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INTEGRATED WATER RESOURCES MANAGEMENT PLAN FOR BHAGIRATHI BASIN IN UTTARAKHAND, INDIA

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INTEGRATED WATER RESOURCES MANAGEMENT (IWRM) PLAN FOR BHAGIRATHI BASIN IN UTTARAKHAND, INDIA

This is an initiative called 'Developing a Glacio-Hydrological Model and IWRM Plan for a Selected Subbasin in the Central Himalayas, Uttarakhand, India' under Strengthening Climate Change Adaptation in the Himalayas (SCA-Himalayas) project of the Swiss Agency for Development and Co-operation (SDC) implemented by FutureWater and University of Utrecht (the Netherlands), University of Geneva (Switzerland) and TERI (India).

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LIST OF ABBREVIATIONS

ATMA	Agricultural Technology Management Agency
BDOs	Block Development Officers
BRVDA	Bhagirathi River Valley Development Authority
CDB	Community Development Blocks
CMIP6	Coupled Model Intercomparison Project Phase 6
CSA	Climate-smart agriculture
CSWCRTI	Central Soil and Water Conservation Research and Training Institute
CWC	Central Water Commission
DECCC	Directorate of Environment, Conservation and Climate Change
DSM	Demand Side Management
DSS	Decision Support Systems
EIA	Environment Impact Assessment
G.B. Pant-NIHE	G.B. Pant National Institute of Himalayan Environment
GLOF	Glacial Lake Outburst Flood
IWRM	Integrated Water Resources Management
MCM	Million Cubic Meters
NBSS & LUP	National Bureau of Soil Survey & Land Use Planning
NDC	Nationally Determined Contribution
NGO	Non-Governmental Organization
NIH	National Institute of Hydrology
NITI Aayog	National Institution for Transforming India
NWM	National Water Mission
PHED	Public Health and Engineering department
PMUY	Pradhan Mantri Ujjwala Yojana
PPPs	Public Private Partnerships
SAPCC	State Action Plan on Climate Change
SARRA	Spring and River Rejuvenation Authority
SBA	Scenario-based approach
SDC	Swiss Agency for Development and Cooperation
SPHY	Spatial Processes in Hydrology
SRI	System of Rice Intensification
UGBO	Upper Ganga Basin Organisation
UJVNL	Uttarakhand Jal Vidyut Nigam Limited
USDMA	Uttarakhand State Disaster Management Authority
WEAP	Water Evaluation And Planning system
WIHG	Wadia Institute of Himalayan Geology
ZMP	Zonal Master Plan

1 INTRODUCTION

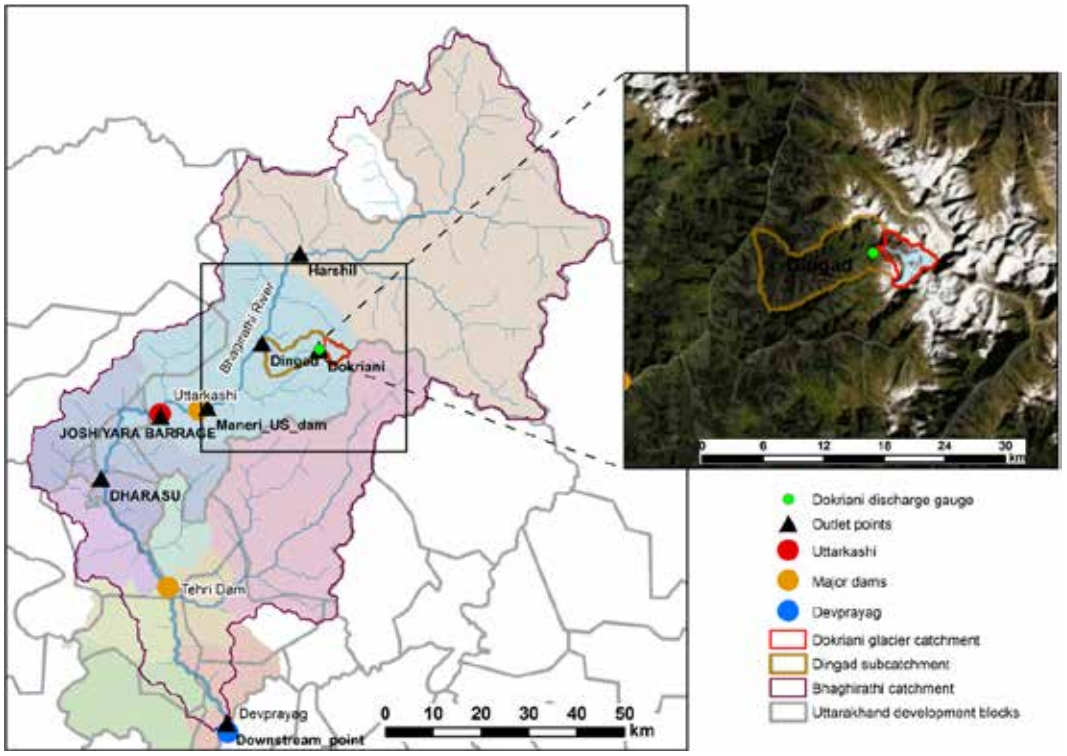
1.1 Background

The State of Uttarakhand, formally known as *Uttaranchal*, was formed on 9th November, 2000 as the 27th State of India. It is situated in the Himalayan region (northern part of India) and covers an area of 53,483 km^2. The State is divided into two major administrative units (Garhwal and Kumaon) with a total of 13 districts, i.e.: Uttarkashi, Dehradun, Haridwar, Tehri, Pauri, Rudraprayag, Chamoli, Bageshwar, Almora, Nainital, Pithoragarh, Champawat and Udham Singh Nagar.

Uttarakhand includes the high mountains and foothills of the Himalaya, resulting in a perennial source of fresh water coming from numerous glaciers and snow-clad mountain peaks. Water discharge from glaciers (1,439 glaciers in total for the Uttarakhand Himalaya; Sati, 2020) and snow melt contribute to streams, lakes, ground water as well as hundreds of small and big rivers in the State, such as the Bhagirathi, Alaknanda, Yamuna, Gori and Kali rivers. The mighty and culturally significant Ganges river originates out of these headwaters. In total, Uttarakhand is characterized by 8 major river catchments, 116 sub watersheds and 1,110 micro watersheds (NWM, 2018) which act as the lifeline for the entire hydrological system of the State, and downstream areas.

Uttarakhand is therefore endowed with numerous water resources which are available in abundance. These water reserves benefit communities (e.g., drinking and domestic use) and are mostly used for agriculture. Indeed, the agriculture sector is the greatest consumer of water in the State, accounting for 75% of total water demand. Water reserves are also used for activities related to industry, tourism (e.g., river rafting and kayaking) and hydro power as demonstrated by the 244 hydroelectric plants (under construction or in operation) dotted along Uttarakhand rivers.

Despite the State's multiple water reserves, water availability remains scarce in many districts. This lack is linked to: (1) challenges in the distribution and sustainable management of water resources; (2) greater demand for water resulting from urban expansion and improvement in living standards. Indeed, the total population of the State increased from 5,726,000 inhabitants (1981) to 10,086,292 inhabitants (2011; Census of India). Furthermore, the quality of water seems to have deteriorated in some regions, resulting in illnesses and difficulties to guarantee good quality standards (ZMP, 2018). As a consequence, management of water resources and supply systems no longer meet community needs. Similarly, soil erosion, frequent floods, landslides, cloud bursts, droughts as well as climate change impacts have become crucial issues for water management practices (Field and on Climate Change, 2012; SAPCC, 2014; NWM, 2018). This is the case for the Bhagirathi river basin, one of the critical water resources of the State and the study area for the Integrated Water Resources Management (IWRM) plan presented in this document. The river basin under investigation corresponds to the Bhagirathi Basin, located in



■ **Figure 1**. Overview of the study area
Source: own elaboration

two districts, i.e., Uttarkashi and Tehri. Figure 1 provides an overview of the study area. An overview of the key characteristics of the basin is provided in Farvacque et al. 2022.

Swiss Agency for Development and Cooperation (SDC), as part of its strategy on climate change adaptation, has been partnering with the national and the sub-national governments of the Himalayan States for water resources management. SDC is supporting the operationalization of climate change adaptation actions in the State of Uttarakhand through the "Strengthening Climate Change Adaptation in Himalayas (SCA-Himalayas)" project during 2020-25. The project works in close collaboration with the Directorate of Environment Conservation and Climate Change, Government of Uttarakhand.

The initiative "Developing a Glacio-Hydrological Model and IWRM Plan for a Selected Subbasin in the Central Himalayas, Uttarakhand, India", is part of SDC's SCA-Himalaya project and aims at the development and application of glacio-hydrological models and approaches for integrated water resources management (IWRM) for a selected glacier-fed sub-basin system in

Uttarakhand. The project also builds capacity and develops guidelines for paving the way for the replication of the approaches across IHR and other mountainous regions.

The main activities of the project are:

1. Glacio-hydrological modelling and climate change impact analysis for the Dokriani glacier watershed
2. Integrated Water System Modelling platform and IWRM plan for Bhagirathi basin
3. Guidelines for glacio-hydrological modelling, IWRM and DSS for IWRM in the Indian Himalayan Region context, and capacity building

1.2 IWRM concept and principles

The IWRM concept emerged around the 1980s in response to increasing pressures on water resources from competition amongst various users for a limited resource, the recognition of ecosystem requirements, pollution and the risk of declining water availability due to climate change. IWRM is based on the understanding that water resources are an integral component of the ecosystem, a natural resource, and a social and economic good. Other basic aspects of IWRM are the enabling environment of appropriate policies and laws, institutional roles and framework, and management instruments for the involved agencies to apply on a daily basis. As maintained in the guidelines for Integrated Water Resources Development and Management by CWC (2016), "IWRM addresses both the management of water as a resource, and the framework for provision of water services to all categories of users, and it addresses both water quantity and quality. The basin/sub basin must be recognized as the basic unit for planning and management, and a firm societal commitment and proper public participation must be pursued." (Guidelines, 2016: 2)

One of the IWRM underlying principles is the recognition that the different uses of finite water resources are interdependent. High irrigation demands and polluted drainage flows from agriculture mean less freshwater for drinking or industrial use; contaminated municipal and industrial wastewater pollutes rivers and threatens ecosystems; if water has to be left in a river to protect fisheries and ecosystems, less can be diverted to grow crops. Several other examples can be reported in relation to the IWRM assumption that unregulated use of scarce water resources is wasteful and inherently unsustainable. Thus, it must be reduced as much as possible.

Further, IWRM adopts a holistic approach that seeks to integrate the management of the physical environment within that of the broader socio-economic and political systems. The river basin management is a key component of IWRM, and it seeks to focus on implementing IWRM principles, on coordination amongst operating and water management entities within a river basin, on allocating and delivering reliable water-dependent services in an equitable manner.

IWRM has three building pillars (the three "Es"): Social Equity (including poverty reduction), Economic Efficiency, and Environmental Sustainability (CWC 2016) (Figure 2).

In greater detail, social equity means ensuring "equitable access to water, and to the benefits from water use, between women and men, rich people and poor, across different social and economic groups both within and across countries, which involves issues of entitlement, access and control". Equity and justice considerations need to be taken into account in parallel. Procedural, distributional and restorative justice are also taken into account by focusing respectively on engagement processes for multi-stakeholder integration, distribution of vulnerability patterns and restoration/ compensation mechanisms (e.g., insurances).

Economic efficiency means bringing the greatest benefit to the greatest number of users possible with the available financial and water resources. This requires that the most economically efficient option is selected. The economic value is not only about price – it should consider current and future social and environmental costs and benefits.

Environmental sustainability requires that aquatic ecosystems are acknowledged as users and that adequate allocation is made to sustain their natural functioning. Achieving this criterion also requires that land uses and developments negatively impacting these systems are avoided or limited.

Last but not least, a core underlying principle of IWRM is that it covers and promotes the coordinated development and management of (1) water, (2) land and (3) livelihood-related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. Thus, water, land and people are three key regulators influencing the success of an IWRM.



■ **Figure 2**. The main underlying principles or pillars of the IWRM process

1.3 Scope and objectives of the Bhagirathi IWRM plan

In Himalayan basins climate change and socioeconomic development put pressure on water resources which are vital for domestic use, industry, agriculture, electricity generation and the natural environment. Under these pressures, a "business as usual" approach is no longer sustainable, and Indian authorities and wider stakeholders are calling for more integrated, inclusive, and transformative pathways for the basin`s future. To guarantee the sustainable use of the available water resources in climate change threatened glaciated watersheds, the development of a replicable IWRM approach for decision support tailored to glacier- and snowmelt dependent basins in the Indian Himalayan Region is a key missing link in the region's water management structures.

This document addresses this missing link and it presents an Integrated Water Resources Management (IWRM) plan for the Bhagirathi Basin, located in two districts, i.e., Uttarkashi and Tehri Garhwal. The main objective of the plan is to support the policy and decision makers from the mountain states in India to manage the available water resources in an efficient and effective manner, benefiting the populations dependent on these resources.

Importantly, for this IWRM plan, specific attention has been dedicated to climate change, by including inputs from glacio-hydrological modelling, climate change impact analysis, water allocation modelling and scenarios. Additionally, a Decision Support System (DSS) has been developed by incorporating the results of Bhagirathi river basin modelling, to support water related decision making processes.

This IWRM plan presents measures needed to address the risks related to impacts of climate change on hydrological regime of the region: "hard" measures (e.g., structural protection measures to reduce flood risk) are combined with "soft" ones (e.g., policies, regulations, institutions, capacity, etc). These measures comply with the regulatory framework for water management in the Bhagirathi basin that includes several acts and regulation along with national plans and regulations such as the State Action Plan on Climate Change. In this way, the adopted approach is in line with relevant water and climate policy frameworks (e.g. National Action Plan on Climate Change, Nationally Determined Contribution (NDC), etc) paving way for their replication across the Himalayas and other mountainous regions.

2 METHODOLOGY AND PROCESS FOR THE IWRM PLAN CO-DESIGN

2.1 Scenario-based approach

The methodology adopted for the IWRM plan co-design in the Bhagirathi River basin is based on the analysis of existing plans and guidelines as well as a review of participatory methodologies for IWRM and other plans co-design (Scolobig et al. 2016; Wada et al. 2020).

