society organisations to build the knowledge base on E-Flows and move towards its implementation. If E-Flows become an integral part of India's water policy and management strategy, it can be hoped that our rivers, including the mighty Ganga, can still be brought back to life.

PURPOSE OF THIS REPORT

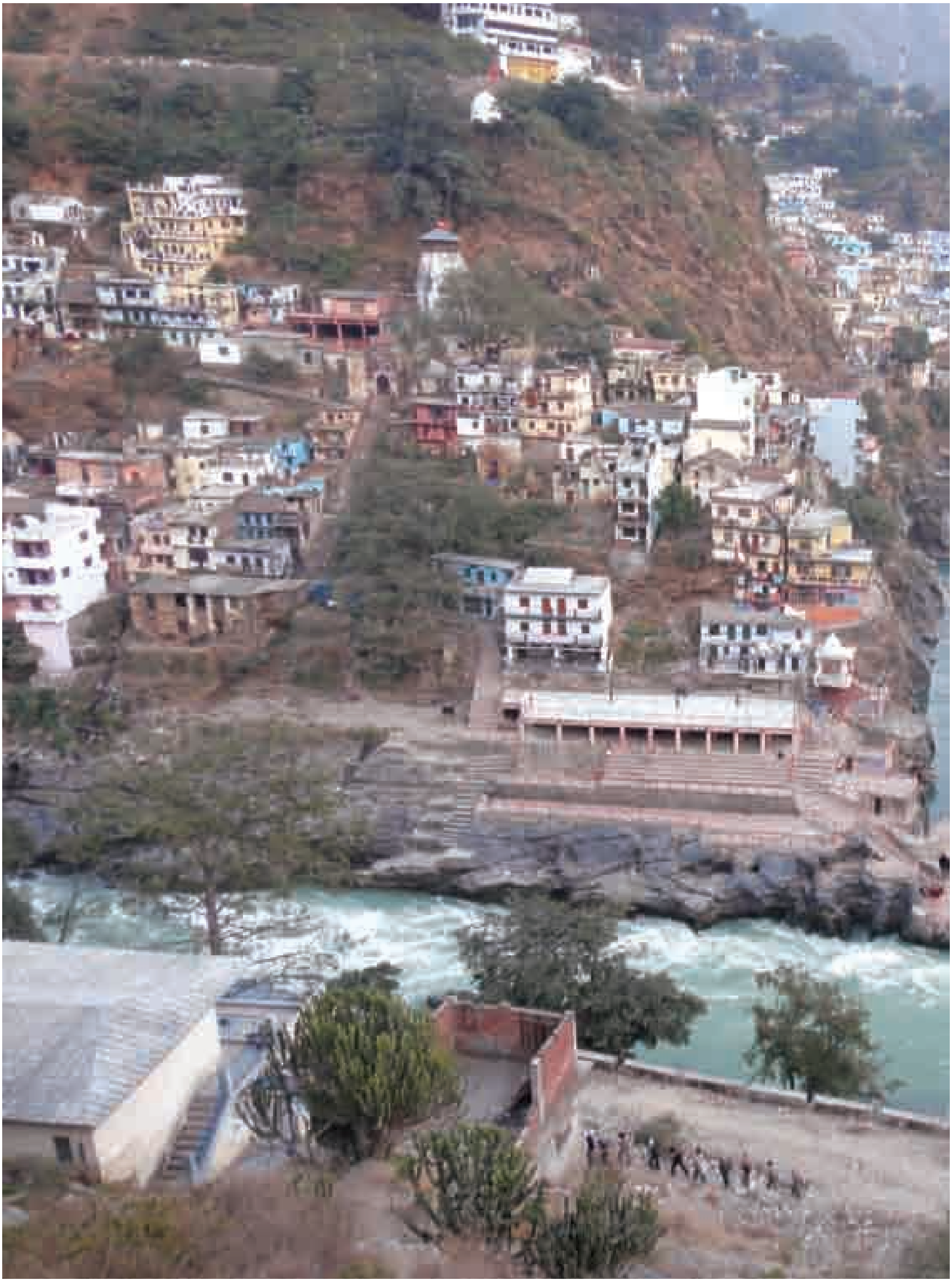
This report is intended to be much more than simply a record of the results of the WWF-India initiative. It is also an account of the first use of a holistic methodology (the BBM) to assess E-Flows for an Indian river. The report is therefore intended to serve as a comprehensive handbook, using the Upper Ganga as a case study, for the application of detailed E-Flows methodologies in India. It is envisaged that, this document will serve the following target audiences:

a. Planners/Practitioners/Researchers/Students in the fields of water research and management – this document will act as a technical, hands-on manual for the assessment of E-Flows for other rivers
b. Other stakeholders – including civil society, NGOs, technical institutions, hydropower developers, financial institutions etc. This report will provide background information about the present state of the Upper Ganga, and steps to decide on the environmental and social objectives (or arrive at the management class) for the river.
c. Policy makers and opinion/decision makers – for this audience, the report is intended to give an idea of the importance of flows as a major driver of environmental conditions in the river, and to outline the available expertise, understanding and methodologies that have been developed in India and worldwide, and the next steps to develop frameworks to mainstream the implementation of E-Flows for sustainable management of rivers.

ORGANISATION OF THIS REPORT

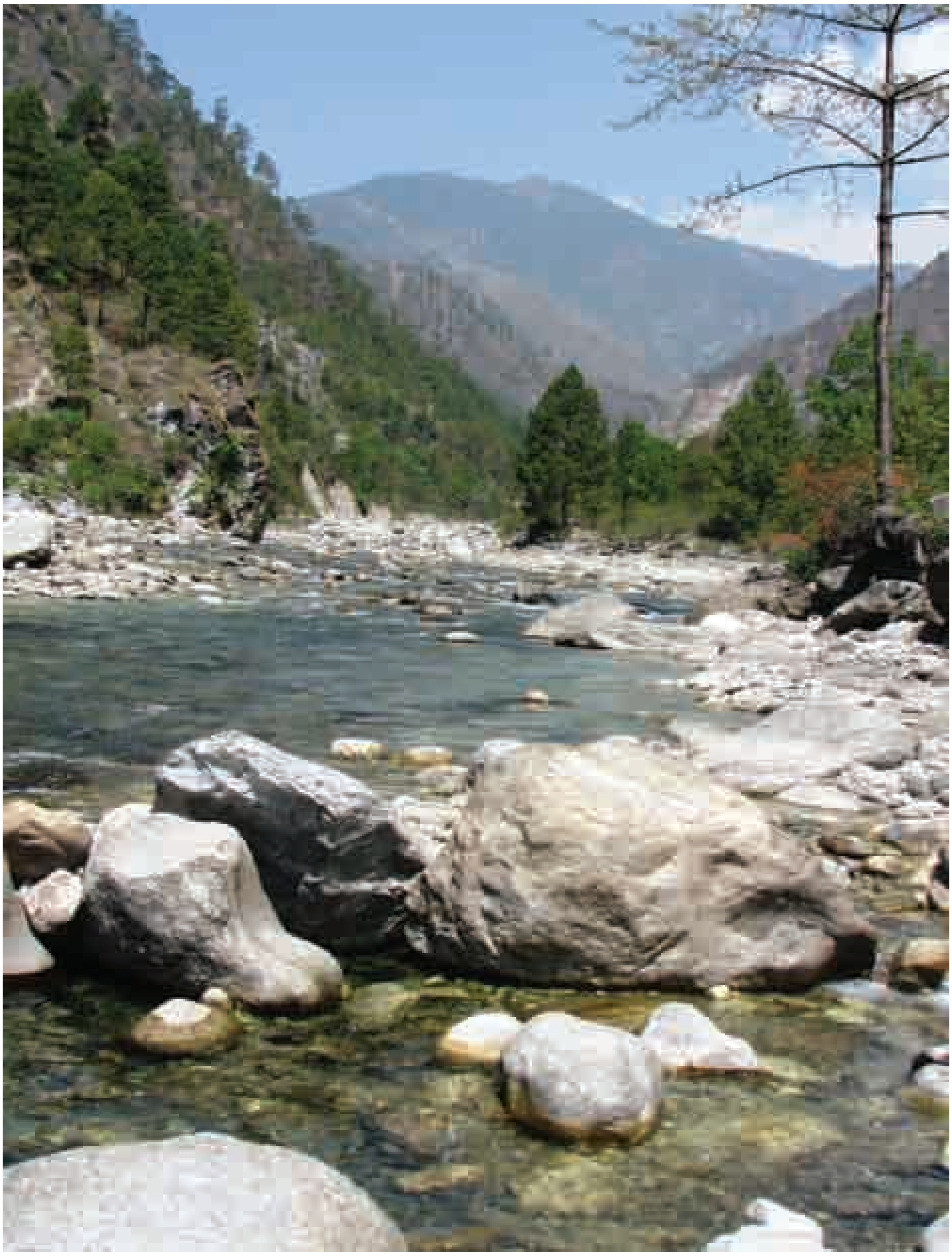
The report is designed to cater for readers with different levels of interest:

- **Executive summary** provides a general overview of the process and results
- Chapter 1 to 6 provides a detailed description of the process, results, motivations, and way forward.
- **Annexure** which comprise a complete set of reports with technical and scientific data from the Upper Ganga assessment and investigations, developed by each specialist or working group. These are included in a CD with this report.



Confluence of Bhagirathi and Alaknanda at Devprayag forms the mighty Ganga

Photo Credit: Nitin Kaushal / WWF-India



During its 2,525 kms journey, the Ganga flows through mountainous terrains with great force carrying large amounts of sediments making its floodplain extremely fertile

Chapter 1
THE CONCEPT OF ENVIRONMENTAL FLOWS AND OVERVIEW OF ESTIMATION METHODOLOGIES

1.1 INTRODUCTION

Under the Living Ganga Programme[1], WWF-India worked with a group of Indian and international specialists (hydrologists, geomorphologists, ecologists, hydraulic engineers and sociologists) to assess the Environmental Flows (E-Flows) required to maintain or improve the environmental conditions of the Upper Ganga River, from Gangotri to Kanpur. This was the first attempt to assess these needs for an Indian river.

1.2 THE PURPOSE AND STRUCTURE OF THIS DOCUMENT

This report builds on the summary report (WWF-India, 2011). The purpose of this report is to provide more detailed results and to describe the process and methodology used, in order to facilitate Environmental Flow Assessments (EFAs) in other Indian rivers, and on the remaining stretch of the Ganga and its tributaries.

This report has been written to inform the following target audience about the flow requirements for the Ganga, and the approaches that can be used for further EFAs:

- Policymakers and opinion/decision-makers
- Planners/practitioners/researchers/students
- Other stakeholders, such as civil society, non-governmental organisations (NGOs), technical institutions, hydropower developers, financial institutions, etc.

The report is organised into six chapters. This chapter describes the concept and the need for E-Flows for rivers, and the different types of assessment methodologies that have been developed in different regions of the world. Each of these methods may be applicable to a particular assessment, depending on the resources, time and expertise available, and the level of confidence required in the assessment.

[1] The HSBC Bank Climate Partnership is a groungbreaking partnership between the HSBC and WWF-India. The Climate group, Earthwatch Institute and the Smithsonian Tropical Research Institute, to combat the urgent threat of climate change by inspiring action by individuals, businesses and governments worldwide. In India, this partnership supported WWF-India's Living Ganga Programme (LGP), which aimed to develop and implement integrated strategies for sustainable energy and water resources management within the Ganga basin in the face of climate change. The critical stretch of 800 kilometers in the upper Ganga, from Gangotri to Kanpur was identified.

Photo Credit: Nitin Kaushal / WWF-India

The Ganga in its magnificent beauty near Rishikesh.

The second chapter describes the methodology that was adopted and modified for the Upper Ganga, its rationale, and the consequences of the results.

Chapter 3 describes the zones which were defined in order to characterise the river in its different reaches, based mainly on the changing gradient and consequent geomorphological conditions, and overlain by the changing land uses and river developments. Further, the background is given for the choice of a specific study site within each zone at which the detailed field work was carried out.

Chapter 4 summarises the present environmental state of the river, describing how it has been modified as it flows from the Himalayas into the increasingly populated and developed plains (up to Kanpur). This chapter also defines the flow-related environmental objectives that should be met.

Chapter 4 also describes the different disciplines which were used to provide a comprehensive analysis of environmental conditions and flow requirements, gives an overview of the available data and information that was used, and of the fieldwork that was carried out by the working groups (or specialist teams) while preparing for the EFA. This work is described in greater detail in the specialist reports which are appended to this document.

Because the Ganga is a trans-boundary river, the historical and present measured flow data are classified, and are thus not available in the public domain. Chapter 4 also outlines the methods that were used to simulate the flow regime at each of the study sites, and provides the resulting hydrology that was used for the assessment. Additionally, it describes the hydraulic cross-sections surveyed at each site, which provided the link through which the geomorphological, ecological and sociological results could be converted into the flows required to fulfill the environmental objectives set for each river zone.

Chapter 5 explains the process, outcomes and reflections from this initiative. It also describes the recommended flow regimes (i.e. the low flows and floods required for both the dry and wet seasons) which the working groups recommended to meet the environmental objectives, and provides the motivation for implementing these flows, and the environmental consequences if these flows are not provided. This chapter also assesses the confidence of the teams in their recommendations, identifying information gaps which need to be filled to increase this confidence.

Chapter 6 summarises the challenges envisaged in taking this work forward, suggests necessary steps for implementation of E-Flows, and makes recommendations for continuing and improving the EFA process, so that it can be refined for the Upper Ganga, as well as applied to other Indian rivers.

The E-Flows are a pattern of flows that are required by a river to maintain itself in a desired environmental condition. As the concept has evolved, there has been significant development of approaches to the assessment of E-Flows.

1.3 AN INTRODUCTION TO E-FLOWS FOR RIVERS[2]

It is becoming increasingly clear that, regionally and globally, freshwater ecosystems are being more heavily impacted by human uses, and that their biodiversity is becoming even more severely endangered than that of terrestrial or marine systems.

Freshwater systems are home to 40 per cent of all fish species whilst occupying less than 0.01 per cent of the world's total surface water. When amphibians, water-dependent reptiles and mammal species are added to those of fish, they together account for as much as one-third of global vertebrate biodiversity. Even at a conservative estimate, the global population decline of freshwater vertebrates has averaged 55 per cent between 1970 and 2000. At the same time, however, communities need to use rivers, lakes and wetlands for diverse purposes: for drinking water, for irrigation and agriculture, for industrial use, fishing, boating, recreation and for cultural activities. If we are careful, rivers can do all these things for us, but increasingly, people see rivers only as source of water and as drains. Many rivers around the world have now stopped flowing, and others carry only wastewater.

Like other natural resources, rivers are most useful if they are used sensibly, becoming useless or dangerous if they are abused. Rivers with little or no flow and an excess of wastewater are likely to become sources of diseases like malaria, cholera, schistosomiasis, and dysentery. E-Flows are 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. The aim of E-Flows is therefore to ensure that water resources are used fairly.

In order to decide on E-Flows, people need to decide what they want a river to do for them: Firstly, do they want its water to grow crops, or generate electricity, or domestic and industrial supply for towns, or to be available to meet ecological needs? The second decision that people have to make is: What state do they want the river to be in? In most cases, they want to make at least some use of the water and other resources of the river, and do not want to keep it entirely natural. Also, in most cases (preferably all cases); they do not want to turn it into a dry river bed or a waste drain for waste. They therefore need to decide in what state (natural to completely modified) they would like to keep it. Assisting key players to make these decisions is the role of EFA.

In many places, stretches of rivers such as the Indus and the Yellow River have stopped flowing during dry seasons. The socio-economic consequences of this disruption and collapse of freshwater systems are often profound: people are much more dependent on natural riverine services than is immediately apparent, and this only becomes obvious when the river is seriously degraded.

In response to this, the concept of E-Flows has been developed over recent decades, and is now being applied in countries as diverse as Australia, South Africa, Tanzania, Mexico and China, as well as in Europe and North America.

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[2] Modified from the publication *Keeping rivers alive: An overview of Environmental Flows and their assessment for all levels of users*. WWF (2009) By J H O'Keeffe and T Le Quesne. WWF Water Security Series 2. Published by WWF-UK, Godalming, Surrey. 39 Pages

Global experiences

From global experiences of EFAs in recent decades, a number of key lessons have been learned:

1. The characteristics and ecosystems of rivers are controlled in a very significant way by physical processes, particularly flows. An E-Flows regime describes all the different flows (wet season, dry season, floods, droughts, etc.) that are needed to keep the river and all its aspects functioning in a desired condition (which will usually be defined by the requirements of the diverse stakeholders in the basin).

2. An EFA is both a social and a scientific process, with a social choice at its core. There is no single correct E-Flows regime for a river: the right answer will depend on what people want from a river. Different sorts of rivers are likely to have different requirements and priorities. For example, flows required for a river in a protected area would contrast with those for a river in a major irrigation or urban area. Choice and judgement, particularly when deciding on environmental objectives, are an essential part of the E-Flows process.

3. An EFA is based on the assumption that there is some 'spare' water in the river that can be used without unacceptably impacting on the ecosystem services that the river provides. The process is therefore aimed at a compromise between sustainable use of the river's resources, and the long-term protection of the resource-base which provides for those uses.

4. E-Flows are not just about establishing a 'minimum' flow level for rivers. All of the elements of a natural flow regime, including floods and droughts, are important for protecting the characteristics and diversity of natural communities in a river.

5. E-Flows don't always require an increase from present flows. In some cases, (for example, 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 than at present. In cases where river resources have not yet been extensively developed, the assessment may identify that some more water can be abstracted for use without unacceptable impacts on the ecology of the river.

6. EFAs are not only useful in rivers for which the water resources have been/are being developed, but also allow managers to find out the environmental requirements before any development plans are made, so that these flows can be factored into the planning process at an early stage.

7. Lack of information and resources should never be a barrier to the implementation of E-Flows. Some attempt to restore the natural flow variability is always better than none, and fine-tuning can be done as more knowledge and resources become available over time.

8. In almost any context, implementation of E-Flows presents an immeasurably greater challenge than assessing the necessary flows. River managers (including engineers and decision-makers at local level) therefore need to ensure that they devote an equal amount of effort to discuss and debate over the appropriate E-Flows methodology, as well as its implementation.

9. Globally, there are now over 200 methods for assessing E-Flows. Some are very quick modelling or extrapolation methods, requiring no or minimal extra work; others require years of fieldwork and specialists from a number of disciplines. The five main categories of assessment are: look-up table approaches; extrapolation approaches; hydraulic rating methodologies; habitat simulation methodologies; and holistic methodologies. The choice of method will depend on the urgency of the problem; the resources (time, expertise, historical database as well as finance) available for the analysis; the importance of the river; the difficulty in implementation, and the complexity of the system.

10. Instead of undertaking extensive prior assessment, an important alternative approach may often be to concentrate immediately on the implementation of some flows. This option then requires careful monitoring of the results of trial flows, to see whether they meet the desired objectives. This is likely to be particularly important in situations where there is already an acute problem of over-abstraction.

11. In all contexts, implementing E-Flows should be an adaptive process, in which flows may be successively modified in the light of increased knowledge, changing priorities and changes in infrastructure (e.g. modifications in dam operation) over time. From this perspective, it may be more appropriate for legislation to require implementation whilst allowing flexibility in the methods of assessment.

In the particular case of the Ganga River, not only it is home to unique and endangered species such as the Ganges river dolphin and *gharial* (freshwater crocodile), but it is also the holy river of India, embodying the spiritual fundamentals of the nation. At the same time, it also supplies water for sustenance of about 500 million inhabitants of the basin. To maintain healthy flowing water in the whole length of the river, its tributaries and floodplain, while supplying the consumptive needs for irrigation, industrial and domestic uses, is an extremely difficult juggling act for the basin managers. E-Flows, aimed at fulfilling the

Ganga river is home to the highly endangered Ganges River Dolphin *(Platanista gangetica gangetica)* which have been recently declared as the National Aquatic Animal by the Government of India

Photo Credit: Francois Xavier Pelletier / WWF-Canon ecological, social and spiritual needs of river users from the upper reaches to the sea, need to be factored into the integrated plan for supplying the water, and removing the wastes of these users, so that the equitable use of this priceless resource can be achieved.

1.4 OVERVIEW OF EFA METHODOLOGIES

The concept of E-Flows arose from the relatively common-sense idea that taking all of the water out of rivers was neither a wise nor sustainable way to manage water resources. Large scale water abstraction mean that downstream users are left without water for their own needs, and a waterless river provides none of the benefits that a flowing river offers.

It was, however, only in the 1970s that far-sighted environmentalists began to promote the advantages of leaving water in rivers, and to develop the original methods for assessing how much water was necessary to maintain downstream ecosystems. The methodologies for assessing E-Flows for rivers range from simple instant look-up tables, to fieldwork-intensive methods that may require several years of investigation and analysis as a background for the recommendation of an appropriate flow regime.

The process of assessing and implementing E-Flows deals not just with maintaining some flow in rivers, but also with managing the magnitude, frequency, duration, timing and rate of change of flow events, so that the mosaic of hydraulic habitat conditions is maintained over time and space, to provide opportunities for the range of species, processes, structures and functions that are characteristic of the natural biodiversity of the river.

Generally, the application of an intensive E-Flows assessment method will lead to recommended flows with a higher confidence level (from the perspective of accuracy and clarity), and more detailed motivations which provide clear consequences for the biodiversity, livelihoods or other aspects. The various EFA methods can be grouped into the following commonly-used generic types which require differing amounts of time and resources:

- Hydrology-based and look-up table approaches
- Extrapolation approach
- Hydraulic rating methodologies
- Habitat simulation methodologies
- Holistic methodologies

The following actions are less commonly taken:
- “See what happens” method
- “Upside down” or "Onus on the user" approach

Table 1.1 describes the general requirements for each generic type of assessment method, and the level of confidence in the resulting recommendations.

Table 1.1: General requirements for each generic type of assessment method

Assessment Type	Requirements	Time	Costs required	Confidence
Look-up Tables	Hydrology	1 day	Low	Low
Hydrological Models	Hydrology	1 day	Low	Low
Extrapolation Model	Hydrology	1 day	Low	Low
Hydraulic Rating	Hydrology/Hydraulics	1 week	Intermediate	Low
Habitat Simulation	Hydrology/Hydraulics/ Ecology	Months	High	Fairly High
Holistic	Hydrology/Hydraulics/ Ecology/Geomorphology/ Social/Water Quality	Months/years	High	High
See What Happens	Controlled Flow Releases	Weeks	Low	Fairly High
Upside-Down	Change in policy	Unknown	Unknown, but long	High but large

1.4.1 Hydrology-based and look-up table approaches

These are the original and simplest of the assessment types. Hydrology-based methods are confined to the use of existing or simulated flow data, on the assumption that maintaining some percentage of the natural flow will provide for the environmental issues of interest. An example is the Index of Hydrologic Alteration (IHA) developed by the US Nature Conservancy. The IHA describes the natural range of hydrological variation using 32 different hydrological indices, which together describe the magnitude, timing, duration, frequency and rate of change that characterise the flow regime of the study river. Flow management targets are then set as ranges of variation for each parameter. The IHA software is available online free of charge.

Look-up tables are typified by the Montana Approach (see Table 1.2), perhaps the original of all the methods, developed by Tennant in 1976. The Montana Approach provides a table which indicates the percentage of the average (natural) flow required in the wet and dry season, to maintain conditions variously described as "optimum (60 to 100%), outstanding, excellent, good, fair or degrading, poor or minimal, and severe degradation (less than 10%)".

Table 1.2: The Montana Approach" Look-up Table for prescribing Instream Flow Regimes for Fish, Wildlife, Recreation and Related Environmental Resources Tennant (1976)

Narrative Description of Flows[1]	Recommended Base Flow Regimes Oct-Mar	Apr-Sept
Flushing or Maximum	200% of the average flow	
Optimum Range	60%-100% of the average flow	
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or Degrading	10%	30%
Poor or Minimum	10%	10%
Severe Degradation	10% of average flow to 0 flow	

[1] Most appropriate description of the stream-flow for all the parameters in the title.

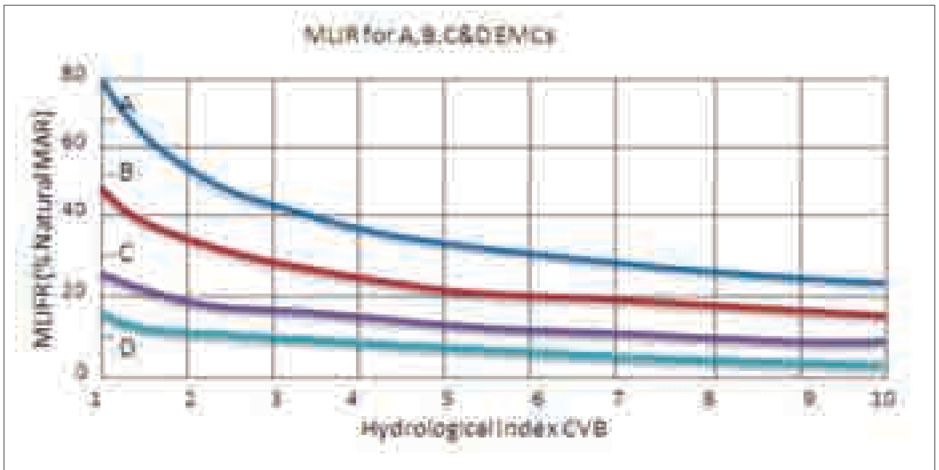
1.4.2 Extrapolation approach

This method, developed in South Africa, is based on the results of a large number of detailed EFA studies. It correlates the results of existing EF estimates with environmental objectives (where A = natural and D = largely modified), and a hydrological index which generally describes the reliability or "flashiness" of the flow regime (See Figure 1.1). The method recommends an appropriate percentage of the natural flow, and allows the EF monthly time series to be subsequently estimated using monthly duration curves.

This method can only be used in regions where numerous existing EFAs have already been done using more comprehensive methods, which provide the data set for the extrapolation.

Figure 1.1 shows that the curves represent decreasing flow requirements for rivers with increasingly unpredictable or "flashy" flow regimes, as measured by the hydrological index CVB. Curves A to D represent the flows required to conserve rivers in EMCs from nearly natural (A) to largely modified (D).

Figure 1.1: The extrapolation approach of Hughes and Munster showing flow requirements for a variety of ecological management classes, as a percentage of the natural mean annual runoff (MAR)



(MLIFR/MLIR =Maintenance Low-flow Instream Flow Requirement; EMC = Ecological Management Class; CVB = Coefficient of Variance for Base flows)

1.4.3 Hydraulic rating methodologies

Hydraulic rating methodologies measure changes in the available hydraulic habitat (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 an estimate of the changes that would occur in that habitat as a result of changing flows. The required flows can be inferred from an assessment of the habitat available for sensitive, or “indicator” species.

1.4.4 Habitat simulation methodologies

Habitat rating simulation methodologies combine hydraulic rating with the characterisation of habitat preferences of target species. Multiple rated cross-sections are used in a hydraulic model to simulate the conditions in a river reach, again based on wetted perimeter, depth and velocity. Biological sampling of indicator species, combined with measurements of the hydraulic characteristics where they are found, are used to populate the habitat part of the model. The combined hydraulic/biological model then calculates the area of preferred habitat available for the indicator species at different flows, and can be used to infer the required flows.

This method, and particularly the Instream Flow Incremental Methodology (IFIM), a type of habitat simulation methodology, has been used extensively, especially in the United States, and flow recommendations based on it have been successfully defended in court.

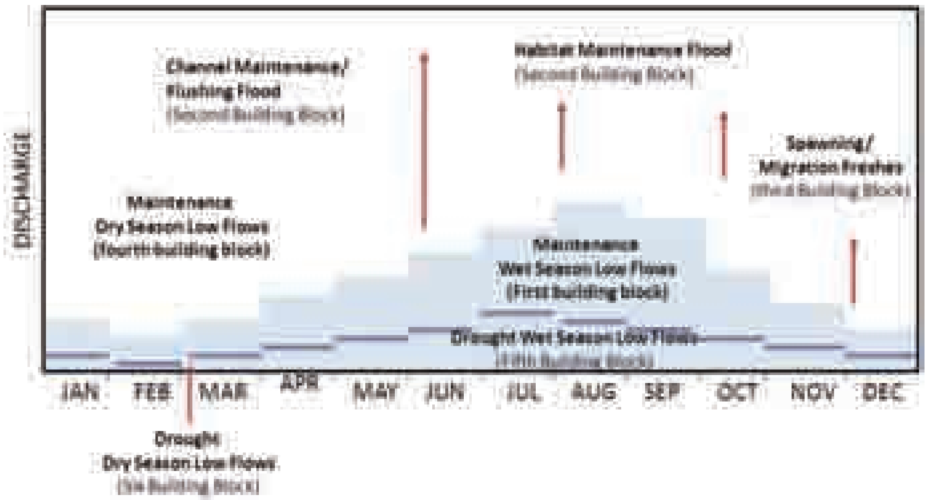
1.4.5 Holistic methodologies

These are multidisciplinary methodologies based on the inputs of multiple specialists (or working groups) from different disciplines, who aim to reach a consensus regarding the setting of appropriate flows to meet a pre-defined set of environmental objectives, and to describe the consequences of different levels of modifications to the flow regime (see Figure 1.2).

Most of these holistic methods make use of a multi-disciplinary team including a hydrologist and a hydraulics engineer to provide the baseline data on flows and hydraulic conditions; freshwater biologists (for fish, invertebrates and riparian vegetation) to characterise the requirements of the biotic communities; a geomorphologist to predict the changes in sediment transport and channel maintenance at different flows; a water quality specialist; and a socio-economist.

A number of different specific methodologies exist, such as the Building Block Methodology (BBM) and the Downstream Response to Imposed Flow Transformation (DRIFT), which provide structured frameworks for the collection, analysis and integration of the data to provide an expert prediction of the effects of flow modifications.

Figure 1.2: Components of the flow regime (known as Flow Building Blocks) of the type used in BBM



The “blocks” are basically those elements of the flow variability that are considered to have particular ecological functions. The holistic group of methodologies has become widely used over the past decade, since they are robust, can be used with different objectives and levels of data available, and have the credibility of the joint expertise of a number of specialists in different scientific disciplines.

In addition, there are two approaches which can be highly effective and appropriate in certain situations. These are actions that can be taken, rather than EFA methods:

- Releasing some water down the river, without a prior assessment, and monitoring to see the effects, and
- Putting the onus on the potential user, requiring them to show that the use will not unacceptably degrade the river. At present, EFA methods try to make the case for the river to retain some of its flow, but it would be more in line with Environmental Impact Assessment (EIA) policy for potential users to be required to justify the environmental impact of their proposed development.

1.4.6 The “See what happens” method

This approach involves releasing water down the river, and monitoring the results to see if they meet specified objectives. This has the advantages of not requiring any sophisticated predictions of the effects of flow, and of being able to provide instant results based on real experience. However, it does need either some form of storage available from which the experimental or Environmental Flows can be released, or require that users are prepared to forego allocated water so that it is allowed to flow downstream. There also needs to be a willingness on the part of river management agencies to release the flows without a detailed justification, which is often problematic in contested environments.

1.4.7 The “Upside down” or "Onus on the user" approach

In this approach the burden of proof is reversed, and the potential user is required to demonstrate that the proposed use of the river’s resources will not unacceptably degrade the resource, or “impair the public trust” in the legal sense in the United

States, where this approach has been pioneered (as yet unsuccessfully). Adoption of this approach would probably be a long-term goal for the protection of water resources, since it is aligned with the other EIA methods where the onus is on the potential user to demonstrate that the proposed development is not fatally flawed, is better than any alternatives, and that impacts will be mitigated as far as possible.

As rivers are so diverse and the ecological, social, cultural and economic contexts are also different for each case, each of the different types of methodology may be useful in particular situations. The South African policy framework for example has accounted for these diversities, as shown in Box 1.1, which describes the approach adopted by South African government for E-Flows assessment and implementation.

Box 1.1: South African approach for E-Flows assessment and implementation

The South African policy has been to adopt a hierarchy of the following four methods of increasing complexity to be used from the initial reconnaissance assessment, to the detailed holistic methods in cases where there may be conflict, or where greater certainty is required:

- Desktop Extrapolation Approach: This is a correlation modelling approach, which can be run instantly on any South African river, and gives an initial recommended E-Flows regime for each of the four management classes (from A: Natural-unmodified to D: seriously modified). This provides quick but low confidence recommendations, with no specific motivations for the recommended flows.

- Rapid Method: This uses the Desktop model, but with some field verification, and may take up to a month to provide a flow assessment. It provides fairly quick but still low confidence recommendations, with some motivations for the recommended flows.

- Intermediate Method: This is a scaled down holistic method, with limited hydraulics and field verification, designed to provide an EFA within 60 days – the time required from date of application for the Department of Water Affairs, Government of South Africa to respond to a water use application.

- Holistic Methods: These detailed studies may require one or more years of investigation and analysis, involving a number of specialists, and are therefore relatively expensive (although normally costing less than one per cent of any substantial water development such as an impoundment). They provide high confidence recommendations with clear and auditable reasons, and motivation for the recommended flows.

The South African policy is designed to provide recommendations for the application of the Ecological Reserve under the National Water Act (Act No.36 of 1998). If a simple, quick assessment is accepted by all parties, it can be used. In the event of conflict, there is no need to defend a quick assessment, but simply to move on to a more complex and higher confidence assessment, in which the flows are more carefully motivated and can therefore be defended.

Some work has been undertaken by the Indian government and experts to understand various aspects of E-Flows requirements for rivers. Some of the pivotal works are discussed in Box 1.2.

Box 1.2
An overview of E-Flows assessment in India

In 2007 the Ministry of Water Resources (MoWR) Government of India, through the Water Quality Assessment Authority (WQAA), constituted a Working Group which used a modified version of the Tennant method to assess minimum flow requirements in Indian rivers. The Tennant method takes only a very short time; however, the confidence in the outputs is correspondingly low.

The working group classified Indian rivers into two groups, namely "*Himalayan*" and "*Other Rivers*" (WQAA 2007), and made the following recommendations for minimum flows:

- Himalayan rivers: Minimum flow to be not less than 2.5% of 75% of the Dependable Annual Flow expressed in m^3/s; One flushing flow during the monsoon with a peak of not less than 250% of 75% Dependable Annual Flow expressed in m^3/s.
- Other Rivers: Minimum flow in any ten-day period to be not less than the observed 10-day flow with 99% exceedence. (Where 10-day flow data is unavailable, this maybe taken as 0.5% of 75% of the Dependable Annual Flow): One flushing flow during the monsoon with a peak of not less than 600% of 75% of the Dependable Annual Flow, expressed in m^3/s.

Smakhtin and Anputhas (2006) from International Water Management Institute, Sri Lanka (IWMI-Sri Lanka) used a hydrology method based on flow duration curves to calculate E-Flows for a range of EMCs for several major river basins in India, including the Cauvery, Krishna, Godavari and Mahanadi basins. The EMCs calculated ranged from "*natural*" to "*severely modified*", with the required flow volumes and elements of flow variability of the E-Flows set to progressively reduce, resulting a decreasing level of ecosystem protection. The final environmental water demands (E-Flows) were presented in two forms: as a flow duration curve and as a monthly time series.

The Global Environmental Flow Calculator (GEFC) is a software package developed by IWMI-Sri Lanka in 2007. It provides a desktop assessment of E-Flows incorporating a built-in global database of simulated flow time series. The GEFC uses a simple approach proposed by Smakhtin and Anputhas (2006) to determine a default flow duration curve representing a summary of E-Flows for each Environmental Management class (EMC).

1.5 THE TASKS REQUIRED FOR ENVIRONMENTAL FLOWS ASSESSMENT (EFA)

This section describes the tasks that are normally required for a holistic EFA, and provides a general guide for detailed assessment methods. These tasks may vary depending on the methodology being used, the size and type of river being assessed, and the time, resources and information available for the assessment.

In the case of the river Ganga, the spiritual and direct social uses of the river proved very important, requiring more effort to be focused on these aspects than is often the case. Figure 1.3 outlines the EFA process, with each stage and task described in more detail below. It is important to note that although the social survey is indicated as only one part of Stage B, (i.e. part of Task 6), it includes the stakeholder process, which ideally should provide an overall framework for the whole assessment within the context of Integrated Water Resource Management (IWRM).

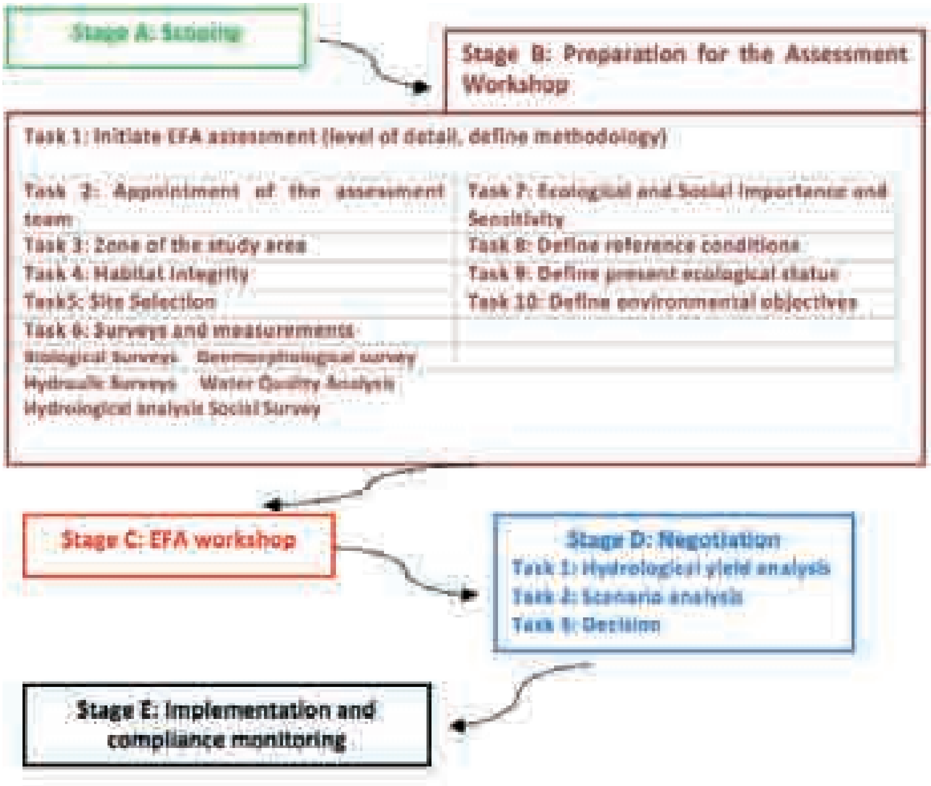


Figure 1.3: Stages and tasks in the holistic assessment of E-Flows

STAGE A: Scoping

This is an initial assessment of the area of interest. The aim is to identify issues of particular importance, and to draw up an initial plan for the assessment.