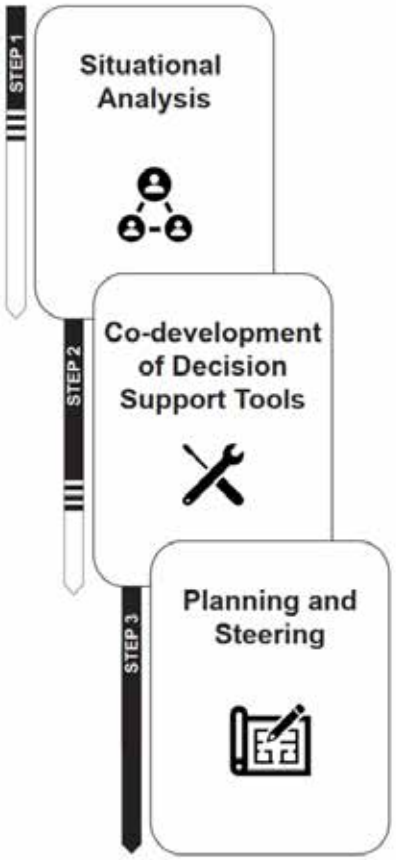
A building pillar of the methodology is the participatory scenario-based approach (SBA). This approach focuses on specifying the impacts of different solutions to a given problem and is widely used in different sectors, including climate modelling (in particular, also through integrated assessment models), water management or energy system modelling.

Scenario analyses are often done as pure desktop exercises with a computer model and no dedicated outreach to stakeholders, following a strict rational choice framework, typically seeking the least-cost option for a specific aim. Scenarios as a decision-making tool help us to better understand the implications of a wide range of future possibilities considering existing development plans, visions, strategies, and global interdependencies. In a typical scenario building process, scenario users jointly delineate their internal sphere of influence i.e., where they can effectively make decisions and develop policies, and an external sphere of uncertainty i.e., where they need to agree on most important but uncertain drivers, many of them global, which impinge on the decision-making space of national and sub-national actors.

In participatory scenario approaches, the participatory engagement can be done in many ways, from merely ranking the finished scenarios to quantifying input data, and setting scenario boundary conditions between stakeholders and modelers. The stakeholders' views/governance analysis is usually conducted at the beginning of the process and linked to the models in an iterative procedure as was done also for this study. From the governance analysis, a large number of potential measures were explored (see Chapter 4). Some of these, relate directly to water allocation, and were thus included in a scenario for water allocation. Then afterwards, these scenario results, were used in a stakeholder consultation, to set adaptation priorities (Chapter 5), Annex 1. A more structured way of presenting this approach, is discussed in the next section.

2.2 IWRM plan co-design

In this section, the key steps for the IWRM plan co-design are described (Figure 3). IWRM aims to analyze and balance environmental, social and economic aspects through a 3 steps process: i). situational analysis; ii) co-development of decision support tools; iii) planning and steering. For each step the objectives, methods, stakeholders, timeline and expected results are described in detail.



Why	*How*	*Who*	*When*	*What*
Objectives	**Methods**	**Stakeholders**	**Timeline**	**Expected Results**
Providing an overview of the water and climate risk issues	Stakeholder mapping, focus groups or interviews to analyse perspectives Analysis of regulatory frameworks	Sample based on stakeholder mapping	6 months to 1 year to conduct an in-depth study	Risk factors, challenges and opportunities
Co-determining scenarios	Glacio-hydrological and water allocation modelling, projections, interventions and adaptation options	Experts and selected stakeholders	6 months to 1 year depending on data availability	Scenarios
Prioritizing measures	Working groups, focus groups, documents on water and climate adaptation measures	Experts and selected stakeholders	6 months	IWRM plan, measures prioritization and future envisioning

- **Figure 3**. Key steps for IWRM plan co-design. IWRM aims to analyze and balance environmental, social and economic aspects through a 3 steps process

2.2.1 Step 01: Situational analysis

The process started with the characterisation of the current situation of the Bhagirathi basin, i.e., the governance analysis and the identification of key stakeholders and of the main water and climate risk management issues.

The in-depth situational analysis included the following aspects:

- Key water and climate risk management issues;
- Glacio-hydrological and water allocation modelling, including modelling of stream flow, assessment of future changes, water allocation model projections, analysis of water sources and demands;
- Water governance analysis, including stakeholder mapping, regulatory frameworks, human and economic resources (Farvacque et al. 2022).

A truly robust IWRM plan co-design process is built around stakeholder inputs. Thus, in this step it has been essential to understand opinions and views of stakeholders involved in water management. The analysis has been conducted through a literature review/desktop search and extensive stakeholder consultations including semi-structured interviews, surveys, focus groups and/or workshops.

The rationale for exploring these perspectives is that stakeholders have a wide range of preferences, values, and worldviews which make it difficult for everyone to agree on one single desired future. For example, divergent priorities manifest in relation to social equity and economic efficiency. Thus, trade-offs need to be addressed and discussed, e.g., developing large scale water infrastructure/dams vs. small scale nature-based solutions for flood risk reduction may lead to alternative pathways.

2.2.2 Step 02: Co-development of decision support tools

This step requires modelling and an analysis of different possible future options.Thus, the collaboration with experts (scientists, researchers, consultants) that have the scientific knowledge on water and climate risk management has been essential. Indeed glacio-hydrological and water allocation models are the background for the co-development of decision support tools (for an overview of the models please refer to the detailed Guidelines on developing glacio-hydrological models (Khanal et al, 2023). Based on a comparison of the potential impact of different possible future scenarios, priorities can be established.

Scenarios are a combination of factors which cannot be changed directly by the decision-maker (climate change, population growth) – this we refer here to as "projections"-; and factors which can be influenced, like infrastructure or agricultural practices – here referred to further as "interventions"/adaptation options. Climate adaptation is thus the response to climate change projections, through a number of interventions. These interventions are to be implemented following the IWRM approach, in which "hard" measures are combined with "soft" ones (e.g., policies, regulations, institutions, capacity, etc). The stakeholder perspectives on social equity, environmental sustainability and economic efficiency (i.e., IWRM key principles, see section 1.2) are the starting point to elaborate different scenarios. In this way stakeholder knowledge is integrated with the modelling and scenario results.

Earlier, glacio-hydrological modelling guidelines were prepared for the Indian Himalayan Region, based on the experience on the glacio-hydrological and water allocation modelling conducted in the Bhagirathi Basin (Khanal et al, 2023). These guidelines provide technical guidance on water resources modelling and scenario analysis and supported the development of the IWRM plan for the region.

2.2.3 Step 03: Planning and steering based on the IWRM plan

Based on the previous step`s results, the IWRM plan draft was prepared. It was presented and discussed in dedicated meetings with stakeholders. In parallel, other analysis (e.g. an IWRM opportunities and convergence analysis) were conducted by integrating a desktop search with interviews with selected stakeholders. Additionally, a decision support system (DSS) has been co-developed on the basis of stakeholder's needs to support development of an IWRM plan and to analyze various water demand-supply scenarios. All along this process, stakeholders and authorities at different levels of governments were consulted using tools like one-to-one meetings, focused group discussions, questionnaire-based surveys etc. (for an overview of stakeholder engagement methods see module 3). The key outputs of this step lead to finalization of IWRM plan (Annex 2).

The final IWRM plan and DSS were presented and discussed together with guidelines for implementation. Specific attention is placed on recommendations and future outlook. Importantly, the IWRM plan development is an iterative process, thus the plan can and must be updated and revised multiple times, e.g. every 5 years. Also, the IWRM plan approval is a process that allows to mainstream it through the different Government programs that play a key role for the IWRM measures implementation. The institutionalisation of a River Basin Development Organisation/Authority could represent a key actor for IWRM planning and implementation, in line with e.g. Meghalaya Basin Development Authority and with the institutional frameworks developed in several other countries (e.g. a vast majority of European countries).

2.3 Stakeholder Engagement

Across all the steps of the IWRM plan co-design described in section 2.2., stakeholder engagement played a key role. The stakeholder engagement process, that used multiple participatory methods, included:

i. a mapping of stakeholders involved in IWRM;
ii. consultations with 38 stakeholders including targeted semi-structured interviews (on-line, telephone and face to face) and one workshop to analyse water governance and identify the key water management issues;
iii. on-line polls to collect quantitative evidence on the key water management problems and solutions identified in the water governance analysis;
iv. two workshops to present the scenarios, glacio-hydrological, water modelling and to co-design the IWRM plan;
v. consultations meetings with more than 100 stakeholders with government officials, NGOs representatives and government departments to collect feedback about the IWRM plan draft and about the prioritization of the proposed adaptation measures;
vi. a survey submitted to 100 households from 4 blocks of Uttarkashi district to understand residents' perspectives.

Overall, more than two hundred stakeholders have been involved in the consultations or deliberations for the IWRM co-design process

3 SITUATIONAL ANALYSIS

3.1 Situational analysis – Bhagirathi Basin

Table 1 and 2 summarise the key issues emerged from the step 01 of the situational and governance analysis of the Bhagirathi basin. These issues are described in detail in Annex 3.

TABLE 1 Key water management issues

Main gaps	▪ Limited understanding of water systems ▪ Glacial lakes monitoring and warning systems ▪ Cascading effects between the climate and water crises ▪ Mountain depopulation and migration impacts on water management ▪ Agriculture impacts and urban population growth ▪ Biodiversity loss and ecosystem restoration ▪ Economic development and water scarcity
Water management solutions and good practices	▪ Local ownership of water management activities ▪ Spring rejuvenation and other good practices ▪ Local water stewardship and income-generating schemes ▪ Traditional solutions
Information Systems, Decision Support, Training Need Assessment and Capacity Building	▪ Capacity building targeted for communities and vulnerable groups ▪ Spring based decision support systems (DSS), DSS to identify climate and water crises hotspots ▪ Assessing impacts of water management solutions ▪ Training needs assessments
Decision Making Processes and Stakeholders	▪ IWRM planning ▪ Water supply and upstream vs. downstream conflicts ▪ Limited support for actions at the local level ▪ Equity and justice in water development programs, social vulnerability and under-represented groups in decision making, role of NGOs
Regulatory frameworks	▪ Regulation and compliance ▪ Groundwater law ▪ Institutional innovation, e.g. strengthening role of Bhagirathi River Valley Development Authority)
Finance	▪ Investment and financing structures ▪ New economic instruments and private sector role ▪ Promoting equitable distribution of financial resources and social change

TABLE 2: Interview and focus groups excerpts about the key water management issues

Key issues				
	Disaster management "serious threats related to Glacial Lake Outburst Floods, flash floods, cloud burst"	**Climate crisis** "water resources are depleting due to disappearance of mountain glaciers and rise of the snow line altitude"	**Urban development and population** "a greater demand for water resulting from urban expansion and improvement in living standard is expected in the future [...]"	**Energy and infrastructure** "infrastructural developments are often blamed as one of the causes of limited water availability (no regulations and planning related to water abstraction from the rivers) "
	Agriculture and allied sector "farmers are practicing flooded irrigation instead of drip irrigation"	**Rural development** "[...] resulting in water shortages"	**Public health and sanitation** "anthropogenic activities and environmentally detrimental practices have often degraded water resources"	**Biodiversity conservation** "need to generate awareness in order to maintain the ecological and biodiversity balance"

3.2 Glacio-hydrology and water availability: current and future projections

The climate of the region is influenced by two major climatic systems: the southwest Indian monsoon and the northern hemispheric mid-latitude westerlies (Khanal et al, 2021). During the past 20 years precipitation varied greatly across the basin with the north and northeast drier than the south (due to the topography of the region) (Khanal et al, 2021). July receives the most precipitation while November has the least. The monsoon season (June, July, August, and September) dominates the seasonal precipitation distribution and accounts for 64% of the annual precipitation. The average annual temperature within the basin ranges from -15.7 to 20.6°C. The northern region is colder compared to the southern parts. The annual average temperature has increased by 0.017°C per year in the past 30 years. The precipitation did not change significantly over the last decades.

The Spatial Processes in Hydrology (SPHY) was used to assess upstream runoff composition in the Bhagirathi river basin. Two model setups were used to evaluate the hydrological components of the whole Bhagirathi river basin (with a large scale model) as well as a more detailed analysis of a small catchment, the Din Gad catchment (a small scale model) in the Bhagirathi river basin.

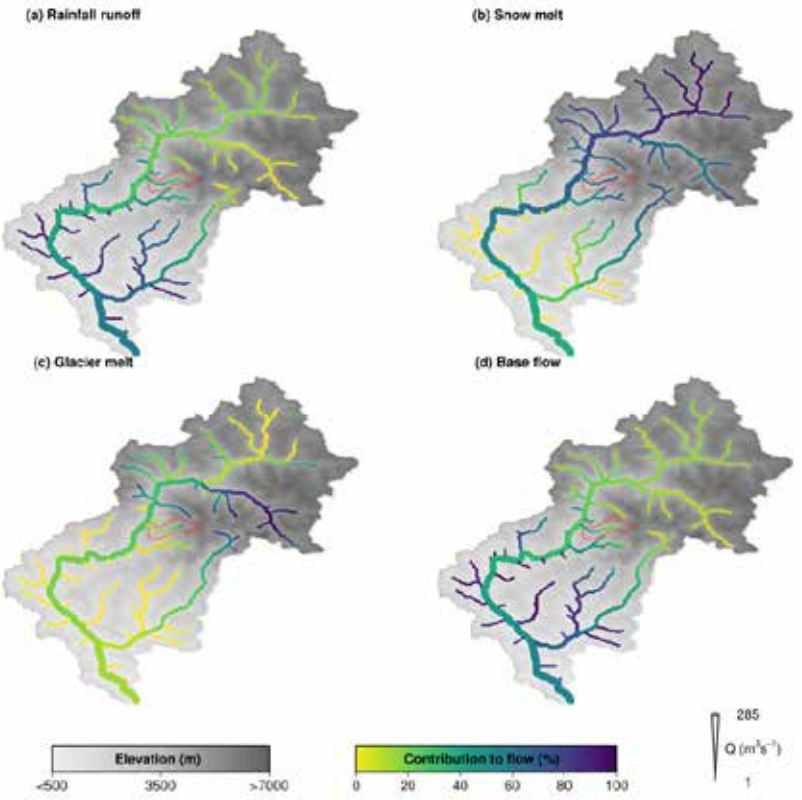
After calibrating and validating the model results for the baseline period (1991-2020), the future hydrological changes were assessed for the selected basin. An ensemble of climate change scenarios of the latest CMIP6 generation were used to assess impacts on flows. These scenarios were first downscaled and bias-corrected before used as input into the SPHY model.

This modelling study demonstrates how runoff composition and total runoff volume are expected to change by the end of the 21st century. Our results show that the total water availability for the whole Bhagirathi catchment will be relatively stable for the two climate change scenarios studied (a "middle-of-the-road" scenario, ssp245 and a more pessimistic global development and emission scenario: ssp370) by the end of the century. However, there are considerable changes in the timing and magnitude of peak water availability and seasonality. This may impose a threat on the livelihood of the local communities if no adaptation measures are taken.

Figure 4 shows the river flow composition for the current climate (baseline) for the Bhagirathi basin outlet. For the downstream outlet of the catchment, key outputs from the models are:

1. Rainfall-runoff provides one third of the total flow. Snow runoff provides almost the second third (31%), with most melt occurring from March/April to July.
2. Glacier-melt runoff is the smallest contributor (6%) to the total river flow, peaking in August.
3. Baseflow contributes 29% to the total flow, with its contribution increasing in the dry and cold season.

The above flow composition is very different for sub-catchments in the Bhagirathi river basin. For example, the modelling work showed that for the sub-catchment that belongs to the Dokriani glacier, 21% of flow comes from glaciers (see the red-marked area in Figure 4). The flow composition differs highly among the various glacier systems in the river basin, depending on its size, altitude, etc. With the modelling results, for each location in the basin, the flow composition can be determined and its sensitivity to climate change impacts.



■ **Figure 4**. Spatial patterns of the flow components (baseflow, snow, glacier, and rain-runoff) at the outlet of the Bhagirathi river basin (just before the confluence of the Alaknanda river) for 1991–2020. The grey and red boundary represent the Bhagirathi river basin and Din Gad catchment (source: Own elaboration based on model output).

As evident from Figure 4, different flow components are relevant at different locations of the river basin (rain and baseflow are important for the lower parts, snow and glacier melt are important for the middle/upper basin); this information is crucial to shape subsequent measures.

For the future climate, results of the glacio-hydrological modelling assessment show how these flow components will change. Figure 5 shows the annual flows for the outlet of the basin. More details from the modelling assessment can be found in the detailed report on the glacio-hydrological modelling report.

Key takeaways for the mid-century are:

1. Glacier-melt runoff increases by the mid-century as compared to the baseline.
2. Decrease in snowfall leading to decreased snowmelt runoff by the mid-century.
3. Significant increase in rainfall-runoff contribution
4. Shift in peak total runoff from July to August for mid-century.

For the end of century, key takeaways are:

1. Similar changes as observed for mid-century scenarios continue towards the end-century.
2. Rainfall-runoff contribution intensifies compared to the mid-century.
3. Snow runoff reduces significantly.
4. Increase in glacier-melt runoff seen in the mid-century recedes by the end-of-century.
5. Shift in the peak total runoff from July to August becomes more evident by the end-of-century.

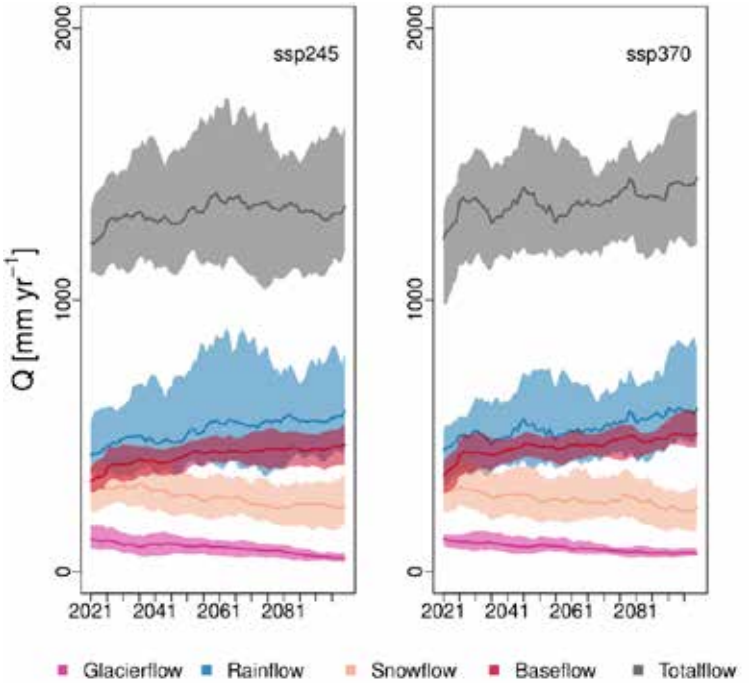


Figure 5. Annual changes in the hydrological fluxes at the outlet of the Bhagirathi river basin (just before the confluence of the Alaknanda River). The shaded color represents the variability (10-year running mean) of the median flow contributors from four climate models. The solid-colored line represents the median of four climate models.

Even though no major changes are expected at the outlet of the basin in total flows, the modelling study indicates an increase in the number of flood events by the end of the century. A flood event is defined as the number of days when the flow is higher than the Q85 percentile flow for at least two consecutive days. This increase in flood wave numbers is likely to have severe implications on critical hydraulic (i.e., hydropower, irrigation, and water supply) and other infrastructures (i.e., road, tunnels, transmission lines, and buildings).

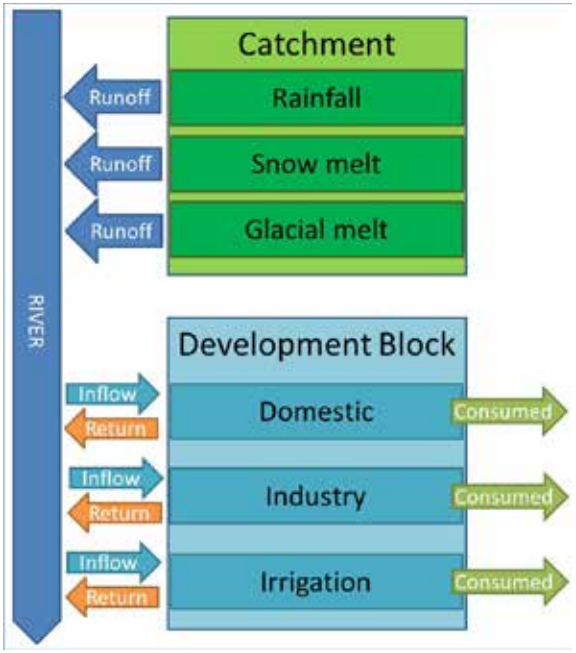
3.3 Water allocation modelling: current and future scenarios

A water resources system model was used to understand the water supply and demand in the Bhagirathi basin and analyze future projections and scenarios with adaptation measures. The model was built using the WEAP software, and was setup using the 11 Community Development Blocks (CDB) that are in the Bhagirathi basin (see for details, the related modelling report). For each of those 11 CDBs three demand side and three supply side options were considered. The three demand sides

were for Domestic (Dom), Industry (Ind) and Irrigation (Irr). The supply side was split into Snow, Rain and Glacial (Glac) (Figure 6).

Water availability data was provided by the SPHY basin scale model for each of the 11 CDBs. Data were provided in millimeters per month for the three components (rain, snowmelt, glacial melt). The model was setup for two time periods: a reference period: 1991–2020, and a future period: 2021–2050.

Annual water demand within the basin for domestic use, industry and irrigation is about 250 MCM per year. About 80% of that water is allocated to be used in the irrigation sector. During the paddy season most of this irrigation water is needed, with a peak around June for puddling, seedbed preparation and transplantation.



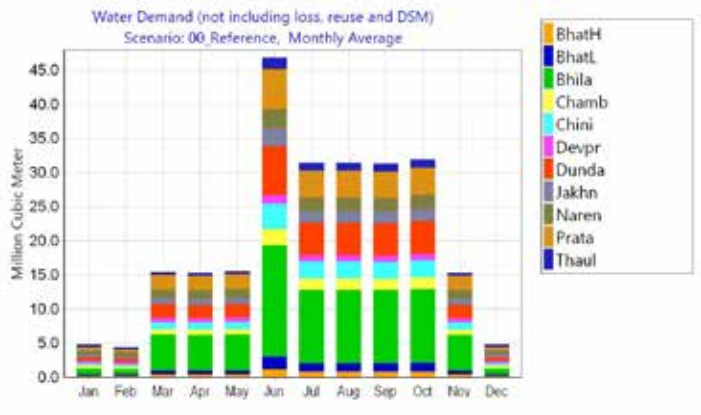
■ **Figure 6**. Schematic representation of one Community Development Block water flows as setup in the WEAP model.

Water need for each of the eleven Community Development Blocks (CDB) depends predominantly on the irrigated area in the CDB and total population. Figure 7 indicates that the biggest water demand is for the Bhilangana CBD in the Tehri Garhwal District has the highest population amongst all the CDB and is also quite big (~ 1300 km^2). Generally, water demand varies highly amongst the CDB - the bigger and lower CDB tend to consume more water. Note though that these demands within the river basin are relatively small compared to the downstream water demands, which are huge and are over 5000 MCM per year, considering downstream irrigation systems and large urban areas that rely on the outflows of the Teri dam (Droogers et al., 2021).

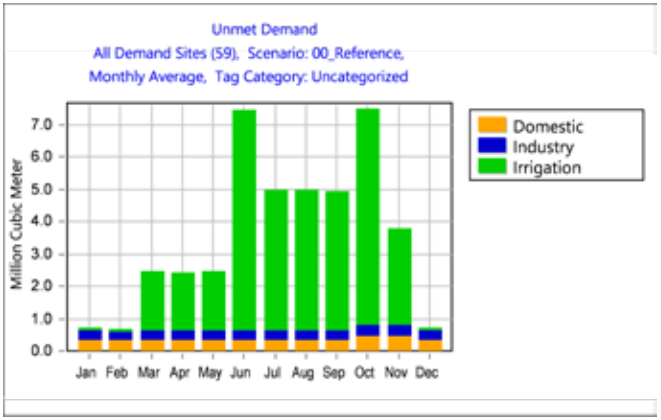
The Bhagirathi basin has vast glacial and snow reserves, feeding large perennial river systems. Consequently, this basin of the Ganges is not inherently water-scarce, given these extensive freshwater resources. However, water shortage in the Bhagirathi often arises from the challenge of accessibility rather than availability. The rugged terrain and the remoteness of water sources necessitate robust infrastructure to ensure reliable water delivery. This limited accessibility has been included in the water supply-demand model. Figure 8 shows the unmet demand per sector and per month, for the Bhagirathi basin as a whole.

Based on projections on population growth and the climate change projections of river flows (see previous section), two scenarios have been explored that project the water supply-demand situation in the future and are used to evaluate the potential impact of interventions (see next section) on the supply-demand gap in the Bhagirathi basin (with or without considering downstream flow requirements).

For the two projections, a most plausible scenario has been defined (Proj_01), and a less plausible but still possible, more extreme scenario (Proj_02).



- **Figure 7.** Monthly water demand in the Bhagirathi Basin for the eleven Community Development Blocks for 2001-2020

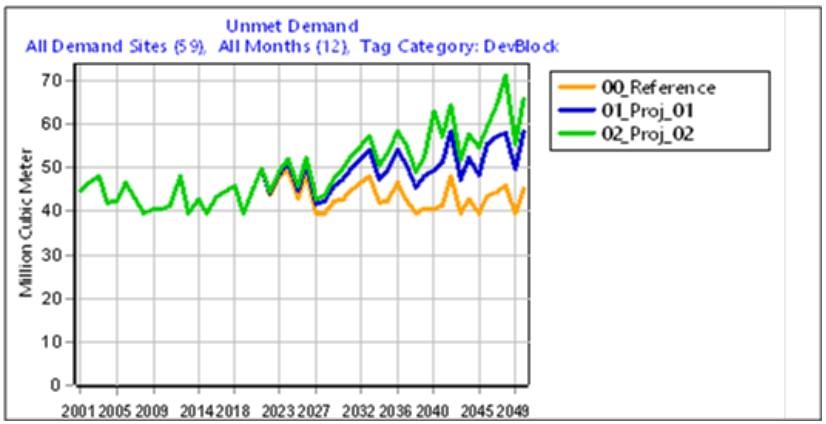


- **Figure 8** Monthly mean water shortage in the Bhagirathi Basin for the three main sectors for 2001-2020. Summer months are critical due to high demand for agriculture

The following assumptions for those projections have been used:

- Proj_01 (most likely)
  - No changes in runoff
  - Population growth
    - » +23% by 2050 (medium projection)
  - Increase in irrigation water demand
    - » +5% by higher temperatures
    - » +23% by expansion of areal

- Proj_02 (extreme)
  - Runoff and inflow
    - » reduction of 5% by 2050
  - Population growth
    - » +34% by 2050
  - Increase in irrigation water demand
    - » +10% by higher temperatures
    - » +34% by expansion of areal



- **Figure 9**. Annual unmet water demand (water shortage) in the Bhagirathi Basin for the reference (2001-2020) and the two projections for the future (2021-2050). Only water demands within the Bhagirathi Basin are considered. This figures aggregates all demands for the entire basin (domestic, industrial and agriculture) for all development blocks.

Figure 9 shows an output of the WEAP model, presenting the annual unmet demand (gap between supply and demand) considering all demands within the Bhagirathi basin. There is an increased water shortage with climate change scenario from 43 to 54 / 60 MCM/y. Results per Development Block, and results including downstream requirements can be found in the detailed report on the water allocation modelling report (Droodgers et. al. 2023) and DSS.

Key takeaways from the water allocation modelling

- Water demand *within* Bhagirathi
  - Increase by 23% (Proj_01) up to 35% (Proj_02)
  - **Substantial increase in demand**
- Unmet demand (water shortage) *within* Bhagirathi
  - Increase from 43 MCM/y (current) to 54 (Proj_01) and 60 (Proj_02) MCM/y
  - Coverage reduction from 83% (current) to 82% (Proj_01) and 82% (Proj_02)
  - **Coverage within the basin projected not to change very much.**
- Reservoir storage
  - Critical low under both future projections
- Origin of water
  - **Most water originates from rainfall runoff. In future snowmelt contribution can be expected to peak one month earlier (from June to May).**
- Reuse of water
  - **Reuse of return flows will double from about 2% current to 4% in future (Proj_02) as more water will be used so more return flow will be generated.**

Note, that when the downstream requirements (below Tehri dam) are included in the analysis, the results show larger relative changes and deficits. These results can be found in the report and DSS.