STAGE B: Preparation for the assessment workshop

Task 1: Initiate the EFA

The purpose of this task is to decide the level of detail, and define the methodology.

The approach to and outcomes of this task will depend on the:

- Urgency of the problem;
- Data availability;
- Resources available;
- Importance of the river;
- Present and future river use;
- Complexity of the system, and
- Difficulty of implementation.

Task 2: Appointment of Assessment Team (working group)

This task entails the appointment of specialists and the constitution of working groups. There are several components, including hydrology, hydraulics, geomorphology, biodiversity, livelihoods, community and water quality which determine the E-Flows requirement of a river. Therefore, specific working groups are needed to study each component. The identification of a facilitator or mentor who will coordinate the EFA process is also a crucial part of this task.

Task 3: Zone the study area

During the zoning process, reaches/stretches of the river are identified in which physical and ecological conditions are similar. Zonation is based on the geology, slope, climate, shape and size of the river channel, and confluences with tributaries. Zone boundaries are likely to be defined by elements such as major changes in channel size, hydrology, geology, gradient, or land use.

A geomorphological assessment forms the basis of the zonation of the river, as well as providing an analysis of the stability of the river channel and the status of sediment transport processes. During the geomorphological assessment, river bed condition, riparian benches and sediment transport data are used to assess how stable the channel is, and how it might respond to changes in the flow regime.

Task 4: Habitat integrity

This overall assessment of the condition of the area of interest is usually done by dividing the river into sections of equal length and surveying the environmental condition of each section separately for the river channel and the riparian zone. This may be done as an aerial survey, from maps with field visits, from reports of previous surveys, and/or from aerial photography if available. The aim is to classify the sections in terms of how much they have been modified from natural conditions. One way of doing this is to apply a scoring system to assess the aspects such as water abstraction, channel modification, water quality, biodiversity and habitat requirements, solid waste disposal, vegetation removal and bank erosion.

Task 5:Sample site selection

Sample sites are selected within the study area for detailed analysis. The ideal approach is to locate one sample site per zone that characterises the conditions throughout that zone, where the EFA-related detailed specialist studies will be

Idol of river Ganga, which is considered as goddess

Photo Credit: Nitin Kaushal / WWF-India

undertaken. The criteria for selecting sites which will be suitable for the assessment of E-Flows include:

- Ease of accessibility;
- Habitat diversity;
- Sensitivity of habitats to flow changes;
- Suitability for measuring a rated hydraulic cross-section and for modelling discharges, velocities and wetted perimeter at different water depths;
- Proximity to a flow gauging site;
- Representation of conditions in the river zone, and
- Critical flow site (i.e. where flow will stop first if discharges are reduced).

Task 6:Specialist surveys and measurements
The specialist surveys are intended to augment information and fill in gaps that have not been covered in previous studies.

Biological surveys
These involve sampling of riverine mammals, amphibians, reptiles, birds, fish communities, benthic invertebrates, phyto- and zooplankton communities, and riparian vegetation to determine amongst other things the diversity of species and composition of communities, to identify their flow requirements, and to derive from this an overview of the current status of the river. The surveys also concentrate on identifying flow sensitive species and defining their seasonal habitat requirements in terms of current velocity, depth and wetted perimeter. The riverine biota are used as indicators of the types of flow that will be needed to maintain different levels of ecosystem health.

Hydraulic survey and analysis
Hydraulic cross-sections (and habitat modelling if resources allow) provide the link between ecological knowledge and flows. For example, if the fish ecologist can define species' habitat requirements in terms of depths, current velocities or river widths, then the hydraulic model can convert these parameters into specific flows in cubic metres per second at the site. Hydraulic analysis can also identify when flows will inundate the floodplain, what flows will move different-sized sediments, and what flows will provide optimal conditions for sacred bathing, ferries and other social and recreational uses of the river.

The accuracy of the hydraulic analysis is crucial to the level of confidence in the flow recommendations: the most detailed ecological knowledge will be rendered useless if the conversion to required flows via the hydraulic analysis is flawed.

Hydrological analysis
Hydrological records are used in an EFA to check that the recommended flows are within the reasonable limits observed in a river. It is a check on the realism of the process, rather than a motivation for recommended flows. Flow variability between different seasons and different years should be provided to guide other specialists involved in the process. An analysis of the frequency of floods of different sizes guides the high flow recommendation by ecologists and geomorphologists.

As with the hydraulics, the accuracy of hydrological analysis is crucial to the level of confidence in the flow recommendations. Inaccurate observed flow records or simulated time series may result in erroneous predictions for E-Flows, no matter how good the information from other disciplines is.

Geomorphological survey
The aim of the geomorphological survey is to assess the types and sources of sediment in the river, analyse the channel morphology in terms of geomorphic features and their stability, and predict the consequences of changing flows on the sediment input-output, and therefore, on the channel shape and substrate types. Geomorphological changes will typically happen at longer time scales than the biological responses (i.e. in decades rather than seasons), but will ultimately sculpt the physical template on which the hydraulic habitats are superimposed. For example, the riparian and marginal vegetation will interact with the sediment dynamics, often anchoring loose sediments that have been deposited during flood recessions.

Water quality analysis
Water quality requirements are assessed in parallel with the flow requirements. A survey of existing information and seasonal measurements of water quality variables is used to understand the current status of the river, and impacts caused by point and diffuse sources of pollution. Present water quality conditions are compared with reference conditions and applicable guidelines in order to categorise the present state.

Social survey
There are two types of surveys associated with the comprehensive EFA methods:

1 The identification of people who are directly dependent on a riverine ecosystem: These may be subsistence fishermen or farmers, those who withdraw domestic water directly from the river, those engaging in recreation related activities such as angling or rafting, and people involved with cultural or religious aspects of the river such as sacred bathing or ritual cleansing. Interviews and other survey methods are used to identify, quantify and prioritise these uses, and to determine the aspects of the flow regime that are important for each use.

2 Consultation with and capacity building of all stakeholders to identify preferences for the management objectives for the river: This is a long-term undertaking which should be part of a broader catchment management planning process, in which the E-Flows will be one aspect of the sustainable management of the resource.

Task 7: Ecological and Social Importance and Sensitivity
Ecological Importance and Sensitivity (EIS) is used to quantify, as far as possible, the relative importance of environmental issues in a river. It can be quantified in different ways, but is a measure of the priority of the study area from an ecological perspective. Typical measures (or indicators) include the number of sensitive and rare species, the resilience of the system to human disturbance, biodiversity, habitat diversity, importance as a migration route, and presence of conservation areas.

Social Importance and Sensitivity (SIS) provides an index of social importance which takes into account the number of people directly dependent on a healthy riverine ecosystem, for example using it as a direct source for drinking and washing, for stock watering, subsistence fishing and farming, recreation, as well as for cultural and religious purposes. The development of such indices should be specific to particular regions and cultures, rather than a "one size fits all" approach.

For the Ganga, EIS should take into account the endemic species such as the river dolphin and gharial, while SIS would need to acknowledge the overwhelming importance of the Ganga as the holy river of India.

Task 8:Define reference conditions
The reference conditions (usually natural conditions) will provide a baseline against which to judge how much the river has been modified. Reference conditions should be described for the main physical, chemical and ecological features. Methods used to define reference conditions may include historical accounts, information and data, or comparisons with neighbouring, less-impacted catchments. Where such information is not available, conditions can usually be inferred with reasonable accuracy from modelled hydrology, geological, soil and vegetation data, and regional data on biodiversity.

In large rivers which have been extensively used and irreversibly modified for millennia, such as the Ganga (India) or Yellow River (China), it may be impossible to define natural conditions as a reference. In these cases, the least impacted reach may be used to define reference conditions.

Task 9:Define present ecological status
The present ecological status is defined on the basis of available data and the judgement of the specialists (working groups). As with the previous step, this should be done for all physical, chemical and ecological features of the river derived from existing monitoring data, or collected in the project surveys. The purpose is to compare present conditions with the reference conditions, to measure how far the river has been modified over time. This process provides the basis for the definition of environmental objectives.

Task 10: Define environmental objectives
There is no single 'correct' range of E-Flows for any given river. Removing water from rivers is always likely to have some impact on their ecology. The question is: How much impact is acceptable, and what objectives should be achieved by managing the river? Much environmental legislation globally incorporates classification systems that recognise that society will wish to conserve the quality of some rivers to a higher level than others. For example, it is likely that the "conservation" rivers that run through national parks, or those rivers with particularly important fisheries should be managed to a higher level. In other situations, there may be vital hydrological processes that need to be conserved: commonly, flows may be necessary to prevent saline intrusion into farmland and groundwater supplies at the mouth of the river (e.g. the Yangtze River in China), or to maintain the structure of important delta ecosystems (e.g. the Indus River in Pakistan).

Ideally, an extensive stakeholder process should be undertaken to identify environmental objectives. This may require a long-term process to identify all interested parties, to inform and educate them about the importance of protecting natural resources for sustainable use, and to capacitate them so that they can make informed input to the setting of environmental targets for the flow regime.

STAGE C: Environmental Flow Assessment workshop

At the EFA workshop, flow recommendations are made through discussion and consensus building within all the working groups.

For each recommended flow (e.g. dry season base flow, wet season base flow, higher flows and floods), the specialists consider the habitats to be inundated, current velocities needed, and river width and floodplain inundation, etc. required to meet the environmental objectives defined earlier. The specialists work to come to a consensus on all these requirements, or otherwise on the critical requirement (the one requirement which will fulfill, or more than fulfill, the others), which is then used to assess the recommended flow. The hydrologist then checks whether the recommended flow is realistic in terms of the flow patterns typically experienced at that point in the river.

At the EFA workshop, the water quality specialist will respond to recommended flows by estimating the consequences of recommended flows on the concentrations of various water quality parameters.

The specialist work session will normally last for four or five days in addition to a day of site visits; this is in addition to usual internal meetings of the specialists. The results from this work session should be fed into the management and decision-making procedures for the river, but must first be collated with the user requirements, and analysed to determine the assurance level at which the river may be able to supply the user needs whilst maintaining E-Flows.

STAGE D: Negotiation

The purpose of this stage is to allow the stakeholders to factor in the EFA results, with the consumptive use requirements for agriculture, domestic and industrial supply, to reach consensus, in terms of a water allocation plan, on their shared vision for the management of the river, and the means by which this will be implemented.

Task 1: Hydrological yield analysis
A hydrological yield analysis calculates the likelihood of being able to maintain the E-Flows and supply the user needs in wet and dry years (based on the current and projected availability of water). If all these requirements can be met with a high assurance, a water allocation plan can be agreed to.

Task 2:Scenario analysis
Scenario development and negotiation take place where there is insufficient water to meet all requirements. Different scenarios are developed, allocating a series of assurance levels to different users (and to the recommended E-Flows), and provide the basis for negotiations and decisions, ideally within the framework of an integrated catchment management plan.

Task 3:Decision
The decision to implement E-Flows may rest with different authorities, depending on the scale of the river (international, national, regional etc.) and the governance protocols of the river basin. In areas where there is competition for scarce water resources, the best chance for a decision in favour of implementation of E-Flows will depend on a high confidence assessment, and on the support of the majority of stakeholders.

STAGE E: Implementation and compliance monitoring

Implementation and compliance monitoring is the culminating step in the process, but lasts indefinitely. Methods of implementation cannot be dealt with in detail here, and will depend on the potential for demand management on any specific river, the availability of storage structures and inter-basin transfers. Implementation should also include participatory negotiations.

Often the implementation of the full range of recommended flows may take some time and ingenuity to accomplish. In the meantime, it is possible to apply an adaptive approach. This may involve releasing some water down the river, by whatever means currently available, accompanied by an effective monitoring operation that allows for the response of the river to the flows to be assessed. This method may be particularly appropriate in the context of extreme water stress, where over-exploited rivers run dry for part or whole of the year.

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Barrages and network of canals divert major chunk of water resources from Ganga river for irrigation, cities and industries. The abstraction to meet ever-growing demand of water has led to reduced flows in the river

Photo Credit: Amrit Pal Singh

Photo Credit: Nitin Kaushal / WWF-India

Thousands of pilgrims and religious tourists gather at Haridwar every day for the evening *aarti* (religious prayer)

Chapter 2
EFA PROCESS AND RATIONALE

2.1 BACKGROUND

WWF-India, with assistance from WWF-UK, initiated the project to coordinate and train a local team to undertake an E-Flows Assessment (EFA) in the Upper Ganga River, i.e. from Gangotri to Kanpur.

WWF's international programmes are increasingly engaging with issues of water scarcity and associated ecological impacts. As part of this work, a number of programmes (e.g. Brazil, China, East Africa, India, Pakistan, Mexico) have established local teams to implement the methods and approaches for EFA. As part of its HSBC Climate Partnership and Water Security programmes, WWF-UK has taken the lead in designing a coordinated programme of support. Within this programme, WWF-UK has provided technical support to WWF-India to conduct an EFA on the Ganga, in association with the International Water Management Institute (IWMI) based in Sri Lanka, and the UNESCO-IHE (Institute for Water Education), based in the Netherlands. Initial planning meetings between WWF-India and IWMI were held during 2007-08.

WWF-India constituted a team of local experts (working groups/specialists) in the following fields – biodiversity, geomorphology, water quality, hydraulics and sociology. This team was provided with initial training in EFA processes by UNESCO-IHE, and IWMI extended the hydrological expertise. A complementary aim of the project was to promote the concept of E-Flows for the sustainable management of other Indian rivers and therefore to disseminate the approach adopted and the lessons learnt about the EFA at a wider scale. The target audience for the project included the following groups:

- Government agencies who evaluate, design and implement water resources development projects and investment programmes;
- State and district level water resources management agencies, e.g. the Department of Irrigation, dam/barrage operation agencies, etc;
- Conservation groups in India who seek to establish environmentally sustainable water resources planning and management practices, and
- Farmers, fishermen and members of other riparian communities that may be affected by water management decisions within the river basin.

The study on E-Flows assessment began in 2007, during which meetings and capacity building workshops were organised. The partnerships with technical, academic institutions and NGOs were made, which formed the working groups for the assessment of E-Flows. Later on, in December 2008, a field trip to the river Ganga at Narora was made to observe and discuss a section of the river in which present flows are adequate to support populations of river dolphins and freshwater turtles. The participants included all the working groups (referred to henceforth as specialist teams in this document), and members of IWMI, UNESCO-IHE and WWF-India.

The field trip was followed by a two-day objective-setting workshop, held in New Delhi on 3-4 December 2008, at which the specialist teams began the process of developing detailed flow-related ecological and social objectives (See section 2.3) which would form the basis for the eventual E-Flows recommendations. Professor Jay O'Keeffe (UNESCO-IHE, the Delft Netherlands) and Dr. Vladimir Smakhtin (IWMI – Sri Lanka) facilitated the workshop, and introduced the concept of an objectives hierarchy.

This formal method of setting environmental objectives consists of an inverted tree of objectives, from a general vision (inspiring but unmeasurable) to detailed indicator objectives, which are measurable but often obscure to non-specialists. In February 2009, the specialist teams gathered again in New Delhi to decide on a suitable methodology for the EFA of Ganga. (See section 2.2)

Table 2.1: Working Groups or Specialist Teams for the E-Flows Assessment of the Upper Ganga

Component	Name	Association
Overall Facilitation	Prof. Jay O'Keeffe Dr. Vladimir Smakhtin	Formerly with UNESCO-IHE, Delft and currently with Rhodes University, South Africa IWMI – Sri Lanka
Hydrology	Dr. Vladimir Smakhtin Dr. Luna Bharati	IWMI – Sri Lanka IWMI – Nepal
Hydraulics	Prof. A. K. Gosain Dr. Sandhya Rao	IIT – Delhi INRM Consultants
Fluvial Geomorphology	Prof. Rajiv Sinha Dr. Vikrant Jain	IIT – Kanpur Delhi University
Biodiversity	Prof. Prakash Nautiyal	Garhwal University – Srinaga
Water Quality	Prof. Vinod Tare	IIT – Kanpur
Livelihoods	Dr. Murali Prasad	IIT – Kanpur
Cultural and Spiritual	Dr. Ravi Chopra Ms. Chicu Lokgariwar	People's Science Institute-Dehradun

2.2 METHODOLOGY ADOPTED

The methodology workshop began with presentations and discussions on the different EFA methods (described in Chapter 1). The following terms of reference and considerations were defined for the EFA of the Upper Ganga:

- The assessment should be confined to the upper and middle reaches of the river, from Gangotri to Kanpur.
- The project would be completed by the first half of 2010 (i.e. over a period of one and a half years), and within a prescribed budget. This meant that although there would be a full year for preparatory field investigations, the number of river sites and the intensity of investigations would be limited.

- Because the aim was to provide a strong motivation for implementing E-Flows on the Upper Ganga and to promote the concept of E-Flows in other Indian rivers, a holistic method would be used.

- The specialist teams constituted by WWF-India consisted of senior experts in their fields. As this was the first application of EFA in India, it was important to choose a method consisting of clear steps and tasks that would be understandable to the target audience, and would provide well-motivated flow recommendations designed to meet well-defined objectives.

- EFA methods have been designed and tested on rivers which are much smaller than the Ganga. The specialist teams were therefore required to examine how the standard methods might need to be modified to suit a large river.

- The position of the Ganga as the "Holy mother river of India" meant that the importance of spiritual and religious aspects would be a major consideration in setting flow objectives to meet the environmental requirements of people, as well as those of the biota of the river.

- The unavailability of the historical flow record for the Ganga in the public domain meant that essential hydrological data, which underpins all EFA methods, would be confined to modelled flow time series. With little or no opportunity to calibrate the models, it would not be possible to assign confidence levels to the modelled outputs, and this would affect the overall confidence with which the team could provide a recommended E-Flows regime.

After examining and discussing a number of different EFA methodologies, and taking the above considerations into account, the team decided to use a modified form of the Building Block Methodology (BBM), which was originally developed in South Africa. The main reasons for this choice were:

- It is a relatively simple and robust method, which has been used successfully in different parts of the world.

- It can be used flexibly for different kinds of rivers, and can be applied using various levels of data and available information. It can rely either on precise data sets, on modeled data or on expert judgement (where data is unavailable). Although the confidence in recommended flows will obviously be affected by the levels of data availability, it can be used where methods with more rigorous and inflexible data requirements, such as habitat simulation methods like the Instream Flow Incremental Methodology (IFIM), would be inappropriate.

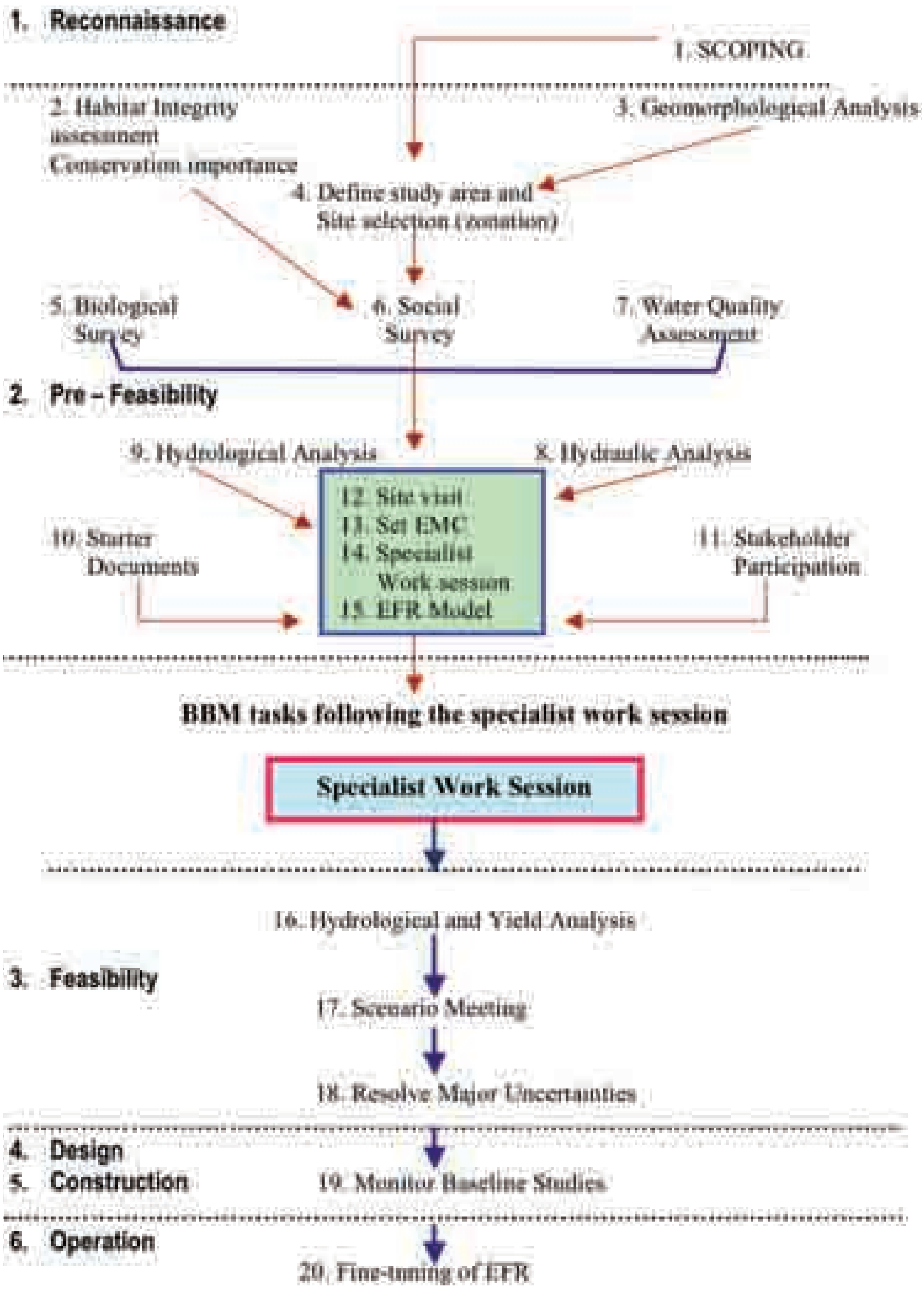
- The method has been well and clearly documented in the BBM Manual, which provides a step-by-step chapter for each of the specialisations. This makes the method ideal for teams attempting EFA for the first time.

- The facilitating team from UNESCO-IHE and IWMI was experienced in the use of the BBM, having applied it extensively in many situations in South Africa, South America, East Africa, Eastern Europe and Australia.

- Because the BBM is robust and flexible, the team felt that it could be adapted and modified for application to the particular characteristics of the Ganga, notably the large scale of the river, the very long history of human use and modification, and the special importance of cultural/spiritual issues.

- Process adopted in the E-Flows assessments is shown in Figure 2.1, which indicates that stakeholders participation is a very important aspect in this exercise.

Figure 2.1: BBM process chart



The BBM manual is available in Annexure – 7.

The scope for adapting IFIM and Downstream Response to Imposed Flow Transformation (DRIFT) for the upper Ganga EFA was also discussed. (See section 1.4 in Chapter 1) Both are excellent and widely used methods, but the decision was made that they were not suitable EFA methods for the Upper Ganga, for the following reasons:

- IFIM: This method was primarily designed for the assessment of target species' flow requirements in American rivers, particularly commercially important species such as salmon and trout. It employs a hydraulic habitat model, based mainly on depths, current velocity and substrate type, and linked to similar measures of the target species' preferred habitat. It provides a detailed picture of the availability of preferred habitat (known as weighted usable area) for any discharge in the modeled river reach. The model currently has no facility for incorporating changes in sediment transport or channel morphology as a result of flow modifications, and does not take into account flow-related differences in water quality. As the Upper Ganga EFA needed to include these issues and assess flows for a variety of different species and human uses rather than concentrating on one target species, IFIM was considered less suitable.

- DRIFT: This is a highly effective method which, in summary, builds a database of consequences and severity of changes caused by successive reductions in flow. The database can then be queried to identify the overall effects of different flow scenarios. Like the BBM, it is a holistic methodology, able to integrate the effects of modified flows on a range of species, processes and human uses. It has been used successfully in various countries, but generally works better when implemented by specialist teams who are highly experienced in EFA procedures. This is because the processes for DRIFT are complex, and may be unclear to specialists who are addressing the EFA process for the first time (as on the Upper Ganga EFA). For example, DRIFT requires more technical knowledge and experience to interpret the outputs of the database analysis model, and requires more initial data input than the BBM. The BBM is more flexible and robust in data/knowledge poor conditions, but ultimately, both methodologies are simply different frameworks for the analysis of whatever data/knowledge is available or can be collected, and this governs the confidence in the final recommendations. Since the Upper Ganga team was embarking on a new and intensive learning process with EFA, and because much of the data was either patchy or unavailable (e.g. hydrology), it was decided that the BBM would be more robust and suitable for this project, and the use of DRIFT should be considered for future assessments, once the team is more familiar with the EFA process.

Typically, the BBM follows the stages and tasks described in Section 1.5 of Chapter 1, but the Upper Ganga specialist team adapted the process in the following ways:

- The BBM requires a set of reference conditions for each zone, to judge the present state of the river, the extent to which it has been modified, and also to use as a benchmark against which environmental objectives for E-Flows could be set. For most rivers, the reference conditions are set as near as possible to the original natural flow fluctuations. This becomes the “A” or “unmodified” state and the present ecological state is defined according to the classes described in Table 2.2. Because the Ganga has been at the centre of a very long-lived civilisation, it has been used, modified and altered from its original, natural conditions over millennia. In the middle reaches, millions of people rely on the river for water supply, irrigation and disposal of waste. Aiming to restore the Ganga to its natural state is therefore unrealistic, and in many reaches, the natural conditions are no longer apparent, having been obscured by barrages and diversions and becoming disconnected from the surrounding floodplains. It was therefore decided that the present day conditions upstream of Narora barrage would be adopted as a realistic set of reference conditions for the middle sections of the river. Because of the requirements of the Narora Power Station, and the backwater effects of the barrage, the flows in the river upstream provide adequate hydraulic conditions to maintain habitat for river dolphins, turtles and other flagship species. The WWF-India's programme in this river stretch has facilitated the maintenance of good ecological conditions with the cooperation of local communities and other stakeholders in managing the ecology of the river sustainably.

- The Ganga is a large river by any definition, and is certainly much larger than the rivers for which most EFA methods were developed. The typical application of the BBM uses flow-dependent ecological indicators such as particular fish species and riverine macro-invertebrates, characterising their habitat requirements in terms of depths, river width, flow velocities etc. In large rivers, even at very low flows, there remains residual hydraulic habitat sufficient for most species, and therefore, the use of habitat indicators is of less relevance, unless the relative abundance of habitat can be taken into account. Fortunately, in the Ganga, the presence of important large species, such as river dolphin and gharial, requiring large areas and depths of river for passage, hunting and breeding, provided useful biological indicators. Fish, invertebrate and phytoplankton habitat requirements were also taken into account, but often the requirements for macro-processes, such as channel morphology and floodplain connection, which are necessary to maintain the scale of this large river, provided the clues for the flows which would maintain or restore the river to the desired state.

- As the Ganga is sacred, its spiritual and cultural significance were always going to be a dominant motivation for maintaining environmental conditions in the river. Accommodating the social and cultural requirements of local populations has become a standard part of EFA in most countries, for example in South Africa, where the identification of sacred sites (often where the spirits of ancestors are believed to reside) has become a routine EFA task. The Ganga, however, provided the first example worldwide in which the spiritual status of the whole river is of utmost priority, not just to a small portion of the population, but to the majority of Indian citizens, who would all like to have the opportunity of ritual bathing in the river. Therefore, the flow and water quality requirements to maintain the spiritual/cultural aspects of the river, formed a very important aspect of the overall EFA for the Ganga. Gratifyingly, though perhaps not surprisingly, the flow requirements articulated in interviews by ritual bathers (see Chapter 4) closely matched those required to maintain the hydraulic habitats of indicator species such as river dolphins, indicating that the long history of human use of the river has become closely adapted to the natural diversity of flows, to which the biota are also adapted.

Table 2.2: A classification system for rivers based on the level of modification from reference (usually natural) conditions (from O'Keeffe and Louw, 2000)

Class	Description
A	Unmodified, natural
B	Largely natural with few modifications. A small change from natural habitats and biotas may have taken place but the ecosystem functions are essentially unchanged.
C	Moderately modified. A large loss of natural habitats, biotas has occurred, but the basic ecosystem functions are still predominantly unchanged.
D	Largely modified. A large loss of natural habitats, biotas and basic ecosystem functions has occurred.
E	The losses of natural habitats, biotas and basic ecosystem functions are extensive.
F	Modifications have reached a critical level and the lotic system has been completely modified, with an almost complete loss of natural habitats and biotas. In the worst instances, basic ecosystem functions have been destroyed and the changes are irreversible.

Note: *This classification system has been adopted for the Ganga EFA.*

In the case of the Ganga, which has been modified for many centuries, the reference condition was defined as that existing in the zone upstream of Narora barrage.

2.3 PURPOSE AND METHOD FOR OBJECTIVE SETTING

E-Flows are a compromise between the consumptive uses and the social, cultural, spiritual and ecological sustainability of the river. Therefore, a careful process for the setting of environmental objectives is essential to develop measurable targets by which the environmental status can be assessed.

There are two commonly-used approaches for establishing E-Flows objectives in rivers. In the first, a detailed set of environmental objectives can be set *a priori,* and the flows assessed to meet this specific set of objectives. Alternatively a series of different flow scenarios (from near natural to extensively exploited) can be examined, in order to evaluate the consequences of successively modified flows on each segment of the environment. Using the latter approach, a decision still has to be made to choose a particular E-Flows regime to meet specific objectives. Most EFA methodologies can be applied to either approach, although some (e.g. DRIFT) have been specifically designed for the latter. In the case of the Ganga, it was decided to set *a priori* objectives, both because this is simpler for a team which was attempting the EFA process for the first time, and because the limited time frame and resources for this assessment were unlikely to allow the time and effort required to assess the consequences of multiple flow regimes.

Ideally, the environmental objective-setting process involves an extensive stakeholder programme to include the various interest groups in the process, and to conduct a capacity building programme to develop their understanding of river dynamics, biodiversity, and the goods and services which depend on the maintenance of an adequate flow regime. Even in a small river, this may take a number of years, especially where there are extensive subsistence level communities with rudimentary education levels. In the Ganga basin, with a population in excess of 500 million, such an inclusive programme would be a monumental undertaking. Since this was a preliminary assessment, it was decided to get extensive inputs from a cross-section of stakeholders (including riparian communities, farmers, government departments, religious groups, tourists, industries, etc.). Interviews were undertaken by the cultural and spiritual team and the livelihoods team, to ascertain the preferences of people making immediate use of the river.

The requirements of the objective-setting process for the Ganga were:

- Objectives should be confined to the environmental conditions of the river, its banks and floodplains (i.e. objectives for consumptive water use and wastewater disposal would not be included) .

- Objectives should be confined to those which could be at least partly achieved by flow manipulation (i.e. not including issues of catchment land use or structural modifications such as barrages, dams and canals).

- Objectives should be clear and understandable to common persons, so that stakeholders could decide on their support for them.

- Objectives should be precise and measurable, so that specific flows could be recommended for their attainment, and a monitoring programme established to check compliance.

These requirements were not always easy to achieve, with especially the third and fourth not always being compatible.

A system known as an “Objectives Hierarchy” has been developed to provide a formal process for objective setting which covers these requirements. It comprises a series of objectives at different levels ranging from an overall vision (e.g. "To maintain adequate flows to provide for the habitat requirements of the riverine biota, to ensure a healthy environment for people, and to meet the cultural, spiritual, livelihood and recreational needs of downstream communities"), to very specific objectives which set limits for indicator species and processes (e.g. "Flows to provide residual habitats with velocities greater than 0.5m sec^{-1}, for more than 85 per cent of the time, to ensure a habitat for hydropsychid *Trichoptera*"). The first (visionary) level is designed to provide an objective that is accessible and inspiring for all stakeholders, but is not necessarily measurable or auditable. The fourth level, specific objectives are designed to be precise and measurable, but they may mean nothing to the majority of stakeholders and decision-makers. The intermediate levels of the hierarchy connect the overall vision with the specific objectives, so that it is apparent how the achievement of the specific objectives is connected with the vision.

This four level hierarchical system of objectives was adopted for the Upper Ganga project, with the levels ranging from the general classes described in Table 2.2, to objectives defining precise habitat/process requirements for indicators. Each specialist team was required to define sets of objectives for each of the three E-Flows sites, which are summarised in Chapter 4 and listed in more detail in each of

Table 2.3: Four-level objectives hierarchy for E-Flows

Hierarchical Level	Objectives
1	A general category (A to D, where A is completely natural, and D is seriously modified, see Table 2.2). This provides a generally understandable objective, but is not measurable.
2	General flow objectives: describing the type of flow regime that will be necessary to achieve the overall objective.
3	Objectives for the specialist component (biodiversity; water quality; geomorphology; sociology etc.): This level should be more specific, with measurable components.
4	Objectives for specific indicators: These should be precise and measurable, so that quantified flows can be recommended to meet these objectives, and can be monitored to check compliance.

the working group reports in the Annexure – 2. Table 2.3 summarises the objectives which guided the teams in their assessment of flows for different seasons and durations, which would restore the river to the desired status.

References

O' Keeffe, J. H. and Louw D, (2000). Ecological Management Classes. Chapter 11 in "Environmental Flow assessments for rivers: Manual for the Building Block Methodology". Edited by J. M. King, R. E. Tharme, and M. S. de Villiers. Report No. TT 131/00 of the Water Research Commission, Pretoria. 8 Pages.

Gharial (Gavalis Gangeticus) is a freshwater crocodile that is endemic to Ganga river system. Distinguished by a *ghara* (pot) on the tip of their snout, Gharials are extremely threatened due to habitat degradation and loss of prey base

Photo Credit: Sandeep Behera / WWF-India

Photo Credit: Amrit Pal Singh

Ganga is a source of livelihood to millions. A boatman doubles up as vendor selling idols, flowers, and other items required for prayer in Varanasi

Chapter 3
ZONATION AND SITE SELECTION

3.1 THE UPPER GANGA FROM GANGOTRI TO KANPUR

The Ganga basin lies between latitude 22°30N and 31°30N, and longitudes 73°30E and 89° 0E. The river extends through India, Nepal and Bangladesh, with a total catchment area of 1,086,000 km^2. In India its length is 2,525km[1], whilst the catchment area covers 861,404 km^2. The surface water resources potential of the Ganga has been assessed at 525 billion cubic meters (BCM) per year (AHEC, 2009). The months of December-May are considered as the lean flow months.

Since time immemorial, human communities have settled in the Ganga basin. Several cities and towns have been established at the banks of the river including - Rishikesh, Haridwar, Meerut, Delhi, Agra, Kanpur, Allahabad, Varanasi, Patna and Kolkata. For the millions of people residing in the Ganga basin, the major source of surface water is the Ganga.

The Living Ganga programme is being implemented in the 800 km stretch of the river Ganga from Gangotri to Kanpur.

It is in sections of this upper stretch of the Ganga that the most serious problems of water quality and quantity are recorded, whereas in the middle reaches, i.e. downstream of Allahabad, once the Yamuna joins the Ganga, the quality and quantity improves. The study in the Upper Ganga was also important because of the impact of a series of dams and barrages on the habitat requirements for maintaining biodiversity. As a whole, this stretch of the river represents most of the problems the Ganga is facing today, such as diversions for hydropower, water abstraction from dams and barrages, agricultural pollution, industrial pollution, sewage disposal from cities, and the inflow of the most polluted tributaries of the Ganga, such as the Ramganga and Kali rivers. In addition to these threats, the presence of endangered aquatic biodiversity such as two species of mammals (river dolphins, otters), crocodiles (*gharial* and *mugger*), 12 species of turtles and 75 species of fishes (including mahseer, *Tor putitora*) makes this a unique ecosystem.

In addition to being guided by the need to address some of the most urgent and serious problems in the system, the upper part of the Ganga was selected for study because WWF considered that the specialist resources, available funding, and time could best be focused on a specific section of the main river, rather than spread throughout the whole river system. As this initiative was a first-time assessment of the application of E-Flows to a major Indian river, it was felt that concentrating on the Upper Ganga would provide urgently needed recommendations and a high profile example of the process.

The other priority was to apply the EFA process to a variety of river conditions, which are provided by the Upper Ganga as it flows from the high altitude mountain sources to the highly populated and developed mid-reaches in the plains. Physiographically, the river in its upper reaches traverses a variety of terrain, from steep mountainous to foothills to wide channels, with decreasing gradients.

[1] Ministry of Water Resources, Government of India

3.2 METHODOLOGY AND PURPOSE OF HOMOGENOUS ZONATION

Zonation and the choice of specific sampling sites that represent each zone for detailed investigation is the standard method used to characterise the river for an EFA. It is intended to identify more or less homogenous zones in which the general river conditions (flow, gradient, size, sediment types, geomorphology, surrounding land use etc.) are constant, and therefore, in which the biota requirements and human usage of the river will likely be similar. The zonation also identifies major disruptions and discontinuities, such as dams, barrages, canal off-takes etc, which change the character of the downstream reaches.

Once the different zones have been identified and described, at least one site is identified within each zone at which a detailed survey of the channel morphology, flow characteristics and biodiversity would be undertaken. The information gathered at these sites is then used to characterise the flow conditions that will be required to maintain the river zone in the required environmental management class (EMC).

The initial zonation of the 800 km Upper Ganga was confined primarily to the mainstream and the floodplains of the river using a buffer of 50 km on each side of the main river channel. It provided a general description of the major physiographic and geomorphologic features and the modifications/alterations along the river in order to assess the flow requirements for each zone.

Figure 3.1 shows the course of the Upper Ganga and some of the major features along its course. The yellow dotted line delineates the 50 km riparian buffer along the main course of the river.

Figure 3.1: Index map of the Upper Ganga with major tributaries and important locations

Source: INRM Report on Homogenous Zonation (Annexure 6)

The methodology to undertake the zonation included a desk study to:

- Analyse the changes in river morphology;
- Analyse land use changes over the flood plain area;
- Identify the confluences of major tributaries, man-made structures such as barrages and other diversions, potential point sources of pollution, meandering and stable sections, etc.
- Collate secondary data on cities, industries, pollution monitoring sites, etc.

This analysis utilised satellite imageries to obtain the land use information. The terrain was analysed from the Shuttle Radar Topography Mission (SRTM) data (90 m resolution).

A GIS platform (ArcGIS) was used to provide a versatile information base that was graphic and highly manageable. All the required information such as terrain, land use, industries, etc. was incorporated as separate layers with extensive attributes explaining the characteristics of the layer. This framework was used to provide the first definition of homogeneous segments.

Discrete reaches of the river were identified where physical and ecological conditions were likely to be similar: major changes in channel size, hydrology, geology, gradient or land use defined the zone boundaries. The zonation also took into account the climate, the shape and size of the river channel, and confluences with tributaries. River bed condition and sediment transport data were used to assess channel stability, and the likely response of the channel to changes in the flow regime.

3.3 FINDINGS OF THE ZONATION STUDY

Climatic features

The average annual rainfall in the Ganga basin varies from 350 mm at the source, to 2,000 mm near the delta. The majority of the rainfall is received during the south-western monsoon from July to October. Some Himalayan mountain peaks in the higher reaches of the river are permanently covered with snow: part of the river flow comes from snowmelt in the summer season (April to June).

In the upper Gangetic plain in Uttar Pradesh, average rainfall varies from 762 to 1,016 mm. The temperature in the plains varies from 5°C to 25°C in winter and from 20°C to over 40°C during summer.

Land use

The major land use in the study area is agriculture (79 per cent), followed by pasture land (12 per cent), with the remainder being urban areas, wetlands and other water bodies. Table 3.1 categorises non-urban land use and summarises the area covered under each category.

Table 3.1: Land use pattern

Land Use	Area (ha)	% Watershed area
Agricultural land	8125477	79.5
Forest-Deciduous	5930	0.5
Summer Pasture/Scrub land	1214401	12.0
Other water-bodies/wetlands	136809	8.4

Source: INRM Report on Homogenous Zonation (Annexure 6)

3.4 ZONATION OF THE UPPER GANGA FROM GANGOTRI TO KANPUR

The initial seven homogenous zones

Seven zones, based mainly on gradient changes, were initially identified along the longitudinal profile of the upper stretch of river Ganga during the Homogenous Zonation exercise described in Section 3.2.

Zone 1: Gangotri to Rishikesh
Zone 2: Rishikesh to Garhmukteshwar
Zone 3: Garhmukteshwar to Narora
Zone 4: Narora to Farrukhabad
Zone 5: Farrukhabad to Kannauj
Zone 6: Kannauj to Kanpur
Zone 7: Downstream of Kanpur (Kanpur to Rai Bareilly)

Figure 3.2 depicts the Upper Ganga and the intial seven homogenous zones delineated during the zonation analysis, whilst Table 3.2 describes the features and prominent activities typifying each homogenous zone.

Figure 3.2: Depiction of the seven zones (cartographically)

Source: INRM Report on Homogenous Zonation

Table 3.2: Summary of various features in each of the seven zones

Zone	Name	Length (km)	Elevation (m)	Slope (m/km)	Tributaries
1	Gangotri to Rishikesh	240	3000-350	14.9	7
2	Rishikesh-Haridwar to Garhmukteshwar	184	480-225	0.7	5
3	U/S of Garhmukteshwar to Narora	121	225-200	0.3	2
4	Narora to Farrukhabad	114	200-175	0.2	2
5	Farrukhabad to Kannauj	177	175-135	0.2	6
6	Kannauj to Kanpur	99	135-115	0.2	2
7	Downstream of Kanpur	175	115-100	0.1	2

Source: INRM Report on Homogenous Zonation (Annexure 6)

The total length of the reach calculated from this table is over 1,100 km (rather than 800 km), as the buffer of 50 km was included in the calculations.

Final designation of four zones

At a meeting in December 2008, based on the limited availability of time and resources, a decision was taken to concentrate on four zones, and to locate one site within each zone for specialist studies. It was decided that the survey of rated hydraulic cross-sections, hydrological analysis, and detailed field investigations of the environmental components (hydrology, hydraulics, fluvial geomorphology, biodiversity, water quality, livelihoods and socio-cultural aspects) would be carried out at these sites.

The four zones were chosen to represent the following conditions:

1. A mountainous sub-stretch (or zone)
2. A sub-stretch (or zone) which is relatively intact
3. A sub-stretch (or zone) which is affected by water abstraction through barrage
4. A sub-stretch (or zone) which is affected by pollution

The four zones that were delineated as a result of this decision making process were:

- Zone 1: Gangotri to Rishikesh;
- Zone 2: (A reference zone) from upstream of Garhmukteshwar to Narora;
- Zone 3: Narora to Farrukhabad, and
- Zone 4: Kannauj to Kanpur

3.5 SELECTION OF SAMPLE SITES FOR DETAILED STUDIES

The second part of the analysis located one site for each zone that would best characterise the conditions throughout that zone. The detailed field investigations by the specialist teams, on which the EFA was based, were to be carried out at these sites.

Criteria for site selection within each of the zones varied according to the perspectives of the different specialist groups. From the viewpoint of the biodiversity group, for example, the sites were selected according to the following criteria:

- Habitat diversity
- Sensitivity of habitats to flow changes
- Suitability for measuring a rated hydraulic cross-section and for modelling discharges, velocities and wetted perimeter at different water depths
- Ease of accessibility
- Representation of conditions in the river zone
- Critical flow site (i.e. where flow will stop first if discharges are reduced)

A workshop was held in February 2009, followed by a field visit in March 2009 to verify the chosen sites. The main criteria that were considered while confirming the suitability of the sites were:

- High diversity of physical habitats for aquatic and riparian species;
- Representation of the larger river section in terms of geomorphology;
- Presence of flow sensitive habitats and critical habitats for important species (e.g. dolphins, turtles);
- Easy access;
- Suitability for accurate hydraulic modelling through a range of flows and low flows in particular;
- Located upstream rather than downstream of major tributaries
- Presence of flow gauging station
- Presence of community that uses river (nearby)
- Proposed water resources development (nearby)

Table 3.3 summarises the four homogenous zones and the sites that were selected to represent them.

Table 3.3: Summary of zones and sample sites in the Upper Ganga EFA

Zone	Name	Sample site	Latitude	Longitude
1	Gangotri to Rishikesh	Kaudiyala	N30°04'29.9",	E78°30'09.9"
2 (Reference)	Upstream of Garhmukteshwar to Narora	Narora	N28°10'51.2"	E78°23'51.2"
3	Narora to Farrukhabad	Kachla Ghat	N27°55'59.8",	E78°51'42.5"
4	Kannauj to Kanpur	Bithoor	N26°36'51.9"	E80°16'28.6"

Source: INRM Report on Homogenous Zonation (Annexure 6)

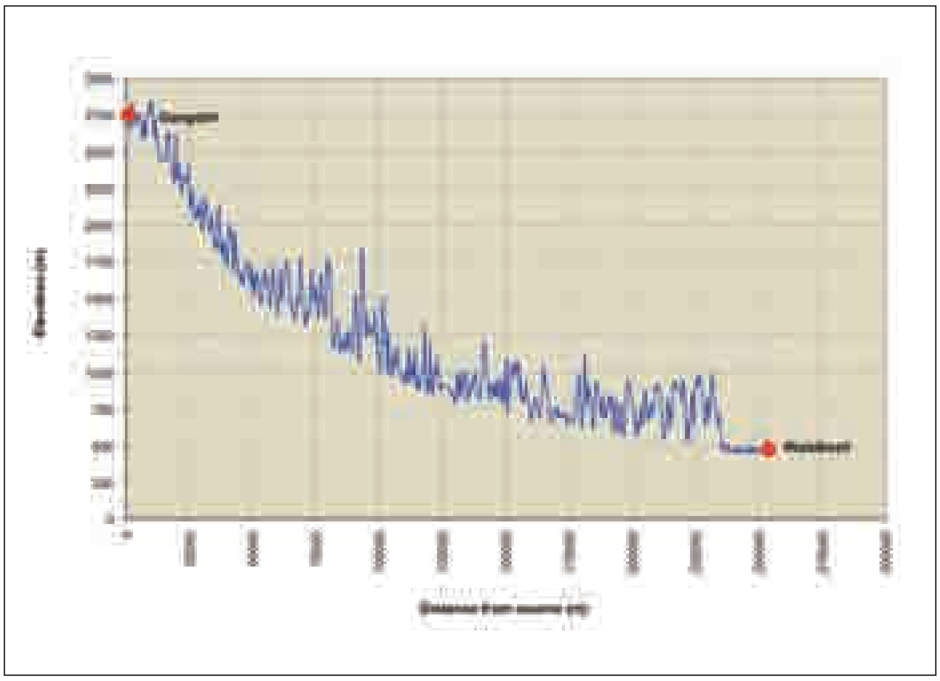
3.6 ZONE 1: GANGOTRI TO RISHIKESH

3.6.1 Description

The Upper Ganga from Gangotri to Rishikesh is situated in high mountains which are snow bound and glaciated, with elevations ranging from 3000 to 350 m asl (meters above sea level). This section of the river has a steep gradient, in the order of 15 m per 1 km. There are many first order streams in this zone which include cascades and bedrock falls. The distance of the river course in this zone is about 240 km.

Typical channel widths range from 50 m to 250 m in this zone, and many of the rivers and streams in the zone are deeply incised in their valleys. The longitudinal profile of the zone is depicted in Figure 3.3 and the main tributaries, towns, barrages/dams and other developments are summarised in Table 3.4.

Figure 3.3: Longitudinal profile of Zone 1 (Gangotri to Rishikesh)



Source: INRM Report on Homogenous Zonation (Annexure 6)

Table 3.4: Summary table: Zone 1

Zone 1: Gangotri to Rishikesh		Details
Length (km)	240	
Elevation (m)	3000 to 350	
Slope (m/km)	15	
Tributaries	7	Nauar, Mandakini, Alaknanda, Bhilangana, Pinder, Nandakini, Dhauliganga
Dams/Barrages	Many	Maneri Dam, Tehri Dam, Pasulok Barrage (Rishikesh) etc.
Canals	-	None
Major Industries	-	None
CPCB WQ monitoring stations	8	Gangotri, Pindar, Rudraprayag Alaknanda After Confluence-Devprayag, Bhagirathi Before Confluence-Devprayag, Alaknanda Before Confluence-Devprayag, Ganga-Rishikesh and so on

Source: INRM Report on Homogenous Zonation (Annexure 6)

3.6.2 Site: Kaudiyala (N30°04'29.9", E78°30'09.9")

The sampling site identified for Zone 1 was Kaudiyala. This site is located about 12 km downstream of Devprayag (where the Alaknanda and Bhagirathi rivers meet to form the Ganga River). The river has a very sharp bend at this location, with gravels and boulders on the concave side, and a road along its right bank. The river is about 100 m wide at this point, while the valley width is in excess of 600 m. The river is flanked on both sides by high mountains. Two reservoirs are planned between this point and Devprayag which are likely to disturb the ecology of the reach significantly, making it an even more important site for an E-Flows assessment.

The channel consists largely of pool/riffle and rapid sequences. The narrow channel widens as the river enters Kaudiyala, forming sandy banks along the left slopes. The dominant sediments carried by the river are gravels, with the river bed at this point consisting of boulders, rocks, cobbles, pebbles and silt.

In the reach between Kaudiyala and Marine Drive (upstream of Lakshman Jhula, Rishikesh), large boulders are common along both banks, suggesting that rock slides are frequent in this area. Figure 3.4 is a photograph showing the sampling site at Kaudiyala.

Figure 3.4:
The Kaudiyala sampling site on the Upper Ganga

Photo Credit: Nitin Kaushal / WWF-India

In this zone, the biodiversity and cultural and spiritual aspects are highly significant, a brief description of which is given below

3.6.3 Biodiversity aspects

A few kilometres upstream of this site, at Pachelikhal, is the confluence of the Nyar river with the Ganga. It is believed that the Nyar is the only tributary of the Ganga in which mahseer (fish) breed in the monsoon period when the flow in the Nyar is sufficient. The construction of dams and hydropower plants in the downstream reaches may change this situation, as the adult mahseer may not be able to migrate upstream to reach the Nyar for breeding.

Downstream of Kaudiyala, a good population of large mahseer was observed at Rishikesh (Ram Jhula) concentrated in the centre of the channel with a gravelly bed and shallow water depth. Along the right bank, the rocky bottom was visible but the deeper water did not encourage the fish population.

The site at Kaudiyala was subsequently found not to be suitable for biodiversity sampling because of a lack of available habitats. Therefore, an alternative site at Shivpuri, 10 km downstream of Kaudiyala, was used for the biodiversity study. The water quality and temperature were similar at the two sites, whilst Shivpuri provided a greater diversity of more accessible habitats. Since both Kaudiyala and Shivpuri are suitable for assessing the riparian vegetation, the biodiversity group decided to carry out their surveys and sampling along the stretch of river from Kaudiyala to Shivpuri.

3.6.4 Socio-cultural and livelihood aspects

There are a number of tourist camps in this area, which are very popular with visitors for rafting and camping. Because of the extreme socio-economic importance of pilgrimage, it was also decided to study prominent towns along the river in this zone. The important characteristics of these towns can be summarised as follows:

- Gangotri: This is the place where the river originates from the snout of the glacier. Gangotri is open only for six months of the year and its population is entirely dependent on the pilgrims and adventure tourists who visit it. Worshipping at the river and associated temples, bathing in the Ganga and trekking to the glacier are popular activities.
- Uttarkashi: The 'Kashi of the North' is situated on the banks of the Bhagirathi. This bustling pilgrim town has some temples dedicated to the Goddess Ganga. An *aarti* (daily prayer, generally done twice a day, i.e. during sun-rise and sun set) is also performed here for the river.
- Devprayag: This is at the confluence of the Bhagirathi and the Alaknanda which forms the Ganga. Considered one of the 108 most sacred spots in India and Nepal, this is the destination of many tourists and pilgrims. Ritual bathing, worshipping and river rafting are all popular on this stretch of the Ganga.
- Rishikesh: Rishikesh is spiritually very important for pilgrims. In addition to the livelihood linked to pilgrims, Rishikesh is also visited for white water rafting and spiritual retreats. In addition, many local people earn their living by operating ferries across the Ganga.
- Haridwar: Located at the junction of the plains and the mountains, Haridwar is a popular pilgrimage site for people from the plains, with millions of pilgrims visiting for ritual bathing on auspicious days. Accordingly, a large part of the local population depends on these pilgrims for their livelihood. An *aarti* is also performed here for the river.

The water quality group did not find any significant pollution issues at or around this site.

3.7 ZONE 2 (REFERENCE ZONE) FROM UPSTREAM OF GARHMUKTESHWAR TO NARORA

3.7.1 Rationale

The main purpose of assessing E-Flows for a particular river is so that its ecology, biodiversity and human uses can be maintained or restored to a predetermined level, assuring its sustainable future use. In particular, it is assumed that the biota of the river will have adapted over millenia to the natural flow and water quality conditions of the river.

In order to define environmental objectives for the various zones, it is necessary to describe reference conditions which provide a baseline against which present day modifications are measured, and for role players to agree on environmental objectives for which suitable flows can be recommended. However, the river Ganga has been utilised and modified over many centuries by the people living in the basin. It is often not possible to describe the natural or unmodified conditions of the river that existed before human intervention began.

In this project, the reference conditions were identified as those existing in the reaches of the river immediately upstream of Narora barrage, where adequate flows and water depths are sufficiently well maintained to support natural biodiversity and especially the flagship species such as river dolphin and gharial. This stretch was therefore designated as a reference zone to benchmark and assess the downstream zones, which have been very heavily modified, overused and polluted. Therefore, the aim of the E-Flows is to restore conditions in the lower two zones to those which pertain in the reference zone.

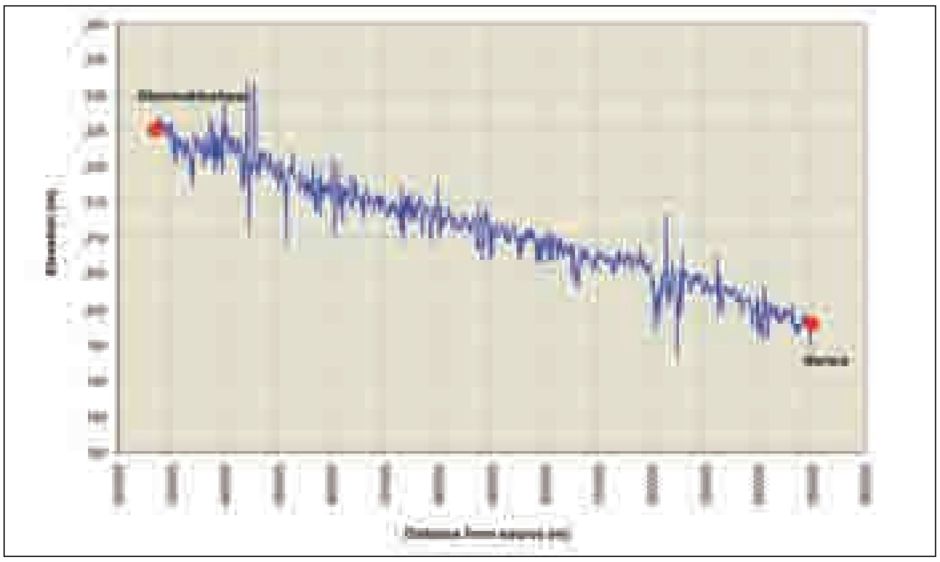
3.7.2 Description

The length of Zone 2 from upstream of Garhmukteshwar to Narora is about 121 km, with a gentle gradient of 0.3 m/km, and altitude ranging from 225 – 200 m. The Baiya and Burh Ganga are the major tributaries joining the main channel. The Lower Ganga Canal take off at Narora barrage is located in this zone.

Channel morphology in this zone includes sand bars, islands, flat floodplains and a few ox-bow lakes. The floodplain on the left bank is wider than on the right bank.

This stretch is characterised by a large number of industries, including sugar mills, distilleries, paper and pulp mills, textile, chemical and fertiliser factories. An atomic power plant is also located in Narora. The longitudinal profile of Zone 2 is shown in Figure 3.5, whilst the main tributaries, towns, barrages/dams and other features of the reference zone are summarised in Table 3.5. Figure 3.6 is a map showing the Ganga basin, including the area around Narora.

Figure 3.5: Longitudinal profile of Zone 2 (reference zone) from upstream of Garhmukteshwar to Narora



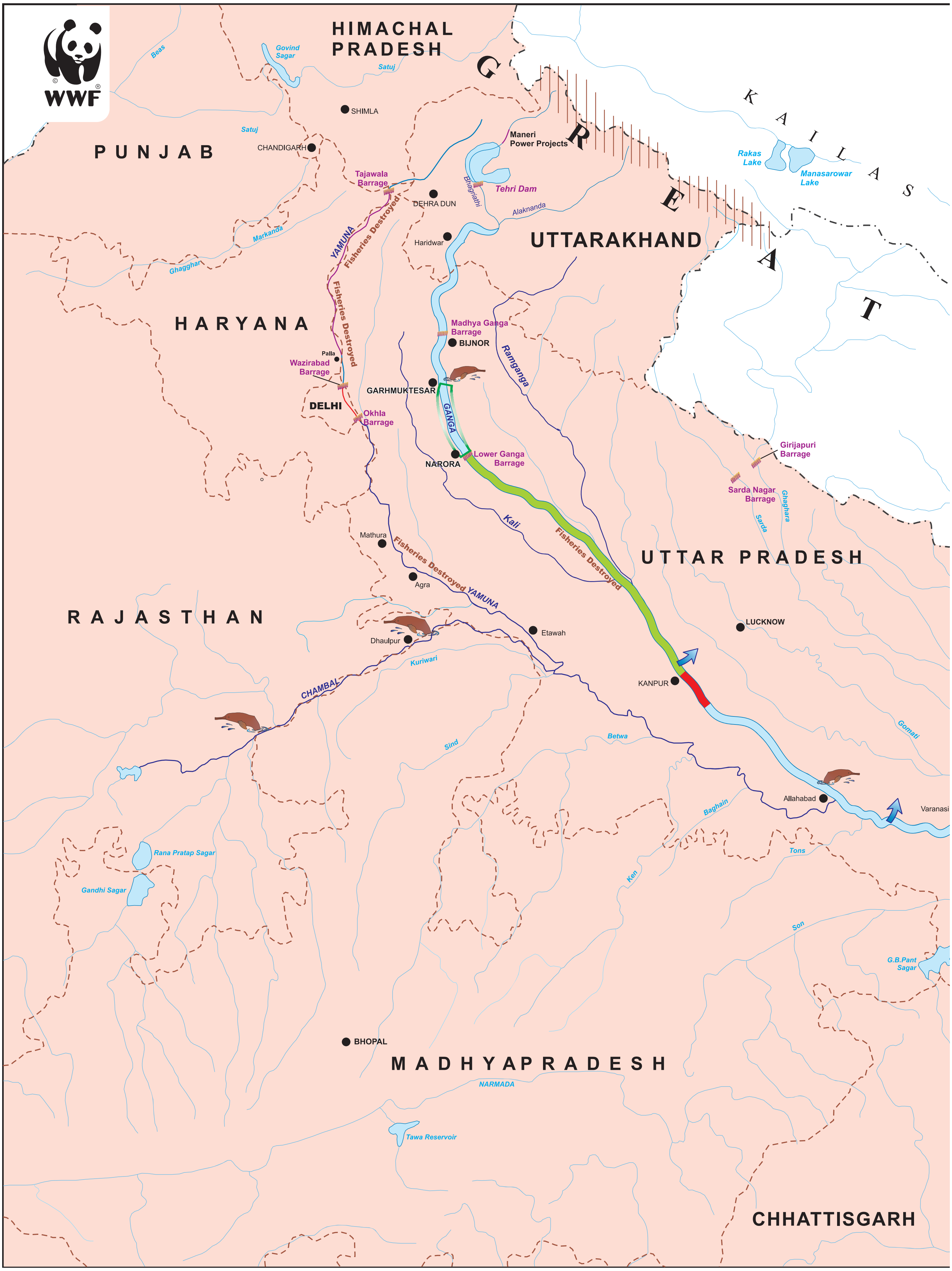
Source: INRM Report on Homogenous Zonation (Annexure 6)

Table 3.5: Summary table: Zone 1

Zone 2 (Reference zone): Upstream of Garhmukteshwar to Narora		Details
Length (km)	121 km	
Elevation (m)	225 to 200	
Slope (m/km)	0.2	
Tributaries	2	Baiya, Burh Ganga
Dams/Barrages	1	Narora Barrage
Canals	1	The Lower Ganga Canal
CPCB WQ monitoring stations	2	Garhmukteshwar, Narora

Source: INRM Report on Homogenous Zonation

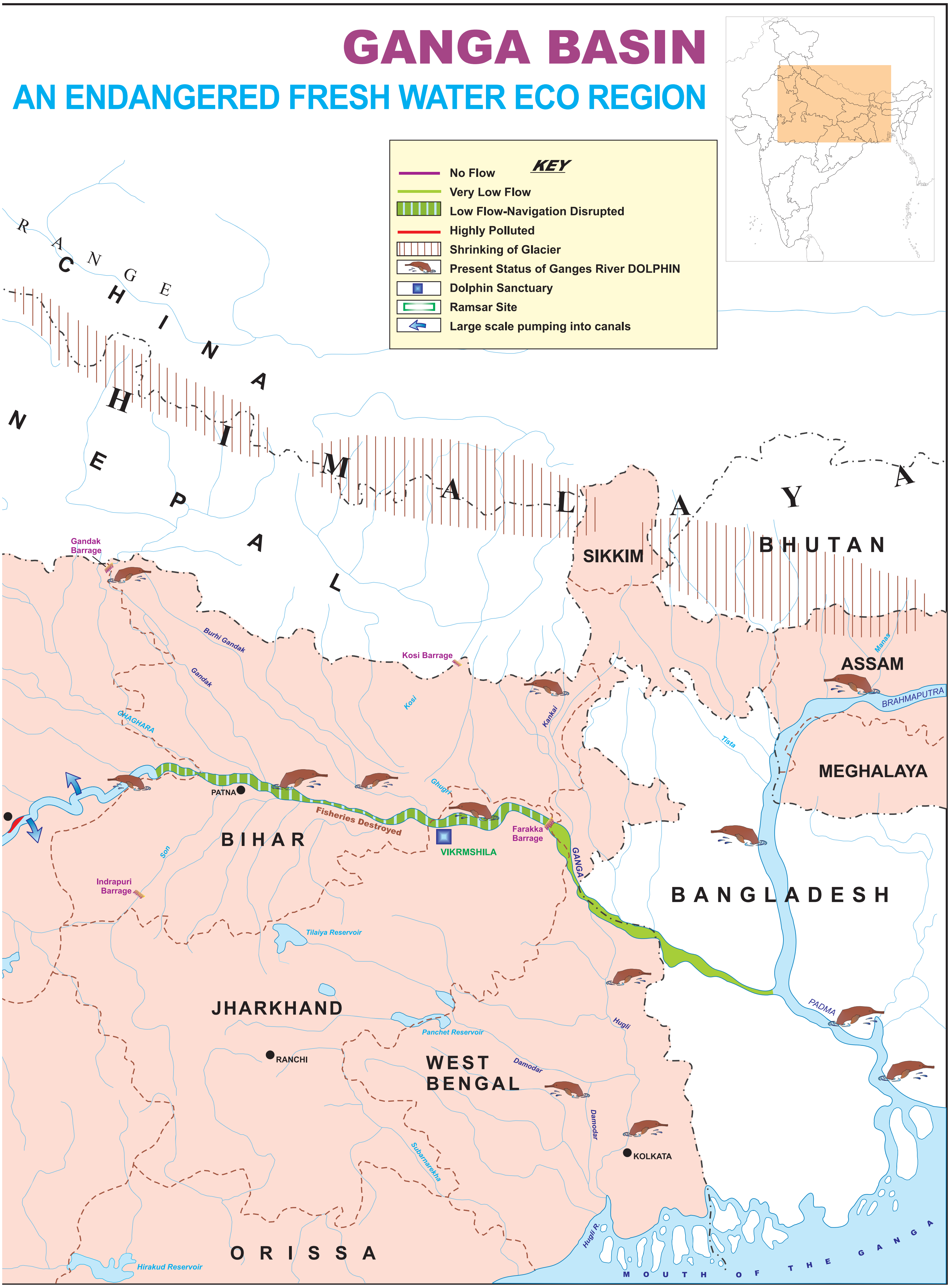
Figure 3.6: Ganga basin, including the area around Narora



Data Sources :- WWF-India

GANGA BASIN

AN ENDANGERED FRESH WATER ECO REGION



(Map Not to Scale)

3.8 ZONE 3: NARORA TO FARRUKHABAD

3.8.1 Description

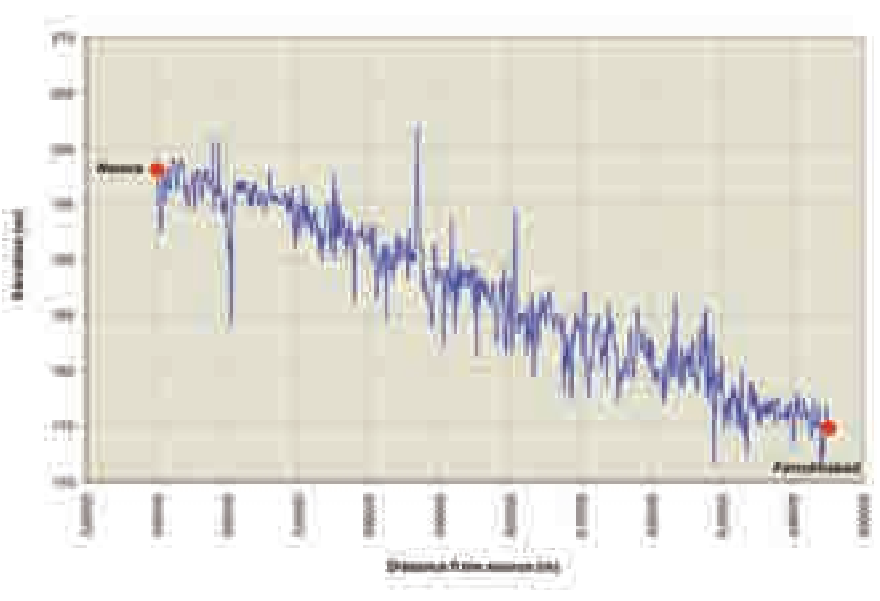
This zone is about 114 km long, with a gradient from Narora to Farrukhabad of 0.2 m in 1 km. The altitude ranges from 200 to 175 m. Mahuwa and Ramganga are the major tributaries joining from the left bank in this zone. There are no dams or barrages within Zone 3, although it experiences very low flows during October to April, because of storage and diversion of water at Narora barrage. This results in dry season releases of less than 9 cumecs (cubic meters per second) from the barrage. Because of these reduced flows, there is increased channel siltation. The Mahuwa and Ramganga tributaries drain large quantities of industrial effluents into the Upper Ganga. This industrial waste is released from factories located at Gajrula, Moradabad and Babrala, Bareilly, etc. The water in this section of the Upper Ganga River turns red during the dry season, an indication of severe water quality problems in this zone.

River morphology in Zone 3 includes sand bars, islands, flat floodplains and a few ox bow lakes. The floodplain on the left bank is wider than on the right bank.

Bareilly is the major industrial town in this zone and has sugar factories, distilleries and chemical/fertiliser factories. There is no water quality monitoring station.

The longitudinal profile for Zone 3 is depicted in Figure 3.7, whilst the details of the main tributaries, towns, barrages/dams and other developments in are summarised in Table 3.6.

Figure 3.7: Longitudinal profile of Zone 3 from Narora to Farrukhabad



Source: INRM Report on Homogenous Zonation

Table 3.6: Summary table: Zone 3

Zone 3: Narora to Farrukhabad		Details
Length (km)	114	
Elevation (m)	200 to 175	
Slope (m/km)	0.2	
Tributaries	3	Mahuwa, Choiya *nadi*, Ramganga
Dams/Barrages	-	None
Canals	-	None
Hydropower	-	None
CPCB WQ monitoring stations	-	None

Source: INRM Report on Homogenous Zonation (Annexure 6)

3.8.2 Site: Kachla Ghat (N27°55'59.8", E78°51'42.5")

This site is located approximately 60 km downstream of Narora, at downstream of the confluence of the Mahuwa with the Ganga River. The Central Water Commission (CWC) has a hydrological station (GDSQ[2]) at this site, where water level, discharge, sediment load and water quality are measured. A new bridge is being constructed across the river Ganga at this site, due to which flow has been temporarily diverted. The river macro-channel at this location is very wide (>3 km) but the water is confined to only about 20 m and the water depth is 1 to 2 m (waist deep) at present. Maps and satellite images clearly show that the river is anabranched[3] and braided[4] in this reach. Two distinct channels which eventually join further downstream (upstream of Kachla Ghat) are clearly visible on the satellite image. Both the banks of the river are quite flat, merging gradually with the floodplain. No sign of any incision was visible on either of the banks. The dominant grain size of channel sediments is fine sand with significant amounts of silt.

Upstream of this site, the Mahuwa River at Jatki village has a much larger valley than the channel occupied by the river at present, suggesting a significant reduction in river discharge in recent times. The river was almost dry at the time of the initial field visit (March 2009), with the river bed being cultivated by local melon farmers, and fishing taking place in the remaining pools. Field investigations revealed that a large amount of effluent from Gajraula is discharged into the Mahuwa, eventually finding its way into the Ganga River downstream of the confluence. Even though the flow from the Mahuwa is diverted, the Ganga River at Kachla Ghat seems to have several other sources of pollution such as city waste. It has a cremation area/*ghat* as well as a bathing *ghat*.

Due to intense human activity at Kachla Ghat, this site was not suitable for the study of aquatic biodiversity, and a better site was selected 1 km downstream where micro-habitats and stable substrate are available. Agriculture is the major form of human impact especially along the right bank.

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2 GDSQ – Gauge, Discharge, Silt and Water Quality station

3 Anabranched river: An anabranch is a section of a river or stream that diverts from the main watercourse channel (or mainstem) and re-joins the mainstem downstream

4 Braided River: A network of converging and diverging streams separated from each other by narrow strips of sand and gravel.

Figure 3.8:
Working group at the
Kachla Ghat site

Photo Credit: Anshuman Atroley / WWF-India

Kachla Ghat's religious importance is not of extraordinary spiritual significance as in the case of Haridwar and Rishikesh, but is important from the point of view of livelihoods. Several livelihood practices that depend on in-stream flows are evident here, including farming on sand banks, ferrying, retrieving coins, pilgrimage, ritual bathing and cremation.

3.9 ZONE 4: KANNAUJ TO KANPUR

3.9.1 Description

The river length in Zone 4 from Kannauj to Kanpur is about 99 km, with a gradient of 0.2 m per km. Altitude ranges from 135 to 115 m. The Isan River joins the main course of the Upper Ganga from the right bank whilst the Gahala River joins from the left. Both these rivers bring in major pollution loads.

The stretch of the Upper Ganga between Kannauj and Kanpur experiences very low flows between October and April. Most of the flow comes from the Ramganga River which meets the Ganga River upstream of Kannauj, before the starting point of the zone.

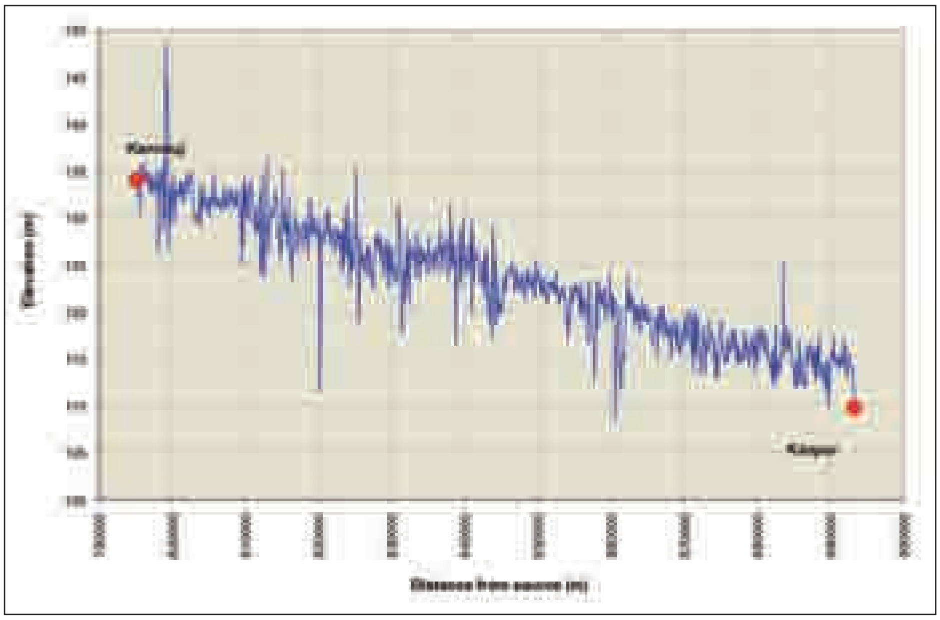
Kanpur is the largest city on the right bank, with a population of 2,715,555 (Class I[5]). Unnao is the other big Class I city on the left bank. Laharapur is a Class II[6] city located in this zone. Kanpur barrage (for drinking water supply to Kanpur city) is the only barrage in this zone.

The channel morphology in this zone includes sand bars, islands, flat floodplains and a few ox-bow lakes. The floodplain on the left bank is wider than on the right bank, and the channel is braided.

5 Class 1 city: with population → 1 00 000
6 Class 2 city:with population 50 000 – 1 00 000

Jajmau, Unnao and Kanpur are home to several tanneries and textile mills. There are three CPCB water quality monitoring stations at Bithoor, Jajmau and Raoli *ghat*. The longitudinal profile of Zone 4 from Kannauj to Kanpur is depicted in Figure 3.9, whilst the main tributaries, towns, barrages/dams and features are summarised in Table 3.7.

Figure 3.9: Longitudinal Profile of Zone 4 from Kannauj to Kanpur



Source: INRM Report on Homogenous Zonation (Annexure 6)

Table 3.7: Summary table: Zone 4

Zone 4: Kannauj to Kanpur		Details
Length (km)	99	
Elevation (m)	135 to 115	
Slope (m/km)	0.2	
Tributaries	2	The Isan from the right bank and the Gahala River
Dams/Barrages	1	Kanpur Barrage
Canals	-	None
Hydropower	-	None
CPCB WQ monitoring station	3	Bithoor, Jajmau, Raoli ghat

Source: INRM Report on Homogenous Zonation (Annexure 6)

3.9.2 Site: Bithoor (N26°36'51.9" E80°16'28.6")

Bithoor is situated at upstream of Kanpur, was selected as the designated site for detailed studies in this zone. The surface elevation at Bithoor is 120-130 m above mean sea level. The active channel presently follows the southern valley margin and has extensive floodplain areas within the valley. Floodplain areas north of the Ganga include abandoned channels, meander scars and ox-bow lakes, together with a few small lakes and waterlogged areas. A very large, conspicuous meander scar which is presently cut off from the present channel is periodically flooded by the

Ganga. The southern valley margin is strongly incised and at Bithoor, prominent cliffs up to 15 m high extend in a south-easterly direction for nearly 2 km. The river bed is mainly composed of sand and clay (on the banks of the river). Except during the monsoon months, the river is multi-channeled, with large bars in the channel dividing the flow.

The Kanpur barrage constructed 6 to 7 years ago is located immediately downstream of this site, together with a diversion canal for the barrage. A hydrological station located at Kanpur reports that the long-term average annual discharge at Kanpur is 1679 m^3/s. Hydrological data published for this station suggest that the discharge variability (represented by Qmax[7]/Qmin[8] = 100) is significant whereas the flooding intensity is low, with a higher bankfull discharge compared to the mean annual flood (Qmaf[9]/Qb[10] = 0.5).

At the site, the aquatic biota and especially the lower organisms (plankton and benthic invertebrates), which are very sensitive, are highly influenced by intense anthropogenic activities, including bathing, pilgrimage activity and boating. The site has religious and archaeological importance. An old temple dedicated to Lord Brahma is situated at Bithoor. Religious fairs are organised on important occasions, during which religious bathing is common. The site is also known for historical remains of the pre-British period all along the banks. Many local livelihoods depend directly on the cultural importance of this stretch of the Ganga.

Whilst this is a good site for generating hydraulic sections, as the right bank is confined by 12 to 14 m high cliffs whereas the left bank is flat, it was not considered suitable for aquatic (biodiversity) sampling. Aquatic sampling was carried out approximately 1 km downstream of the Bithoor temple.