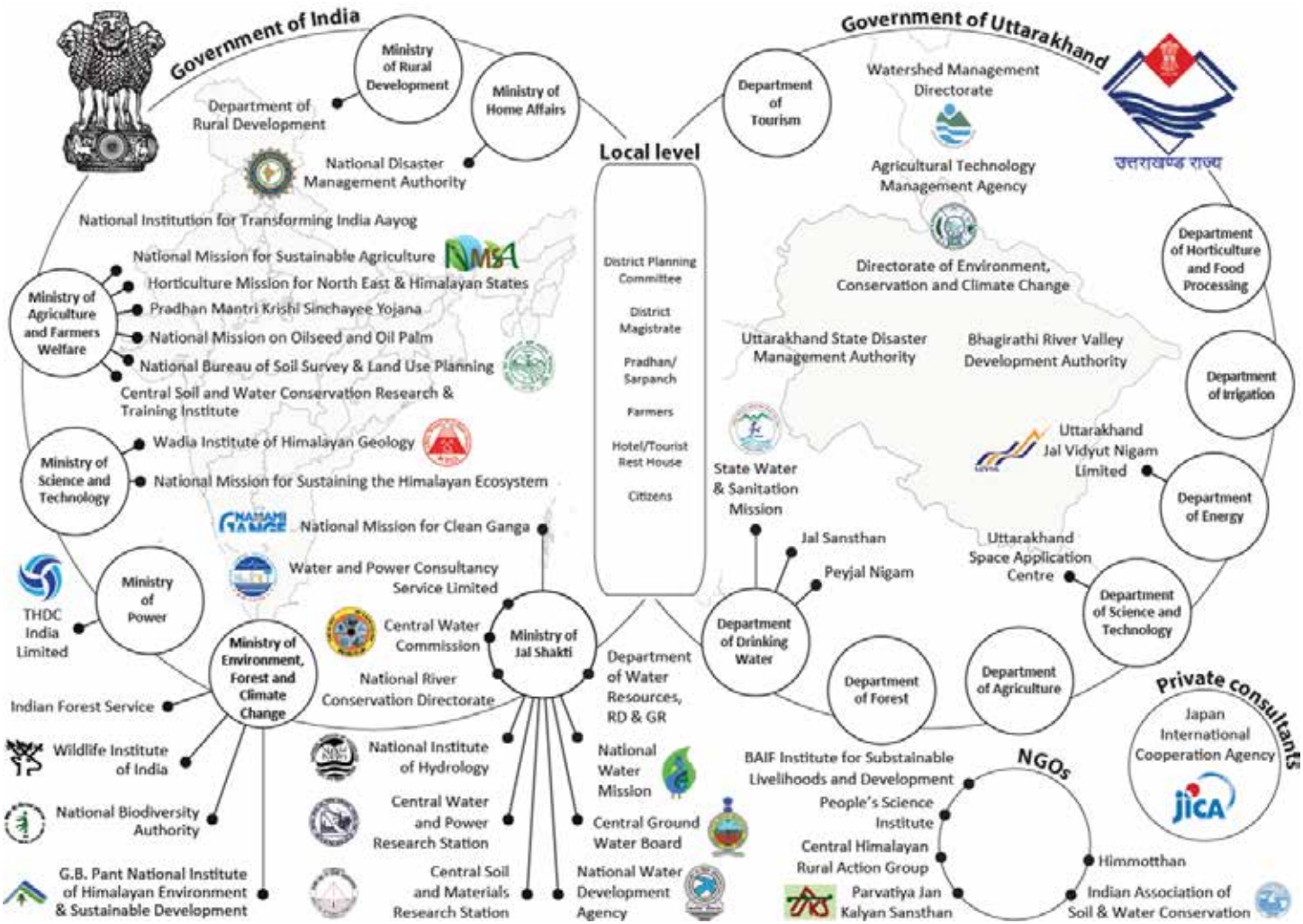
3.4 Water governance

3.4.1 Stakeholder mapping

IWRM is a cross-sectoral policy approach, designed to replace the traditional, fragmented sectoral approach to water resources and management that has led to poor services and unsustainable resource use. Figure 10 shows the government departments and authorities that are involved in watershed conservation activities in Bhagirathi basin. The stakeholder landscape is complex - different actors' roles, capacities, needs and needs to be well understood for IWRM. Stakeholders can collaborate and use synergies or complement each other (Annex 3).

The upper area of the watershed is under the management of Forest Department. The Agriculture & Horticulture Department manages the lower areas including agricultural land near the villages by implementing various schemes of Central and State Government. In addition to it irrigation canal system, river bank protection works is done by the Irrigation Department.

The stakeholder mapping identified 47 organisations as the main actors in the water governance network of the State. In greater details, 26 out of the 47 analyzed organisations are part of the Central Government, distributed across 7 ministries



- **Figure 10**. Main stakeholders involved in water resource management in Uttarakhand (Farvacque et al., 2022)

including: the Ministry of Rural Development; the Ministry of Home Affairs; the Ministry of Agriculture and Farmers Welfare; the Ministry of Science and Technology; the Ministry of Power; the Ministry of Environment, Forest and Climate Change; the Ministry of Jal Shakti (formed in 2019 by merging of two ministries, i.e., the Ministry of Water Resources, River Development and Ganga Rejuvenation, and the Ministry of Drinking Water and Sanitation).

The Ministry of Jal Shakti, the Ministry of Agriculture and Farmers Welfare, and the Ministry of Environment, Forest and Climate Change, gather the largest number of institutions (21 in total) that are involved in the water governance network. For instance, they include the Central Water Commission (CWC; Ministry of Jal Shakti), the National Institute of Hydrology (NIH; Ministry of Jal Shakti), the National Bureau of Soil Survey & Land Use Planning (NBSS & LUP; Ministry of Agriculture and Farmers Welfare), and the G.B. Pant National Institute of Himalayan Environment (G.B. Pant NIHE; Ministry of Environment, Forest and Climate Change). This wide range of stakeholders from Central Government also integrates the National Institution for Transforming India (NITI Aayog) which acts as a public policy think tank.

At the State scale, 8 out of the several Government Departments of Uttarakhand are concerned with water governance, i.e.: the Department of Tourism; the Department of Horticulture and Food Processing; the Department of Irrigation; the Department of Energy; the Department of Science and Technology; the Department of Agriculture; the Department of Forest; the Department of Drinking Water (Jal Sansthan). The Forest Department, the State Water and Sanitation Mission (SWSM) as well as the Uttarakhand Jal Vidyut Nigam Limited (UJVNL) act under the Forest, Drinking Water, and Energy Departments, respectively. The State Government also relies on the Watershed Management Directorate (WMD), State Environment Conservation and Climate Change Directorate (SECCCD), the Uttarakhand State Disaster Management Authority (USDMA), Agriculture Department, and the Bhagirathi River Valley Development Authority (BRVDA) in the process of planning, developing, and managing water resources.

Private consultants (Japan International Cooperation Agency) and NGOs (6 in total, i.e., Indian Association of Soil and Water Conservationists, People's Science Institute, CHIRAG and BISLD) also participate in the process of water management. Likewise, civil society (e.g., citizens, farmers, hotel and tourism guest houses) plays a major role in nurturing the overall architecture of water governance in the State.

The stakeholders mentioned above are working jointly on the numerous issues related to water management. Presently some of them are very active in water activities in the Bhagirathi River basin (SAPCC, 2014; ZMP, 2018). For better local governance, the basin is divided into 10 Development Blocks: Bhatwari, Bhilangana, Narendranagar, Chinyalisaur, Pratapnagar, Thauldhar, Jakhanidhar, Dunda, Devprayag and Chamba. The upper area of the basin is under the management of Uttarakhand Forest Department. This Department, for example, is currently supporting a special watershed programme in the Bhatwari block aiming at the treatment of 9 micro watersheds of river Bhagirathi. Lower development blocks, characterized by agricultural lands, are mainly managed by the Department of Agriculture at the Government of Uttarakhand. The latter also implements the institutions like National Mission for Sustainable Agriculture,National Mission on Oilseeds and Oil Palm, and Pradhan Mantri Krishi Sinchayee Yojana (Government of India). Similarly, river bank protection works is done by the Irrigation

Department while activities for the restoration of disaster affected infrastructures like roads and landslides in the basin are funded by the Japan International Cooperation Agency. Water activities in the Bhagirathi river basin are also addressed by the Upper Ganga Basin Organisation (UGBO), one of the fourteen regional organisations of the Central Water Commission, and the Watershed Management Directorate. More specifically, NIH, CSWCRTI, NBSSLUP and WIHG institutes monitor and study water resources in the basin. Regarding energy, UJVNL agency deals with hydro-projects in the Bhagirathi zone. Finally, on a smaller scale, district magistrates as well as village Pradhan/Sarpanch (contact point between government officers and the village community) participate to water management in the river basin.

3.4.2 Policy integration and regulatory frameworks

The national level policies and activities in water resources management in India are being coordinated by the Ministry of Jal Shakti, Department of Water Resources, River Development and Ganga Rejuvenation, Government of India. The National Water Mission of the Ministry focuses on ensuring basin level management strategies to deal with variability in rainfall and river flows due to climate change. The Central Water Commission (CWC), which is part of Ministry of Jal Shakti, plays a key role in promoting integrated and sustainable development of India's water resources. Also, the National Water Mission (NWM) is coordinating the development of a state specific action plan on water -first draft report released in 2018.

The regulatory framework for water management in the Bhagirathi basin is complex and includes several acts and regulations. The most relevant ones for the IWRM plan are the following

- Uttarakhand Ground Water (Regulation and Control of Development and Management) Act, 2016.
- The Uttarakhand Water Management and Regulatory Act, 2013.
- The Water (Prevention and Control of Pollution) Act, Amendment Rules, 2011.
- The Water (Prevention and Control of Pollution) Cess (Amendment) Act, 2003.
- The Water (Prevention and Control of Pollution) Cess Act, 1977.
- The Water (Prevention and Control of Pollution) Rules, 1975.
- The Water (Prevention and Control of Pollution) Act, 1974.

Several policy instruments are under development including:

- Preparation of master plan. Dehradun Mussoorie, Nainital and Haldwani regions have a master plan but it is lacking for high-altitude regions.
- A flood zonation map of the whole of Uttarakhand is currently being prepared.
- Watershed management plans are updated.

Environmental and ecological issues are being monitored and new laws and policies are being prepared such as the State Action Plan on Climate Change. Moreover, several water-related missions are being currently implemented in the region such as *Jal Jivan Mission, Har Ghar Nal, Prime Minister Krishi Sinchayee Yojana* and *Namami Gange* Project.

During the stakeholder consultations, it emerged that emphasis should be given to establishing flexibility and a clear hierarchical prioritization in the distribution of water rights during emergency situations, enabling the governance system to better respond to climate change and related threats. Building restriction in high risky areas should be better enforced to avoid flood/ flash flood related loss of lives, severe households and infrastructural damages. Moreover, especially at the local level in high mountain regions, responsibility allocation is not always clear and improved management at the micro-catchment is advocated.

A regulation scheme of agriculture and farming practices in preserved areas (e.g., natural parks) should also be introduced to prevent degradation. Moreover, unplanned infrastructure development (e.g., road construction) had, for example, led to the depletion of water resources. The existing sanctions' system needs to be implemented and respected more systematically. More broadly, environment impact assessment (EIA) reports before infrastructure development and construction should be provided by authorities that are independent of the project (Annex 4).

Under the 'Panchayati Raj Act', there are six subcommittees, called the Water Management Committees in charge of water management project implementation. 50% women participation is requested for these committees in order to ensure gender balance.

3.4.3 Human and economic resources

The stakeholder consultations revealed that there is a need to better mobilize public and private finance to value water as a limited resource whose exploitation should be limited. There should be more scopes/schemes to mobilize financial resources for water conservation schemes.

Moreover, there is a need to identify new models of community and business engagement in water management. This engagement should be promoted without the need of constant institutional interventions. Therefore, in the future the private sector is expected to play a bigger role than it does presently. Yet, water business models are highly debated and are part of the much wider topic of public service's privatization.

Social mobilization must be promoted to build community's knowledge, to change the behavior of water users and water managers towards more sustainable practices, to reinforce confidence on collective actions and to offer the opportunity to engage communities in managing water resources. A stronger involvement of women in water governance is also crucial. For example, women could have two to three hours of free time to take part of decision-making process if the *Pradhan Mantri Ujjwala Yojana* (PMUY) scheme (under which the central Government distributes LPG connections and subsidized refill cylinders to women of Below Poverty Line families) is implemented on a larger scale in the hills.

4 SCENARIO ANALYSIS

This chapter provides an overview of the results of the governance analysis and scenarios developed to address the water and climate challenges in the Bhagirathi basin. The results are structured on the basis of the three IWRM key pillars: (1) social equity, (2) environmental sustainability and (3) economic efficiency. Stakeholder consultations revealed that each pillar inevitably leads to different priorities, e.g., on what type of adaptation measures should be implemented, how responsibilities should be allocated, etc.

Below, for each of the three IWRM pillars, the following sub-sections can be found:

1. Description of the main trends
2. A summary of measures
3. Considerations for responsibilities and resources
4. Potential impacts
5. Recommendations based on other IWRM plans in India

4.1 Social equity

4.1.1 Trends

When prioritizing social equity, a key issue is access to clean drinking water. Anthropogenic activities, including environmentally detrimental practices (such as building roads or unplanned infrastructural development), have often degraded water resources, increased ecosystems vulnerability, and led to drying up of springs, and reduction in water quality.

Moreover, social equity is also related to potential upstream-downstream river basin conflicts due to competing water uses and users. Construction of dams and diversions can create these sort of conflicts if water is not allocated and managed well. Large water users, like large scale farming can also have unsustainable side effects. For example, public officials reported that large scale farming owners often build water channels in their own fields, thus reducing equitable water distribution.

In the future, the middle Himalayas are expected to face increased water shortages. Under increasing socio-economic development, the urban population of the Bhagirathi basin is likely to grow considerably and converge towards the basin's largest cities (e.g., Uttarkashi, Haridwar, Rishikesh). Nowadays, of the 15,000 villages in Uttarakhand, approximately 250 are "ghost villages" and have been recently abandoned due to reduced livelihood options.

The present and expected future trend (unless counter-acting measures are enacted) is that locals are less and less involved in the agriculture sector, partly also due to the depletion of water resources. Biodiversity loss is expected to have adverse effects on water quality in the future as healthy ecosystems plays an important function in the cleaning of water.

4.1.2 Measures maximizing social equity

For more equitable water use, optional adaptation approaches are: (i) promote investments at the micro catchment level, benefiting local communities; (ii) the promotion of traditional practices and climate smart agriculture with low environmental impact; (iii) water resources investments together with water allocation mechanisms in the Bhagirathi basin, controlling and monitoring water availability and use, and promote sustainable catchment measures.