Figure 3.10: Ferrying at Bithoor

Photo Credit: Amrit Pal Singh

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7 maximum discharge
8 minimum discharge
9 mean annual flood
10 bankfull discharge

References

Alternate Hydro Energy Centre (2009), Status paper on River Ganga – state of environment and water quality. Submitted to the National River Conservation Directorate, Ministry of Environment and Forests, Government of India. Pages 38

Government estimates show that almost 3 billion litres of sewage (partially treated and untreated) is discharged into Ganga everyday from cities, thereby severely degrading the water quality

Photo Credit: Amrit Pal Singh

Photo Credit: Kiran Rajashekariah / WWF-India

Run-of-the-river hydropower projects leads to diminishing flows in the river length for which the water has been diverted through tunnels

Chapter 4
THE PRESENT STATE AND ENVIRONMENTAL OBJECTIVES FOR THE UPPER GANGA RIVER

4.1 INTRODUCTION

This chapter summarises the assessment by the specialist groups of the present state, and the setting of the desired future state, for each of the four zones of the Upper Ganga described in Chapter 3. Zones 1, 3 and 4 were the assessment zones, for which the present state formed the background information to define the desired future state in terms of objectives and targets for flow maintenance or improvement. Zone 2, upstream of Narora, was the designated reference zone, as described in Chapter 3, against which specific flows in the other zones could be recommended.

The Environmental Management Classes (EMCs) are described in Chapter 2, (Table 2.2). The expert opinions of the specialists in the working groups were the basis on which the EMC of various sites were classified (i.e. A, B, C or D); however, the Central Pollution Control Board (CPCB) river water quality criteria were adhered to in case of water quality.

The hydraulics group surveyed the cross-sections for all four sites, taking at least three cross-sections for each of the sites, i.e. one upstream, one at the centre and one downstream of each site.

4.2 CURRENT STRESSES ON THE WATER RESOURCES OF THE RIVER GANGA

Population growth

The demographic trends in the Ganga basin are alarming with the population of major cities within the Ganga river basin increasing by about 32 per cent from 1991 to 2001, The Ganga river basin constitutes 26 per cent of the country's land mass, but supports about 43 per cent (about 500 million) of the population. In fact, the population density of the Ganga river basin, at 512 persons/km^2, is much higher than the national average of 312 persons/km^2. (AHEC, 2009)

Surface water use

Irrigation

This region serves as one of the crucial food baskets of the country, and with the increase in population, there is an increasing demand to grow more food.

There are several canal systems taking water from the Ganga river. The head-works (diversion structures) of the Upper Ganga Canal, which was the first canal system to be constructed on the Upper Ganga, is located at the Bhimgoda barrage at Bhimgoda. This diversion is located about a kilometre from the *Har-ki-pauri*, which is one of the most sacred points on the Upper Ganga for taking holy baths. The canal serves the district of Haridwar in the state of Uttarakhand and the western part of Uttar Pradesh. In Uttar Pradesh, total annual surface water withdrawal for irrigation is around 58 BCM[1].

After the Upper Ganga Canal, a number of other canals were constructed and commissioned, including the Lower Ganga Canal, the Madhya Ganga Canal, and the Eastern Ganga Canal. Collectively, these canals draw a significant proportion of water from the main river, bringing agricultural prosperity to the districts of western and central Uttar Pradesh. Water abstraction via these canals is summarised in Table 4.1:

Table 4.1: Details of abstractions from the Ganga River through various canals

Serial Number	Canal System	Diverted Flow Rabi[2] (cumec)	Diverted Flow Kharif[3] (cumec)	Total (cumec)	Location
1	Upper Ganga Canal (UGC)	297	297	594	Upstream of Bhimgoda Barrage
2	Eastern Ganga Canal (EGC)		135	135	Upstream of Bhimgoda Barrage
3	Madhya Ganga Canal-I (MGC-I)		234	234	Upstream of Raolighat Barrage
4	Madhya Ganga Canal-II (MGC-II)[4]		192	192	Planned: u/s Raolighat Barrage
5	Lower Ganga Canal (LGC)	240	240	481	Upstream of Narora Barrage
6	Parallel Lower Ganga Canal (PLGC)		118	118	Upstream of Narora Barrage
	Total	537	1220	1758	

Source: Inception Report: Study on 'Problems and Prospects in Saving Water and Energy in Agriculture in Upper Ganga River Basin' by Phanish Kumar Sinha (2009)

Kaushal and Kansal (2010) conclude that the current proportion of water allocation for agriculture is bound to be reduced in the future. In case of Uttar Pradesh (as per SWaRA[5]), it has been decided that the current allocation of 93 per cent of total water allocation for the state of Uttar Pradesh for agriculture in the year 2001 will be reduced to 79 per cent by the year 2050. However, this saving is bound to be re-allocated to municipal and industrial uses, which may lead to further aggravation of the problem of pollution.

[1] BCM - Billion Cubic Meters
[2] Rabi crop - sown in the months of October and November and are harvested in the months of March and April
[3] Kharif crop – sown in summer and rains (during April-July) and harvested by October
[4] Under construction
[5] SWaRA - State Water Resources Agency, Government of Uttar Pradesh

Domestic and industrial water use

In addition to significant agricultural abstractions, the river water is used for domestic purposes by municipalities and a small but growing portion is also used for industrial purposes, In Uttar Pradesh, domestic and industrial abstraction was 0.79 and 0.18 BCM respectively in the year 2009 (Phanish Kumar Sinha 2009).

Waste discharge

The municipal sewage disposed into river Ganga by thirty-five Class I[6] cities, and fifteen Class II[7] cities in four states (Uttarakhand, Uttar Pradesh, Bihar and West Bengal) is about 2 683 MLD (million litres per day) (CPCB, 2009), whereas about 12 000 MLD[8] of sewage is generated in the Ganga river basin as a whole. Sewage treatment capacity is far below the amount generated, causing serious water quality issues.

Around 286 MLD of industrial effluent is released into the river Ganga (CPCB, 2009). Although this effluent is required to be treated before disposal, these requirements are often not adhered to.

Hydropower

A major use of the flow in the upper reaches is for run-of-river hydropower development, particularly at Uttarakhand where large scale hydropower development has taken place. This has led to local water quantity deficits in the river reaches below the hydropower off-takes where water is abstracted to pass through tunnels to supply the turbines at the power house. These Head Race Tunnels often run from 5 to 15 km, leaving little or no water in the river course, with a resulting loss of biodiversity in these stretches. This is an additional motivation for maintaining E-Flows in the Upper Ganga River.

Groundwater use

According to SWaRA, the increase in the number of tube-wells in the last 2-3 decades has led to a lowering of the water table within the Ganga Basin. SWaRA estimated that, there are about 29,000 state tube-wells, and about 4.6 million private tube-wells in the state of Uttar Pradesh. Most of the irrigation water abstractions are located in UP state. Ultimately, this leads to a reduction of base flows in the river, especially during the lean season.

Tourism

With economic liberalisation and growing standards of living, there has been considerable enhancement in tourist influx during the last 10-15 years, especially in the upper part of the basin. The tourism activities have diversified from being primarily religious, to recently including high value adventure activities such as camping, rafting, kayaking, tracking etc. Whilst this has enhanced the economic status at the tourist destinations, at the same time it has also brought more stress to the river and its resources.

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6 Class I city: with population - 1,00, 000

7 Class II city: with population 50,000 – 1,00, 000

8 Source: http://moef.nic.in/modules/recent-initiatives/NGRBA/Need.html

4.3 RECENT MANAGEMENT INITIATIVES

The Ganga Action Plan (GAP) was one of the key initiatives of the government during the 1980s. Whilst the original integrated plan was aimed at restoration of the river, it was reduced to a sewage treatment exercise for a few cities bordering the river. Sharma (1997) concluded that GAP was mistakenly assumed to be a sewerage improvement plan, causing the initial rise in general expectations to be followed by disappointment when GAP was found to limit itself only to river pollution abatement, without pursuing other popular measures to address the pollution issues in a comprehensive manner. This could have been one of the main reasons why it attracted some sharp criticism. Jaiswal (2007) also concluded that the GAP launched by the Government of India has not achieved any success, despite expenditure of approximately Rs. 2 billion.

In 2009, the Prime Minister of India declared the river Ganga a 'National River'. Taking this lead, a National Ganga River Basin Authority (NGRBA) was constituted by the Ministry of Environment and Forests (MoEF). The NGRBA consists of members from Central and State Government departments, civil society, non-governmental organisations (NGOs), and social activists. In 2010, the MoEF, through NGRBA, commissioned a study to a consortium of seven Indian Institutes of Technology[9] (IITs) to develop the Ganga River Basin Environment Management Plan (GRBEMP). The consortium set up several thematic groups for handling the diverse river basin management components, such as hydrology, water quality, fluvial geomorphology, biodiversity, socio-economics, policy and law, etc. It is envisaged that the GRBEMP will lay the foundation for a range of activities and works targeting the management of the Ganga River Basin in a holistic manner.

One of the components of the IITs' study was the assessment of E-Flows for the river Ganga. There is unanimous opinion among the members of the constituted group that there is an urgent need to maintain E-Flows throughout the river in order to restore the river as a sustainable ecosystem. The conservation of the river is critical not only to address present day needs, but also for those of generations to come. The maintenance of the iconic and mighty nature of the Ganga river requires that society should define the condition in which it would like to see it maintained for current and future generations. While recognising the need for economic development and overall societal upliftment, there is also a need to conserve the ecology which is dependant on the Ganga's water resources. In this regard, an Integrated Water Resources Management (IWRM) strategy is required, of which the assessment and maintenance of E-Flows is a stepping stone.

4.4 FIELD INVESTIGATIONS

Field surveys form a crucial part of the E-Flows assessment. As described in Chapter 3, an initial desk study was undertaken to identify homogenous zones within the river, followed by meetings and fieldwork to finalise the zones and select study sites. Even though most of the specialists already had extensive exposure to and experience of working in the Upper Ganga, the field visits in 2008 allowed for ground-truthing that would ensure a high confidence level in the outcomes of the EFA.

[9] IIT – Kanpur, IIT – Roorkee, IIT – Delhi, IIT – Bombay, IIT – Madras, IIT – Kharagpur, IIT – Guwahati

Following these field visits, groups were constituted by WWF-India on the themes of hydrology, hydraulics, fluvial geomorphology, biodiversity, water quality, livelihoods, and socio-cultural aspects. These thematic groups conducted detailed field investigations from April 2009 to March 2010. This gave them adequate time for data collection throughout a complete year cycle of conditions in the river Ganga.

The hydrology and hydraulics groups played a vital role in helping other groups to derive E-Flows recommendations at a later stage. They provided surveyed cross-sections and hydraulics models, which allowed the conversion of the habitat/process-requirements recommended by other groups, into flows required to meet the expectations.

4.4.1 Hydrology and hydraulics

The flow regime is recognised as a key factor in determining biological and physical processes and characteristics in rivers. The EFA needs to consider natural flows, in other words the flows that occurred in the river prior to significant hydrologic modifications. Unfortunately, historic discharge data are not available in the public domain for the Ganga River system in India. Therefore, a catchment-scale distributed hydrological model the Soil-Water Assessment Tool (SWAT) was used to simulate water balances and generate the flows that were likely to have existed prior to any infrastructure projects (dams, barrages and reservoirs) in the Upper Ganga Basin in India.

The purpose of this exercise was to:

1) Understand the Upper Ganga Basin in its present state, as well as in more "natural[10]" conditions; and

2) Generate "naturalised[11]" flows for the purpose of calculating E-Flows requirements in three sites along the main river[12].

SWAT is a process-based continuous hydrological model that predicts the impact of land management practices on water, sediment and agricultural chemical yields in complex basins with varying soils, land use and management conditions. The SWAT requires three basic spatial input files: Digital Elevation Model (DEM), Soil Map, and Land Use/Land Cover (LU/LC) map. For this study, the DEM was obtained from the 90 m Shuttle Radar Topography Mission (SRTM) data; for soils, the FAO[13] soil map was used; and the LandSat TM was used for the LU/LC map. SWAT also required time series of observed climate data, i.e. rainfall, minimum and maximum temperature, wind speed and relative humidity. In this study, the data from 15 climate stations within the Ganga basin were used. Data from the climate stations were spatially interpolated by the SWAT model to produce a gridded map of climate input.

In order to validate the model, flow data from the Bhimgoda, Narora, and Kanpur barrages were used. Due to the restrictions on public access to the data on flows,

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[10] Natural Condition: a naturally occurring condition, with no abstractions/diversions or interception of flows

[11] Naturalised Flows: the flows which would occur under natural (undeveloped) conditions,

[12] E-Flows assessment for the Reference Zone was not done.

[13] FAO: Food and Agriculture Organisation of the UN

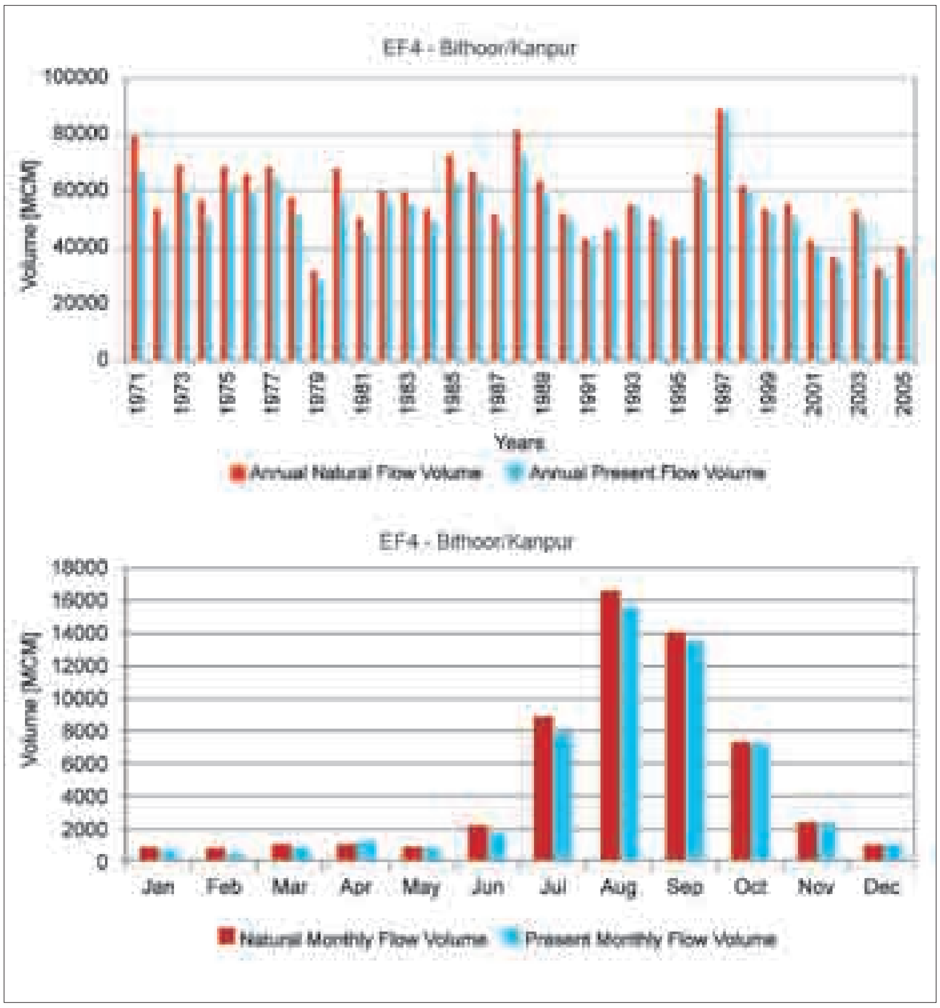
only a very short time series of data from each of these barrages was available. With the exception of one site (Narora), the observed flow data are monthly time series, while the model works with a daily time step. Simulated daily flow values therefore had to be accumulated on a monthly basis for comparison, introducing some uncertainty into the data. Further, the quality of the observed data could not be ascertained by the hydrology group. Therefore, the model was set up and calibrated in the absence of reliable observations.

The existing dams, barrages and irrigation systems/abstraction were incorporated in the model using available salient features from the relevant barrage/dam authorities.

Simulation of natural flow conditions for the four E-Flows sites

Scenarios for natural flow conditions represent minimal human intervention in the basin, i.e. without dams and irrigation infrastructure; this was done to mimic the natural/undisturbed state of the river. Due to a lack of real measured flow data under such conditions in this study, the calibrated model for present conditions (from 1971 to 2005) was run by removing all infrastructure from the model set up.

Figure 4.1: Annual flow totals (top) and average monthly flow distribution (bottom) for Bithoor/near Kanpur



Source: Hydrology of upper Ganga (Annexure 1)

In addition, land use varies between the present day and natural conditions. Irrigated crops such as rice, wheat, corn, *bajra,* sugarcane and potato represent the major crop types during present conditions. The scenario for natural conditions was characterised by rain-fed crops such as moong, bean and wheat. Parameters in the model were therefore changed accordingly, to reflect the difference between the scenarios in the model. The natural flows simulated for Bithoor are given below for reference (for simulated natural flow of other sites, please refer to Annexure – 1 i.e. Hydrology of Upper Ganga). In addition to this, simulated daily flows for Bithoor site (EF 4) are summed up at monthly and annual time steps and are presented in Figure 4.1.

Table 4.2 details some typical flow sequences at each of the E-Flows sites selected within each zone for each calendar month, including the range of base flows, magnitude, number and duration of floods.

The following should be noted with reference to Table 4.2:

- This information was obtained from visual inspection of the simulated time series for each E-Flows site.
- Base flow, i.e. the groundwater contribution to stream flow, has been estimated from modeled stream flows by using the automated SWAT base flow filter.
- Where the number of floods in Table 4.2 is specified as << 1, it implies that in 35 years of record, only a few (less than 10) events have been identified for the particular month. In cases when this value is < 1, the floods in this month occur more frequently, but their total count is less than 30 (e.g. 20-30) in 35 years. If the number of floods is specified as "0", it implies that none or only a few insignificant events in this month were simulated. In monsoonal months, it is difficult to separate events from each other and the approach was to rather identify these events over the entire wet period. In such cases, the range of event numbers is given, which is normally 1-2, implying that there are 1 or 2 large events often spanning through the wet months.

Table 4.2: Typical natural flow characteristics of E-Flows site [flows in m^3/s and durations in days]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
EF1 – Kaudiyala/Rishikesh; area: 20,800 km^2 MAR (nat) = 38,445 MCM**												
Range of Base Flow	123-273	123-294	149-492	164-332	165-414	257-1096	576-4714	1147-5259	785-3253	1305-315	170-457	136 255
No. of Events	0	0	0	0	0	<<1	1	1	0	0	0	0
Range of Peaks	137-602	214-2130	170-1408	198-759	173-3296	477-21180	1983-15070	2268-14020	1694-7556	816-4962	257-1027	166-565
Average of Peaks	327	445	461	339	743	3082	5067	6915	4636	2127	662	299
Main Duration	N/A	N/A	N/A	N/A	N/A	6	6-7	6	N/A	N/A	N/A	N/A
EF2 - Narora; Area: 26,090 km^2 MAR (nat) = 42,608 MCM												
Range of Base Flow	128-314	124-316	153-528	159-384	160-437	242-1064	637-4808	1388-5735	945-3560	383-1474	183-528	141 289
No. of Events	0	0	0	0	0	<<1	<1	1	0	0	0	0
Range of Peaks	158-735	236-1823	166-1417	202-787	169-2727	500-17970	1891-15280	2955-13190	1809-10260	909-6350	290-1564	177-1536
Average of Peaks	366	474	488	354	653	2761	5254	7284	5250	2518	777	349
Main Duration	N/A	N/A	N/A	N/A	N/A	8	8	8-9	N/A	N/A	N/A	N/A
EF3 – Kachla Ghat; Area: 30,030 km^2 MAR (nat) = 42,909 MCM												
Range of Base Flow	134-327	126-318	154-544	150-432	125-388	197-819	464-4181	1450-6169	1124-3938	479-1926	196-689	149-381
No. of Events	0	0	0	0	0		1-2*		0	0	0	0
Range of Peaks	167-663	165-1169	175-1296	197-693	148-1420	387-7640	1508-12330	2534-11700	1799-9728	1090-4295	344-1568	179-695
Average of Peaks	322	391	437	342	461	1775	4473	6510	5245	2651	909	362
Main Duration	N/A	N/A	N/A	N/A	N/A		14-30*		N/A	N/A	N/A	N/A
EF4 – Bithoor Area: 86,950 km^2 MAR (nat) = 57,061 MCM												
Range of Base Flow	143-358	131-334	148-557	123-458	77-506	159-702	559-3804	1652-7222	1590-5658	876-3593	248-1123	161-559
No. of Events	0	0	0	0	0		1-2*		0	0	0	0
Range of Peaks	200-1485	186-1041	212-1325	157-1040	116-1543	329-4032	1584-13220	3809-13560	4164-13170	1336-7946	596-4110	212-883
Average of Peaks	429	436	474	362	460	1677	5282	8663	7687	4811	1675	496
Main Duration	N/A	N/A	N/A	N/A	N/A		15-30*		N/A	N/A	N/A	N/A

Source: Hydrology of upper Ganga (Annexure 1)

**June, July and August are combined together for the sites EF3 and EF4 as it is difficult to estimate some parameters.*

*** Mean Natural Annual Runoff*

4.4.2 Water quality

Water quality is an extremely important influence on the river ecology and biodiversity, as different species have different tolerances to various chemical concentrations, temperature, turbidity, pH and dissolved oxygen levels.

The quality of water in a river primarily reflects the quality and quantity of pollution load it carries. This also depends on factors such as the number of point and non-point sources, the pollution load, and dilution, besides the inherent mechanical and biological processes in the river.

Data availability

Historical
Prior to the construction of the Upper Ganga Canal and Bhimgoda Barrage in the 1850s, the river may be assumed to have been close to its natural state. In the absence of water quality data from this time period, the group made this assumption, for the following reasons:

i. The river was essentially un-modified (no major water storage/diversion projects).
ii. The catchment area did not have any significant industrial and/or agricultural activities (negligible use of synthetic fertilisers/pesticides).
iii. Pollution due to domestic activities including pilgrims/tourists was much lower.

The working group used the limited historical water quality database and their experience to assess overall water quality trends. They also referred to data from:

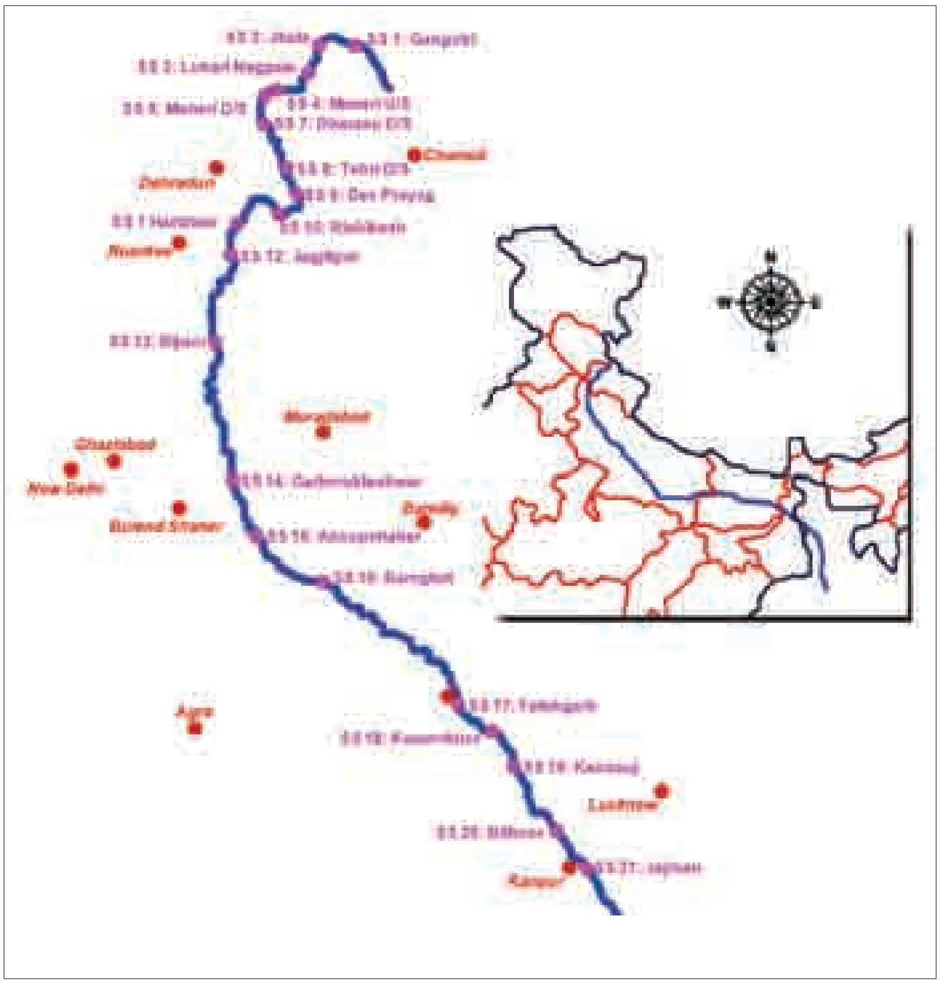
- CPCB,
- Central Water Commission (CWC),
- The National River Conservation Directorate (NRCD),
- The Indian Institute of Toxicological Research (IITR) formerly known as the Industrial Toxicology Research Institute (ITRC),
- The Ministry of Environment and Forests (MoEF),
- The People's Science Institute (PSI), and
- numerous universities and research institutions.

The project team had access to extensive water quality data from 2003 onwards, mainly from the CPCB database for 2003-2004, and from IIT, Kanpur for 2004-09.

Present day
The water quality team took samples at twenty two stations (Figure 4.2) between Gangotri and Kanpur, sampling was done at the chosen sites during the three seasons, i.e. pre monsoon, during monsoon, and post monsoon, from June 2009 to January 2010 in order to get a clear picture of present day water quality trends throughout the year.

The team also collated relevant data on present-day water quality from other available sources.

Figure 4.2: Location of 21 water quality sampling sites



Source: Starter Document – Water Quality (Annexure – 2 D)

Desired future state

A detailed Starter Document for Water Quality (Annexure – 2 D) was prepared, based on the primary and secondary research described above. The desired future state for water quality was estimated for each of the chosen EFA sites.

Table 4.3 is a description of desired water quality conditions and classifications for the EFA sites

Table 4.3: Desired class (as per CPCB standards) for various zones

Zone	Site and class as per CPCB standards	Desired water quality parameters
1. Gangotri to Rishikesh	Kaudiyala Class – 'A'	(i) pH between 6.5 to 8.5, (ii) Dissolved Oxygen (DO) > 6 mg/l, (iii) Biochemical Oxygen Demand (BOD) < 2 mg/l, Total Coliform (TC) < 50 MPN/100 ml
2. Garhmukteshwar to Narora (Reference Zone)	Narora Class – 'B'	(i) pH between 6.5 to 8.5, (ii) Dissolved Oxygen (DO) > 5 mg/l, (iii) Biochemical Oxygen Demand
3. Narora to Farrukhabad	Kachla Ghat Class – 'B'	(i) (BOD) < 3 mg/l, (ii) Total Coliform (TC) < 500 MPN/100 ml
4. Kannauj to Kanpur	Bithoor Class – 'B'	(i) (BOD) < 3 mg/l, (ii) Total Coliform (TC) < 500 MPN/100 ml

Source: Starter Document – Water Quality (Annexure – 2 D)

Choice of indicators

The water quality group analysed the following parameters in samples collected from the locations shown in figure 4.2 along the Upper Ganga from Gangotri to Kanpur:

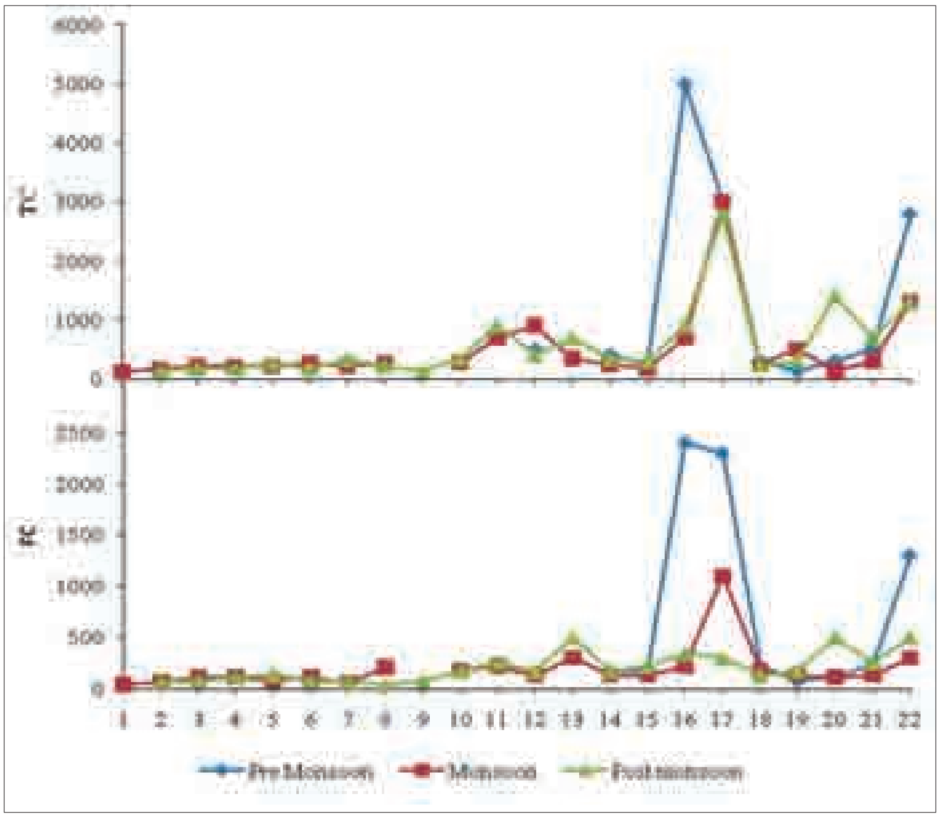
- Temperature;
- Total Suspended Solids (TSS) in settled/unsettled water, and colour (apparent and true);
- Salinity in terms of Total Dissolved Solids (TDS), pH and alkalinity;
- Dissolved Oxygen (DO) and diurnal variation in DO;
- Biological Oxygen Demand (BOD)and Chemical Oxygen Demand (COD);
- Faecal coliforms (FC)and total coliforms (TC), and bacteriophages;
- Heavy metal contamination, including mercury, nickel, cadmium, copper, cobalt, silver, etc. as well as radioactivity levels;
- Biodiversity and biological indices of pollution;
- Pesticides;
- Fertilisers;
- Chlorides, sulphates and sulphides, and
- Nutrient levels (in terms of ammoniacal and total Kjeldahl nitrogen, nitrates and phosphates).

Results and analysis

The standards prescribed by the Central Pollution Control Board (CPCB) were adhered to when classifying the river stretches (Annexure – 2 D).

Faecal contamination was found in the entire stretch of the river studied, from Gangotri to Jajmau, Kanpur, with the most serious faecal contamination occurring in the stretch downstream of Narora to Jajmau, Kanpur. This is illustrated in Figure 4.3.

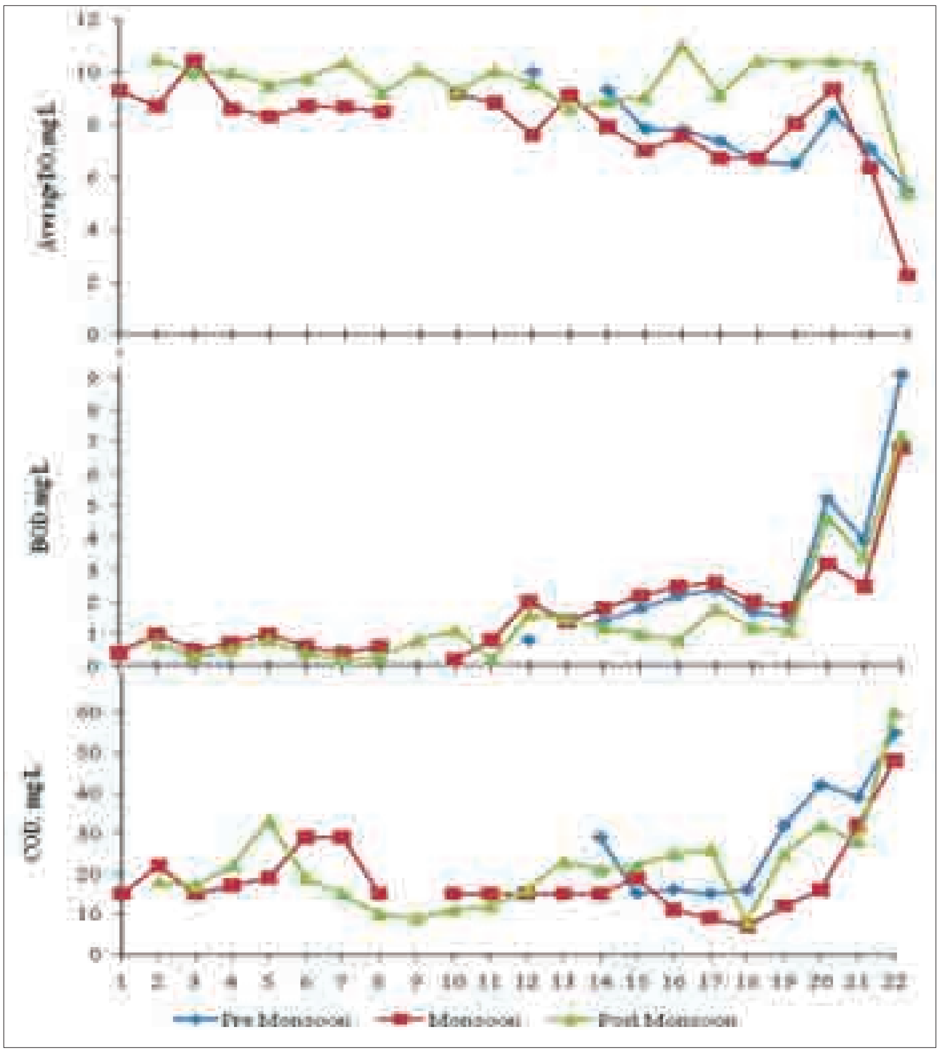
Figure 4.3: Total Coliform and Faecal Coliform status at twenty-two sampling stations from Gangotri to Kanpur



Note 1: *All values in MPN/100 ml*
Note 2: *The values on X-axis represent sampling stations, as depicted in Figure 4.2.*
Source: Starter Document – Water Quality (Annexure – 2 D)

Figure 4.4 shows the variation in DO, BOD and COD across sampling sites.

Figure 4.4: The Dissolved Oxygen, Biological Oxygen Demand, and Chemical Oxygen Demand status at twenty-two sampling stations from Gangotri to Kanpur



Note 1: *All values in MPN/100 ml*
Note 2: *The values on X-axis represent sampling stations, as depicted in Figure 4.2.*
Source: Starter Document – Water Quality (Annexure – 2 D)

The values of various water quality parameters seem to be greatly dependent on the pollutant loads the river received.

Although an extensive database of historical water quality was available for analysis, it was not possible to link the water quality data to specific flows, because of the unavailability of hydrological records. The team was therefore forced to use professional judgement to assess the effects of different flows on water quality, and to determine whether the E-Flows recommended by other specialist teams would result in acceptable water quality concentrations.

The group felt that the deviation of river water quality from natural/pristine conditions was essentially due to the pollution loads from point and non-point (dispersed) pollution sources, but estimating flows required to maintain acceptable water quality based on neutralising these pollution loads would violate the principle that "dilution is no solution to pollution". Therefore, the water quality group did not specifically make E-Flows recommendations from a water quality perspective. However, the group participated in the E-Flows discussions, and was of the considered opinion that the E-Flows recommended by other groups would help in improving the assimilative capacity of the river.

4.4.3 Fluvial geomorphology

Background

Fluvial geomorphology plays an important role in assessing the sustainable flows through an understanding of the processes controlling the channel size, shape and form. The most important process is that of sediment transport and its deposition under different flows, as it controls the types of substrate and therefore, the habitat template for each section of river. Flows and sediment availability also control the distribution of different geomorphic units within the channel (e.g. islands, bars), the floodplains and their wetlands which provide a further diversity of habitats through time and space.

Modifications of the flow regime results in a change in the sediment transport dynamics, leading to channel changes in the long term.

Data availability

Although the river Ganga has been modified by humans for many centuries, there are few historical geomorphological records of the changes to the channel and floodplain of the river. It is therefore difficult to define a reference condition as a benchmark against which the present changes to the river geomorphology can be measured.

The earliest data available for the present study came from the 1955 topographic maps, which provide general geographical information, such as channel size, the shape and quantity of major in-stream features and the extent of the active floodplain, but with little possibility of interpreting the geomorphological changes taking place. The geomorphology group therefore used available information to develop reference conditions and determine the geomorphic classes that would provide habitats suitable to maintain the present day biodiversity.

Choice of indicators

The river reaches were first classified according to their differing gradients. Typically, steep cascading reaches were distinguished from step/pool channels, channels that exhibit riffle/pool sequences in high gradient reaches, slow moving and braided reaches (which have less clearly defined riffles and pools) and may even exhibit ripple-dune bed features in low gradient reaches.

Study method

The geomorphological characteristics (lateral connectivity, bank stability, channel sinuosity, hydraulic radius, riparian vegetation, riffle pool sequence, channel shifting, etc.) which are important for supporting biota in a river, were evaluated in terms of four classes (A to D).

The group used GIS-based applications to develop descriptions of different reaches according to the above characteristics, including DEM, Linear Imaging Self Scanning (LISS) III and LISS IV images from the National Remote Sensing Centre (NRSC).

The group undertook a comparison of the river from the 1950s (or from the 1980s or 1990s in cases where no earlier information was available) to 2010, in order to understand bank stability and the variability of geomorphic features.

Bank stability is a measure of actual or potential river bank erosion. Extensive erosion of the river banks indicates a problem of sediment movement and deposition, and suggests a scarcity of cover and sediment input to the rivers. Steep banks are considered unstable as these are more likely to collapse and suffer from erosion than are gently sloping banks.

The detailed analysis of all the geomorphic characteristic at each sites is described in the Starter Document for Fluvial Geomorphology in Annexure - 2 A.

Geomorphic analysis of the parameters mentioned above was carried out to assess the habitat suitability in different reaches of the river.

At the Kaudiyala site in Zone 1, the river has a very sharp bend with gravels and boulders on the concave side, with the river flow hugging the road along its right bank. The width of the river at this point is about 100 m. The river is bound on both sides by high mountains, and the dominant sediments carried by the river at this site are gravels. In the reach between Kaudiyala and Marine Drive (downstream of Kaudiyala), large boulders are common along both banks, suggesting that rock slides are frequent in this area. An attempt was made to understand the temporal variation over the last 20 years, and it was found that the channel position has not shifted much over this period of time, due to its confinement between the hills.

The river channel belt at the Kachla Ghat site in Zone 3 is very wide (>3 km) but the water is confined to only about 20 m and the water depth is <1.5 m during the dry season. The maps and satellite images clearly show that the river is anabranched and braided in this reach. Two distinct channels are clearly visible, which eventually join further downstream, although the river was a single channel in 1995. Both banks of the river are quite flat and gradually merge with the floodplain. No sign of any incision is visible on either bank. The dominant channel sediments are fine sand with significant amounts of silt. The channel has aggraded significantly in the reaches upstream and downstream of Kachla Ghat.

The active channel belt at Bithoor presently follows the southern valley margin and has extensive floodplain areas within the valley. Floodplain areas north of the Ganga include abandoned channels, meander scars and ox-bow lakes, together with a few small lakes and waterlogged areas. A very large, conspicuous meander scar is cut off from the present channel but is periodically flooded. The southern valley margin is strongly incised and prominent cliffs up to 15 m high extend in a south-easterly direction for nearly 2 km. The river is multi-channel and large bars within the channel divide the flow. There have been significant changes in the channel in the last 50 years: the active channel has reduced specifically in the downstream of Bithoor. Most of the channel belt area in 1995 merged with the floodplain in 2009.

The absence of any hydrologic data at the sites limited the interpretation of the geomorphic parameters in terms of flow characteristics.

4.4.4 Biodiversity

Background

The aquatic biota in Himalayan glacier-fed rivers has adapted to annual flow pulses, which vary from a gradual increase in discharge in summer, through floods in the monsoon period, and reduce to low flows in winter. During the dry season, the waters become clear, allowing algae (primarily diatoms) to obtain necessary light and carbon dioxide for photosynthesis.

Data availability

Singh (1988) sampled the biota at Marine Drive (nearly 14 km downstream of Kaudiyala and 9 km upstream of Shivpuri). During that study, samples were taken at Devprayag, Marine Drive and Rishikesh. Later, Nautiyal (1997) sampled at Rishikesh and in the downstream sections till Haridwar.

Other studies of the Upper Ganga biota that were referenced by the biodiversity group included: Anderson (1878), Schnapp and Adloff (1986),Sinnerker et. al. (1987) (Haridwar to Kanpur), Perrin and Brownell, 1987, Mohan, 1989, Rao, et al., 1995, and Smith et al., 1994.

In the stretch from Rishikesh to Kanpur, a detailed bio-monitoring study to assess the species biodiversity and habitat was conducted from 1991 to 1994 by Dr. R. J. Rao (Jiwaji University). This study was used extensively for defining the reference condition by the group engaged in investigations for higher vertebrates.

Choice of indicators

Two criteria were used for the selection of indicator species:

a. Species which are sensitive to flow conditions, e.g. species of achnanthidium (diatoms) which indicate good flow conditions;
b. Flagship species, which are iconic and often endangered, like dolphin, gharial, otter, etc.

Groups from which these indicators were selected included phytobenthos (including algae and diatoms); phytoplankton and zooplankton; benthic macro-invertebrates; fish; mammals such as the Indo-Gangetic dolphin and otters, and reptiles such as the gharial and mugger crocodiles and turtles. Riparian and floodplain vegetation types were used as indicators for high flow requirements.

Study method

Sampling was carried out during each of the following flow regime periods.
a. Lean flow, from November to February/March
b. Enhanced flow, due to melting of glacier and snow – April to June
c. Flood flow, due to rainfall and glacial melt – July to October

Sampling was undertaken during the pre-monsoon (May 2009), monsoon (September 2009) and post-monsoon (December 2009) seasons to ascertain the variation and changes throughout the year, if any, in the aquatic flora and fauna.

The team sampled at Kaudiyala and Rishikesh in Zone 1, as well as at Devprayag in summer. Sampling was done for aquatic flora including phytoplankton and benthic diatoms, fauna including zooplankton, benthic micro-invertebrates, and nekton, and observations were made of dolphin, crocodile, turtle and otter.

Results, analysis and interpretation

The flora and fauna of Himalayan streams and rivers is highly specialised, having evolved over millennia of evolutionary processes, and is therefore also very fragile in the face of disturbances.

From the downstream reaches (Haridwar to Kanpur), Sinnerker et. al. (1987) concluded that, with the increased utilisation of water resources for development projects, the water quality in the Ganga River had deteriorated considerably. This view was echoed by Jones (1982), who ascribed the deterioration to both the high population density and natural disasters.

Barrages on the rivers have an impact on the habitats of all aquatic animals (Rao, et al., 1993). Schnapp and Adloff (1986) and Smith et al. (1994) reported that due to the construction of barrages in the upper reaches of the river systems, local populations have been cut off from the continuous distribution range and new immigrants are blocked from mixing with upstream and downstream populations, ultimately resulting in the extinction of the isolated populations. Other threats include fishing, hunting and pollution (Perrin and Brownell, 1987; Mohan, 1989; Smith et al., 1994).

Anderson (1878) also concluded that insufficiency of flow is one of the factors for restricted distribution of dolphins. Historical distributions indicate that dolphins were present at Balawali, 50 km downstream of Haridwar, but during the present study, no dolphins were sighted there. Mortality in fishing nets would have contributed to the decline of dolphins, since large scale fishing activities were located here.

The river reaches around Kaudiyala are largely natural with few modifications. About 30 fish species were found from Devprayag to Rishikesh, including 20 carp species, 3 species of catfish, etc. There has been appreciable decline in richness within the benthic macro-invertebrate community at the Devprayag-Rishikesh stretch. In this stretch, there used to be 20 taxa but now this number has reduced to 9. There has also been a general decline in mahseer catch.

Around Kachla Ghat, it has been found that, herbs dominate the riparian vegetation in the summer, herbs-shrubs in the monsoon and shrubs in the winter. The annual composition consists of 4 macrophytes, 10 grasses, 33 herbs, 23 shrubs and 18 trees. In the fish community, the ratio of carp: catfish: others is 8:7:14, the carp species number being lower than expected, and lower than at Narora.

At Bithoor site, about 31 fish species were observed, including 12 carp and 7 catfish species. Eleven of these species were also found in the upper zone, with the additional species generally being small-sized, bottom and water-column feeders. Amongst the riparian vegetation, herbs dominate in the summer and monsoon, and shrubs in the winter. The annual composition consists of 3 macrophytes, 10 grasses, 25 herbs, 20 shrubs and 16 trees.

In the area between Rishikesh and Kanpur, dolphins were restricted to the river between Bijnor and Narora barrages, (a stretch of approximately 165 km). Between these two barrages, the population density is greatest at Brij ghat. Upstream of Brij ghat, the Ramganga feeder canal originating from the Kalagarh dam on Ramganga River feeds the main Ganga at Tigri ghat. The habitat is suitable for dolphins here, due to the high volume of water, whereas upstream of Bijnor barrage, the volume of water is very low: Ganga water is diverted from Rishikesh and Haridwar barrages for hydropower production at Chilla and for irrigation at Bhimgoda, respectively, making the river very shallow and unsuitable for dolphins.

The planned and completed hydropower projects will impact aquatic biodiversity, especially in the stretch from Gangotri to Haridwar, as water is diverted through tunnels for kilometres, resulting in a dry stretch of river in which habitats are severely impacted, and which form barriers to the up- and downstream movement of aquatic fauna. Downstream of Haridwar, most of the dry season flow is diverted to irrigation canals.

Impoundments are also barriers which modify the natural flow of a river, and in the case of hydropower generation, the flow patterns change to conform to peak electricity demand.

4.4.5 Livelihoods

Background

Since time immemorial, the livelihoods of people residing in and around the banks of the Upper Ganga are directly or indirectly dependent on the river and its resources, be it for cultural tourism, pilgrimage activities, ferrying, fishing, agriculture, or adventure. In this EFA initiative, the working group concentrated on subsistence livelihoods that are directly dependent on the flow conditions and water quality of the river, rather than large scale commercial ones, such as industry.

Study method

Initially, livelihood activities, their economic and social significance were mapped, after which investigations were undertaken to identify past and emerging trends, and to assess the impact of the deteriorating water quantity and quality of the river Ganga on livelihoods. Efforts were also made to understand the social and economic impact of diminishing flows and any shift from past livelihood activity toward other new activities.

Detailed structured questionnaires were developed. Discussions with the respondents and interactions with elderly residents in the riparian communities also helped in mapping the evolution of livelihoods.

The group had detailed discussions with about 600 individuals which mainly included religious tourists, tour operators, and local fishermen, priests and shopkeepers. Their insights were very useful in understanding the present scenario. The key indicators used were –

- changing patterns or modification of livelihood practices;
- introduction of new livelihoods;

- decline in any specific livelihood activity, and
- flow requirements for adequate sustainability of livelihood activities.

Analysis

Based on the literature review and corroboration through preliminary field surveys, it was concluded that:

- Zone 1 – Rishikesh and Haridwar predominantly support livelihoods related to culture, religion and entertainment. Over the past decade, adventure tourism has also developed in this region, especially upstream of Rishikesh.

- Zone 3– Kachla Ghat and settlements around this area: Significant livelihood activities include fishery and riverbed farming. Both fishery and ferrying are suffering due to diminishing flow levels and in some cases, this is prompting people in local communities to explore other professions.

- Zone 4 – Bithoor and nearby area: Key livelihood activities include cultural-religious activities and riverbed farming. In this area, the problem of reduced flows has been compounded by deteriorating water quality, leading to a reduction in cultural and religious activities.

4.4.6 Cultural and spiritual aspects

Background

The river Ganga has an immense vitality in the mythology of the country. There are numerous anecdotes about its origin and its interfaces with society. According to legend, the river was created by Bhagirath, to wash away the sins of his forefathers. Ever since, the societal belief is that one’s sins are washed away by taking a holy bath in the river: People across the length and breadth of the country visit the river for this purpose. Not only Indians but many foreigners fulfill their spiritual and salvation aspirations by visiting the river, especially at Rishikesh, Haridwar, Varanasi and other cities. Some of them visit for months, whilst some of them have even permanently settled in these towns.

The cultural and spiritual significance of the river Ganga is unquestionable and the faith of people in the river Ganga is unshakable. Often, ‘culture’ ‘religion’ and ‘spirituality’ are considered as interchangeable terms, whereas religion is only one aspect of culture. For the purposes of this study, culture is used in the broader sense of ‘civilisation’, and includes spirituality, literature, art and crafts among others.

Riparian communities feel linked to the river, and derive a sense of identity from it. These communities depend on the continued existence of ‘their’ river, and any threat to the river is perceived to be a threat to the communities’ cultural heritage. At the same time, the Ganga is considered to be the ‘Holy River’ by all Indians, and it therefore has a much broader cultural significance which affects the whole nation.

Cultural and spiritual activities and practices have greatly influenced the local economy in many ways – the influx of pilgrims adds on to the local economy and uplifts the living standard of local people.

Data availability

There is ample data and information available to understand the historical perspective of cultural and spiritual significance of the river Ganga. Notable among them are – 'Skanda Purana' which lists terminologies that describe the river; and the 'Ganga Namawali' which includes names that are evocative of the physical status of the river Ganga. These encompass the appearance of the river Ganga, the sound it makes, and the force with which it flows. Table 4.4 lists many of these Sanskrit names, together with their English meaning.

Table 4.4: Sanskrit names of Ganga with meaning in English

Name in Sanskrit	Meaning in English
Sughosa	Noisy
Ksira-shubra	White as milk
Bahu-ksira	Giving much milk
Dhavalambara	Having a dazzling white garment
Nayananda-dayini	Affording delight to the eyes
Niranjana	Colourless
Nitya-suddha	Eternally pure
Nira-jal-pariskrta	Adorned with a net of water
Sagarambhusa-medhini	Swelling the waters of the ocean
Amritkara-salila	Whose water is a mine of nectar
Lila-lamghita-parvata	Leaping over the mountains in sport
Sankha-dundubhi-nisvana	Making a noise like a conch shell and rum
Sighra-ga	Swift-flowing
Saphari-purna	Full of fish
Krida-kallola-karini	Sportively billowing
Japa	Whispering
Jangama	Moving, alive
Jangamadhara	Support of what lived

Source: Starter Document: Cultural and Spiritual aspects by PSI – Dehradun (Annexure 2 E)

In order to understand the significance of the river Ganga, mythological literature was referred to. Interactions with elderly citizens, saints and local priests were also very fruitful in order to compare past and present cultural and spiritual aspects. One such respondent pointed out during the interview that, "*Aadikaal se ganga-jal swarg ke dwar kholta hai, thoda sa jal ghar mein rakhney se hi, kalyan hota hai. Toh sakshat Ganga darshan ka labh toh aap samajh hi saktey hai.*" (Since time immemorial, the Ganga's water opens the gates of heaven. A little bit of water kept at home washes one of all sins. So just imagine what the soul receives when it views the Ganga in its entirety.) There is a rich history of generations after generations visiting the river Ganga to practice their cultural activities and customs.

Table 4.5 provides comments on flow from 'The Garhwal Gazetteer' which in 1910[14] described the catchment through which the Ganga flows, describing the Ganga in detail and with the use of many superlatives.

[14] Walton, H. (1910). *British Garhwal, volume XXXVI of the District Gazetteers of the United Provinces of Agra and Oudh*. New Delhi: Indus Publishing Company

Table 4.5: Comments on the flow of the Ganga in 1910 from the Garhwal Gazetteer

Zone 1: Gangotri to Rishikesh	At Gangotri: 'an infant stream, 27 feet broad and 15 inches deep (8.22 m broad and 0.4 m deep). For the first 180 miles (290 km) of its course, it is a 'snow-fed mountain torrent, rapidly developing into a river of broad shoals, long deep pools and occasional rapids'.
Zones 2, 3, 4: Rishikesh to Kanpur	For the next 1000 miles (1609 km), the Ganga is a broad shining river, flowing in easy channels through a flat landscape. The flood discharge amounts to a million and a half cubic feet per second (42,475 cumecs).

Source: Starter Document: Cultural and Spiritual aspects by PSI – Dehradun (Annexure 2 E)

However, although the flow is obviously an essential element of the cultural and spiritual importance of the Ganga, the assessment of flow requirements from this perspective is a totally new concept, and there is no past literature dealing with this specific issue.

Choice of indicators

The key indicators for flow requirements from the cultural and spiritual perspectives were the perceptions of pilgrims in terms of flow and water quality requirements for the satisfactory fulfillment of holy bathing, worship (for instance, *aachman*, a religious activity, in which pilgrims dip their right hand in the river, carry some water on the palm and drink it), carrying of Ganga water back home, *aarti* (a regular religious ritual, done at the bank of river during sun-rise and sun-set), etc.

Study method

The assessment was carried out by interviewing people at the river sites, to find out whether they felt that conditions in the river were conducive to cultural/spiritual activities, or if they felt that low flows and deteriorating water quality were significantly reducing the potential of the river for these activities. The selected criteria included an analysis of the perceptions of different stakeholders both amongst residents, including local shopkeepers, priests, etc. and amongst visitors including saints, tourists, pilgrims, etc. The specialist report (Annexure – 2 E) describes the outcome of these stakeholder meetings and discussions.

Results, analysis and interpretation

The flow requirements defined by respondents were often expressed in terms of depth at the banks, and also in terms of the depths and width of the channel. The rated hydraulic cross-sections surveyed at each site were then be used to convert such required depths and widths into flow requirements.

Respondents accepted that the flows in the river do show seasonal variation. The duration of flows and the importance of flow variation were often mentioned by the interviewees. Of those interviewed, 114 required waist-deep water at the *ghat* steps, while a further 54 wanted water above the waist. Some responses, such as people requiring 3 m of water at the river edges, can be interpreted as a deep-rooted desire for a bountiful river.

The surveys repeatedly brought out the inter-connectedness of all elements of the river ecosystem. Culture – the living of life with dignity and pleasure – is affected not only by the quantity of water available for rituals, but also by the quality of water, and other riverine biota.

The analytical part of this exercise was challenging as the majority of respondents found it difficult to comprehend the concept of quantified flows. Therefore, for the working group, it became imperative to translate the statements made by respondents for fulfillment of cultural and spiritual activities into figures related to flow requirements. Attention was also given to include diverse voices of boatmen, adventure enthusiasts etc, even where they were in the minority, ensuring a balanced understanding of the issue and recognising and articulating divergent voices.

Ultimately, the perennial nature of the river was important to all the respondents. Most people found the idea of Ganga as a seasonal river impossible to comprehend. They believed that if the Ganga would cease to flow, the world would end.

4.5 ZONE 1: GANGOTRI TO RISHIKESH (SITE: KAUDIYALA)

4.5.1 Hydraulics

The hydraulics group surveyed cross sections at Kaudiyala where the E-Flows assessment was to be done.

Figure 4.5 is a Google image of the Zone 1 sampling site at Kaudiyala, showing the locations of the hydraulic cross sections.

Figure 4.5: Google image of the Zone 1 sampling site at Kaudiyala site showing cross-section locations

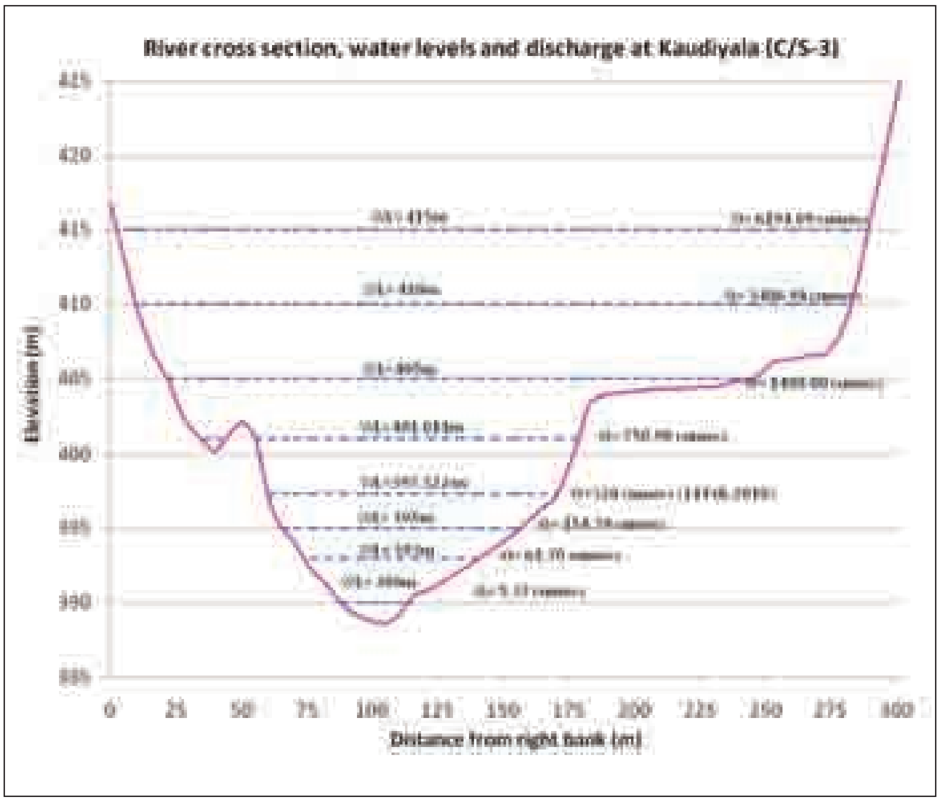
Source: Hydraulics Report (Annexure 3)

Table 4.6 provides details of cross section 3, (CS/3) whilst Figure 4.6 depicts the cross section itself.

Table 4.6: Details of Cross Section 3 at the Zone 1 sampling site at Kaudiyala

Location:	Kaudiyala (C/S-3)
Date of Monitoring:	14-02-2010
Time of Monitoring:	2.00 PM to 5.30 PM
Discharge:	305 Cumecs
Water level:	397.32 m
Substratum:	Mix (Debris, gravel, boulders, etc)

Figure 4.6: Cross Section 3 at Zone 1 Kaudiyala site



Source: Hydraulics Report (Annexure 3)

4.5.2 Fluvial geomorphology

Present state

The river bends sharply at Kaudiyala, with gravels and boulders on the concave side and the river flow hugging the road along its right bank. The width of the river is about 100 m, while the valley width exceeds 600 m. The river is bound on both sides by high mountains and the dominant sediments carried by the river at this site are gravels. Figure 4.7 is a photograph depicting general morphological features around Kaudiyala site, showing that the channel is quite narrow at this location with the development of large bars both at the sides and in the middle of the channel.

Figure 4.7: Morphological features near Kaudiyala (December 2009)

Source: Starter Document Fluvial Geomorphology (Annexure 2 A)

Temporal variation
The changes in the position and characteristics of the channel from 1990 to 2007 were studied, and it was concluded[15] that the channel position has not shifted much through the years, due to its confinement between the hills. The analysis also shows that there is no change in sinuosity[16] and the channel thalweg[17] has shifted very little as compared to its width; in other words, there has been no significant change in terms of river morphology.

Land use/Land cover
In mountainous regions, a land use/land cover (LU/LC) map provides an understanding of the materials transferred from the hills during landslides and other means as well as indicating the sources of sediment supply. The features identified as important parameters in terms of the LU/LC layer were running water, dense vegetation, medium vegetation, sparse vegetation, non-vegetated areas and built up lands.

Habitat Suitability Index
From the perspective of the Habitat Suitability Index[18], the group concluded that most of the reaches of the Upper Ganga around Kaudiyala are in EM Class B (shown in green in Figure 4.8) and Class C (shown in blue), indicating slight (Class B) and moderate (Class C) modifications due to anthropogenic causes. The classification system is described in detail in Chapter 2.

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[15] Please refer Annexure – 2 A (Starter Document from Fluvial Geomorphology group).
[16] Sinuosity: Referring to the degree of curvature and bends in a river channel.
[17] Channel Thalweg: Refers to the deepest continuous section within a valley or watercourse system.
[18] Habitat Suitability Index: An index which measures the suitability of habitat

Figure 4.8: Habitat suitability classes around Kaudiyala site

Where:
Yellow indicates Class A
Green indicates Class B
Blue indicates Class C

Source: Starter Document Fluvial Geomorphology (Annexure 2 A)

Desired future state

The fluvial geomorphology group concluded that the desired future state for the Kaudiyala site is Class B

As present conditions indicate Class B/C for the Kaudiyala site, it is preferable that no further human interventions take place, in order to maintain (or improve) these conditions. The geomorphic characteristics which require improvement in order to increase the habitat suitability in these reaches are longitudinal connectivity, width to depth ratio, hydraulic radius, lateral connectivity, and geomorphic complexity in terms of riffles and pools.

The group concluded that an increase in flow depth of 2.5 to 4 m may be required to raise the geomorphic class of this segment from Class C to Class B. This will also increase the depth of the pools and hence, the hydraulic radius. The width to depth ratio will also decrease.

4.5.3 Water quality

Present state

Based on the limited BOD, COD, DO, and Coliforms from CPCB, data available, together with some scattered investigations, the present state was assessed as Class A/B (very slightly modified from natural conditions), with reference to CPCB water quality standards.

Desired future state

The water quality group concluded that the desired future state for this site is Class A, requiring the following conditions:

i) TSS and TDS varying from low to moderate seasonally
ii) No colour
iii) Very low BOD/COD and coliforms
iv) High DO levels
v) Absence/very low levels of nutrients to cause any significant photosynthetic and/or heterotrophic microbial activity

4.5.4 Biodiversity

Present state

The stretch between Gangotri and Rishikesh shows three flow regimes:

a) Lean flow from November to February/March
b) Enhanced flow due to melting of glacier and snow – April to June
c) Flood flow due to rainfall and glacial melt – July to October

The river has been modified for hydropower development projects at Maneri Bhali Phases I and II, and Tehri and Rishikesh several other hydropower projects are under various stages of construction. Downstream of Maneri Bhali Phases I and II, at least 30 km of river (from Maneri to Dahrasu) is deprived of flow (due to diversion of water into tunnels).

A 40 km stretch of the river between Dharasu and Tehri has been regulated by the construction of Tehri Dam. Additionally, the major towns in this zone dispose off their municipal waste into the river.

The discharge in the main river depends on the flow from the Alaknanda River which joins the Bhagirathi River at Devprayag and which has been similarly modified and impacted. Both rivers lie along major pilgrim routes and all *prayags*, in addition to Gangotri and Badrinath witness recreational bathing.

The present state of the biodiversity at Kaudiyala was determined to be Class D/E (extensive to critical loss of habitats, biota and basic ecosystem functions), because the food web has been modified due to the loss of habitat caused by human interventions, such as impoundments and diversions for multi-purpose river valley projects (e.g. hydropower projects).

Micro-habitat diversity
The following species were observed during the biodiversity surveys at Kaudiyala.

- Benthic flora: Diatoms (220-250 species and varieties)
- Phytobenthos:
  - Devprayag *Cymbella* and *Navicula* at 30 cm depth;
  - Kaudiyala *Cymbella* and *Navicula* at all depths and additionally *Gomphonema* at 60 cm depth;
  - Rishikesh *Cymbella* and *Navicula* at 15 and 60 cm depth while *Cymbella*, *Navicula* and *Gomphonema* at 30 cm depth Abundance & Assemblages: A. *bisolettianum* var. *bisolettianum, A. minutissimum* var. *minutissimum,* at all depths of these 3 stations.
- Benthic Macro-invertebrate Community:
  - Density: 110 individuals/m^{-2} at 15 and 22 individuals/m^{-2} at 30 cm depth.
  - Percentage composition: Diptera 80%, Odonata 20%
- Fish species:
  - 21 fish species, with Snow trout (*Schizothorax richardsonii* and *S. plagiastomous*) and *mahseer* (*Tor putitora*) the most abundant and representative species for this zone because they occur in all seasons.
  - Carp: Catfish: Other ratio = 18:2:1
  - Summer: 6 species
  - Monsoon: 8 species
  - Winter: 21 species

- Riparian vegetation:
  - Summer: 25; 4 grass, 10 herbs, 8 shrubs, and 3 trees.
  - Monsoon: 34; 3 grass, 16 herbs, 7 shrubs and 8 trees. Grass Cyanodon dominant
  - Winter: 55; 1 macrophyte, 8 grasses, 13 herbs, 22 shrubs and 11 trees. Grass *Cyanodon* dominant.
- Herbs were the dominant form at this station, except during winter, Only 1 macrophyte, *Phragmites*, was observed only during the winter season. The abundant forms in this season were *Cyanodon, Polygonum, Saccharum* and *Equisetum*.

Desired future state

The desired future state for biodiversity at Kaudiyala was determined to be Class C (moderately modified), in order to improve the availability of suitable habitat conditions for indicator species representing fish, benthic flora and fauna, and riparian vegetation.

This improvement in EMC would require alternate riffles and pools for development of habitats and food webs for different trophic levels. The riffles are also required for benthic flora and fauna which provide the food for *mahseer* and other species. Backwaters and marginal habitats are essential for successful breeding/spawning of hill-stream fish.

In order to provide depth requirements for *mahseer,* pools deeper than 2 m are required. A river width of approximately 50-100 m is suitable for *mahseer*. About 30-50 per cent of the riparian zone has to be flooded during summer (March to June).

4.5.5 Livelihoods

Present state

The present state with regard to livelihood indicators at Kaudiyala was assessed as Class C, moderately modified due to anthropogenic activities.

Flows around this site are generally required in terms of cultural tourism, entertainment (water sports/adventure) tourism, ferry and fishery. The existing flows are sufficient to carry out sustainable livelihood practices, but if flows are further reduced, there will be negative returns to the users of resources.

Desired future state

The livelihoods group, while suggesting Class B as desired future class, concluded that the E-Flows of the river Ganga around this site should provide sufficient resources to meet the sustainable livelihood practices.

4.5.6 Cultural and spiritual

Present state

The present state with regard to cultural and spiritual indicators is Class B (slightly modified). The places around/near Kaudiyala, including Rishikesh and Haridwar, are of immense cultural and spiritual significance, and the emotions of the population are so powerful that they attach their lifetime memories to the river and to these places. Therefore, the cultural and spiritual group focused more on Rishikesh and Haridwar than on Kaudiyala itself.

The visiting pilgrims and local people have the greatest respect for the river; this is evident from one of the statements made by a respondent,*"Duniya mein do hi cheezen hai. Suraj devta aur Ganga maiya. Pratyaksha cheez toh Ganga maiya hi hai.* (There are only two things in this world – the sun and mother Ganga. And of these, mother Ganga is the only one we can touch.) The current flow conditions in terms of cultural and spiritual aspects are tabulated in Table 4.7.

Table 4.7: Current flow conditions in terms of cultural and spiritual aspects

Parameter	Low flows	Monsoon flows	Winter flows
Depth at banks	River bed exposed at the *ghats*	Water reaches the first platform (2 m above the bed)	Water touches the bottom step of the *ghats*
Depth in central channel	Boulders exposed with sandbank near the bridge	Deep water (corresponding with level at banks)	Some boulders exposed
Width	Approximately 1 m away from bottom step	Up to the top of the first platform	As demarcated by the *ghats*

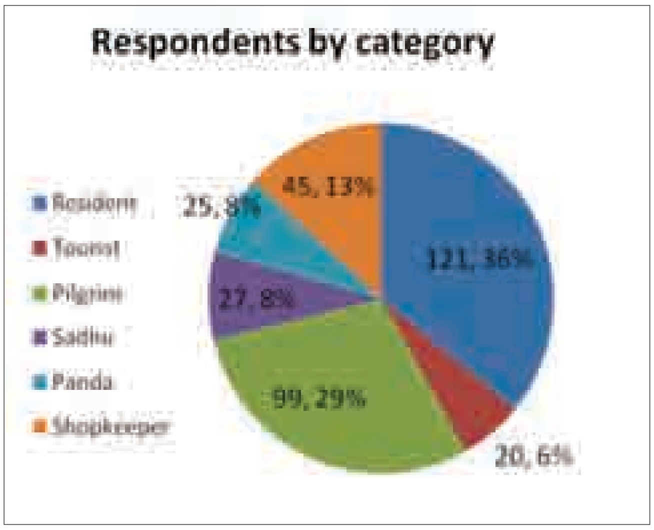
Source: Starter Document: Cultural and Spiritual aspects by PSI – Dehradun (Annexure 2 E)

Desired future state

Rather than classifying the desired future state of this site as a specific class, the group provided descriptions of the desired flow conditions for all the seasons.

The group held extensive field surveys and discussed issues using structured questionnaires with approximately 265 respondents representing a series of stakeholders including the local priests, pilgrims, residents, saints, shopkeepers, etc. Additionally, the group also held focus group discussions with various stakeholders to understand their aspirations which were then translated into desired width, depth and velocity for various conditions/seasons. These parameters are summarised in Figure 4.9 and Table 4.8.

Figure 4.9: Cultural and spiritual survey respondents by category



Source: Starter Document for Cultural and Spiritual aspects (Annexure- 2 E)

Table 4.8: Flow conditions at Rishikesh required for cultural and spiritual activities

Parameter	Condition
Low flow conditions at Rishikesh (summer flows)	
Width	Touching the bottom steps of *ghats*
Depth	Approx 0.5 m at the bottom step of the *ghats*
Velocity	Current velocity is adequate
High flow conditions at Rishikesh (monsoon flows)	
Width	At the top of the *ghats*, i.e. approximately 5 m above current winter levels
Depth	NA[19]
Velocity	Current velocity is adequate
High flow conditions at Rishikesh (winter flows)	
Width	Up to the first platform, or approximately 1.5 m above current winter flow
Depth	Not less than 1 m at the bottom step of the *ghats*
Velocity	Current velocity is adequate

Source: Starter Document for Cultural and Spiritual aspects (Annexure-2 E)

4.6 ZONE 2 (REFERENCE ZONE): UPSTREAM OF GARHMUKTESHWAR TO NARORA (SITE: UPSTREAM OF NARORA BARRAGE)

The demonstration site, upstream of Narora barrage is located approximately 150 km away from the national capital, Delhi. The River Ganga at this site has experienced large human interventions. The barrage at Narora was constructed around 1878; however, its modernisation took place during 1982. The stretch downstream of the Narora barrage is highly braided with a very narrow channel. The depth of the water is approximately 7-10 m in the reaches upstream of Narora barrage where an artificial ponding has been created due to the barrage.

4.6.1 Hydraulics

The hydraulics group took three cross sections at Narora. Figure 4.10 is a Google image of the reference zone sampling site at Narora, showing the locations of the hydraulic cross sections

Table 4.9 provides details of Cross Section 3 (C/S-Central), whilst Figure 4.11 depicts the cross section itself.

[19] Depth is critical and width is secondary parameter.

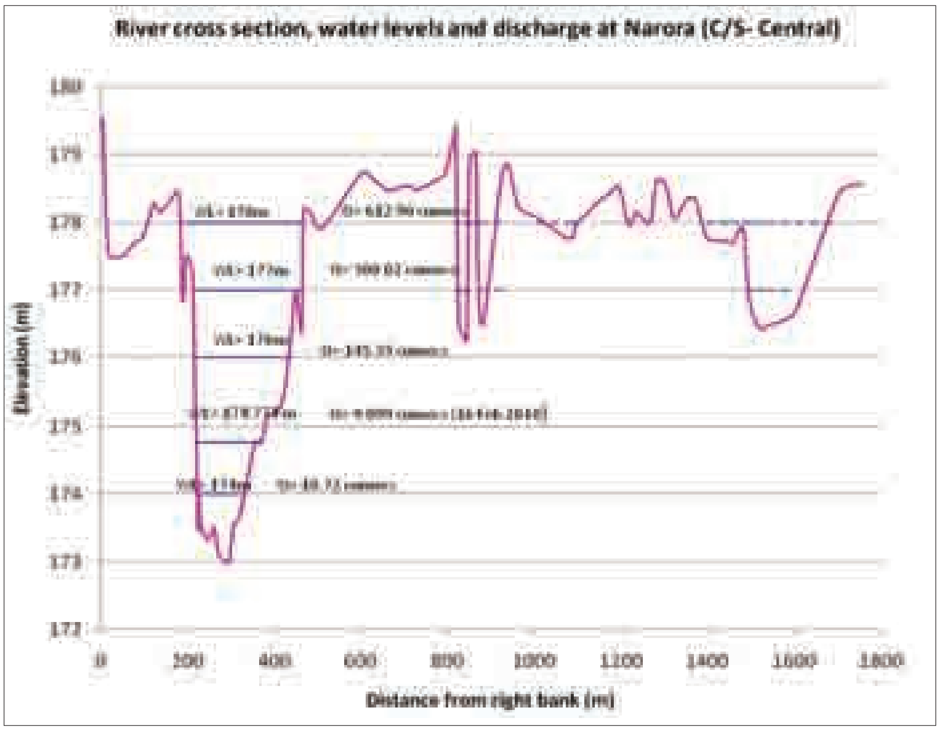
Figure 4.10: Google image of the reference zone sampling site at Narora showing cross-section location

Source: Hydraulics Report (Annexure 3)

Table 4.9: Details of Cross Section 3 at the reference zone sampling site at Narora

Location 2:	Narora (C/S-Central)
Date of Monitoring:	17-02-2010
Time of Monitoring:	12.30 PM to 3.30 PM
Discharge:	8.2 Cumecs
Water level:	174.77 m
Substratum:	Sand

Figure 4.11: River cross-section, water levels and discharge at Narora (C/S-Central)



Source: Hydraulics Report (Annexure 3)

4.6.2 Fluvial geomorphology

Present state

Reaches of approximately 15 km both upstream and downstream of the barrage were considered for geomorphic analyses. The river bed in the upstream section is almost flat until the Narora barrage, whereas there are severe aggradations and degradation in the reaches downstream of the Narora barrage. The main substrate type at and around Narora is mostly sand particles.

Geomorphic analysis of the reaches around Narora barrage showed significant differences between the present condition of the river in the upstream and the downstream of the barrage. The reaches upstream of the barrage are in very good condition in terms of geomorphology, though some improvement in the geomorphic complexity in terms of sinuosity and morphological units is desirable. For the purpose of this study, the zone/site upstream of Narora barrage is considered to be the reference or demonstration zone, providing a template for improvements to downstream zones.

Figure 4.12 is a photograph depicting the downstream of Narora Barrage and some local geomorphic features.

Figure 4.12: Downstream of Narora Barrage and some local geomorphic features

Source: Starter Document Fluvial Geomorphology (Annexure 2 A)

Sinuosity
At Narora, the river is much less sinuous[20] than at Kaudiyala, but is highly braided. In the upstream reaches, the channel area and bar variation is greater than those in the downstream reaches: the downstream reaches of Narora barrage are highly disturbed due to the presence of the barrage. There are sharp differences between all the plan form[21] parameters upstream and downstream of the Narora barrage.

[20] Sinuous: The degree of bending or curving shape of a river.
[21] Channel Plan form: Describes whether a river is braided, meandering or straight in nature.

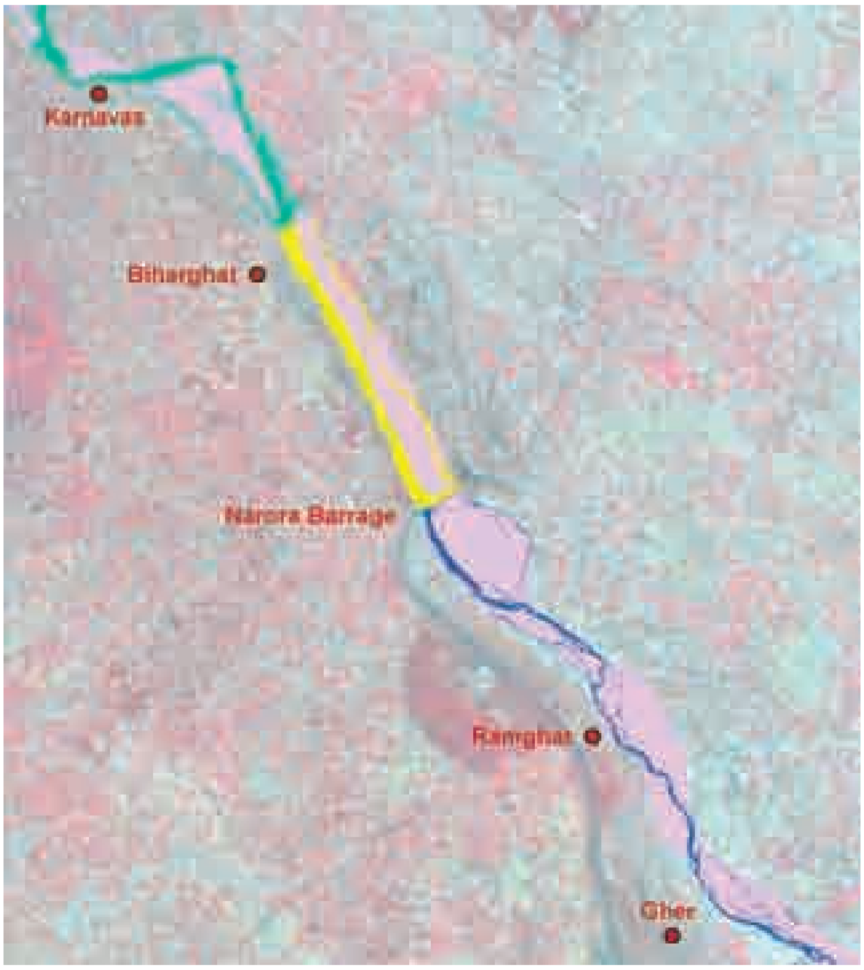
Temporal variation
The group studied the temporal variations that have taken place in the channel between 1955 and 2009, in terms of position and geomorphic characteristics. It was evident that there have been significant changes in channel morphology over the last 50 years, not only downstream of the barrage, but with some gradual changes in morphology also taking place upstream of the barrage, as the channel has adjusted to the man-made changes. The channel as well as the entire channel belt has reduced in almost all the reaches. The overall effect of the barrage has been to reduce the flow, and create large bars in the downstream reaches.