The adaptation measures conceived for this IWRM building pillar consist of a mix of water supply measures such as traditional water conservation techniques or traditional water harvesting systems. In the views of stakeholders prioritizing social equity, some income-generating schemes should also be promoted to ensure livelihood for the local population, e.g., promote agriculture prospects through propagating drip irrigation, promote religious tourism at the villages as a traditional source of income; promote industries such as horticulture, beekeeping, aquaculture, etc; promote rooftop rainwater harvesting schemes; promote sustainable livelihood practices. "Privileges" to access water must be abolished, in order to guarantee an equal distribution of resources (water resources on private areas should, for example, be accessible by everyone and not only the owner – and even more so if water is scarce). Other measures include: (i) rainwater harvesting and recharge of springs and groundwater; (ii) watershed management and priority mapping; (iii) nature-based agro-business for instance artisan based skills in bamboo, natural fiber etc.; (iv) climate-smart agriculture; (v) water disposal management.

4.1.3 Adjustments in term of responsibilities and resources

The capacity of communities to preserve the fragile ecosystem should be improved. The local authorities and communities have to work together to improve integrated water resources management. Capacity building, educational programs and social mobilization are essential to generate a sense of ownership and responsibilities: there is a need to build the capacities of the locals, to make them understand the ecological significance of their actions against the small economic gains.

Women plan a key role and their engagement in water decision making processes should be strongly promoted. In this context, the Government can be the facilitator, but communities should be responsible for the sustainable management of their water resources. Stricter sanctions and penalties have to be imposed on violators (e.g., those depleting water resources). Also, ground water management should receive more attention, from an institutional and legal perspective.

When social equity is prioritized, more resources are needed at local level and more responsibilities should be delegated to Village Panchayats. Local voluntary organisations and groups should play a key role. Social mobilization must be promoted to build community's knowledge, to change the behaviour of water users and water managers towards more sustainable practices, to reinforce confidence on collective actions and to offer the opportunity to engage communities in managing water resources. Involvement of women in water governance is also crucial. Moreover, the upstream-downstream fairness issues

need to be addressed. Payments for ecosystem services could be an option, e.g., while the upstream population's measures will ensure recharge of the springs, the downstream population may support a payment system for the structure's maintenance.

4.1.4 Potential impacts of measures

The potential impact of the adaptation measures are compared using the following key indicators (all using conditions for 2041-2050):

- Irrigation demand
- Irrigation unmet demand
- Agricultural yield
- Outflow from the basin to downstream
- Occurrence of low Teri Reservoir levels

The following scenarios are explored:

- **Int_01_a**: increasing rainwater harvesting at the farm and livelihood-level.
  - This scenario looks at what happens if we assume that by implementing various rainwater harvesting techniques, 10% more water can be retained locally, and will thus be available to meet local demand, improving social equity.
- **Int_01_b**: converting rice cultivation area to wheat cultivation area
  - This scenario looks at what happens if we assume that all area under rice cultivation is converted to have less water-intensive wheat. Although from a socio-economic perspective, probably not a plausible or feasible scenario, this scenario gives a sense of to what extent, crop type changes can reduce water shortages, and possibly increase social equity.
- **Int_01_c**: stop growing rice at all
  - This scenario is a more extreme version of the previous, and looks at what happens if we assume that no rice cultivation takes place anymore, and thus a reduction in irrigated area. Although from a socio-economic perspective, given the current context, this is not a plausible scenario, but this scenario gives a sense of how land abandonment impacts water supplies and demand.

Table 3 shows a comparison of the outputs of the scenario modelling, by means of a number of key output indicators. More detailed results can be found in the water allocation modelling report (Droogers et al, 2023). In terms of effectiveness of these adaptation scenarios, key takeaways are:

- Irrigation demand reduces under all scenarios, due to the changes in land use and management.
- Thus, also unmet irrigation demand is reduced. This can lead to benefits to other water users (domestic, industry, or downstream users of the Bhagirathi basin)
- The impact of crop changes on yield is very high, and unfavorable – flagging that these type of changes would have significant impacts on livelihoods and the agricultural sector in the region. Note here again, that this scenario gives insight in the potential impact of crop changes on water shortages, but cannot be considered a realistic scenario to be implemented at scale. Also, other crop changes may be more feasible, given the local context.
- For the rainwater harvesting scenario, yields remain practically unaltered when expressed in ton/ha, but (not shown here), the total productivity (in tons) will go up due to the reduction in unmet water demand
- Occurrences of low reservoir levels of Tehri Dam is predicted to occur more frequently (increase in occurrence). This is under the assumption that operational rules of the reservoir remain unaltered – if these (operational rules) are more aligned to changed demand-supply patterns, this impact may be reduced. Overall, total outflow to downstream areas outside of the Bhagirathi basin is hardly influenced

TABLE 3: Impact of adaptation measures on water demands, crop yields, outflow and reservoir levels. Relative changes are compared to a "no adaptation" scenario. Values are based on simulations for the period 2041-2050.

	Irrigation demand (MCM/y)	**Irrigation unmet (MCM/y)**	**Yield ton/y**	**Outflow (MCM/y)**	**Reservoir low (months in 10 years)**
int_01_a	-10%	-11%	-1%	-1%	+6%
int_01_b	-49%	-31%	-53%	+0%	+31%
int_01_c	-76%	-75%	-76%	+0%	+6%

Note: - values indicate a reduction compared to the no adaptation scenario; + values an increase

4.1.5 Recommendations towards improved social equity

In the following table, we summarize some examples of recommendations for social equity mentioned in other IWRM plans in India. Concretely for the Bhagirathi basin, Chapter 5 presents the prioritized adaptation measures.

(1)	■ Pricing following cost recovery principles (water users effectively and proportionately participate financially in the recovery of the costs of water services), especially for commercial and affluent domestic consumers ■ Allocation of water rights and entitlements to stakeholders ■ Management of aquatic resources should shift from "centralized government control" to "decentralized stakeholder control" combined with "expert guidance and regulation" ■ Regular collection, compilation and dissemination of environmental data and maintenance of a historical database in public domain for ready access by any person/ agency ■ Conducting regular educational programs – through competent non-profit/ for-profit agencies and institutions – for: (i) public awareness of environmental problems and their remediation, and (ii) developing a healthy civic sense of environmental proprieties ■ Periodic review of "GRBMP Action Plans and Their Implementation" with feedback from all concerned individuals and agencies including rural and urban local bodies ■ Review governmental Policies and Plans ■ Frame suitable Policies to ensure that the environmental needs are met ■ Formulate good governance guidelines ■ Impose penalties/damages on individuals and agencies for any violation of its norms and guidelines on restrictions and prohibitions of environmentally harmful activities ■ Reward individuals and agencies who contribute exceptionally to the health either by their reformative actions or by their watchdog/investigative actions in conformity with goals and guidelines.
(2)	■ Exploration of the viability of alternate development and service models such as public-private-partnerships; ■ Expanding Urban Water Supply and Sanitation service standards.
(3)	■ Regulation of Water Extraction and Use; ■ Irrigation Management Policy

(1) Ganga River Basin Management Plan Interim Report, September 2013 by Consortium of 7 "Indian Institute of Technology"s (IITS).
(2) Integrated Water Resources Management in Karnataka, India: A New Approach. KV Raju, Clive Lyle, Yasmin Siddiqi.
(3) Integrated Water Resources Management in Sabarmati Basin: Some issues and options. M. Dinesh Kumar, Om Prakash Singh and Katar Singh. Supported By Sir Ratan Tata Trust. India Natural Economics and Management Foundation.

4.2 Environmental sustainability

4.2.1 Trends

Household's water over-consumption, industrial and water pollution, excessive development, and unsustainable agricultural practices are to blame for poor water resources quality and quantity. Water intensive agricultural activities (e.g., sugarcane farming) are hindering water recharge capacities. A better understanding of rural migration drivers is also missing this region, thus adding to the problem of mountain depopulation and environmental degradation.

In the future, the disappearance of mountain glaciers and reduction of snow cover is expected to increase land degradation, and threaten the provision of ecosystem services. Flash floods, cloudbursts, glacial lake outbursts, erratic rainfall and shifts in rainfall patterns are expected to contribute to the problem in the future (Kumar and Prabhu, 2016). Past disastrous events like the Kedarnath 2013 flash flood and 2021 Nainital cloud burst could happen again, with increased frequency in the future.

4.2.2 Measures maximizing environmental sustainability

Achieving better environmental sustainability requires a comprehensive and integrated adaptation approach that addresses various aspects of human activities impacting the environment. Key priorities for adaptation to enhance environmental sustainability are:

- Encourage soil and water conservation practices that promote soil health, retain water, and reduce the need for synthetic fertilizers and pesticides, and enhance biodiversity. Typical examples are: contour plowing, terracing, cover cropping, buffer strips, mulching, conservation tillage, water harvesting pits, etc
- Support crop diversification and change in cropping pattern that require less water, and reduce the environmental impact of food production and distribution. Promoting crop diversity helps improve soil fertility, reduce pest and disease risks, and enhance overall resilience to climate change. Crop rotation and intercropping are effective strategies to maintain soil health and reduce the dependence on a single crop.
- Establish and expand protected areas to conserve natural habitats and biodiversity.
- Implement measures to combat illegal wildlife trade and poaching.
- Support reforestation and afforestation projects to restore ecosystems and mitigate climate change.

To achieve successful adoption and implementation of these types of measures at the landscape-level, cross-agency cooperation and coordination should be promoted to improve convergence of state-level schemes and plans for the river basin and catchments. There is a need to better integrate different sectors in water management, by drawing on experiences from other countries and regions to provide technical input and support mechanisms in the regulation drafting process. A careful mix of planning, monitoring, forecasting and decision support tools will allow to considerably improve environmental sustainability.

The development of effective land use plans, and river catchment plans is a priority together with the provision for effective hydrological monitoring, the open access availability or improvement of existing databases, the systematic collection of historical timelines, and the monitoring of several parameters in the field. Suggested steps for effective IWRM planning include an in-depth understanding of the basin, identification of critical issues, development of tools aimed at improved management, e.g., springshed management, and groundwater resources mapping. Water resources scenarios and climate models are useful planning support tools. Also, more attention should be dedicated to groundwater management. Groundwater data, models, aquifer maps, and pollution risk maps should be developed.

4.2.3 Adjustments in terms of responsibilities and resources

It is the responsibility of the Uttarakhand government, and other public authorities (e.g., Water Management Directorate, Irrigation Department/Water Supplies Department), to improve water management and to reduce the climate risk. Decentralized community-based water management approaches should certainly be used, but it is a priority to develop holistic planning tools and to implement/update the existing guidelines or plans, e.g., the 2014 Uttarakhand Climate Change Action Plan, rural development schemes, and new river catchment plans. The objectives identified in the analysis of eco-sensitive zones - launched with the Zonal Master Plan of the Bhagirathi Eco-sensitive Zone – should be pursued.

Government authorities are in the best position to have an overview of the main needs and to re-distribute resources accordingly. Stronger partnerships between public, private actors (e.g., energy sector, hydro power plants) and NGOs should be built, for example by working together for improved agricultural practices or favouring public/private cooperation for the promotion of small-scale farming.

4.2.4 Potential impacts of measures

To support decision-making and prioritize adaptation measures, modelling tools can be useful that simulate how water supplies and demand can change in the future under various scenarios. These scenarios are a combination of assumptions on implemented adaptation measures – so called “what-if scenarios”. The Bhagirathi water allocation model WEAP was employed to explore the potential impact of a number of measures that are related to this IWRM pillar. Note that this scenario analysis focuses on water quantity, not water quality, and that this modelling analysis is limited to allocation-related measures. Chapter 5 presents a more comprehensive set of adaptation measures to promote IWRM in Bhagirathi river basin.

As mentioned before, the overall projection is that demand for water within the basin and for downstream users will increase substantially in the future, especially irrigation demand. This can lead to impacts on water availability on environmental assets in the region. Thus, the adaptation measures focused on environmental sustainability stands from the assumption that a reduction in demand is desirable given downstream economic development and environmental flow requirements, even if the water that is released from Tehri Dam is sufficient to supply the planned additional demand.

The following measures have been explored.

- **Int_02_a**: Deficit irrigation by 5% in the entire basin
  - Crop production can often remain unaltered, if well managed, when deficit irrigation practices are applied. This scenario looks at what happens if we assume that the currently irrigated crops receive 5% less of irrigation supply by implementing in a coordinated way, deficit irrigation practices, conscious of the right crop-dependent seasonal timing and dosing.
- **Int_02_b**: Deficit irrigation by 10% in the entire basin
  - The same as the previous, but this scenario assumes a 10% reduction.

Table 4 shows a comparison of the outputs of the scenario modelling, by means of a number of key output indicators. More detailed results can be found in the water allocation modelling report (Droogers et al, 2023). The results show that these two adaptation scenarios have:

- some impact on water use: less demand and less unmet demand
- the positive impact on downstream water outflow is non-existent, as the reduction in demand is absorbed by demand elsewhere in the river basin
- The occurrence of low reservoir levels reduces, but this is mainly a seasonal effect: mean reservoir inflows remain the same.
- Yields reduce, but this may depend on the crop type: yields can be sustained using deficit irrigation practices, if well managed

TABLE 4 Impact of adaptation measures on water demands, crop yields, outflow and reservoir levels. Absolute values (top) and changes compared to the "no adaptation" option (bottom). Values are annual averages in 2041-2050.

	Irrigation demand (MCM/y)	Irrigation unmet (MCM/y)	Yield ton/y	Outflow (MCM/y)	Reservoir low (months in 10 years)
int_02_a	-5%	-6%	-5%	+0%	+0%
int_02_b	-10%	-11%	-10%	+0%	-6%

4.2.5 Recommendations towards improved environmental sustainability

In the following table, we summarize some examples of interventions for environmental sustainability mentioned in other IWRM plans in India. Concretely for the Bhagirathi basin, Chapter 5 presents the prioritized adaptation measures.