Land use/Land cover
For low gradient zones, an LU/LC map provides an understanding of the nutrients as well as sediments transferred from the floodplain during flooding and also through groundwater movements. The features identified as important parameters in terms of LU/LC were running water, vegetation, vegetated cropland, non-vegetated cropland, barren areas and built up lands.

Habitat suitability index
From an assessment of the Habitat Suitability Index for this stretch of the Ganga it was concluded that, the present state of the reach just upstream of Narora barrage falls under Class A (depicted in yellow in Figure 4.13), whereas the present state of the area before Bihar *ghat* falls under Class B (depicted in green in Figure 4.13). Below Narora

Figure 4.13: The present state of river reaches around the Narora barrage in terms of the Habitat Suitability Index

Where:
Yellow indicates Class A
Green indicates Class B
Blue indicates Class C



Source: Starter Document Fluvial Geomorphology (Annexure 2 A) barrage, the present state of the river is Class C (depicted in blue in Figure 4.13). Thus, there is a significant difference between the present state upstream and downstream of Narora barrage. The reaches upstream of the barrage are unmodified to largely natural, whilst all reaches downstream of the barrage are moderately modified, and require significant improvement.

Desired future state

The present state of the reaches upstream of the Narora barrage are either Class A or B, which implies that they should be maintained in this state.

Downstream of the Narora barrage, the EMC of the reaches should be improved to Class B. The width to depth ratio is very high, which is undesirable for habitat suitability. This parameter can be improved by increasing the flow depth, leading to more favourable conditions. The lateral connectivity is very poor (<20 per cent) and can also be improved by increasing the flow. Whilst an increase in depth of less than 1 m may not change the class of the river, a change in depth from 1 m to 1.3 m could improve the EMC from C to B.

However, an additional increase in flow depth will also lead to an increase in the width of the river, and hydraulic radius decreases in the cross-sectional morphology of the river. Bank erosion and deposition were noted in a few reaches upstream of the barrage as well as in lower reaches downstream of the barrage: To improve the habitat suitability, these reaches may have to be stabilised through river training works along the banks.

4.6.3 Water quality

Present state

The present state of the water quality upstream of Narora barrage is in Class B.

The classification of the present state is based on limited data from CPCB on BOD, COD, DO, coliforms (Source: CPCB, New Delhi), indirect evidence such as the absence of excessive aquatic growth (such as algae, water hyacinth, etc.) and the presence of some sensitive aquatic life (such as dolphins, turtles, etc.) at some locations.

The water quality assessment revealed low BOD/COD ratio, low levels of coliforms, and acceptable DO levels , i.e. >5 mg/l. There is an insignificant increase (above natural/background concentrations) in the levels of toxic substances such as heavy metals, insecticides, pesticides, etc. A tolerable degree of photosynthetic and heterotrophic microbial activity was also observed, perhaps due to low levels of nutrients such as ammoniacal nitrogen, organic nitrogen, nitrates, phosphorous etc.

Desired future state

The present condition at this location matches the desired condition, (Class B) which provides sound rationale for selection of this location as a Reference/Demonstration Zone.

Maintaining the future state for the water quality of this section of the Upper Ganga at Class B requires low BOD, high DO and less diurnal variation in DO; as well as low levels of FC and TC. The turbidity of settled water should also be low. The water should be colourless and odourless, and water quality should be fit for bathing (CPCB Class 'B': DO >5 mg/l, BOD <3 mg/l, total coliforms <500 MPN[22]/100 ml, 6.5 < pH <8.5).

4.6.4 Biodiversity

Present state

The present state in terms of biodiversity was assessed at Class C. The species richness of this zone may be used as a reference for other zones. The physical and chemical conditions of this zone may also be considered as a reference to other zones.

The food web has been moderately modified due to loss of habitats resulting from human interventions, the pollution load from industrial units and domestic sewage, as well as water abstraction for supply to the atomic power station, and for irrigation through the Narora barrage.

A deep pool of water is maintained throughout the year above the Narora barrage. There is only one tributary (the Biaya river) which joins this stretch before Garhmukteshwar. A canal from Kalagarh dam on the river Ramganga brings water during the dry season, and feeds the Biaya river which ultimately meets the river Ganga approximately 5 km above Garhmukteshwar (at Tighri *ghat*). Present biodiversity in this stretch includes:

- Insects: 36 Taxa
- Phytobenthos:
  - Species rich genera: *Cocconeis, Cymbella,* and *Navicula* were abundant at 15 cm, *Cocconeis, Cymbella*, and *Nitzschia* abundant at 30 and 60 cm depths
  - Abundance and assemblages right bank - *Cocconeis placentula, C. placentula* var. *euglypta, Cyclotella glomerata* at all depths and additionally *C. excisa* at 60 cm depth.
- Plankton:
  - Abundance and Assemblages right bank: – *C. placentula, C. placentula* var. *euglypta, C glomerata* at 15 cm and 60 cm depth and *Nitzschia palea, Sellaphora pupula* at 30 cm depth.
  - Abundance and Assemblages left bank: *C. placentula, C. placentula* var. *euglypta, C glomerata* at all depths, as well as *Cocconeis pediculus* at 15, 30 cm, while *Cyclotella menenghiana* at 60 cm depth.
- Fish: 58 species including carp 26, catfish 18, and others 14,(March 2010)
- Reptiles: Crocodiles (*Mugger* and *Gharial*); Turtles (12 species)
- Riparian Vegetation:
  - Summer: 44 species; 2 macrophyte, 5 grass, 16 herbs, 12 shrubs, and 9 trees.
  - Monsoon: 56 species; 3 macrophyte, 7 grass, 19 herbs, 18 shrubs and 9 trees.
  - Winter 50 species; 8 grasses, 12 herbs, 20 shrubs and 10 trees.

[22] Most Probable Number

Desired future state

The desired future state of this section of the Upper Ganga in term of the biodiversity is Class C. The objectives are to maintain the present ecosystem conditions in the river channel and floodplains, and to reduce the pollution and improve suitable habitat conditions of the following freshwater indicator species: Gangetic Dolphin; a dozen species of freshwater turtles, and two species of crocodiles (*gharial* and *mugger*). This is achievable, because there are deep pools, marginal areas, fast flowing shallow areas, backwater areas, floodplain areas during high floods, side channels, etc.

4.6.5 Livelihoods and spiritual-cultural issues

Present state

Livelihood and cultural surveys were not carried out at this site, but the assumption has been made for the purpose of this study that the conditions are conducive to the traditional river activities and rituals. There is sufficient depth at the river banks and *ghats* for ritual bathing, even during the dry season, sufficient current to carry out cremation ceremonies, and good quality and clarity of water. There should also be sufficient flow for traditional livelihoods, such as ferrying and floodplain farming.

Conditions in the reference zone, while not completely natural due to the effects of the downstream barrage and power station were found (following hydrological, geomorphological and ecological monitoring) to be only slightly modified, and suitable to provide a reference benchmark for the more modified flow, water quality and channel morphology conditions in the downstream zones.

The site immediately upstream of Narora barrage is also the focus of WWF-India's community-based conservation programme, focusing on eliminating the threats to the critical aquatic biodiversity. This programme on dolphins and turtles facilitates sustainable floodplain agriculture and use of animal compost.

4.7 ZONE 3: NARORA TO FARRUKHABAD (SITE: KACHLA GHAT)

This site is located approximately 60 km downstream of Narora. The river channel belt at this location is very wide (>3 km), but the water is confined to a channel of approximately 20 m with a water depth of <1.5 m during the low flow season.

4.7.1 Hydraulics

The hydraulics group took three cross sections at Kachla Ghat where the E-Flows assessment was to be done.

Figure 4.14 is a Google image of the Zone 3 sampling site at Kachla Ghat, showing the locations of the hydraulic cross sections.

Figure 4.14: Google image of the Zone 3 sampling site at Kachla Ghat showing cross-section location

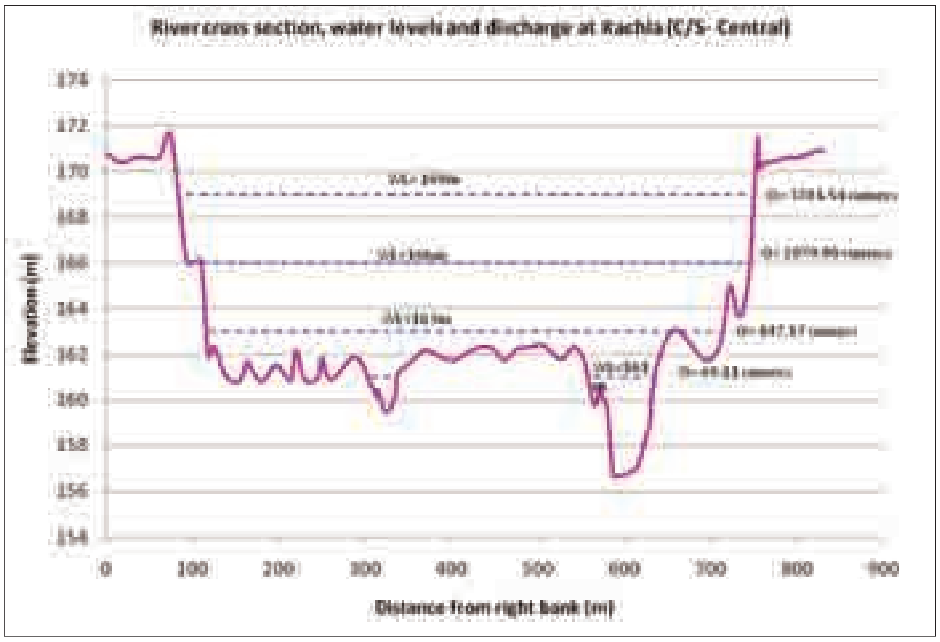
Source: Hydraulics Report (Annexure 3)

Table 4.10 provides details of Cross Section (C/S-Central), whilst Figure 4.15 depicts the cross section itself.

Table 4.10: Details of Cross Section 3 at the Zone 3 sampling site at Kachla Ghat

Location:	Kachla Ghat (C/S-central)
Date of Monitoring:	18-02-2010
Time of Monitoring:	12.00 PM to 3.50 PM
Discharge:	15.0 cumecs
Water level:	159.9 m
Substratum:	Sand

Figure 4.15: River cross-section, water levels and discharge at Kachla Ghat (C/S-Central)



Source: Hydraulics Report (Annexure 3)

4.7.2 Fluvial geomorphology

Present state

Almost all reaches around Kachla Ghat in Zone 3 are in Class C, with the cross-sectional parameters and bank stability providing the two main reasons behind this assessment. At this site, the width to depth ratio is good, but the hydraulic radius requires improvement. The biggest problem at this particular site is that the river changes its course very frequently, which makes the banks unstable. However, these shifts have not changed its sinuosity and braiding index in the long term.

Longitudinal form
The stretch considered for investigation included the reaches approximately 15 km upstream and downstream of Kachla Ghat. The elevation of the river decreases by 4 m over 37 km in this zone.

Both the banks of the river are quite flat and gradually merge with the floodplain. No signs of any incision were visible on either of the banks. The dominant channel sediments are fine sand with significant amounts of silt.

Plan form
In most of the reaches in this zone, the river has very low sinuosity, but there are significant numbers of braids within the channel. In general, there are multiple channels, increasing downstream. A large part of the channel is occupied by point bars.

Temporal variation
The river near Kachla Ghat shows a huge lateral movement of the channel through time. The river moves through the process of erosion and deposition, which clearly indicates that the banks near this site are prone to erosion.

The changes in the position and characteristics of the channel from 1955 to 2009 were studied using toposheets and historical images. There is a significant change in the channel during the last 50 years.

From 1955 to 1990, the channel has aggraded significantly in the reaches upstream and downstream of Kachla Ghat. New bars have been formed and multiple channels increased. The position of the river has shifted towards the north-east upstream of Kachla Ghat and towards the south-west downstream of the site.

For most of the reaches, both the sinuosity and the braiding index[23] have increased. Although in 1955, the river was almost straight in comparison to the river in 2009, in fact the sinuosity has decreased at the the location of Kachla Ghat.

Land use/Land cover
The features identified as important parameters through the LU/LC analysis were running water, vegetation, vegetated cropland, non-vegetated cropland, barren areas and built up lands.

Habitat suitability index
The present state in terms of the Habitat Suitability Index of the reaches of the Upper Ganga around Kachla Ghat is Class B and C. Figure 4.16 depicts habitat suitability around Kachla Ghat. Green indicates Class B whilst blue indicates Class C.

[23] Braiding Index: A measure of the intensity of braiding in a river channel.

Figure 4.16:
Map showing various classes for habitat suitability in river Ganga around Kachla Ghat (Kachla Bridge)

Where:
Yellow indicates Class A
Green indicates Class B
Blue indicates Class C

Source: Starter Document Fluvial Geomorphology (Annexure 2 A)

Desired future state

An increase in flow depth beyond 2 m would improve the class of the river at this site from Class C to Class B. The river should be also improved in terms of lateral connectivity and sinuosity. It is observed that the increase in depth improves the hydraulic radius, lateral connectivity as well as the types of morphological units.

4.7.3 Water quality

Present state

Based on existing data on BOD, COD, DO and coliforms from CPCB, it was concluded that the river in this stretch is in class C/D. The levels of BOD, COD and FC were found to be high, whilst the DO levels were low, with high diurnal DO variability. High levels of nutrients such as ammoniacal nitrogen, organic nitrogen, nitrates, phosphorous etc. were observed.

There was evidence of excessive aquatic growth (e.g. algae, water hyacinth, etc.) and sudden loss of aquatic life (such as fishes) at certain locations and times.

Desired future state

The desired future state is for water quality at Kachla Ghat is Class is B, typified by the following parameters:

- Low BOD
- High DO and less diurnal variability in DO
- Low FC and TC counts
- Low turbidity
- Colourless/Odourless water

4.7.4 Biodiversity

Present state

The present state of the biodiversity at this site was assessed as Class D: the food web has been modified by a loss of habitats due to human interventions, the pollution load from industrial units and domestic sewage, and water abstraction for drinking/irrigation at the barrage.

This stretch is quite dry during October to April, because of increased upstream water storage at the Narora barrage and reduced releases from the barrage (8.5 cumecs). The major source of pollution in this section of the Ganga River originates from two major tributaries, the Mahuwa and the Ramganga, which drain large quantities of industrial effluents released from industries located at Gajrula, Moradabad and Babrala. The river turns red during very low flow in the dry season.

Based on secondary literature and research, present biodiversity at this location includes the following:

- Phytobenthos:
  - Right bank: *C. glomerata*, *C. menenghiana*, *A. granulata* and *S. ulna* at 15 cm, *C. glomerata*, *C. menenghiana*, *Amphora ovalis* and *S. ulna* at 30 cm, *C. glomerata*, *C. menenghiana*, *A. granulata* and *A. ovalis*.
  - Left bank: *A. granulata* and *C. glomerata* at 15 cm, *Cymbella kolb*
- Plankton:
  - Right bank: *Navicula, Nitzschia*, *Scenedesmus* at all depths while *Cymbella* is additional at 30 and 60 cm depths.
  - Left bank: *Navicula, Cymbella* at 15 and 30 cm depth and additional *Scenedesmus* at 30 cm depth. *Nitzschia* and *Cymbella* at 60 cm.
- Benthic Macro-invertebrate Community:
  - Chironomidae (65%) and Potamanthidae (35%) are abundant at 15 cm and only Chironomidae (89%) at 30 cm depths.
- Fish: Presently, 27 species are recorded in this zone. Of these, ten species are common to Bithoor. (The Carp:Catfish:Other ratio = 8:7:14).
  - Summer: 8 species
  - Monsoon: 18 species
  - Winter: 6 species
- Reptiles: Crocodiles (*Mugger*);Turtles (9 species)
- Riparian vegetation:
  - Summer: (total 47 species), 2 macrophytes, 6 grasses, 19 herbs, 11 shrubs and 9 trees. Grass Saccharum sp. Dominant
  - Monsoon: (total 63 species), 3 macrophytes, 8 grasses, 23 herbs, 20 shrubs and 9 trees. Grass Saccharum sp. dominant.
  - Winter: (total 71 species), 3 macrophytes, 9 grasses, 19 herbs, 24 shrubs and 16 trees. Grass Saccharum sp. dominant

Desired future state

The desired future state suggested by the biodiversity group is Class C, implying the maintenance of normal ecosystem functions (e.g. water quality and nutrients load assimilation) to help increase the populations of important species (such as dolphin, turtles, *mugger/gharials*, fishes) in the river stretch, and to restore ecosystem conditions in the river channel and floodplains to a level equivalent to those in the reference zone.

The reductions in pollution levels and improvements in suitable habitat conditions (i.e. deep pools, marginal areas, fast flowing shallow areas, backwater areas, floodplain areas during high floods, and side channels) which is conducive for freshwater indicator species, would allow the EMC to be restored to the desired Class C. This would bring the desired condition similar to that of the Reference Zone (Site: Narora)

4.7.5 Livelihoods

Present state

The present class of this location in terms of livelihoods is Class D, the main reason being the diminishing flows and increasing pollution load, which have led to a decrease in fisheries, ferrying and income generation opportunities from cultural/spiritual visitors.

Kachla Ghat is considered to be one of the most important places in the middle stretch of river Ganga for pilgrimage. For the purposes of the study surveys were also undertaken in other villages along the surrounding stretch of river.

The river resources in and around Kachla Ghat provide livelihoods through:

- Cultural/spiritual tourism;
- Fisheries, (diminishing but still being practiced);
- Ferrying, (diminishing but still being practiced);
- River bed farming which provides livelihoods to the landless labourers, and
- Cremation activities at the banks of the river.

The livelihoods of shopkeepers and priests (*tirth pandas/purohits*), also depend on the visitors/tourists.

According to those interviewed, there were approximately 100 tourists per day visiting for holy bathing in the 1990s. The number of tourists has risen over the last few years. The river changes its course at this location and that is why there are no structured *ghats*.

Interviews with fishermen revealed that in the 1960s, there were approximately 100 families and each of them used to catch 15 to 20 kg of fish per day. At present, only 15 families are engaged in the fisheries, and there is uncertainty about the quantities of the present fish harvest. The fishermen now harvest approximately 2.5 kg fish per day. The fishing activities are seasonal (July- November), with the community depending largely on river bed farming for the remaining year.

Interviews and secondary literature indicate that around 20 varieties of fish inhabit this part of the river, reduced from 100 during the 1960s. Whilst the Ganga becomes a ‘floating repository’ of high quality fish spawn during rainy season, the Narora barrage diverts the river water into canals and additionally hampers fish migration[24] which has affected livelihoods.

Ferrying using boats to carry primarily passengers and goods was effectively developed and used by the British during the 19th and 20th centuries, and was highly prevalent at that time. Since the damming of the river, which diverts most of the flow into canals, ferrying has however declined.

Interviews with local shopkeepers indicated a typical earning of Rs. 150 to 200 per day, except during the festivals when income is higher. There are approximately 120 shops in Kachla Ghat, with a total average daily income of about Rs. 16,000.

Kachla Ghat is emerging as one of the prominent holy places for cremation. On an average, there are about 100-120 cremations taking place at Kachla Ghat and the average monthly income for around 30 people engaged in this activity is Rs. 8000–10,000.

The dry river bed areas in this stretch are used for river bed farming, with wheat, mustard, sugarcane, cucumber, pumpkins, tomato, water melon, musk melon and bitter melon being grown. The crop pattern changes from place to place and according to season. The best season for river bed farming is November–May. The rent collected by the Revenue Department. Interviews with people engaged in this activity indicated that river bed farming in this stretch generates Rs. 26.74 million per season (November–May), and supports the livelihoods of about a thousand families.

Desired future state

The desired future state at this location is Class C. The flows at this location should be sufficient to provide resources capable of sustaining livelihood practices in terms of fishery, tourism and ferrying.

4.7.6 Spiritual/Cultural

Present state

Based on the statements made by respondents and the broad message received at stakeholder meetings, the group concluded that the present state at this location is Class C, which is mainly because of both quality and quantity issues of water in the river Ganga.

At Kachla Ghat, the water levels were quite low and were definitely a cause of dissatisfaction amongst those interviewed. It is now possible to simply walk across the river due to the low flows, and only a few of the respondents stated that bathing in the river is still satisfactory.

According to residents and frequent visitors, two decades ago there used to be two streams during the summers with a depth of at least 1.2 m at the banks. During the monsoons, the water was around 2.1 m deep at the banks. At that time it was difficult

[24] The ~ 20 fish species in the stretch include *Bekar, Bhuchila, Chittal, Mugure, Rampyadhi, Bhaduva, Chall, Detol, Mothuna, Rohu, Bhata, Chena mirrakhal, Karae, Narayan, Simran, Bham, Soar, Kedar, Chirang, Laachi.*

for boatmen to ferry across certain river stretches because they were so deep. Ironically, at present, the reverse is true.

Respondents reported that along with the water levels, the width of the flowing river had also reduced over the years. Compared to the earlier winter flows, the river had receded by 50-60 m on each bank, leading to a total reduction of width of 110-120 m.

One of the respondents pointed out that, *"Jal itna zyada tha, 4-5 kilometre aur chauda tha aur gaon tak milta tha aur snan udhar hi hota tha."* (The water used to be a lot more. It would extend up to 4-5 km more to the village, and the bathing would take place there.)

The same feeling was echoed by another respondent during the interview, *"10 varsh pehle Magh ke hi samey pani isse dugna rahta tha."* (Ten years ago, this very month (February), the water was double what it is now). Most of the respondents felt that at the banks, the water should be enough to bathe easily, and so should be at least 4-5 feet deep.

Pollution was another cause of concern to those interviewed. Apart from domestic sewage, the tanneries located upstream regularly released effluents in the water. This worried the devotees immensely because not only did it make the water visibly dirty, but also caused skin infections in both humans and animals.

The current flow conditions at Kachla Ghat are summarised in Table 4.11:

Table 4.11: Current flow conditions at Kachla Ghat

Parameter	Low flows	Monsoon flows	Winter flows
Depth at banks	0.1 m for 2-3 m away from the banks	NA	0.1 m for 2-3 m away from the banks[25]
Depth in central channel	0.3-0.5 m	NA[26]	0.3-0.5 m[27]
Width	15-20 m in the main channel	Approximately 1 km	30 m in the main channel

Source: Starter Document for Cultural and Spiritual aspects (Annexure-2 E)

Desired future state

All the respondents gave their flow preferences in terms of depth, width and velocity. Figure 4.17 illustrates these preferences by indicating the desired future levels compared to the present dry season flow.

[25] This is due to a very gentle slope. Here, the width of the river will be the deciding parameter, and the depth a function of that.

[26] Unreported during the surveys as people do not venture into the river during the monsoons.

[27] Shallow depth due to construction of the bridge.

Figure 4.17: Desired flow levels at Kachla Ghat

Source: Starter Document Cultural and Spiritual aspects (Annexure 2 E)

The flow requirements for various seasons are summarised more precisely in Table 4.12:

Table 4.12: Desired future flow conditions at Kachla Ghat

Parameter	Condition
Low flow conditions at Kachla Ghat (summer flows)	
Width	50 m wider than current winter width
Depth	Approximately 0.5-1 m at the existing banks
Velocity	Flows to carry away flowers etc
High flow conditions at Kachla Ghat (monsoon flows)	
Width	Touching the base of the Ganga mandir in the village
Depth	NA
Velocity	Velocity sufficient to enable clearing of the channel and removal of sand deposits from the banks
Peak Floods	Floods extending to the core village of Kachla
High flow conditions at Kachla Ghat (winter flows)	
Width	100 m wider than current winter width
Depth	Approximately 1m at the existing banks and 3-4 m at the centre
Velocity	Velocity should be enough to flush sand deposits

Source: Starter Document for Cultural and Spiritual aspects (Annexure 2 E)

4.8 ZONE 4: KANNAUJ TO KANPUR (SITE: BITHOOR)

4.8.1 Hydraulics

The hydraulics group surveyed three cross sections at Bithoor where the E-Flows assessment was to take place.

Figure 4.18 is a Google image of the Zone 4 sampling site at Bithoor, showing the locations of the hydraulic cross sections.

Figure 4.18: Google image of the Zone 4 sampling site at Bithoor showing cross-section locations

Source: Hydraulics Report (Annexure 3)

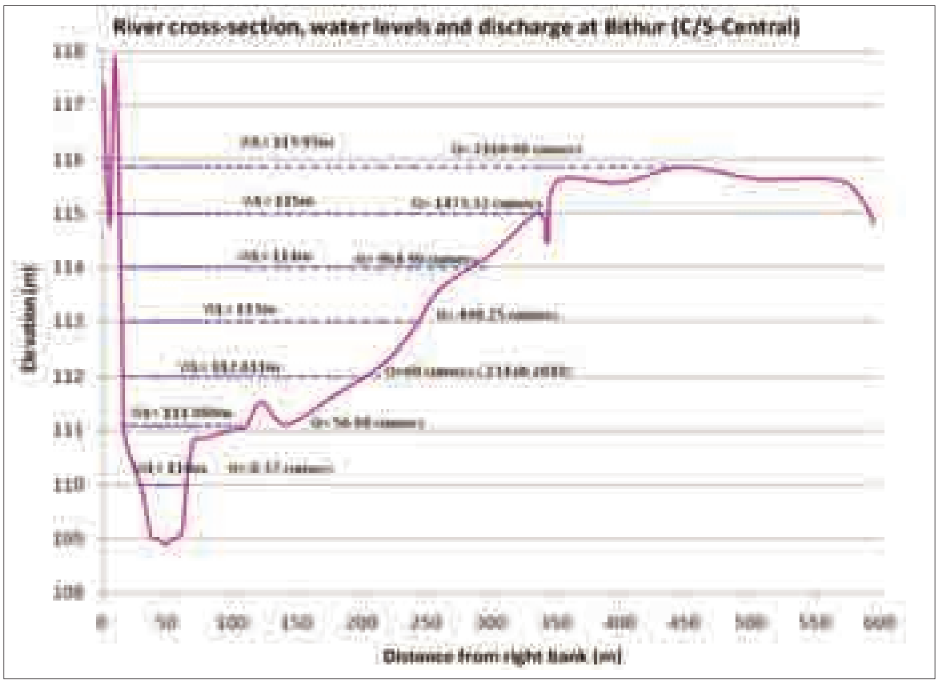
Table 4.13 provides details of Cross Section (Bithoor C/S-Central), whilst Figure 4.19 depicts the cross section itself.

Table 4.13: Details of Cross Section 3 at Bithoor in Zone 4

Location:	Bithoor (C/S-central)
Date of Monitoring:	23-2-2010
Time of Monitoring:	1.30 PM to 5.0 PM
Discharge:	57.9 cumecs
Water level:	112.01 m
Substratum:	Sand

Source: Hydraulics Report (Annexure 3)

Figure 4.19: River cross-section, water levels and discharge at Bithoor (C/S-Central)



Source: Hydraulics Report (Annexure 3)

4.8.2 Fluvial geomorphology

Present state

A section of the Upper Ganga extending approximately 20 km upstream and 20 km downstream from Bithoor was investigated during the fluvial geomorphology assessment. Most of the river reaches near Bithoor were assessed as Class C. Whilst there is little erosion of the banks near Bithoor, the cross-sectional parameters (width, depth and velocity) are inadequate to maintain habitat diversity. The geomorphic complexity (anabranching, braiding etc.) is also low.

The course of the river is about 20 km wide at Bithoor. The active channel presently follows the southern valley margin[28] and has extensive floodplain areas within the valley. The floodplain areas north of the Ganga include abandoned channels, meander scars and ox-bow lakes, with a few small lakes and waterlogged areas. A very large, conspicuous meander scar is cut off from the present channel but is periodically flooded by the Ganga. The southern valley margin is strongly incised and at Bithoor, prominent cliffs up to 15 m high extend in a south-easterly direction for nearly 2 km. The river is multi-channel, with large bars within the channel dividing the flow.

Longitudinal form
In the 40 km-long reach, there was an approximately 6 m elevation difference between the upstream and the downstream point. Major breaks in the bed slopes were noticed at several points.

[28] Valley Margin - It primarily defines the 'water divide' which is the line dividing neighbouring drainage basins on a land surface. It can be visualised as a line on the ground on either side of which water droplet will start a journey to different rivers and even to different sides of the region. In other words, valley margin can be explained as the limit of 'lateral connectivity' between the river channel and floodplain.

Plan form
Whilst the river is almost straight at Bithoor, (with the exception of one or two reaches), there is a comparatively large degree of braiding, with multiple channels in most of the reaches. The river channel area is almost constant throughout all the reaches, but there is a significant variation in bar areas throughout the length of the channel in study area.

Temporal variation
Changes in the position and characteristics of the channel in this zone have been studied for the period from 1955 to 2009 using topographic maps and images. There has been a significant change in the channel size over the last 50 years. The entire macro-channel has reduced downstream of Bithoor, although, since the western side of the channel in this stretch is highly elevated in the form of a cliff, the channel position has not changed significantly.

Between 1955 and 1990, a new channel formed upstream of Bithoor, increasing the number of multiple channels, as well as the river complexity. The new channel (formed in 1990) presently has a much reduced flow but has otherwise been fairly stable during this period.

Downstream of Bithoor, the channel and channel belt areas have decreased significantly between 1955 and 1990. Most of the channel belt area evident in 1955 has since merged with the floodplain by 2009. From 1990 to 2009, the number of multiple channels has reduced, but lateral bars have increased. The main channel position has also slightly changed in these reaches, and the river has become more sinuous since 1955.

In all reaches, there has been a significant decrease in channel area, but less change in the bar area. This shows a level of aggradation in the reaches around Bithoor.

Figure 4.20: Map showing various classes for habitat suitability in river Ganga around Bithoor

Where:
Yellow indicates Class A
Green indicates Class B
Blue indicates Class C

Source: Starter Document Fluvial Geomorphology (Annexure 2 A)

Substrate condition
The substrate present in river Ganga at and around Bithoor is mostly sand particles.

Habitat suitability index
The present state in terms of the Habitat Suitability Index of the reaches of the Upper Ganga around Bithoor is Class B and C, as depicted in Figure 4.20

Desired future state

Similar to the situation in Zone 3 at Kachla Ghat, most of the reaches of river Ganga around Bithoor are in Class C, and it is desirable to improve this to Class B. An increase of more than 2.5 m in the flow depth would improve the hydraulic radius and lateral connectivity which would in turn improve the Class. However, this would decrease the channel sinuosity and the bank stability on the left bank of the river. Therefore, an increase of 3-4 m of depth would be desirable in the Ganga River around Bithoor to achieve the desired future state of Class B.

4.8.3 Water quality

Present state

Based on visual observations and data for BOD, COD, DO, FC and TC, from CPCB, NRCD, MoEF as well as some indirect evidence such as excessive aquatic growth (algae, water hyacinth, etc.) and sudden loss of aquatic life (such as fishes) at certain locations and times, the water quality group concluded that the present state at this location is Class D.

The present state is typified by high BOD/COD, FCs and TCs, and low DO, whilst the diurnal variability in DO is high. There are toxic substances such as heavy metals, insecticides, and pesticides, and also high levels of nutrients such as ammoniacal nitrogen, organic nitrogen, nitrates, phosphates etc.

Desired future state

The future state is Class B typified by the following water quality parameters:
- Low BOD
- High DO and reduced diurnal variability in DO
- Low FC and TC counts
- Low turbidity of settled water
- Colourless/odourless water

This would result in a water quality class deemed fit for bathing (CPCB Class 'B': DO >5 mg/l, BOD <3 mg/l, Total Coliforms <500 MPN/100 ml, 6.5 < pH <8.5)

4.8.4 Biodiversity

Present state

The present state of the stretch of the Upper Ganga around Bithoor was assessed as Class D. The food web has been modified by a loss of habitats due to human interventions, and the pollution load from industrial units and domestic sewage, and due to water abstraction for drinking/irrigation via the barrage.

The stretch of the Upper Ganga between Kannauj and Kanpur is quite dry during October–April. Major flows are derived from the Ramganga River which meets the Ganga River before Kannauj. Small tributaries such as the Kali, Isan and Gahala river introduce a significant pollution load to this stretch. A barrage has been constructed at Bithoor, upstream of Kanpur, from which drinking water is supplied to the city of Kanpur.

Effluents discharged into the river from industrial units and municipal sewage have led to severe impacts on the aquatic life.

Current status of key species

- Phytobenthos:
  - Right bank: *Navicula*, *Nitzschia Cymbella*, at 15, *Navicula, Nitzschia*, *Synedra* at 30 and *Navicula*, *Cymbella*, at 60 cm depth.
  - Left bank: *Navicula*, *Nitzschia* at 15 cm depth, *Navicula*, *Cymbella* at 30 cm and *Navicula*, *Nitzschia Cymbella* at 60 cm. In winter season phytobenthos was not present.
- Plankton:
  - Right bank: *Navicula, Cymbella*, at 15, *Navicula, Nitzschia*, at 30 and *Navicula, Nitzschia,Cymbella*, at 60 cm depth.
  - Left bank: *Nitzschia Navicula*, at 15 cm depth, *Navicula, Nitzschia* and *Pediastrum*, at 30 and 60 cm.
- Benthic Macro-invertebrate Community:
  - Right bank: *Diptera* (47%), *Coleoptera* (18%), *Pelecypoda* (35%) at 15 cm, *Diptera* (92%), *Odonata* (8%) at 30 cm and *Diptera* (50%) and *Coleoptera* (50%) at 60 cm depths.
  - Left bank: *Diptera* (17%), *Coleoptera* (17%), *Pelecypoda* (66%) at 15 cm and *Pelecypoda* (100%) at 30 cm depths.
- Fish: Only 31 fish species were recorded in the present study (Carp 12: Catfish 7: Other 12), of which eleven species were also present in the upper zone. The "new" species found in this zone were generally small sized bottom and water-column feeders.
  - Summer: 8 species
  - Monsoon: 18 species
  - Winter: 22 species
- Fisheries (as %): Indigenous Carp: Catfish: Other ratio = 24:13:63. 'Others' consist mainly of common (introduced) carp and tilapia.
- Reptiles: Crocodiles (*Mugger*); Turtles
- Riparian Vegetation:
  - Summer: (total 49 species), 2 macrophytes, 5 grasses, 21 herbs, 11 shrubs and 10 trees.
  - Monsoon: (total 45 species), 1 macrophyte, 10 grasses, 22 herbs, 3 shrubs and 10 trees.
  - Winter: (total 57 species, 8 grasses, 14 herbs, 24 shrubs and 11 trees

Desired future state

The desired future state defined in terms of the biodiversity is Class C. This EMC would be typified by:

- Maintenance of normal ecosystem functions (e.g. improved water quality and nutrient-load assimilation)
- Reduction in pollution and improved suitable habitat conditions of freshwater indicator species, including dolphin, 12 species of freshwater turtles, crocodiles

(*gharial* and *mugger*), 49 species of fish, 33 species of insects, and 5 species of bi-valve molluscs.
- Restoration of ecosystem conditions in the river channel and floodplains to the equivalent of the reference zone (Garhmukteshwar to Narora).

4.8.5 Livelihoods

Present state

The present state at this location is Class E, based on key livelihood activities, including cultural tourism, fisheries, ferrying, cremation etc.

The key reasons for classifying this location in Class 'E' include:
- Diminishing fish catch and species diversity due to reduced flows and pollution, leading to a reduction in associated livelihood activities.
- Reduction in the influx of cultural tourists due to diminishing flows and deterioration of water quality to an extent where many people think twice before taking a holy bath in the river, or taking holy water back to their houses. This has reduced associated livelihood opportunities for the local people.
- Reduction in flows has impacted ferrying activities and thus reduced the associated livelihood opportunities.

Bithoor is located about 20 km upstream from Kanpur, the industrial centre of Uttar Pradesh. Kanpur is situated on the southern bank of the Ganga and is well-known for its leather industries.

The river resources in and around Bithoor and Kanpur provide livelihoods such as cultural tourism, fisheries and ferrying. In addition, cremation activities at the *ghats* on the river Ganga also generate livelihoods. River bed farming also provides income to the local farming communities, however, the activity is inversely related to river flows.

Cultural tourists visit *ghats* at Bithoor and Kanpur for holy bathing. a daily average of 300 to 350 tourists visit Bithoor and spend Rs. 250 to 300 per trip, which supports livelihoods worth over Rs. 60,000. However, during auspicious days, this number can go up to 400,000, generally during *Karthik Poornima* (November/December), *Dussehra* (September/October) and *Magh Poornima* (January/February).

Cultural tourists prefer to bathe in the middle of the river or to cross the river. Hence, the *ghats* in Bithoor-Kanpur promote ferry services for the visitors. Based on feedback from the respondents, the *ghats* have 25 to 55 boats and a total of 100 to 300 ferry service providers are available. They earn Rs. 50-70 per day on normal days and Rs. 2,000–3,000 per day on auspicious days such as '*Karthik Poornima', Dussehra,* and *Magh Poornima*.

The most important cremation *ghats* in Kanpur are:
- Bhairon *ghat*
- Shuklaganj *ghat*
- Jajmao *ghat*

Among these *ghats*, Bhairon *ghat* is the oldest and is considered the most sacred, accounting for roughly 50 or more cremations per day. Cremation costs are on an average Rs. 1,200–1,500.