(1)	▪ Restoration and preservation of wetlands, forests and grasslands, combined with various water and soil conservation measures; ▪ Direct reuse of water where possible, e.g., reuse of irrigation return flows; ▪ Treatment and recycling/reuse of domestic and industrial wastewaters where feasible; ▪ Identify the type of polluting wastes, their sources of generation, and the techno-economic feasibility of collecting and treating them for their safe environmental discharge and/or possible recycle or reuse; ▪ Prohibition of environmentally ruinous activities; ▪ Restriction of environmentally harmful activities; ▪ Development of much-needed pollution-controlling infrastructure; ▪ Facilities for environmentally safe cremation/burial of corpses and disposal of animal carcasses; ▪ Ground water recharge with unpolluted water to raise groundwater levels where needed and enhance river base flows; ▪ Higher efficiencies in institutional, commercial, industrial, domestic, municipal and community water uses through minimization of losses, wastage control and provision of adequate water treatment facilities; ▪ Higher efficiencies in irrigation water use for agriculture, horticulture and fodder cultivation; ▪ Afforestation/ grassland development of degraded forests/ grasslands, wastelands and denuded hill slopes; ▪ Appropriate measures for flood mitigation in floodplains; ▪ Protection of breeding areas and natural habitats of indigenous and migratory species, and preventing the spread of exotic species in rivers and water bodies; ▪ Eco-friendly tourism, pilgrimage and recreational activities in rivers and riverbanks; ▪ Removal of slum clusters and other human encroachments from active flood plains of rivers, and the use of the flood plains for development of water-recharge structures and ecological parks; ▪ Use of bio-fertilizers and bio-pesticides in agriculture, horticulture, aquaculture, forestry, etc., to protect groundwater from agricultural pollutants; ▪ Continuous ground-level monitoring through competent non-profit/ for-profit agencies.
(2)	▪ Facilitate increased “crop per drop” and strengthening of participatory irrigation management (PIM); ▪ Enhancing irrigation performance from modernization of infrastructure and management systems.
(3)	▪ Promotion of water savings for irrigation, and optimization of fertilizer usage

(1) Ganga River Basin Management Plan Interim Report, September 2013 by Consortium of 7 “Indian Institute of Technology”s (IITS).
(2) Integrated Water Resources Management in Karnataka, India: A New Approach. KV Raju, Clive Lyle, Yasmin Siddiqi.
(3) Integrated Water Resources Management in Sabarmati Basin: Some issues and options. M. Dinesh Kumar, Om Prakash Singh and Katar Singh. Supported By Sir Ratan Tata Trust. India Natural Economics and Management Foundation.

4.3 Economic efficiency

4.3.1 Trends

Due to activities like construction of houses in flood plains, building roads, industrial activities, forest degradation and soil erosion, flooding is one of the biggest problems related to water resource management in the basin. Climate change may be worsening the situation but its exact role has to be better understood.

In the future, flooding, forest fires and landslides occurrence is expected to increase with devastating effects for many communities. Understanding the role of climate change in increasing the frequency and intensity of flood events is a priority together with the understanding of cascading effects between the climate and water crises.

4.3.2 Measures maximizing economic efficiency

Water is a public but also a private good and individuals should feel more responsible for water resources maintenance. There is a need for both the upstream and downstream communities to collaborate and cooperate more pro- actively for the preservation of water resources. To reduce river basin misuse, more carefully designed catchment area protection plans -that also include more explicitly floodplain and wetland- should be developed to prevent flooding and other man-made disasters leading to loss of life and property.

The adaptation water measures conceived for this IWRM building pillar consist primarily of measures that can be adopted at the individual or household level, including e.g., climate support services for farmers, water saving measures at household or farm level, greywater management, water conservation, rainwater harvesting, increase in individual household tap connections. Replicable small scale solutions are key to drive change in the long term. Moreover, good practices are already in place and should be upscaled, like the Participatory Irrigation Management Programme including water user groups and associations. Raising individual awareness about flood risk, building constraints but also about water resources management and their depletion through educational and other activities is also essential. Cleaning drains and properly managing forests is also essential to reduce flood and landslide risks. Economic efficiency is a core principle to decide about water measures.

4.3.3 Adjustments in terms of responsibilities and resources

Individuals should take responsibilities for water resources management. Capacity building, educational programs and social mobilization are essential to generate a sense of ownership and responsibility. There is also a need to identify new models of business engagement in water management, an engagement that should be promoted without the need of constant institutional interventions. Therefore, the private sector should play a bigger role than it presently does.

It is very important to allocate scarce public resources more wisely and to calculate better the costs and benefits of the adoption of different water conservation measures. Affordable techno-economic business models should also be identified, for individuals and communities to be more responsible for their water management practices without institutional interventions. More resources should also be dedicated to provide better tools for farmers, e.g., decision support tools to improve farmer's forecasting capabilities and innovative approaches to bring climate information and agriculture support services to local farmers.

4.3.4 Potential impacts of measures

The prioritization of economic efficiency leads to overcome water shortage by using infrastructure solutions. As indicated above, overall water demand (within the basin and downstream requirements) will increase. At the same time rainfall will increase slightly according to the climate projections. A quantitative analysis of the environmental economic efficiency adaptation measures (technical adaptation) using the WEAP model is undertaken to explore the impact quantitatively.

The scenario focused on environmental economic efficiency aims at overcoming water shortage by using technological or infrastructure solutions. Note that these adaptation scenarios were used to run the water allocation model to study all kind of scenarios and understand the potential impacts.:

- **Int_03_a**: Increased water retention by grey and/or green infrastructure
  - This scenario looks at what happens if we assume that the storage capacity in the landscape is increased by 1770 MCM (approximately 50% of the capacity of Tehri Dam Reservoir). This could be implemented by a combination of green infrastructural measures (Nature-based solutions, like wetland restoration etc) and grey infrastructure, i.e. new reservoirs.
- **Int_03_b**: Extensive increased water retention by grey and/or green infrastructure
  - This scenario similarly looks at the potential of enhancing storage capacity, up to 3540 MCM (comparable with doubling the capacity of Tehri dam reservoir Tehri). This can be implemented by improved catchment management and/or by reservoirs.
- **Int_03_c:** Improve access to water by developing pumping and/or canal capacity.
  - This scenario looks at increases in the connectivity and access to water across the basin. As explained, the Bhagirathi river basin is not water scarce if looked at the basin level, but due to lack of the right infrastructure, local water shortage problems are common. Here it is assumed that access is no limiting factor and only total water shortage in a development block can cause unmet demand.

Table 5 shows a comparison of the outputs of the scenario modelling, by means of a number of key output indicators. More detailed results can be found in the detailed report on the water allocation (Droogers et al, 2023). Results of these scenario analyses can also be accessed through Decision Support System (DSS) developed under the project (Annex 5). From these scenarios, the following takeaways can be drawn:

- There is some positive impact on reducing water shortage in the basin (Irrigation Unmet)
- There is a positive impact on yield in case the connectivity in the river basin improves, due to reduced unmet demand and thus higher agricultural productivity
- There is a small positive impact on outflow from the river basin
- The occurrence of low reservoir levels (last column of the table “reservoir low”) will diminish by 100%, so overall there is a positive impact on Tehri reservoir levels.

TABLE 5 Impact of adaptation measures on water demands, crop yields, outflow and reservoir levels. Absolute values (top) and changes compared to the "no adaptation" option (bottom). Values are annual averages in 2041-2050.

	Irrigation demand (MCM/y)	Irrigation unmet (MCM/y)	Yield ton/y	Outflow (MCM/y)	Reservoir low (months in 10 years)
int_03_a	0%	-1%	+ 0%	+1%	-88%
int_03_b	0%	-1%	+ 0%	+0%	-100%
int_03_c	0%	-81%	+18%	+0%	-100%

4.3.5 Recommendations towards improved economic efficiency

In the following table, we summarize some recommendations for economic efficiency mentioned in other IWRM plans in India. Concretely for the Bhagirathi basin, Chapter 5 presents the prioritized adaptation measures.

(1)	▪ Pricing following cost recovery principles of fresh water (especially for commercial and affluent domestic consumers; ▪ Techno-economic assistance; ▪ Identify the type of polluting wastes, their sources of generation, and the techno-economic feasibility of collecting and treating them for their safe environmental discharge and/or possible recycle or reuse; ▪ The unit cost of the above tertiary treatment was worked out for Year 2010 price levels at approx. Rs.10/- per m^3. This cost should be borne by the users of treated water, while the cost of fresh water should be at least 50% higher (considering the minimum cost of full treatment of such wastewaters in the natural environment). These costs should be chargeable from water-users – especially urban and commercial users – thereby ensuring economic use of water and safety of the environment; ▪ The water pricing mechanism may be periodically reviewed;
(2)	▪ Water distribution efficiency and management of operation and maintenance.
(3)	▪ Volumetric Pricing of Irrigation Water from Canals; ▪ Pricing of Electricity for Groundwater Pumping based on Unit Power Consumption; ▪ Use of Markets for Managing Demand for Water in Sabarmati River Basin.

(1) Ganga River Basin Management Plan Interim Report, September 2013 by Consortium of 7 "Indian Institute of Technology"s (IITS).
(2) Integrated Water Resources Management in Karnataka, India: A New Approach. KV Raju, Clive Lyle, Yasmin Siddiqi.
(3) Integrated Water Resources Management in Sabarmati Basin: Some issues and options. M. Dinesh Kumar, Om Prakash Singh and Katar Singh. Supported By Sir Ratan Tata Trust. India Natural Economics and Management Foundation.

5 ADAPTATION PRIORITIES

An extensive stakeholder consultation with policy makers, experts and local communities was conducted for the Bhagirathi basin (see section 2.3. for a description of the activities and Annex 1 for the list of consulted stakeholders). Their opinion and suggestions have led to the building of a set of recommendations, which are being proposed as part of IWRM plan for the Bhagirathi basin.

These recommendations have been grouped according to the three key regulators i.e., land, livelihood and water synchronizing with the three pillars of sustainable development i.e., economic efficiency, environmental sustainability, and social equity (see section 1.2. for an overview of the core IWRM principles). These groups are:

- Measures for Water Management
- Measures for Land Management:
- Measures for Livelihood Management

Under each category, recommendations are grouped into 3 sub-sections that provide an analysis of opportunities and convergences with the existing system:

- Regulatory Measures
- Institutional Measures
- Technological/ Infrastructural Measures

The measures are classified, based on their recommended time of implementation:

short-term – measures that are recommended to be implemented over the next few years;

long-term – measures that are recommended to be implemented over the next decade.

5.1 Water Management Adaptation Measures

The Water Allocation Modelling performed for the Bhagirathi basin for this study, indicates that water demand for the reference period within the basin for domestic use, industry and irrigation is about 250 MCM per year. As such, the amount of water used within the Bhagirathi Basin itself is a very small fraction of the fresh water available in the streams. Water shortage within the Bhagirathi Basin is therefore quite limited, at the given time resolution (monthly) and spatial resolution

(development block). However, at smaller timescales (e.g., days) and/or spatial scales (e.g., villages) water shortage might occur. Moreover, projections for the future show that demand within the basin will increase substantially. On the other hand, most climate change scenarios suggest an increase in rainfall in the future, although also more extreme.

Overall, some water shortages can be expected within the basin, but very local and irregular. They may be notable though at the local scale, like drying of springs, pollution of water resources (surface/ ground water/ river water) and depletion of traditional water bodies have been reported by the local communities. This is leading already to local water shortages during the non-monsoon period.

Moreover, the more extreme temperature and rainfall conditions, have increased the incidences of GLOF and recurring flash floods in the region and are leading to economic losses, affecting community life and livelihood. Hence, it becomes necessary to adopt comprehensive water management measures which may help in improving water availability scenarios for local population.

Following these challenges, and based on extensive stakeholder consultation, the following set of water management-related adaptation measures have been selected, categorized in regulatory, institutional and technological measures.

5.1.1 Regulatory Measures

For the effective management of water resources, regulatory and policy measures play an important role in guiding the response of residents as well as government officials towards water. Considering this, some specific measures are proposed:

- **Appoint Water Resources Manager:** Currently, the water resources in Uttarakhand are managed by Pey Jal Nigam/ Uttarakhand Jal Sansthan, and water bodies in villages are looked after by Panchayats or Paani Samitis. However, due to lack of specialized skills as well as resources, Paani Samitis needs additional support. It is recommended to appoint a Water Resources Manager in each block with responsibility to manage local water resources, as well as its utilization, allocation, tariff regulation and grievance redressal. *Time for implementation: short-term*
- **'Zero liquid discharge' policy:** This policy is commonly applicable for water polluting industries like Distilleries, Pulp and Paper, Tanneries, Chemicals, and textiles. However, considering the influx of tourists in Uttarakhand, commercial establishments like hotels and restaurants are causing severe pollution to local water resources. Hence, it is necessary to regulate the water discharge from these establishments through enacting specific regulations for this purpose. Time for implementation: short-term
- **Guidelines to ensure convergence of state-level government schemes:** Water governance is distributed over multiple government departments, leading to formulation of schemes which are overlapping sometimes. Also, some of these schemes have tradeoffs with schemes of other departments. Considering this, convergence of state level government schemes from different departments is widely recognized as a solution for better water governance. However, this has not become a reality, due to several constraints on practical grounds. Hence, it is proposed that government revenue

department should release guidelines for allocation of funds to different government schemes related to water sector, that may reduce overlap as well as tradeoffs, while ensuring convergence of efforts to manage water. Time for implementation: long-term

5.1.2 Institutional Measures

- **Engaging with the Spring and River Rejuvenation Authority (SARRA)** under the Watershed Management Directorate for enhanced water supply management: The purpose of establishment of SARRA at State level is to identify all the water sources of the state which need to be rejuvenated on priority basis to ensure increase in water discharge and perenniality of the springs and rainfed rivers. SARRA is also mandated to measurement and monitoring the impacts of recharge interventions by ensuring community participation of local people for sustainable flow of rain-fed rivers etc. *Time for implementation: short-term*
- **Village level coordination committee on water:** Village Water and Sanitation Committees or Paani Samitis are responsible for managing the water resources at the village level. However, it is necessary to change the attitude and behavior of people towards water. Behavioral changes are best motivated by the people who have the capacity to influence. Hence, it is proposed to facilitate the creation of an independent institution/ committee at block/ village level, with the involvement of local influencers like religious preachers, teachers, *sarpanch* etc. to monitor and influence the behavior of both permanent as well as seasonal population. *Time for implementation: short-term*
- **Disaster risk preparedness**: A holistic and collaborative approach towards disaster risk trainings and awareness building should be adopted in order to develop action plans to spread awareness and preparedness measures for disaster risk reduction (for GLOF and floods). The measures should include early warning systems for alerting communities at risk and initiating disaster response procedures. *Time for implementation: long-term*
- **Village level Flood Safety Officers:** Recurring flood events in the region require immediate action to be taken to save life of residents, in case of emergency. Hence, it is necessary to appoint/ designate flood safety officers/ committee for each village with the involvement of local youth and build their capacity to minimize the localized risks and losses. *Time for implementation: short-term*

5.1.3 Technological Measures

Besides regulatory and institutional measures initiatives, also investments in technological measures, and infrastructure are required. Key measures are:

- **Improving water storage:** For those regions of the Bhagirathi basin, where there is a vast difference between supply and demand, or where even some shortages occur now and then, there is the need for measures that increase supply, through enhanced water storage, like wetland restoration, building structures for water storage, (reservoirs, dams, etc.), rainwater harvesting, various urban water management techniques (where applicable), etc. This should be studied in more detail, for those areas where there is more water demand than supply. *Time for implementation: long-term*

- **Research on Uttarakhand Glaciers:** There exists a limited understanding about the impacts of climate change on glaciers in the state. Research on the influence of snow/ glaciers in state's river runoff is further limited. Hence, it is necessary to promote research on impacts of climate change on glaciers in the state. It is proposed that the state government support the establishment of permanent research stations on selected benchmark glaciers, in individual sub-basins of the state. These stations to be equipped with the latest instruments for hydrometeorological measurements, and available for *in-situ* experiments to all the researchers. *Time for implementation: long-term*
- **Centralized database repository:** Collection of real time data and building a centralized database repository on parameters related to water resources (rivers, lakes, ponds, springs, tube wells, etc.) is required to improve the understanding about state's water resources. Also, an institutional arrangement is necessary for sharing hydro-meteorological information. *Time for implementation: short-term*
- **Identification of flood impact zones** and building infrastructure to regulate the impact of rapid flow of water in river – embankments/ planting trees/ engineering solutions to strengthen the landslide prone areas. Conduct land impact analysis after every major disaster event and update flood impact zone maps. *Time for implementation: short-term*
- **Waste water treatment**: treating waste water for reuse especially within the industry campuses for cleaning, irrigation etc., use of water efficient gadgets and equipment is recommended. *Time for implementation: long-term*

5.2 Land Management Adaptation Measures

Land is an important resource and significantly influences the water resources of the region itself, and regulates the water availability and supply of the downstream regions. Changes in landcover lead to change in water consumption locally, and have thus an impact on the water resources of the entire river basin. As such, land conservation and maintenance of its productivity make an important part of IWRM.