Fisheries used to provide the primary source of livelihood for thousands of '*Mallahs*' and '*Sahnis*'. Fish-catch has drastically declined due to reduced flows and increased pollution load. Currently, the fishermen spend a whole day to harvest 1-2 kg of fish during winter and summer. However, the harvest may increase up to 5-6 kg during the rainy season.

River bed farming has become the best source of livelihood for many people. The river bed is used for cultivation of fruits and vegetables. The crops grown are labour intensive, thereby generating employment opportunities for unskilled labourers. River bed farming is divided between winter and summer. In winter, farmers primarily produce wheat, barley and mustard. In summer, vegetables and fruits such as tomato, bottle gourd, bitter melon, sponge gourd, cucumber, water melon and musk melon are produced.

In Bithoor, around 250 households are involved in river bed cultivation on about 300 hectares of land. The monthly income per family unit ranges from Rs. 3,000–4,000. On average, revenue generation at this location is Rs. 0.75-1.0 million per month.

Desired future state

The desired future state of the river at this point from the livelihood perspective would be Class C, as this should be able to provide subsistence livelihood opportunities for the local communities along the banks of the river at this location.

4.8.6 Spiritual/Cultural

Present state

The present state of the Upper Ganga River at Bithoor is deemed to be Class C from a spiritual/cultural perspective. The water here is very shallow and extremely polluted, and the associated reduction in velocity has led to siltation. This has had negative impact on ferrying and bathing. Fishing and the disposal of human remains are also severely compromised by the disappearance of wildlife. People are dissatisfied with the present state of the river, but it is nevertheless still venerated, and the waters still used.

The state of river in this stretch and more specifically at Bithoor is bad. There is a prophecy that the Ganga will disappear due to the sins of those who wash in it. Several interviewees stated that flows have reduced and the river channel has become narrower in the last 20 years, whilst there has also been a reported rise in the bed level (especially by boatmen).

There has also been a drastic increase in the pollution of the water, which has been attributed to the upstream industries. Most people are aware of the role that flow has in diluting pollution, and have expressed a desire for increased flow to combat the increased pollution.

The presence of the turtles is important for the water quality of the river. Turtles used to be abundant in this location and would eat the partially-burned corpses along with other waste. However, since the turtles are no longer found in this stretch, organic matter accumulates and decomposes slowly. The presence of this decaying matter fills some of the bathers with revulsion.

People who drink the water are aware that it is polluted, but drink it nevertheless. Urban pilgrims are so offended by the pollution that they do not bathe in the river, preferring to pay their obeisance from the river banks. However, for the villagers, the river is still holy. Two of the respondents claimed to drink no water other than Ganga water. One of them revealed that, *"To call Ganga polluted is a crime. She embraces everyone. I still drink only Gangajal"*. Table 4.14 summarises the current flow conditions of the Upper Ganga at Bithoor.

Table 4.14: Current flow conditions at Bithoor

Parameter	Low flows	Monsoon flows	Winter flows
Depth at banks	0.4 m at the *ghats*, and 1 m away from the banks	NA	0.7 to 1 m near the *ghats*
Depth in central channel	Approx. 1 m	NA	1 to 1.5 m
Width	0.2 to 0.3 km	Extends up to Parihar, a distance of approximately 4 km	0.2 to 0.3 km

Source: Starter Document for Cultural and Spiritual aspects (Annexure-2 E)

Desired future state

Maintaining an acceptable flow regime, including flushing flows and also controlling pollution, will help restore biodiversity and cultural functions of the river.

The desired flows for various seasons were discussed during meetings with the stakeholders. The terms in which this desired state was expressed was left to the respondents, to ensure that the respondents' focus was the flow regime. All respondents gave their flow preferences in terms of depth, width and velocity. These are summarised in Table 4.15.

Table 4.15: Desired flow conditions at Bithoor

Parameter	Condition
Low flow conditions at Bithoor (summer flows)	
Width	NA[29]
Depth	Not less than 0.5 m on the river bed, next to the ghats
Velocity	Sufficient to carry away flowers, trash etc.
High flow conditions at Bithoor (monsoon flows)	
Width	Reaching the village of Parihar
Depth	NA[30]
Velocity	Velocity sufficient to enable clearing of the channel
High flow conditions at Bithoor (winter flows)	
Width	NA[31]
Depth	Not less than 1 m at the bottom step of the ghats and 3-4 m at the centre
Velocity	Velocity enough to flush sand deposits from the channel

Source: Starter Document for Cultural and Spiritual aspects (Annexure-2 E)

[29] Unreported during the surveys as the people do not venture into the river during the monsoons.
[30] Here, depth at the bottom step of the ghats is the main parameter, and width a function of that.
[31] Here, width was a function of the depth required at the bottom step of the ghats.

At Bithoor, the local community expects that the temple of Brahma (at Bithoor Ghat) should be inundated in the monsoon – seeing that inundation as a washing of Brahma's feet. While this might not occur throughout the monsoon, it does need to occur at least once a year, as an expected and welcome event of the year for the local community. The Brahma temple is shown in Figure 4.21.

Figure 4.21: Brahma temple at the bank of Ganga at Bithoor

Photo Credit: Naveen Kumar / WWF-India

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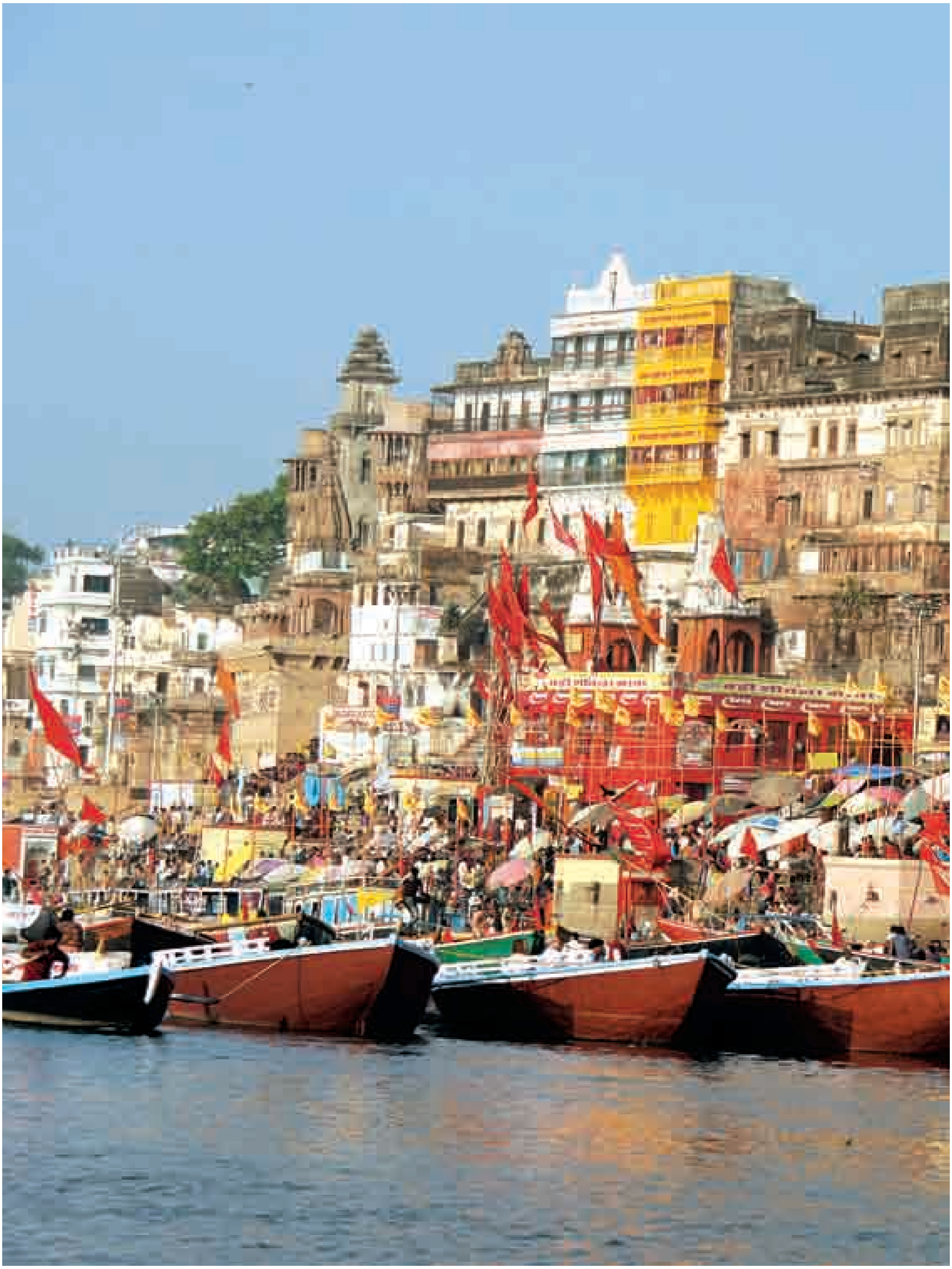


Varanasi or Kashi is one of the oldest inhabited cities in the world and oldest in India. It is regarded holy by Hindus, Buddhist and Jains, and receives thousands of pilgrims round the year

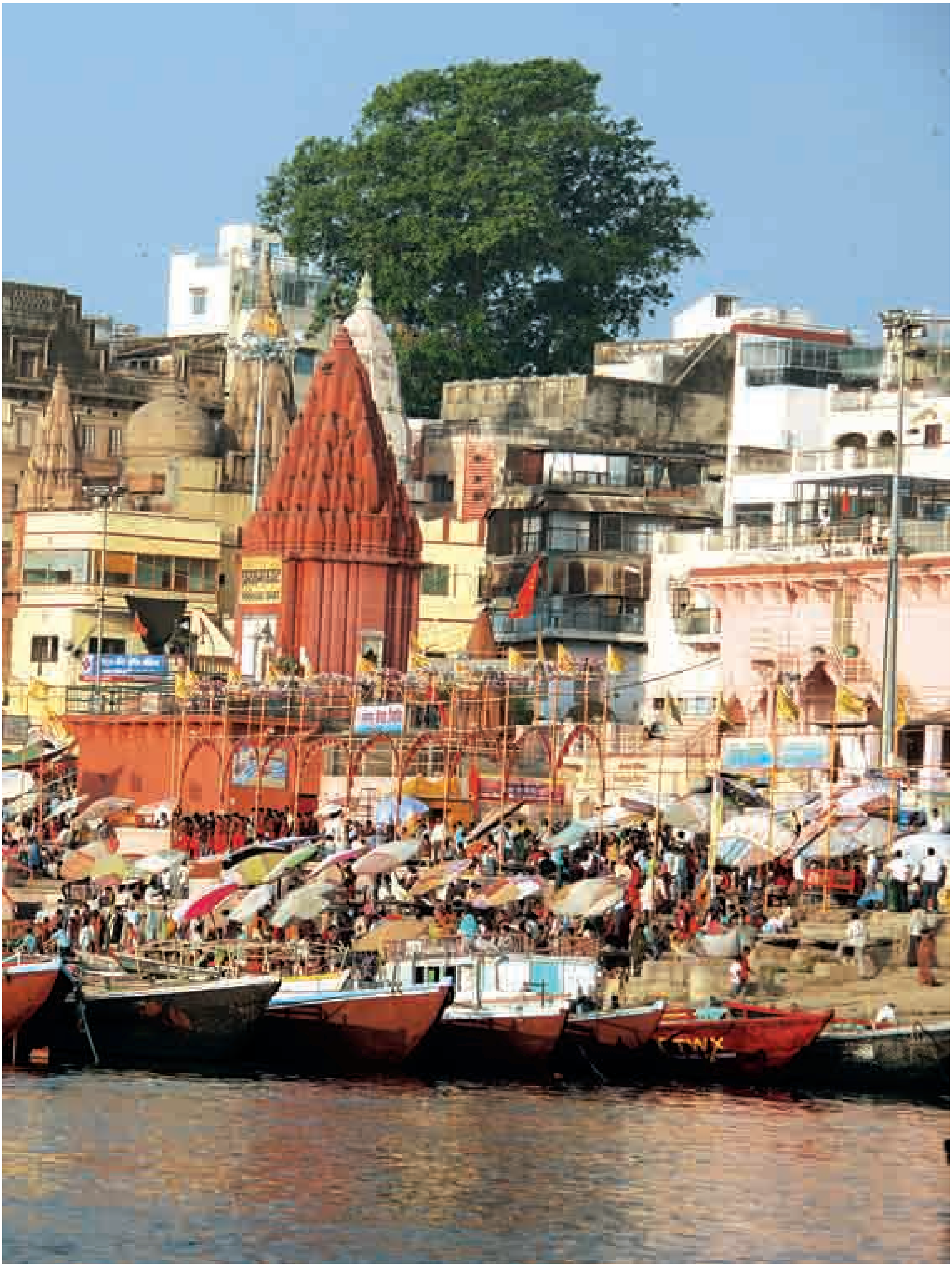


Photo Credit: Amrit Pal Singh

Photo Credit: Amrit Pal Singh

Sunset at Allahabad

Chapter 5
RECOMMENDED FLOWS FOR THE UPPER GANGA: PROCESS AND RESULTS

5.1 BACKGROUND

The preceding chapters have described the background to the study, the choice of EFA methodology, the river zonation and choice of sites, the information that was collected to assess flows, the present state and the desired future state of the river at each site.

This chapter summarises the flows which the specialist groups recommended would be required in order to maintain or restore the Upper Ganga River to the state which would achieve the environmental objectives set for the river sections, as described in Chapter 4. It also describes the process by which the flows were arrived at.

Whilst the recommendations in this Chapter are based on the best available information at the time of the study, the recommended E-Flows values here are based on simulated data, due to the lack of access to observed flow records.

5.2 THE PROCESS

The goal of the EFA process is to achieve a consensus among all the specialist groups on a modified flow regime that will meet the requirements of all species, components and processes in the river during different seasons at particular Environmental management classes (EMCs) during the setting of the desired future state. The recommended flows are based on the flow indicators that were chosen by each specialist group during their assessment.

In each case, the flow-related parameters are converted to discharge values using hydraulic relationships for cross-sections at each site. The values based on various motivations were discussed and deliberated by the team to arrive at the E-Flows value (e.g. a maintenance flow in the driest month of the year, or a high flow in the wettest, etc.). The feasibility of these flows is evaluated by a hydrologist to ensure that the river can in fact produce them within the bounds of its normal functioning. The concept of maintenance flows is explained in Box 5.1 below.

The E-flows setting process that was undertaken for each site at the Ganga EFA workshop is described in more detail below.

5.2.1 STEP 1 Presentation of hydrology and hydraulics cross sections for each zone

The role of the hydrologists and hydraulics specialists was to provide the other specialist groups with information about the natural flow patterns in the river, the seasonal and year-to-year variability, and the relationship of the different flows to depths, widths and velocities in different parts of the river, so that the ecologists, geomorphologists, sociologists, etc. could relate their habitat, activity, and process requirements to flows (in cubic metres per second), which would achieve the pre-set objectives.

- The hydrology group presented a summary of the natural flow regime at each site, illustrating intra-annual and inter-annual flow variability, and flow conditions throughout a normal (maintenance) year and a "drought" year. The driest month (January) and wettest month (August) were identified.

Box 5.1: Maintenance flows

Maintenance Flows are for "normal" years, neither very wet nor very dry, when all the ecological functions and processes (fish breeding, invertebrates emerging, floodplain wetlands full, sediment transported, etc.) can be expected to be working properly.

For river Ganga, it has been estimated that the Maintenance Flows would be equaled or exceeded 70 years out of 100. However flows would be lower for 30 years out of 100 or in other words, 70% probability on the flow duration curve. Drought flows are the lowest that would still provide some habitat and survival conditions (i.e. fish would survive but may not breed that year). So, for long-term E-Flows, the water volume required would be at maintenance recommendations or higher for 70% of the time, and between drought and maintenance for 30% of the time.

- The hydraulics group presented and explained the surveyed cross-sections, which illustrated the relationships between river depth, width and flow velocity for any discharge.

5.2.2 STEP 2 Flow motivations by working groups

At each site, "maintenance" years were addressed first, starting with an estimation of the low flows for the driest month (January), followed by estimation of the low flows in the wettest month (August). Next, the high flow requirements for the driest and wettest months were estimated.

The process was then repeated at each site for the "drought" years.

To estimate each such "building block" (E-Flow) above, each specialist group first considered the river characteristics (depth, width, current velocities, riparian and floodplain inundation, substrate type) necessary to achieve the pre-set environmental objectives.

This information was collated by each specialist group using a *flow motivation form* that summarises the depth, width or flow velocity required to achieve the objectives relevant to the group for a particular month. The specialist groups explained (or motivated) the rationale behind the values they recommended, as well as the consequences of *not* providing this flow on their respective component. The recommendations were based on the *flow indicators selected* by each specialist group:

- **The fluvial geomorphology group** concentrated on the flow velocities and depths required to move, sort and deposit different sizes of sediment, so as maintain or restore channel size and other important channel features (such as multiple channels and bars).
- **The biodiversity group** concentrated on the habitat characteristics required for important flow-dependent species such as the river dolphin, selected fish species, macro-invertebrates and floodplain vegetation. These characteristics included the depth, flow velocity, river width, and substrate types required for different parts of their lifecycle.
- **The livelihood group** focused on depth, water quality and river width required to maintain certain livelihood activities (such as ferrying or rafting).
- **The spiritual/cultural group** had to ascertain the depth and water quality issues that would affect religious and cultural activities (such as ritual bathing).
- **The water quality group** responded to the recommendations of the other groups, estimating the effects that the recommended flows would have in mitigating pollution or other water quality issues.

The hydraulics group converted this information into flows, using the modeled hydraulic characteristics from the surveyed cross-sections.

An example of a flow motivation form is shown in Box 5.2. All the flow motivation forms are attached in Annexure – 5.

Box 5.2:
A flow motivation form filled by the fluvial geomorphology group

FLOW MOTIVATION FORMS

River: Ganga **Date:** 11-05-10 **Site:** Kaudiyala

Specialist: Geomorphology **Month:** January

Low flow or flood? Low Flow (MAINTENANCE Year)

Discharge: 400 m^3/s **Depth:** 9.5 m **Average velocity:** 0.64 m/s

Reasons for recommending this flow:
At low flow, maintenance of longitudinal connectivity will be critical. Otherwise, the geomorphology is in good condition. According to the cross section (CS-3), plus the plan form parameters in longitudinal direction and field observation, the longitudinal connectivity will be lost at water level lower than 397 meters above mean sea level (depth 9.5 m), while water level at 404 meters above mean sea level will be good to maintain lateral connectivity. Since discharge of 1400 m^3/s at 404 meters above mean sea level is unrealistic, lateral connectivity cannot be maintained at low flows. Hence, the final recommendation at low flow is 9.5 m of flow depth (400 m^3/s discharge).

Consequences of not providing this flow:
Flow less than 400 m^3/s (corresponds to 9.5 m flow depth) will break the longitudinal connectivity and will be critical for movement of biota. A water level of less than 404 m amsl will break the interaction between channel and adjoining bars which has implications for nutrient supply and habitat conditions as well as the general functioning of the river system.

5.2.3 STEP 3 Calculating critical flows

Based on the flow motivations by different working groups, the critical flows for each site were identified. The largest of the flows recommended by the specialist groups was considered to be a critical flow for each "building block". The assumption was that critical flows would satisfy the requirements of all specialist groups. For example:

- At Kaudiyala, the January maintenance flow was determined by fluvial geomorphology, whereas the August maintenance flow was determined by biodiversity requirements.
- At Kachla Ghat and Bithoor, cultural and spiritual needs drove the recommendations for the August flows (both during maintenance and drought years).
- Almost half of the critical flow recommendations were influenced by the biodiversity requirements as these were usually higher than the other requirements.

5.2.4 STEP 4 Calculating annual E-Flow requirements

Using the final critical flow recommendations for the driest and wettest months under maintenance and drought conditions (Table 5.1 – 5.12), the E-Flow values were then interpolated by the hydrologist for the remaining months of the year. The monthly flow volumes for each month of the year for low-flow and high-flow components were then calculated. Finally, the total annual volume of E-Flows for maintenance and drought years were calculated and expressed as a percentage of natural and/or present-day mean annual runoff (MAR[1]).

Although the recommended Environmental Flows constitute a significant proportion of the total flow in the river, it is important to recognise that the water required during the monsoon months (July to September) forms the bulk of the annual requirement, and is presently unused for consumptive purposes: no flow restoration is necessary to maintain these flows. It is mainly during the dry season (January to June and November and December) that flow restoration is required, because the present flows in the river are significantly lower than the recommended E-Flows. The annual volume of water required for this restoration constitutes a much smaller proportion of the MAR, therefore requiring smaller adjustments to present water allocations to be met.

5.3. THE RESULTS

The results of the Ganga EFA, in terms of recommended E-Flows for each of the zones/sites together with their motivations, and a comparison with the available natural and present day flows are detailed in the following section.

E-Flows are actually a *pattern* of flows: In addition to annual MAR percentages, the monthly and seasonal flow requirements, depicted on the graphs, should be noted.

[1] **Mean Annual Runoff:** The average volume of water flowing through that site in the river in one year

5.3.1 Zone 1: Site: Kaudiyala

Figures 5.1 and 5.2 depict the monthly E-Flows recommendations at Kaudiyala in Zone 1, for the low and high flows for maintenance and drought years, respectively. The Naturalised Flows[2] are also plotted.
The E-Flows recommendations at this site were calculated as 72% of the natural Mean Annual Runoff (MAR) during normal years, and 44% during drought years.

The present day flows were not available for this site, hence could not be plotted.

Figure 5.1: Recommended E-Flows requirement for maintenance years for the Kaudiyala site in Zone 1

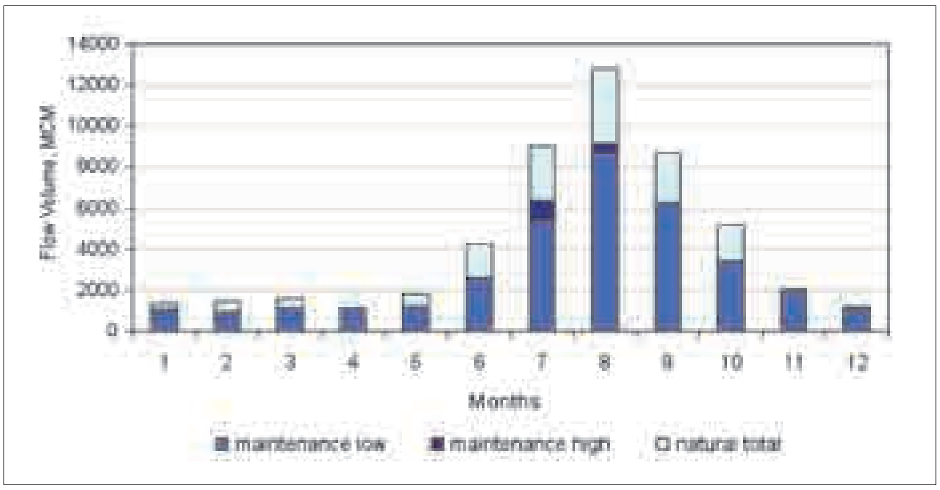
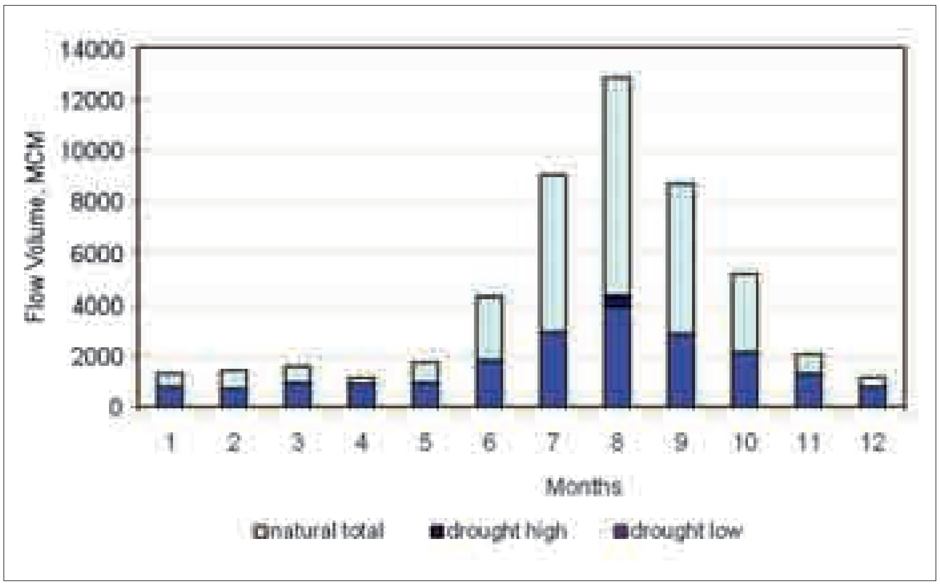


Figure 5.2: Recommended E-Flows requirement for drought years for the Kaudiyala site



Tables 5.1 to 5.4 provide the data on which the above graphs are based, summarising the critical flow requirements for the driest and wettest months in maintenance and drought years at Kaudiyala, and providing the specialists' motivations for each flow.

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[2] **Naturalised Flows:** The flows that would have occurred historically, in the absence of reservoirs, water supply diversions and return flows and other types of water management activities that are reflected in the present day input dataset

Table 5.1: Critical flow requirements and their motivations at Kaudiyala for January in a maintenance year

Speciality	Critical Flows (m^3/s)	Depth (m)	Average Velocity (m/s)
Biodiversity	265	8	0.5
This is highest production period after the floods. The river is recharged due to various organic and inorganic inputs from the catchment. The suggested flow is therefore a basic requirement. An average current velocity of 0.5 m/sec is suggested to maintain the oxygen rich water to which the biodiversity has adapted.			
Fluvial Geomorphology	400	9.5	0.64
At low flow, maintenance of longitudinal connectivity will be critical. According to the cross section, plan form parameters in the longitudinal direction, and field observation, longitudinal connectivity will be lost at a flow lower than 397 m amsl (depth 9.5 m), while a water level of 404 m amsl will be sufficient to maintain lateral connectivity. Since a discharge of 1400 m^3/s at 404 m amsl is unrealistic, lateral connectivity cannot be maintained at low flows. The final recommendation at low flow is therefore 9.5 m of flow depth (400 m^3/s discharge).			
Cultural and Spiritual	386	0.5	NA
An extra flow of ~37.6 m^3/s is needed at Rishikesh in January to satisfy spiritual needs. This additional water will allow holy bathing in the Ganga within 2 m of the *ghats* and provide a depth of 0.5 m at the lowest step on this *ghat.* Assuming that between Kaudiyala and Rishikesh the volume of flow is the same except for a small addition of 1.6 m^3/s from river Nayar and other streams, an additional 36 m^3/s is expected at Rishikesh. The minimum amount of water to satisfy spiritual needs is present when "boulders in the middle of the river should not be visible from the *ghats.*" If the bed is visible, it means that the river has shrunk to an unacceptable level and is not the imagined mighty river. This volume of water also prevents decomposing offerings, flowers and other debris from becoming visible.			
Livelihoods	305	8.7	0.58
The recommended flow is close to the present flow conditions since the adventure tourists and Service Providers (white water rafters and beach campers) are satisfied with this flow.			
Recommended Flows: 400 m^3/s (Fluvial Geomorphology)			

Table 5.2: Critical flow requirements and their motivations at Kaudiyala for August in a maintenance year

Speciality	Critical Flows (m^3/s)	Depth (m)	Average Velocity (m/s)
Biodiversity	3250	21.05	1.15
The flood/high-flow is required to bring the nutrients needed by algae and riparian vegetation, and to deposit fine sand along the banks. It is also necessary for the mass emergence of macro-invertebrates. The constant water temperature is necessary for their proper metabolism during emergence. The high flood level connects the spawning grounds for *Mahseer* and other fish species. For fish which lay eggs during this season, the high oxygen level is necessary for hatching, particularly for the Snow Trout and Catfish. To fulfill this requirement, the river should span up to 240 m in width, with a depth of 21.05 m.			
Fluvial Geomorphology	1494	16.37	0.91
Lateral connectivity should be established at least once in a year; hence the lateral bars should be submerged. The water should also touch the banks so that the riparian zones and vegetation are inundated. However, prolonged high flows are not desirable as they may erode the bars, modifying the channel morphology. Compared to low flow, the recommended flow represents a 3.7 times increase in discharge, a doubling of width, and 1.5 times increase in hydraulic radius. This multiplies the unit stream power by ~2.5. Such variability is acceptable for the functioning of the river ecosystem.			
Cultural and Spiritual	295-300	1 m additional at *ghats*	1.6
Based on what respondents recalled about conditions about 40-50 years ago, and on what they imagine a resplendent Ganga should look like in the monsoon season, it is estimated that an extra depth of 1m is required so that people can bathe conveniently at the first platform of the *ghats.* This amounts to an additional flow of 315 m^3/s. Transposing this flow to Kaudiyala requires accounting for additional in-stream flows from small streams and river Nayar, estimated at about 15-50 m^3/s			
Livelihoods	-	-	-
Adventure sports are not supposed to be carried out during August, because of the prevailing high water currents and resulting high risk.			
Recommended Flows: 3250 m^3/s (Biodiversity)			

Photo Credit: Prakash Nautiyal

Figure 5.3: Mahseer, an endangered fish species, loosing migration routes due to loss of connectivity

Table 5.3: Critical flow requirements and their motivations at Kaudiyala for January in a drought year

Speciality	Critical Flows (m^3/s)	Depth (m)	Average Velocity (m/s)
Biodiversity	206	7.27	0.5
This is the period of maximum productivity in the river; hence the maximum substrate area should be submerged for maintaining minimum productivity in the river to sustain the freshly recruited macro-invertebrates and fish population. The recommended flow in the river is also necessary to hydrate the banks enough for the survival of riparian grasses and sedges present in this zone.			
Fluvial Geomorphology	33.3	3.4	0.32
Allowing for the monsoonal variability, which accounts for about 6 m water depth variation, the level for the driest drought year was analysed. Mostly, there will be reduced or no longitudinal connectivity, but some biota will survive in the disconnected pools.			
Cultural and Spiritual	NA	NA	NA
The respondents believe that the present flow conditions in January are the low flows for a drought year. The river barely touches the *ghats* at Rishikesh and there is no longitudinal connectivity along the *ghats*. This means that people have to enter the river even to pour some water over their heads: there is not enough water for them to have a ritual bath.			
Livelihoods	290	8.28	0.57
The Threshold of Potential Concern (TPC) for adventure sports (from a livelihood point of view) is 290 m^3/sec, because there is a need for a certain water depth and velocity in order to carry out this activity.			
Recommended Flows: 290 m^3/s (Livelihoods)			

Photo Credit: Sandeep Behera / WWF-India

Figure 5.4: Ganga basin is home to rich aquatic biodiversity with several species of flamingoes, pelicans etc. Shown here is a snapshot of the rich biodiversity in National Chambal Sanctuary

Table 5.4: Critical flow requirements and their motivations at Kaudiyala for August in a drought year

Speciality	Critical Flows (m^3/s)	Depth (m)	Average Velocity (m/s)
Biodiversity	1469	16.28	0.91
This flow is required to maintain ecosystem integrity in terms of adequate nutrient replenishment for the upcoming season. This flow is necessary for preventing the invasion of mesophytic shrubs and trees in the riparian zone. The migratory passage of the *mahseer* and other fish, as well as otters can be maintained at this flow. It would also offer adequate food for otters			
Fluvial Geomorphology	400	9.5	0.65
In a drought year, the wettest flow should be the equivalent of the driest flow of the normal year. At this flow, longitudinal connectivity will be maintained, which will allow free migration of biota, and movement of nutrients and sediment.			
Cultural and Spiritual	1055	2-2.5	1.5
The current low flows in August are considered adequate for a drought year. Here, water touches the 1st platform (2-2.5m above the bed level) of the *ghat*. The quantum of water required for this period is derived by adding the required flow from the bottom of the ghats to the 1st platform, and the existing flow in January for a maintenance year			
Livelihoods	-	-	-
Adventure sports are not supposed to be carried out in August because of the prevailing high water currents and resulting high risk.			
Recommended Flows: 1469 m^3/s (Biodiversity)			

5.3.2 Zone 3: Site: Kachla Ghat

Figures 5.3 and 5.4 depict the final monthly E-Flows recommendations, naturalised flows, and simulated present day flows for Zone 3 (Kachla Ghat).

The E-Flows recommendations were calculated as 45% of the natural MAR during normal years and 18% during drought years.

The present day flows are lower than the environmental requirements in the dry season months. During the wet season, the E-Flows requirements are met by present day flows.

Figure 5.5:
Recommended E-Flows requirement for maintenance years for the Kachla Ghat

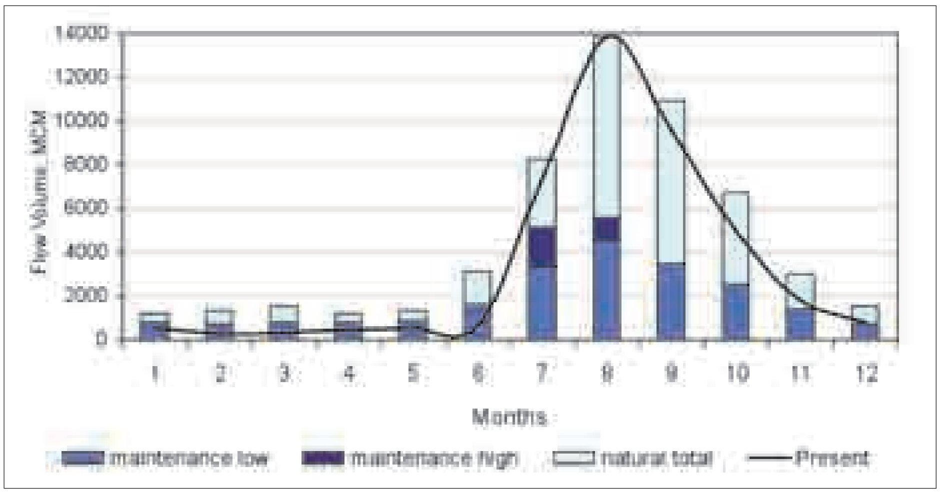
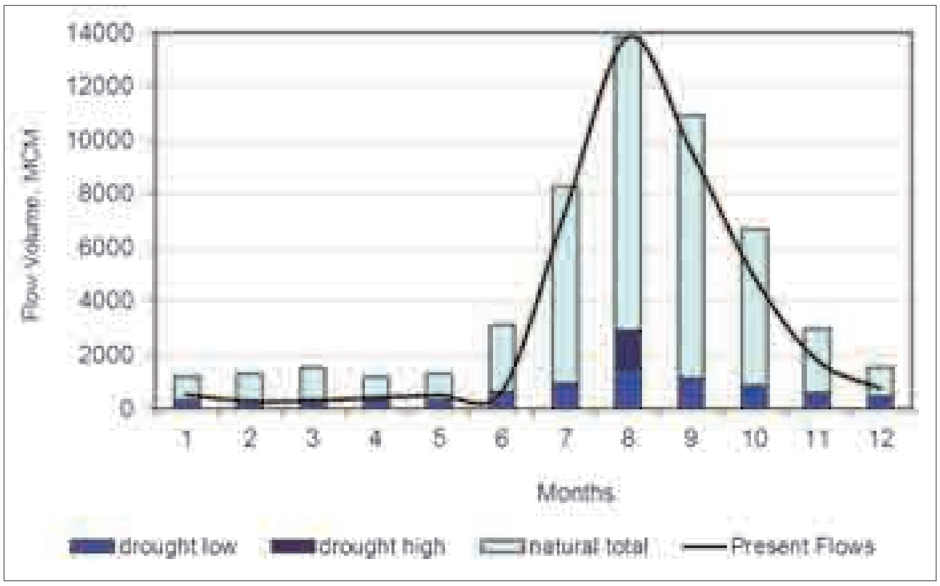


Figure 5.6:
Recommended E-Flows requirement for drought years for the Kachla Ghat



Tables 5.5 to 5.8 provide the data on which the above graphs are based, summarising the critical flow requirements for the driest and wettest months in maintenance and drought years at Kachla Ghat, and providing the specialists' motivations for each flow.