Crop failure due to unpredictable meteorological changes and degradation of local land and forest resources has been reported widely by stakeholders. This demands for specific measures should be taken up management of land and forest resources in the Bhagirathi basin.

Based on extensive stakeholder consultation, the following set of land management-related adaptation measures have been selected, categorized in regulatory, institutional and technological measures.

5.2.1 Regulatory Measures

- **Regular 'Tree Census' and creation of 'Land Bank' in the state:** Land Use-Land cover changes are detected through satellite images to assess the percentage green cover in an area. However, this does not present an accurate status of health of trees and forests. Hence, it is necessary to conduct Tree Census at regular intervals following the approach and methodology used for the population census. Also, it is proposed to create a Land Bank for the basin to acquire, manage, maintain, and repurpose vacant, abandoned, and foreclosed land units. These land units shall be used for the planting of trees or can be

let out for commercial logging purposes. The Land Bank would need a strategic plan to prioritize these projects based on the specific needs and characteristics of the basin, ensuring that water management goals are integrated with land use planning. Collaboration with local communities, environmental organizations, and water management experts would be crucial to align these efforts with broader sustainability and climate resilience objectives. *Time for implementation: long-term*

- **Land Quality Indicators:** Indicators are already in regular use to support decision-making at global, national and sub-national levels. Land quality refers to the condition or "health" of land, and specifically to its capacity for sustainable land use and environmental management. Assessment of sustainable land management requires appropriate evaluation tools, such as revised Land Quality Indicators. *Time for implementation: long-term*

5.2.2 Institutional Measures

- **Organic Farming through Public Private Partnerships (PPPs):** Organic farming is being practiced in Uttarakhand but individually by farmers on a very small scale. Large scale organic farming requires specific skills, infrastructure and investment. For this purpose, Public Private Partnerships (PPPs) must be forged to stimulate investments for the organic farming and water efficient irrigation systems in the state. These partnerships will also be responsible for promotion of an integrated Climate-smart agriculture (CSA) approach to managing landscapes, cropland, livestock and forests is necessary in order to address the interlinked challenges of food security and climate change. *Time for implementation: long-term*
- **Agency for Carbon Neutrality Projects:** Carbon neutrality projects lead to improvement in the quality of land and forests, and enhance the earning potential of local communities. For better coordination and implementation of carbon neutrality projects in the state, an agency associated with Forest department shall be established to facilitate such projects in the state. The agency aims to regularize, make policies and take actions for clear demarcation of land for forests, and land for farming and non-farming activities. *Time for implementation: short-term*
- **Capacity building**: Capacity building, educational programs and social mobilization of farmers are necessary to train them on eco-friendly agricultural practices, protection of forests and conservation of soil. School children and college students need to be trained to take measures at the local level and help in transformation of conventional agriculture to climate resilient agricultural practices. *Time for implementation: short-term*
- **Payment for Ecosystem Services schemes:** financial mechanisms that reward land managers (farmers) for good sustainable practices, have proven to be viable ways to promote sustainable land and water management, in many river basins around the world. This avenue should be further explored for this river basin, with downstream water users (those relying on the Tehri dam outflows) supporting financially upstream land management that sustain ecosystem services. *Time for implementation: long-term*

5.2.3 Technological/ Infrastructural Measures

Investments in technologies and infrastructure for land management are closely linked to water resources, and the IWRM paradigm requires an integrated approach. Key measures identified for land (and water) management are:

- **Regular mapping of endangered species**: Bhagirathi valley is home to several endangered species (both flora & fauna). To keep track on the status of these species and to prevent illegal activities in the forested areas, it is necessary to conduct regular mapping of these species which may ensure biodiversity conservation in the area. Implementing measures for biodiversity conservation to protect and preserve species diversity and to ensure a sustainable management of ecosystems is also a priority. *Time for implementation: long-term*
- **Mountain specific construction activities:** Infrastructure creation in mountains should be in sync with local lithology, geology as well as soil profile. The delicate nature of mountain ecosystem needs to be considered while initiating construction activities in the area. Government needs to promote as well as make it mandatory for the infrastructure developers to use mountain specific construction design, material and techniques to reduce the flood related impacts on building infrastructure. *Time for implementation: long-term*
- **Identification of flood, landslide and debris flow impact zones** and building infrastructure to regulate the impact of rapid flow of water in river – embankments/ planting trees/ engineering solutions to strengthen the landslide prone areas. These include active and passive measures to reduce landslide risk such as piles and retaining walls, levees, grouting rock joints and fissures, diverting debris pathways, rerouting surface and underwater drainage, and natural engineering measures. Conducting land impact analysis after every major disaster event and updating flood and landslides impact zone maps are also necessary. Construction of storm water harvesting, and soil binding structures should be enhanced to increase the ground storage capacity. *Time for implementation: short-term*
- **Erosion control measures** should also be promoted – mostly through improved land management and agricultural practices. *Time for implementation: short-term*

5.3 Livelihood Adaptation Measures

Water plays a key role in regulating the livelihood activities of communities in a watershed/ basin. In mountain areas, more than 85% of total income is derived from the activities dependent on water, especially agriculture, horticulture, and agro-based industries.

Tourism in mountain states is also supported by the water either directly or indirectly. Water based recreation activities directly influence tourism, however, indirect influence from water is through its role in ensuring sustainability of local ecosystem and biodiversity which are prime attraction for tourists. Thus, any impact on water resources directly influences the livelihood of local communities and specific measures are required to reduce the impact of changes in hydrological regime on local livelihood.

Hence, a set of measures are being proposed for livelihood management which may improve the effectiveness of IWRM initiatives within the Bhagirathi basin. Based on extensive stakeholder consultation, the following set of livelihood-related adaptation measures have been selected, categorized in regulatory, institutional, and technological measures.

5.3.1 Regulatory Measures

- **Alternative livelihood options:** To reduce the dependence of mountain communities on water related activities and the influence of climate change on their livelihood activities, it is necessary to facilitate the alternative livelihood options or additional income generating activities. For the purpose, cottage industries suitable for each block in the valley should be identified and promoted through different schemes. Training and credit facilities should be provided by expanding the coverage of Skill Development programs, ensuring enrolment of every local youth to the program. Also, policies and programs are required for the direct purchase or facilitate selling of local agro and non-agro products at adequate prices. *Time for implementation: long-term*
- **Guidelines for Eco-tourism in the valley:** Initial stakeholder discussions during the development of this IWRM highlighted the strong need for a s tourism policy and regularization of tourism services industry. However, the Government of Uttarakhand released 'Uttarakhand Tourism policy 2030' in April 2023. This is a comprehensive policy covering various aspects related to development of tourism infrastructure, investment for tourism promotion, skill development as well as identifying focus tourism segments. The policy lays down an implementation framework for eco-tourism and highlights the measures to ensure sustainable tourism in the state. However, there is a strong need to promote eco-tourism practices in the state and broaden the horizon of sustainable tourism as laid in the Uttarakhand Tourism Policy 2030. Training and sensitization of tourists visiting the state, consideration of carrying capacity of tourist place, promotion of usage of eco-friendly materials etc. is required. Government needs to release specific guidelines covering the various aspects related to ecotourism for the tourists as well as tourism service providers. *Time for implementation: short-term*

5.3.2 Institutional Measures

- **Active role of Bhagirathi River Valley Development Authority (BRVDA):** Bhagirathi River Valley Development Authority was constituted in 2005 with a mandate to maintain Ecological Balance, provide Environment Protection, ensure Sustainable Development and establish mechanism for Redressal for Public Grievances. The authority is primarily responsible for development of master plan and sectoral plans for the valley, approve/disapprove any development scheme outlined in the Master Plan and till finalization of Master Plan, regulate developmental activities undertaken by development agencies etc. As such, the authority is focused on regulation of development projects in the valley. BRVDA can ensure continuous monitoring, implementation and maintenance of guidelines and plans related to socioeconomic development in the Bhagirathi valley. Time for implementation: short-term
- **District Coordination Committee:** Constitute District Coordination Committee of departments and relevant stakeholders, influencing local livelihood, with specific guidelines on its role and responsibilities. Such a committee may be led by BRVDA which will ensure greater transparency and accountability in terms of committee's roles and responsibilities. BRVDA may take an important role in the inter-departmental coordination for implementing the IWRM plan Time for implementation: short-term
- **Block level adaptation plans:** Block Development Officers (BDOs) are responsible to supervise the execution of all the programs related to the planning and development of the blocks. They make sure that plans and programs approved by

the appropriate authorities are executed efficiently within the block. However, it is necessary to develop block level climate adaptation plans integrating all the relevant departments, and implemented jointly by departments with surveillance of its implementation through BDOs and BRVDA. *Time for implementation: long-term*

5.3.3 Technological Measures

The consultation did identify only two broad measures related to technology or infrastructure, and livelihood. Obviously though, the measures presented in the water and land management sections do also have major positive impacts on livelihoods overall.

- **Monitoring and reporting of livelihood Indicators for the basin:** In the socio-economic sector, indicators are considered to be an effective tool which aid in decision making process. They help in assessment, monitoring, and evaluation of changes in the quality of life. They also help in making a comparative assessment at both spatial as well as temporal scale. Develop state/ valley specific livelihood indicators and establish system for regular update of data related to individual indicators (indicators related to water productivity, land productivity, exposure to climate change, access to socio protection programs, access to water infrastructure, etc). There should be consistent monitoring of changes in indicator values, over time. *Time for implementation: long-term*
- **Basin specific technological/engineering adaptation measures**: several technological/engineering measures are recommended. Overall, an improvement in agricultural production can improve livelihood. To this aim, crop diversification, the use of drought resistant crops, increase in coverage of irrigation, improvements in irrigation techniques (e.g. use of micro-irrigation, intermittent irrigation' or 'Alternate Wetting and Drying, SRI -system of rice intensification for water scarce areas) are recommended. *Time for implementation: long-term*

6 CONCLUSION AND OUTLOOK

Glacio-hydrological modelling for the Bhagirathi Basin indicates that the snow melt decreases in the future primarily due to a decrease in the solid fraction of precipitation caused by enhanced warming. However, the decrease in snow and glacier melt is compensated by the increase in precipitation at a larger scale. So, the total water availability will slightly increase in the future. However, extreme (flooding) events will likely increase. Increase in number of flood waves by the middle as well as end of the century is reflected by the modelling results and this will have severe implications on critical hydraulic and other infrastructures, affecting life and livelihood of local communities. There are some regions within the basin which face severe water scarcity during certain periods of the year even in current scenario which needs to be addressed.

Hence, there is an urgent need to adopt a comprehensive Integrated Water Resources Management (IWRM) Plan, which balances the management of issues related to water scarcity as well as increased incidences of flood events within the basin.

Lessons learnt during the IWRM co-design process adopted for this study include:

i. the scientific analysis of climate and environmental aspects is crucial;
ii. a joint effort and common understanding of the stakeholders involved, of their needs and perspectives is required;
iii. multiple measures exist and have to be combined smartly. These include finance, regulations and capacities related measures;
iv. implementation is a challenge and requires joint effort of multiple authorities and stakeholders.

The adaptation measures that were identified, described and prioritized in this plan, as well as the adaptation scenarios, will require regular updating. Environmental, economic, and demographic changes, along with the impacts of climate change, necessitate a responsive and adaptive approach to water resource planning. By updating the plan regularly, authorities can incorporate the latest scientific data, technological advancements, and community feedback, ensuring that the management strategies remain relevant and effective.

Additionally, a periodic review allows for the identification of emerging issues and potential risks, enabling proactive measures to mitigate the impact on water resources. It also provides an opportunity to reassess priorities, allocate resources efficiently, and incorporate sustainable practices that align with evolving environmental standards.

Furthermore, a well-maintained and updated IWRM plan enhances resilience against uncertainties, such as extreme weather events or population growth, by allowing for timely adjustments to infrastructure, regulations, and conservation measures.

In essence, regular updates to IWRM plans are indispensable for promoting long-term sustainability, ensuring equitable access to water, and safeguarding ecosystems that depend on these vital resources.

To implement the IWRM Plan successfully, it is necessary to bring together decision-makers across the various sectors that impact water resources. Convergence of state level government schemes from different departments is widely recognized as a solution for better water governance. However, this does not become a reality, due to several constraints on practical grounds. Hence, it is proposed that government revenue department may release guidelines for allocation of funds to different government schemes related to water sector, that may reduce overlap as well as tradeoffs, while ensuring convergence of efforts to manage water.

It is necessary to expand the mandate of Bhagirathi River Valley Development Authority (BRVDA) to ensure its active role in continuous monitoring, implementation and maintenance of guidelines and plans related to socioeconomic development in the Bhagirathi valley.

The loss of natural storage by glaciers and snow might be compensated to some extent by strengthening of other natural storage in the landscape (natural depressions and groundwater), and in some areas by additional artificial storage reservoirs. Interventions (local stewardship, basin-level cooperation and infrastructure-investment focused) to increase storage, for example through groundwater recharge, might be explored. Also, small-scale local water shortages might be overcome by rooftop water collection, local village ponds, and similar local interventions as mentioned in the IWRM plan.