Table 5.5: Critical flow requirements and their motivations at Kachla Ghat for January in a maintenance year

Speciality	Critical Flows (m^3/s)	Depth (m)	Average Velocity (m/s)
Biodiversity	300	3.49	0.38
These flows provide the ecosystem's requirement to sustain the biodiversity, particularly critically endangered vertebrates such as gharial, dolphins and other vertebrates such as otters, turtles and the major Indian carp species. These flows are required to re-establish the species composition of fish and the higher vertebrates, and to replace current levels of pollution-tolerant forms of *Cyclotella sp.*, *Chyronimids* by pollution sensitive *Cymbella sp. & Gastropods,* and to sustain riparian vegetation.			
Fluvial Geomorphology	244	5.6	0.46
This amount of water will submerge the bars at lowest elevation, helping to maintain the longitudinal connectivity and multi channel system. Centre bars will remain exposed for habitat shelter.			
Cultural and Spiritual	90.73	1 m above current level at bank	0.25 - 0.3
The current water level is at the threshold of concern. Bathing is no longer possible as water is above knee depth only in a few isolated pools. The desired low flows are the historical flows. A depth of 1 m is desired at the current bank. The velocity needs to be higher than at present: sufficient to carry away offerings and to scour the top of the sandy bed to remove algal growth.			
Livelihoods	250	3.31	0.36
The proposed flows support livelihoods such as ferries transporting goods between villages along the river. Lower flows will lead to a lot of dissatisfaction (i.e. sometimes a negative rate of return).			
Recommended Flows: 300 m^3/s (Biodiversity)			

Table 5.6: Critical flow requirements and their motivations at Kachla Ghat for August in a maintenance year

Speciality	Critical Flows (m^3/s)	Depth (m)	Average Velocity (m/s)
Biodiversity	551	4.49	0.33
This flow is required to create floodplains and promote riparian cover for successful spawning of carp. The young of dolphins, gharials and turtles use the side channels and shallow flood plains created at this flow for shelter. This flow ensures replacement of nutrients, and the consolidation of the sand bars and islands.			
Fluvial Geomorphology	551	4.5	0.33
At this flow, all the bars except two lateral bars at the channel sides will be submerged. It will establish good lateral connectivity and make the river a single channel system. The lateral bars can be used by biota. This flow will not adversely affect the bank stability.			
Cultural and Spiritual	1740	5.52	0.3
The respondents require that the flow in the monsoon extends across the channel to touch the base of the temple at Kachla village (approx. 0.5 km from the main channel). The total width of the river required is approximately 1 km. This flow is necessary for moving sand downstream and laying fertile silt across the bed			
Livelihoods	601	4.5	0.34
The objectives for the proposed flow include fisheries, ferrying and cultural tourism.			
Recommended Flows: 161.5 m^3/s (Cultural and Spiritual)			

Table 5.7: Critical flow requirements and their motivations at Kachla Ghat for January in a drought year

Speciality	Critical Flows (m^3/s)	Depth (m)	Average Velocity (m/s)
Biodiversity	161.5	2.99	0.33
These flows are required to sustain biodiversity and critically endangered species, by increasing food productivity. It will also help to retain pollution sensitive species of algae and invertebrates.			
Fluvial Geomorphology	91	2.5	0.27
These flows provide a bare minimum requirement: for sustainable functioning, longitudinal connectivity should not be broken. On the basis of field data, a 3 m difference between pools and riffle levels has been assumed. By taking the flow of around 1.5 m over the riffles, the water level should be at 161 m amsl to maintain the longitudinal connectivity.			
Cultural and Spiritual	39.62	0.5	0.25
The desired flow levels enable pilgrims to bathe with some comfort. During a drought year, people are willing to wade through nearly one third of the channel width to reach waist deep water. For this, the water needs to be 0.5 m above the present water level, even in a drought year. This translates as a maximum depth of 4.5 m in the channel, with a total submerged width of approximately 120-130 m. The velocity needs to be sufficient to carry away offerings and debris, i.e. 0.25-0.35 m/s.			
Livelihoods	120	2.68	0.29
During a drought year, subsistence livelihood activities are affected drastically in terms of earnings, as the flows decrease. The recommended flows are the minimum needed to maintain these activities.			
Recommended Flows: 161.5 m^3/s (Biodiversity)			

Table 5.8: Critical flow requirements and their motivations at Kachla Ghat for August in a drought year

Speciality	Critical Flows (m^3/s)	Depth (m)	Average Velocity (m/s)
Biodiversity	300	3.49	0.38
These flows are required to maintain ecosystem integrity, food chains and survival of critically endangered gharials and dolphins. The increase in water level will maintain the riparian vegetation, so that it becomes moist and prevents invasion of nuisance species.			
Fluvial Geomorphology	244	3.29	0.36
In a drought year, connectivity (longitudinal and lateral) should be achieved at least once in a year. Therefore, the recommended water level is similar to low flow of dry period in a maintenance year. This flow will provide sufficient depth and width to maintain biodiversity and enough velocity for sediment movement.			
Cultural and Spiritual	551	6	0.33
In a drought year, water does not necessarily reach the temple. However, it is expected to cover the river bed, providing a total width of approximately 700-800 m at the suggested flows.			
Livelihoods	500	4.4	0.45
The proposed levels are intended to support livelihood activities and provide reasonable profits. However, the (fishing) levels may not be maintained sufficiently. Overall, the communities who depend on livelihoods such as fishing and ferrying will be able to earn reasonable profits.			
Recommended Flows: 551 m^3/s (Cultural and Spiritual)			

5.3.3 Zone 4: Site: Bithoor

Figures 5.7 and 5.8 depict the final monthly E-Flows recommendations for the Bithoor site (Zone 4: Kannauj - Kanpur). The figure also shows the naturalised flows as well as simulated present day flows.

The E-Flows recommendations were calculated as 47% of the natural MAR for normal years and 14% for drought ones. The present day flows are lower than the E-Flows requirements during the dry season months.

Figure 5.7: Recommended E-Flows requirement for maintenance years for the Bithoor site

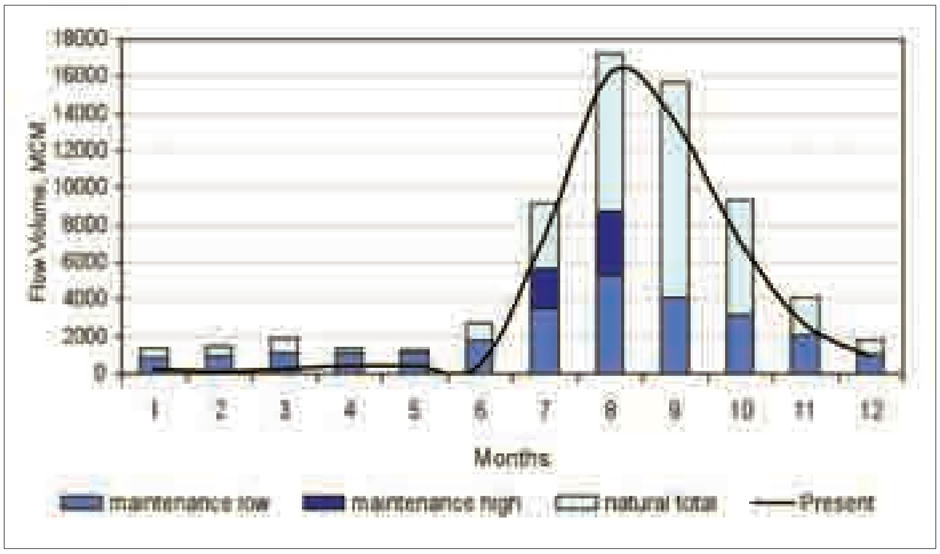
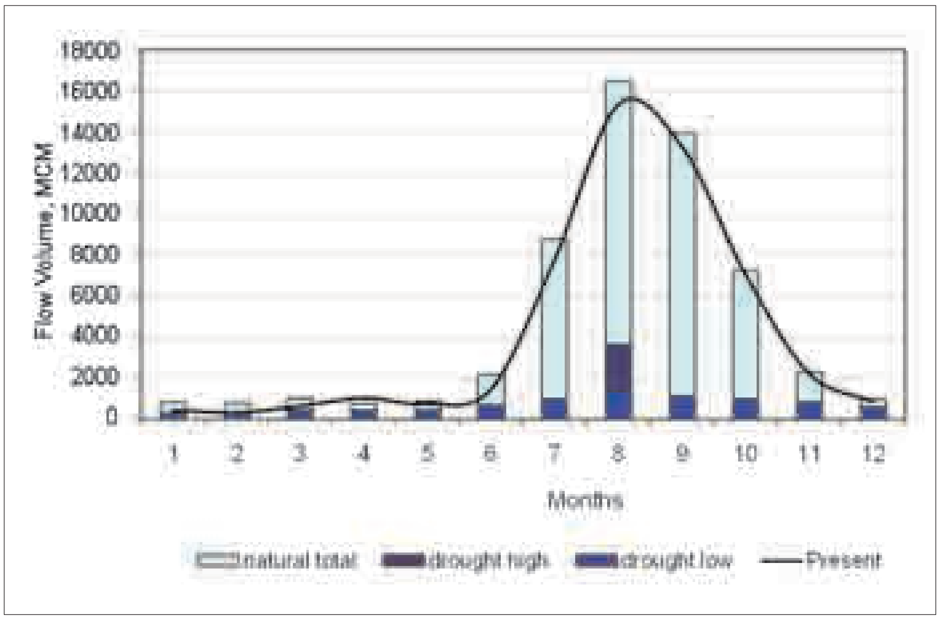


Figure 5.8: Recommended E-Flows requirement for drought years for the Bithoor site



Tables 5.9 to 5.12 provide the data on which the above graphs are based, summarising the critical flow requirements for the driest and wettest months in maintenance and drought years at Bithoor, and providing the specialists' motivations for each flow.

Table 5.9: Critical flow requirements and their motivations at Bithoor for January in a maintenance year

Speciality	Critical Flows (m^3/s)	Depth (m)	Average Velocity (m/s)
Biodiversity	330	3.5	1.03
These flows are required in order to maintain food sources such as plankton, periphyton, benthic invertebrates and fish for the critically endangered species, thus maintaining the food web. This is the period of major productivity in terms of biomass. Improvement in the species ratio and productivity of Indian carp is also a major issue for the food of higher vertebrates such as gharial, dolphin, otters and turtles. Immature dolphins, turtles, otters and gharial need food in the form of small fishes, and gharial and turtles also need access to islands, for basking At this flow dolphins can use the habitat as a passage way and feeding ground, however not as a permanent habitat.			
Fluvial Geomorphology	330	3.5	1.03
At this discharge, some of the bars will be submerged, and geomorphic diversity of the channel will be maintained. A velocity of 1.03 m/s will be sufficient for sediment and nutrient movement.			
Cultural and Spiritual	98.78	1 m at bottom step	0.73
Respondents require a flow that enables them to bathe from the bottom step of the banks. This requires a water depth of 1 m at the bottom step. This depth will also cover the river channel and enable the visitors to be ferried across the river rather than walk the long way around by the bridge. Respondents also believe that increased flow levels will reduce the visible pollution in the water. In addition, they hope that the increased depth and decreased pollution will lead to the return of *rita rita* (cat fish).			
Livelihoods	330	3.81	1.03
The proposed levels are intended to support livelihood activities and provide reasonable profits. However, these levels may not maintain fisheries sufficiently. Overall, the communities who depend on livelihoods such as fishing and ferrying will be able to earn reasonable profits.			
Recommended Flows: 330 m^3/s (Biodiversity)			

Table 5.10: Critical flow requirements and their motivations at Bithoor for August in a maintenance year

Speciality	Critical Flows (m^3/s)	Depth (m)	Average Velocity (m/s)
Biodiversity	1986	6.69	1.67
Floods bring much needed silt and nutrients into the flood plains for survival and growth of algae, macrophytes and riparian vegetation. Flood flows are important for the regular flushing of the accumulated debris and xenobiotics which harm the biota due to the activities at the river banks. The channel width will offer a shallow substratum rich in slit and detritus for the establishment of a good plankton population for fish, and periphyton for the gastropods, other micro-invertebrates and fish, and increase the food sources needed for dolphins, *gharial* and turtles. This will also help in maintaining a natural ratio of Carp to Catfish, as the latter has outnumbered the former.			
Fluvial Geomorphology	1985	6.69	1.67
During monsoon time, all bars should be connected with the channel. At this level, lateral and longitudinal connectivity should be well maintained. Geomorphic analysis also suggest at ~ 115 m amsl, the geomorphic class will be improved.			
Cultural and Spiritual	3303	8.08	1.2
The suggested flows will provide adequate water to inundate the valley of *Parihar* at least once a year. This translates into a flow level of 117 m amsl.			
Livelihoods	1500	6.13	1.51
Key livelihood objectives at recommended flows include fisheries, ferry and agriculture at enhanced profit margins. The inundation of the entire area is necessary for the irrigation of the fields. It is also an expected and welcome part of the year for the residents. These floods clear silt accumulation and maintain the channel of the river.			
Recommended Flows: 3303 m^3/s (Cultural and Spiritual)			

Table 5.11: Critical flow requirements and their motivations at Bithoor for January in a drought year

Speciality	Critical Flows (m^3/s)	Depth (m)	Average Velocity (m/s)
Biodiversity	193.8	3.08	0.88
These flows are required in order to maintain food sources i.e. plankton, periphyton, benthic invertebrates and fish for the critically endangered species so that the food web is maintained. This is the period of major productivity in terms of biomass. Immature dolphins, turtles, otters and gharial need food in the form of small fish. Reptiles such as gharial and turtles also need access to islands for basking. At this flow dolphins can use the habitat as a passage way and feeding ground, but not as a permanent habitat. The improvement of the Indian carp fishery is a crucial issue in this stretch because it forms the beginning of the middle zone of distribution for these species.			
Fluvial Geomorphology	100	2.58	0.73
In a drought year longitudinal connectivity should be maintained during the driest period. Therefore, at this water level, riffles will be covered by ~ 1 m water. By maintaining a general variation in water depth of ~ 2 m between pools and riffles, a level of 112 m amsl could be achieved.			
Cultural and Spiritual	15-18	0.5	0.65
While the ideal level for bathing is waist deep water, devotees are willing to accept lower flows in a drought year. With 0.5 m of water at the bottom steps, of the *ghat,* bathers will need to wade further into the stream, or pour water over themselves. Sand banks will be visible and ferrymen will need to make detours to cross the river. This is acceptable in a drought year.			
Livelihoods	151	2.89	0.82
At the suggested flows, the livelihood activities are supposed to provide reasonable profits. In this case the fishing levels may not be maintained. Overall, the communities who depend on livelihoods such as fishing and ferrying will be able to earn reasonable profits.			
Recommended Flows: 193.8 m^3/s (Biodiversity)			

Photo Credit: Sandeep Behera / WWF-India

Figure 5.9: Soft shell turtle *(Aspideretes gangeticus)* is an endangered species, mainly due to habitat degradation

Table 5.12: Critical flow requirements and their motivations at Bithoor for August in a drought year

Speciality	Critical Flows (m^3/s)	Depth (m)	Average Velocity (m/s)
Biodiversity	498	4.09	1.16
Flood/high-flows bring much needed silt and nutrients into the flood plains for the survival and growth of algae, macrophytes and riparian vegetation. These flows are important for the regular flushing of the accumulated debris and xenobiotics which harm the biota due to the activities at the river banks. The channel width will offer shallow substratum rich in slit and detritus for the establishment of a good plankton population for fish, and periphyton for the gastropods and other micro-invertebrates and fish. It will increase the food sources needed for dolphins, *gharial* and turtles. This will also help in maintaining a natural ratio of Carp to Catfish, as the latter has outnumbered the former. During drought flows, the water should touch the shrub zone for a fortnight to sustain the riparian vegetation.			
Fluvial Geomorphology	330	3.5	1.03
In a drought year, lateral and longitudinal connectivity should be developed at least in the wet period to help the sediment and nutrient transport between different compartments of the river.			
Cultural and Spiritual	1469	6.08	1.5
The community expects that the temple of Brahma be inundated in the monsoon, seeing this inundation as a washing of Brahma's feet. While this might not occur throughout the monsoon, it does need to occur at least once a year. The suggested flow should satisfy this requirement.			
Livelihoods	431	3.9	1.11
At the suggested flows, the livelihood activities are supposed to provide reasonable profits. In this case the fishing levels may not be maintained. Overall, the communities who depend on livelihoods such as fishing and ferrying will be able to earn reasonable profits.			
Recommended Flows: 1469 m^3/s (Cultural and Spiritual)			

Table 5. 13 summarises the recommended flows for each site indicating the component that determined the critical flow as a requirement to meet specific objectives.

Table 5.13: Critical flows agreed upon for various sites and seasons

Scenario	Critical Flows (m^3/s)	Depth (m)	Average Velocity (m/s)	Component
KAUDIYALA				
January – Maintenance	400	9.5	0.64	Fluvial Geomorphology
August – Maintenance	3250	21.05	1.15	Biodiversity
January – Drought	290	8.28	0.57	Livelihoods
August – Drought	1469	16.28	0.91	Biodiversity
KACHLA GHAT				
January – Maintenance	300	3.49	0.38	Biodiversity
August – Maintenance	1740	5.52	0.3	Cultural and Spiritual
January – Drought	161.5	2.99	0.33	Biodiversity
August – Drought	551	6	0.33	Cultural and Spiritual
BITHOOR				
January – Maintenance	330	3.5	1.03	Biodiversity
August – Maintenance	3303	8.08	1.2	Cultural and Spiritual
January – Drought	193.8	3.08	0.88	Biodiversity
August – Drought	1469	6.08	1.5	Cultural and Spiritual

5.4 CONFIDENCE IN THE E-FLOWS RECOMMENDATIONS

All the specialists assessed the information available at each of the sites, in terms of their confidence in the assessment methodology and recommendations, and the need for further work to increase these confidence levels. The assessment was based on a scale of 5 (= absolute certainty) to 1 (= very uncertain).

The BBM methodology was assessed as robust and the level of confidence as high, since the justifications are scientific in nature and based on firm background knowledge.

On average, the expert groups were less confident in the specific flow recommendations, giving 3 marks out of 5 (equivalent to reasonable confidence, but with some uncertainties).

The specialists' major uncertainties centered on the unavailability of long-term hydrological records, which meant that E-Flows recommendations could not be checked against measured present or historical flow trends. The surveyed cross-sections, (which provided the data for the hydraulic model which converted flow depths, velocities and widths to discharge), needed improvement.

Only one calibration flow measurement was taken at each cross-section, resulting in low confidence in the extrapolations in the model and the flow readings. These uncertainties can be reduced by further calibration of cross sections.

Table 5.14 summarises the levels of confidence expressed by the specialists in their findings. The confidence forms are attached in Annexure – 8.

Table 5.14: Critical flows agreed upon for various sites and seasons

Speciality	Confidence score	Reason
Kaudiyala		
Hydrology	2	Unavailability of flow data at or near to the site; Rainfall from upper catchment could not be accurately estimated; Model did not simulate glacial contribution.
Fluvial Geomorphology	3	Conceptual understanding of geomorphic process is good, however this can be improved with the help of repetitive cross sectional and flow measurements.
Biodiversity	3	Recommendations are based on scientific observations, however confidence level may improve, if the relationship between flow and ecology could be explicitly ascertained.
Livelihoods	3	Recommendations are a mix of opinion by the respondents and the group.
Water Quality	4	The available water quality data and trends over the past clearly concludes that water quality is not an issue here, as the existing water quality matches the designated best use of the river.
Cultural and Spiritual	3	Since the respondents have clearly articulated the water levels desired at the banks/bridges, the group could understand this with clarity. However the group observed that Rishikesh is more important from their perspective than Kaudiyala.
Kachla Ghat		
Hydrology	4	Inadequate data from Narora and Bhimgoda barrage, i.e. longer time series data from both the points is needed.
Fluvial Geomorphology	3	Geomorphic evaluation has been reasonably satisfactory, however high resolution topographic data could have enabled the demarcation of different geomorphic units with more accuracy.
Biodiversity	2	Uncertainty about flow availability from the available cross section.
Livelihoods	3	Difficulty in setting the recommended flow for maximum productivity in the drought year.
Water Quality	5	The group was not very confident about the recommended flows, but was absolutely convinced about the methodology. The score given by them actually indicates their satisfaction level about the methodology.
Cultural and Spiritual	4	Survey of the rated cross section was done together with the biodiversity group, which enhanced confidence level. Available rated cross section has limited width. The survey needed to include a much wider cross section (across the entire width of the floodplain).

Continue...

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Bithoor		
Hydrology	3	Inadequate data from upstream barrages. There is a need for longer time series data; Unavailability of dry season flow data from Kanpur barrage.
Fluvial Geomorphology	4	Geomorphic information and understanding of this site is good.
Biodiversity	3	Largely satisfactory, however uncertainties arise due to lack of real time flow data and lack of precise information about the cross section.
Livelihoods	3	Overall opinion of interviewees largely complemented the flow requirements suggested by other groups.
Water Quality	5	The group was not very confident about the recommended flows but was absolutely convinced about the methodology. The score given by them actually indicates their satisfaction level about the methodology.
Cultural and Spiritual	4	Respondents clearly articulated the water levels desired at the bank/bridge, so the group could understand the needs with clarity. The available rated cross section has limited width: Survey needs to include a much wider cross section (across the netire floodplain).

As a follow up to the evaluation, the groups also discussed the ways in which the confidence levels could be improved. It was concluded that the level of confidence could be improved by supplementing the existing information/datasets. The groups felt that the following critical information requirements would do most to increase the levels of accuracy and confidence in their recommended flows:

Hydraulics

- More comprehensively surveyed cross-sections, including the entire width of the floodplain.
- While surveying the cross-sections, substrate types, prominent features and vegetation types to be captured so as to allow specialists (fluvial geomorphology, biodiversity, livelihood etc.) to estimate E-Flows in relation to these features.
- Additional flow measurements at high and low flows, to calibrate the depth/discharge model.

Hydrology

- Measured flow/discharge data.
- Rainfall datasets from the upper catchment.
- Simulation model or for glacial contribution.
- Flow data from barrages/dams.
- Longer time series data.

Fluvial geomorphology

- High resolution topographic data.
- High resolution images at regular intervals for assessing geomorphic variability.
- More detailed habitat information for different biota.

- Improved hydraulic modeling using the cross section extending up to floodplain boundaries.
- Validation of hydrologic models with observed data particularly for high flows.

Biodiversity

- More research to ascertain relationships between flows and ecological indicators.
- Validation of cross sections in consultation with biodiversity group.
- Cross section extended to floodplain boundaries and information pertaining to the usual duration of submergence of flood plains.
- Information related to the type and concentration of sediments and nutrients brought into the river course and floodplains.
- The impact of xenobiotics and organic load to be assessed across the spectrum of biodiversity, especially for critically endangered species.

Livelihoods

- Information on post-flood fisheries in floodplain lakes.

Water quality

- Information on point and non-point sources of pollution, particularly nutrient and pesticide load.
- Analysis of long term changes in terms of pH and salinity levels.
- More hydraulic sections for more accurate stage-discharge modeling.

Cultural and spiritual aspects

- Rated cross section at bridges in Rishikesh, just downstream of Ram Jhula.
- Measured velocities at identified bridges for various flows.
- Surveying of cross sections to include the entire width of the floodplain.
- Validation of both hydrological simulation and stage discharge curve.

5.5 REFLECTIONS AND CONCLUSIONS

This was the first attempt to carry out a comprehensive assessment of E-Flows for a river in India. Previous EF assessments for Indian rivers by IWMI were primarily based on the use of hydrological information and were largely desktop exercises.

The E-Flow assessment in this study integrated multiple disciplines including ecology, geomorphology, water quality, social/cultural and livelihood aspects, in order to provide a holistic assessment of environmental objectives and the flows needed to achieve them.

The EFA assessment brought together different knowledge sets and perspectives which helped shape the holistic approach to the EFA. The composition of the multi-disciplinary, multi-stakeholder team and partnership constituted to carry out the EFA was critical.

The specialist groups made use of existing and historical information and databases, and supplemented these with carefully designed and directed fieldwork.

The BBM proved to be a robust, easy to use and adaptable methodology for the working groups unfamiliar with E-Flows.

Without detracting from the effective and useful outcomes of the EFA, it is important to acknowledge some short-comings which can hopefully be learned from and improved upon in future Indian E-Flows initiatives, and in taking forward the sustainable management of the river Ganga:

- The non-availability of the extensive hydrological database for such (or any other) initiatives reduced the confidence of the flow recommendations.

- There is a need to improve cross-sections, i.e. the surveyed cross-sections could be extended across the floodplains. This would have had significantly enhanced the ability of the biodiversity, livelihood and spiritual/cultural groups to link their requirements to specific features of the river channel at the study sites.

- A more detailed knowledge of the hydraulic habitat requirements to ensure the persistence of different biotic communities could have improved the recommendations of the biodiversity group.

- The impact of recommended flows on diluting the pollution in the river, and on the ability to provide appropriate water quality to enable the survival or recolonisation of sensitive species needs to be studied in more detail.

Despite these constraints, the project has adapted and pilot tested a holistic EFA methodology in the Upper Ganga Basin, for the first time in India and built national capacity to conduct further EFA for Ganga and other rivers in India.

References

Smakhtin, V.; Anputhas, M. 2006. An assessment of environmental flow requirements of Indian river basins. Colombo, Sri Lanka: International Water Management Institute. 42p. (IWMI Research Report 107)

A sunrise near Allahabad offers a picturesque view of the confluence. Ganga and Yamuna merge at Sangam, while it is widely believed that Saraswati - the third river at confluence - has ceased to flow

Photo Credit: Amrit Pal Singh

Photo Credit: Sandeep Behera / WWF-India

The Ganga river supports a rich variety of flora and fauna all along its course. Seen here is Cormorant in Ganga

Chapter 6
THE WAY FORWARD

This report presents the results of the first comprehensive assessment of E-Flows requirements for a major Indian river. The project has been a learning experience, both for WWF-India, and for the members of the specialist working groups who provided the expertise for the assessment.

The report has therefore been designed, not only to present the recommendations of the teams, and the motivations for the required flows, but also to describe in detail the process and methodology adopted, and to explain how this has been adapted to meet the challenges presented by the unique characteristics of the Ganga. We have not shied away from the uncertainties, the lack of data and the incompleteness that are an inevitable consequence of such ground-breaking work.

The report should therefore be viewed as a case study, and as a hand-book for similar studies on other Indian rivers. The results should be seen as preliminary, rather than definitive, and are intended to summarise existing knowledge, to spark debate about the state of the Ganga, and to suggest further research that would improve the confidence in the recommendations. This chapter makes suggestions as to how this work can be used and taken forward.

This preliminary assessment of the E-Flows requirements for the Upper Ganga from Gangotri to Kanpur has contributed to a much greater awareness among freshwater scientists, water resources managers (mainly engineers) and policy makers. One of the major spin-offs from this initiative are that, the capacity has been built and strengthened amongst experts and organisations who would be able to undertake various aspects of EFA for Indian rivers. Further, the knowledge and the databases on biodiversity, geomorphology, water quality, livelihoods and spiritual/cultural issues have been significantly enhanced for the Upper Ganga.

As an initial stepping stone in EFA for Indian rivers, this work has provided a detailed experiment of the application of field-based assessment of E-Flows, which will hopefully take the debate to the next level. There are, however, several challenges, which need to be addressed before the concept of E-Flows is mainstreamed into river basin policy and planning. These include the E-Flows assessment itself as well as implementation.

6.1 CHALLENGES IN THE ASSESSMENT OF E-FLOWS FOR THE UPPER GANGA

The Building Block Methodology that was used during the assessment and recommendation of the E-Flows was exhaustive and comprehensive, and the confidence level in the methodology itself was very high, with the recommended flows firmly based on scientific motivations and consultative processes. However, the confidence level of the results could be improved by making adequate and more reliable data available for such studies. WWF-India and its partners were faced with several challenges during the assessment and recommendations of E-Flows for the Upper Ganga.

Data availability

The source of flow data for this exercise included:

- Global datasets;
- flow data from the Uttar Pradesh Irrigation Department available in the Public domain
- Data and information from previous research studies.

Requirements to improve the level of confidence in the results include observed/real time flow data, high resolution satellite images, and further research to understand the relationship and localised inter-dynamics between the flows and other key ecological components such as riparian flora and fauna. Simulation of basin-wide water allocation scenarios with inclusion of E-Flows under current and future climate scenarios would require long-term climate change and hydrology related data. The assessment of E-Flows is an evolving process, with the levels of confidence being improved based on any new data that emerges over time.

Setting the Ecological Management Class of rivers

Setting the Ecological Management Class (EMC) of rivers is the aspect that determines the desired future state of the river, in terms of the needs of its ecosystems and of the people who depend on it to function at a particular level.

In this study, the recommended EMC's were set by the specialist teams. Ideally, this process requires the identification of the EMC to be done in a consultative manner, which should ensure that the aspirations of the local community as well as the ecosystem's needs are accommodated. Given the size and scope of this project, and the central role played by the Ganga in environment and in the spiritual and day to day lives of its people, ensuring a fully consultative and equitable process in the setting of the EMC for the various river reaches is a daunting responsibility.

6.2 CHALLENGES IN THE IMPLEMENTATION OF E-FLOWS IN THE UPPER GANGA

This study has made the first attempt to define the required flows to be maintained in the Upper Ganga, in order to achieve defined EMCs and objectives.

It does not, however, address the much more difficult question of how these E-Flows can be maintained or restored in the river. Across the globe, Governments and water management authorities have made significant progress in developing policies and laws to recognise the need for E-Flows. Despite this, in the majority of cases, the provisions for E-Flows remain at the stage of policy and debate rather than of implementation.

Absence of an enabling policy environment in terms of the existing water uses, allocations and trade-offs makes implementation of E-Flows in India an intricate and challenging task.

There is a need to initiate a process to assess the E-Flows requirement of all the rivers in the country. This would ensure that any decision related to basin planning would be influenced by the knowledge of E-Flows. Representative study sites need to be identified to ensure consistency of results. The type of locations that could be considered for study sites include:

- Major abstraction/diversion structures;
- Confluence with tributaries;
- Downstream of cities, and
- Places of religious/heritage/livelihood importance.

In many parts of the Ganga, flows are already over-allocated, and the provision of E-Flows would require either that existing uses are rationalised, or that additional storage is provided to intercept monsoon flows for allocation during the dry season. Both of these solutions are complex and would entail costs, as well as social and environmental impacts.

In this preliminary project, no attempt has been made to evaluate the costs and benefits of implementing E-Flows, but this would be a priority for further development.

Two principles should be introduced here:

- Implementation may be phased and gradual: It is not necessary to deal with the implementation of E-Flows as an "either/or" situation. E-Flows are by their nature a balance between maintaining a healthy environment in the river, and using the river's resources for economic benefits – the balance between use and protection of the natural resource. Further, the environmental and social costs of environmental degradation of rivers is usually a gradual process – as more water is abstracted, the reduction of the ecological goods and services on which people rely is not a sudden threshold. This makes decisions about the threshold of acceptable exploitation difficult for water resources managers (mainly engineers) and policy makers. However, it also allows a gradual process of implementation, in which, if it is too difficult or expensive to implement all the recommended flows immediately, small steps can be undertaken to improve E-Flows (e.g. an initial increment of dry season low flows that meets some proportion of the recommended E-Flows quota). The effects of initial steps can then be evaluated before further implementation is considered. This adaptive management process is well-suited to E-Flows implementation.
- The results of implementation may emerge slowly: The costs and benefits of consumptive water use are usually quite simple to calculate, at least in the short-term, but the environmental costs and benefits are often very long-term and complicated. For example, this initiative has highlighted that the spiritual value of the Ganga is of overwhelming importance, and is founded in history and culture. How those values are compromised by environmental degradation is multi-faceted and extremely complex. The actual volume of water required for purification rites is very little, and the perceived holiness of the river leads to the belief that even a few drops of water are sufficient for rituals. This is reflected through a quote from one of the respondents at Haridwar, *“The water should be enough to cover a cow’s hooves, even this will do. But ideally it should be up to the waist for a holy bath”*. So it is far from easy to compare the short-term profit/loss accounts of consumptive uses against the long-term historical and future cultural/spiritual and ecological consequences of exploitation versus sustainable management.

Two issues are typically highlighted during any EFA process: the source of the water required to achieve the desired future state and whether the recommended E-Flows can practically be implemented. These are indeed difficult challenges but ways can generally be found to address them.

Finding the water for E-Flows

In the present water sector scenario of the country, the rivers and other water bodies have served Indian citizens in many ways, as sources of drinking water, domestic supply, irrigation, hydropower and industry. However, over time, the ecological/environmental, socio/cultural and recreational requirements of rivers have largely been overlooked, and this is reflected in the prioritisation of various uses of water in the National Water Policy, 2002, in which ecology comes as the fourth priority. The prioritisation of water usage at national level, as mandated by the policy is:

1. Drinking water
2. Irrigation
3. Hydro-power
4. Ecology
5. Agro-industries and non-agricultural industries
6. Navigation and other uses

A dialogue has been initiated by the Ministry of Water Resources (MoWR) to seek people's opinions in order to formulate amendments to the policy. The Draft National Water Policy 2012 is now available on the website of MoWR, which, under section 3.1 recognises, that "Ecological needs of the river should be determined recognising that the natural river flows are characterised by low or no flows, small floods (freshets), large floods, etc., and should accommodate developmental needs. A portion of river flows should be kept aside to meet ecological needs ensuring that the low and high flow releases are proportional to the natural flow regime, including base flow contribution in the low flow season through regulated ground water use". Later on section 3.3 states that, "after meeting the minimum quantity of water required for survival of human beings and ecosystem, water must be used as an economic good with higher priority towards basic livelihood support to the poor and ensuring national food security". However, there is still a long way to go, as various stakeholders still need to understand the vitality of rivers from an environmental perspective.

Since water resource management is a State function in India, each State formulates its own water policy using the National Water Policy as its basis. This means that the need to address the issue of flows occurs at the level of Central Government, but that a bottom-up consultative process with the States is required.

The share of water required for the environmental needs to be continually negotiated, especially for the river Ganga. Ultimately, it all comes down to the question of, 'how we wish to see river Ganga – a free-flowing mighty entity or a tiny rivulet!'

The other related issue here is also to re-examine some of the existing water allocations, uses and trade-offs. This would mean rationalising or re-allocating existing abstractions, for example to hydropower, agriculture, industries and urban use, within a basin or sub-basin. It is important to have a demand management strategy that will reduce the "water footprint" of agriculture, cities and industries. Simultaneously, efforts to increase base flows to supplement river flows would also be needed.

Managing the required flow regime

Implementation of E-Flows in the Ganga river will present challenges. If the decision is made to implement the E-Flows, restoring dry season flows in the river will require some revision of water allocation policies. To assist with such difficult decisions, a study is required that would quantify and compare the costs and benefits of providing the E-Flows against those of the present consumptive uses. Ultimately, the decision to look after the Ganga River in the long-term, is to be based on societal values and judgement.

The institutional and operational framework presents another implementation challenge: Given the multitude of organisations working on water in India, the framework for the implementation and monitoring of E-Flows becomes important. The key questions are who will implement, who will monitor and what will be the enabling policy and legal environment? Transparent, effective, democratic institutions and rules for water allocation and management are essential for the implementation of E-Flows. It is important to debate this and take a phased approach to implementation. This could include increasing the level of detail of the scientific assessment to refine the methodology and the values, resulting in increased confidence in, and detail of recommended flow regimes.

6.3 PROOF-OF-CONCEPT PILOTS

It is imperative to pilot the EFA and implementation in a manageable river basin or a sub-basin, especially in light of growing concern for rivers around the country. It is also important to demonstrate and test the various mechanisms for the enforcement and monitoring of E-Flows. This would help in refining the strategy for mainstreaming the implementation of E-Flows both at river basin and national level.

Recognising that the implementation of E-Flows in the main Ganga River will be a complex and long-term process, it would be very useful to develop a small-scale pilot implementation of E-Flows in a tributary sub-basin. This would demonstrate the benefits and possibilities for E-Flows in the short-term, which would be especially effective in building on the growing concern for rivers around the country.

There is a need to develop a model for successful implementation of E-Flows in Indian rivers. There is a growing number of successful implementation pilots in other parts of the world (the USA, Australia, South Africa, Lesotho and China among others), but a local example would be far more effective to convince authorities and stakeholders of the viability of the concept. An effective demonstration will also showcase the variety of benefits to society and for the ecosystem as a whole.

Both cases, i.e. an over-allocated basin, and a less-stressed river basin can be ideal pilots, as each have their own significance. In an over-allocated basin, an EFA followed by implementation of E-Flows will demonstrate how E-Flows can help the river to retain its sustainability, and more specifically how to balance competing uses. On the other hand, a less-stressed basin can provide an opportunity for future planning and allocation, whilst keeping in mind the essentials of sustainable river health before undertaking or authorising development within the river basin.

Nevertheless, for both the cases, such a sub-basin pilot needs to be carefully selected in terms of the following aspects:

1. A small tributary sub-basin, so as to reduce the number and variety of stakeholders and simplify the issues, assuring a rapid assessment and consensus, minimising the time delay to implementation.
2. A local authority which recognises the opportunities and advantages of E-Flows.
3. A river with important ecological aspects to highlight the importance of flow maintenance for biodiversity.

Meeting all the above requirements may not be possible in one sub-basin, but the priority would be to put a pilot study in place as soon as possible, to provide an effective demonstration that would complement and support the much larger and longer term efforts for the implementation of E-Flows on the main Ganga River. There is certainly the expertise and, to some extent, the political will to develop a successful E-Flows programme for the Ganga basin, and to use this to promote a programme of sustainable development for India's water resources as a whole.

6.4 TAKING THE WORK IN THE GANGA BASIN FORWARD

Over the past two decades, there has been a gradual acceptance within the Indian water sector of the need to look after rivers and other natural water resources. From an initial policy of complete exploitation (any drop of water reaching the sea is wasted), there is now an acceptance of the idea of maintaining at least some flow in rivers (the idea of "minimum flow").

More recently, there has been a growing concern not only amongst environmentalists, but also in government circles, about the deteriorating state of rivers in the country. In this context, the current condition of the Ganga is no better than many other rivers in India, despite the fact that this river is considered as a goddess or mother according to Hindu mythology. To add to its importance, the Government of India also declared the Ganga as a 'National River' in late 2008.

The MoEF, through a Gazette Notification, formulated the National Ganga River Basin Authority (NGRBA) in February 2009, whose chairman is the Prime Minister of India and members include state governments of riparian states, civil society members and scientists. The MoEF assigned the responsibility of the preparation of Ganga River Basin Environment Management Plan (GRBEMP) to the consortia of seven IITs in October 2009.

With a view to benefiting from the diverse expertise available, and in order to approach basin management planning in a comprehensive manner, the IITs have partnered with several institutions and organisations including WWF-India. Through this platform, an attempt to integrate the EFA into the basin plan is being made. The team engaged in preparation of this plan has recognised and adopted the same methodology, as used in the upper Ganga study, for assessment of E-Flows, i.e. the BBM with some modifications, for the complete stretch of river Ganga. The next step is to assess the E-Flows at different critical locations along the 2,525 km stretch of the river.

Once the plan is finalised, the implementation stage will be initiated. Implementation will have to deal with complex challenges, such as the trade-offs necessary to free additional water for E-Flows; changes to present demand under different future trajectories; the possibilities for water re-allocations, and, perhaps most importantly, reaching a consensus among wider stakeholders.

It is hoped that this work would inspire the different Union ministries including the MoEF and MoWR, the State Governments, academics, and civil society organisations to build on the knowledge base on E-Flows and move towards its implementation. There is a lot of capacity building needed on this count.

India will need to urgently work towards an implementable policy that demands fresh water in its rivers, with E-Flows an important part of the strategy. If this becomes an integral part of India's water policy and management strategy, it can be hoped that our rivers can still be brought back to life.

References

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Photo Credit: Amrit Pal Singh

For a living Ganga

LIVING GANGA PROGRAMME

The HSBC Bank Climate Partnership is a groungbreaking partnership between the HSBC and WWF-India. The Climate group, Earthwatch Institute and the Smithsonian Tropical Research Institute, to combat the urgent threat of climate change by inspiring action by individuals, businesses and governments worldwide.

In India, this partnership supported WWF-India's Living Ganga Programme (LGP), which aimed to develop and implement integrated strategies for sustainable energy and water resources management within the Ganga basin in the face of climate change. The critical stretch of 800 kilometers in the upper Ganga, from Gangotri to Kanpur was identified.

The programme has four arms—research, demonstration (pilot) projects, policy advocacy and communication and awareness creation. In order to have an integrated approach to Ganga basin management, LGP brought together components of climate adaptation, vulnerability assessment, environmental flows and water allocation coupled with pollution abatement and co-management of water and energy. The programme also established partnership with key stakeholders with a focus on river restoration, community education and engagement, business and government involvement, and biodiversity conservation.

Thematic areas

- Sustainable Water Management
- Vulnerability Assessment and Climate Adaption
- Pollution Abatement
- Water and Energy Co-management
- Sustainable Hydropower
- Biodiversity Conservation
- Communication and Business Engagement

ANNEXURE

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