A stronger involvement of women in water governance is crucial. Women need to be involved in the IWRM plan implementation.

Awareness raising activities are considered critical to change responsibility perceptions. Concerning capacity building the following four areas have been identified:

a. Technology transfers to the future generation. Training in schools and colleges on advancement in water management techniques.

b. Integration of traditional knowledge with new state-of-the-art modern techniques (e.g. advanced modelling techniques)

c. Para-hydrologist training (water sampling, field data collection, analysis, and data storage)

d. Training on socio-economic impacts of climate change and adaptation mechanism.

Importantly, social mobilization must be promoted to build community's knowledge, to change the behaviour of water users and water managers towards more sustainable practices, to reinforce confidence on collective actions and to offer the opportunity to engage communities in managing water resources.

Thus, IWRM plan provides a potential for effective management of water resources in the Bhagirathi basin but could also be useful to build climate resilience among communities as well as develop better plans and strategies for climate change adaptation.

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ANNEXES

Annex 1 List of consulted stakeholders

- Dr. Jitendra Vir Sharma, Indian Forest Officer; Director, Centre for Forest Management & Gover-nance, Land Resources Division, TERI
- Mr. H.P. Uniyal, Director and Advisor, Planning Commission, Uttarakhand; Former Chief General Manager of Uttarakhand Jal Sansthan
- Mrs. Neena Grewal (I.F.S), Project Director Watershed Management Directorate, Dehradun, Uttarakhand
- Mr. Jay Prakash Sharma, Chief Officer, BAIF Institute for Sustainable Livelihoods and Developmen(BISLD), Uttarakhand
- Mr. Dinesh Prasad Raturi, Senior Project Officer, BAIF Institute for Sustainable Livelihoods and Development (BISLD), Uttarakhand
- Dr. Manohar Arora, Scientist 'E', National Institute of Hydrology, Roorkee, Uttarakhand
- Mr. STS Lepcha, IFS (Retired) and Member Springshed Management Consortium, Uttarakhand Working as the Vice president in Sustainable Development Forum, Uttarakhand
- Ms. Corinne Demenge, Hear of Cooperation, SDC, India
- Ms. Neha Verma, Additional Secretary, Forest and Environment, Government of Uttarakhand
- Mr. S.P. Subudhi, Director, State Environment, Conservation and Climate Change Directorate (SECCCD), Government of Uttarakhand
- Ms. Neelima Garg, General Manager, Uttarakhand Jal Sansthan, Uttarakhand
- Ms. Neena Grewal, Director Gramya, Watershed Management Directorate, Uttarakhand
- Dr. Piyoosh Rautela, Executive Director, Uttarakhand State Disaster Management Authority, Uttarakhand
- Mr. Mayur Dixit, District Magistrate, Uttarkashi, Uttarakhand
- Mr. P. Tomar, District Forest Officer, Uttarkashi, Uttarakhand
- Mr. Dheeraj Pandey, Conservator of Forests, Bhagirathi Circle, Uttarakhand
- Mr. Rajesh Kumar, Superintending Engineer, CWC, Dehradun
- Mr. Sharad Shrivastava, Superintending Engineer, State Irrigation Department, Uttarakhand
- Mr. S.K. Saha, Superintending Engineer, Irrigation Research Institute, Roorkee, Uttarakhand
- Dr. Sanjay Kr. Jain, Scientist G, National Institute of Hydrology, Roorkee, Uttarakhand
- Dr. Gopal Kumar, Principal Scientist, Indian Institute of Soil and Water Conservation, ICAR Uttarakhand
- Mr. A. K. Singh, DGM (OMS Civil & Dam Safety), Tehri HPP & KHEP, THDC India Ltd.
- Dr. Manohar Arora, Scientist, National Institute of Hydrology, Roorkee, Uttarakhand
- Dr. Manish Mehta, Scientist D, Wadia Institute of Himalayan Geology, Uttarakhand
- Dr. Santosh K. Rai, Scientist E, Wadia Institute of Himalayan Geology, Uttarakhand
- Mr. Manoj Kumar Kaistha, Director, Geological Survey of India, Dehradun, Uttarakhand
- Mr. Rajeev Govil, AGM(Dam), THDC India Ltd., Uttarakhand
- Mr. Vaibhav Srivastava, Manager, Dam Dept., THDC India Ltd., Uttarakhand
- Mr. Ravindra Singh, DGM (OMS Civil & Dam Safety), THDC India Ltd., Uttarakhand
- Mr. Vipan Mandwal, Senior Researcher, State Environment, Conservation and Climate Change Directorate, Uttarakhand
- Ms. Neetu Tyagi, Research Associate-II, State Environment, Conservation and Climate Change Directorate, Uttarakhand
- Ms. Tripti Jayal, Research Associate-II, State Environment, Conservation and Climate Change Directorate, Uttarakhand

- Mr. Sonu Khanal, Hydrologist FutureWater, The Netherlands
- Dr. W.W. Immerzeel, Professor Utrecht University, The Netherlands
- Dr. Joel Fiddes, scientific Assistant Institute for Snow and Avalanche Research, Switzerland
- Dr. Farooq Azam, Asst Prof. IIT Indore, India
- Ms. Shrinkhla Shiromani, Software, Developer, TERI, India
- Ms. Divya Sharma, Deputy Head of Cooperation, SDC India
- Dr. Mustafa Ali Khan, Head, Carbon and Climate Strategy, Climate Connect Digital, India
- Mr. Bhupendra Bhaisora, Technical Expert, Disaster Risk Management (Uttarakhand), SDC India
- Dr. Debashish Goswami, Sector Lead, Water Resources Management, SCA Himalayas, SDC India

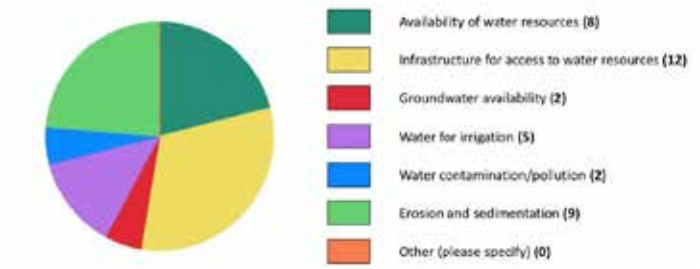
Annex 2 Stakeholder meeting

Stakeholder Meeting – Glacio-hydrological modelling and IWRM for a selected sub-basin in Bhagirathi Basin, Uttarakhand (24-May-2022, online due to COVID)

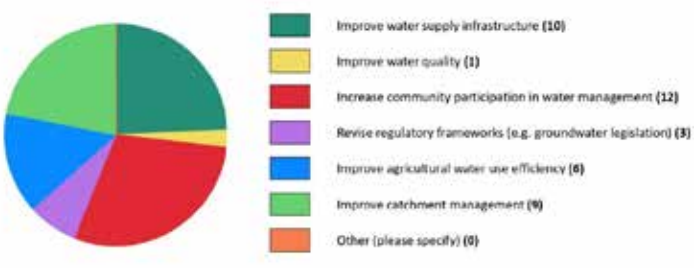
Survey results

Below the results are shown of the survey done during the meeting

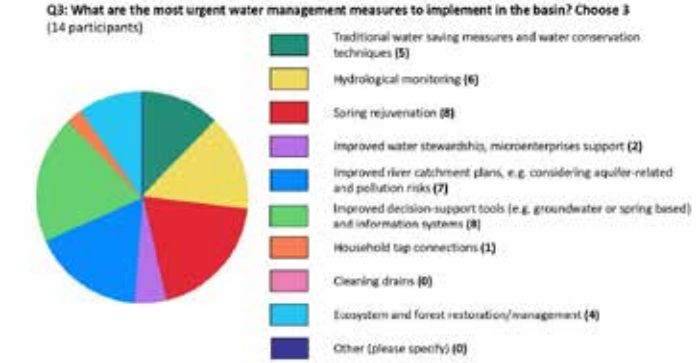
Q1: What are the most serious water management problems in the Bhagirathi river basin? Choose 3 (14 participants)



Q2: What are the priorities to improve water management in the basin? Choose 3 (14 participants)



Q3: What are the most urgent water management measures to implement in the basin? Choose 3 (14 participants)



Q4: What convergences with existing initiatives and programs should be prioritized in the IWRM plan design? Choose 1 (14 participants)



Followings were the key issues and potential solutions discussed in the panel discussion

1. What are the main barriers and enablers to promoting social equity in the Bhagirathi basin?
   - Shift in responsibilities from community to government institutions in recent times.
   - Change in land use and agricultural practices (fertile land in past are now barren) have consequences on hydrology.
   - Inadequate recharge of springs and groundwater
   - Traditional water harvesting methods have been neglected
   - Fragile landscape, frequent landslides, and flash flood issues.
   - Water is not used (allocated) judiciously by (among) the stakeholders.
   - All the stakeholders are not involved in the IWRM planning. It's a must to have good coordination among the stakeholder.
   - Lack of public awareness among the communities regarding climate change issues.
   - Population and urban water demands are ever-increasing. The hydraulic and water-related infrastructures are planned/ built considering the current demand but future supply and demand should also be considered. Most of the structures and technologies are outdated now and require modernization.
   - No regulations and planning related to water abstraction from the rivers.
   - The collaborative effort is required for the monitoring of water-related data. All the government, public, academic and research institutes should work together.
   - Migration due to lack of opportunities.

2. What are the main barriers and enablers to promoting economic efficiency in the Bhagirathi basin?
   - Changes in general lifestyle and water use.
   - Shifts in seasons and water availability.
   - Adaptation and mitigation measures for climate change impacts are expensive.
   - Need new hydraulic and water-related infrastructures due to increasing demand.
   - Shifts in cropping patterns, crop type (fruits and vegetables) and drought-resistant crops are promoting economic efficiency.
   - Tourism is promoting economic efficiency in the mountains as it generates income, gives jobs and sustains the livelihood of the people. But on the other hand, it is also creating pressure on the system as more people are migrating from flat lands to mountains. So migration should be regulated.
   - Disaster risk and its management are one of the main enables in the mountains.
   - Policy and legislation for the efficient use and transfer of water from one basin to another (inter-basin water transfer)

3. Which is the one main policy, mechanism, or resource that could help overcome the identified barriers to support IWRM plan development?

- Long-term monitoring of water resources is required. Observational network density should be increased to improve the understanding of water availability and its seasonality.
- Demand and supply should be estimated systematically. The upstream and downstream water users and relevant stakeholders should participate in the development and implementation of the IWRM plan in the Bhagirathi basin.
- Legal reforms (waste and debris disposal, stopping illegal construction and flood plain zoning), policies, proper governance and transparency are a must for a successful implementation of IWRM.
- Robust adaptation and mitigation plans.
- Learn from other good practices (for instance example of Israel), holistically use water and do not waste a single drop of water.
- Change in the perception of people "Saving water and conserving nature" is our responsibility.

4. To support an IWRM plan, what your department/institution has to offer and what are your expectations from the IWRM plan?
   - THDC will liaise and coordinate with CWC to implement the IWRM plan in the region.
   - USDMA will provide the real-time data from the automatic weather station and rain gauges across Uttarakhand state (167 stations) to the educational and research institutes to better predict future weather events. USDMA will further strengthen the observational station network by installing three new compact radars in different regions (Naina Devi, Mukteshwar and Lansdowne).
   - USDMA will do the landslide, flood, flash-flood, earthquake and industrial hazard and vulnerability assessment for each development block and make those results available in public domain for free use.
   - USDMA will share the results of the Uttarakhand River Morphology Information system which deals with 4-5 major rivers of Bhagirathi, Alaknanda, Mandakini, and Kali rivers.
   - USDMA will collaborate with THDC to model and forecast the inflow in to the reservoir.
   - USDMA will help THDC to build an early warning system between Koteshwar and Rishikesh for disaster risk management purposes.
   - NIH is carrying out scientific studies in the Himalayan region (including glaciers studies) to understand the impact of climate change for the past 25 years. NIH is also monitoring and setting up high-altitude data observation system, especially in Gangotri and Keerti Basin. NIH is establishing a separate department for the cryosphere and climate change.
   - NIH is closely monitoring the development of the DSS system in this project. As per NIH understanding, the DSS from this project should cover all the relevant aspects (glaciers, snow, groundwater and climate change) of high mountain hydrology.
   - CWC has prepared two IWRM plans with the help of the European Union and Australian partnership in the past (Bramhini basin in Orissa and Tapi basin). CWC is willing to help SDC to formulate an effective IWRM plan for the Bhagirathi basin. CWC in the future will expand the observational network for Uttarakhand (currently 81 hydrological, 83 meteorological,

7 snow gauges). CWC suggests involving the other stakeholders such as the department of agriculture and forest in this project to make an inclusive IWRM plan.

After the panel discussion, a breakout session followed, in which the stakeholders were split into four groups (random). The breakout groups discuss in more detail the key challenges outlined during the panel discussion. The key aspects discussed during the breakout sessions are summarized below.

Team 1: Socio-economic aspects

1. What are the visible impacts of climate change to the current socio-economic situation in the region? Do you have any personal stories or experiences which you can share?
   a. Agricultural-related impacts:- changes in cropping patterns, early flowering, and late peeling have affected the community and their livelihood.
   b. Due to land acquisition, farmers who were earlier dependent on agriculture are now becoming labor oriented. Market experts are advising farmers to grow certain crops. The agro-business is overexploited.
   c. Climate change impacts on agriculture: Migration is a key issue in Uttarakhand. In old days people from the community were taking responsibility to protect water resources to safeguard water from pollution and usage of water so judiciously. But this has changed in recent times as the responsibilities have been shifted to the government agencies.
2. What people are doing to meet those challenges? What are traditional practices which you can highlight?
   a. Changes in cropping patterns and crops (Kiwi and cash crops such as natural fiber, Australian crop, and silk trees)
   b. Rainwater harvesting and recharge of springs and groundwater
   c. Watershed management and priority mapping
   d. Nature-based agro-business for instance artisan based skills in bamboo, natural fiber etc
   e. Climate-smart agriculture
   f. Water disposal management
   g. Wildlife conflict reduction
3. What should be done to strengthen the socioeconomic resilience at the livelihood level? Which practices at the local level can be introduced to make the communities more climate resilient?
   a. Revival of drying springs
   b. Promotion of indigenous technologies
   c. Community participation.

Team 2: Regulatory and policy aspects

1. What regulations and policies are specifically affected by climate change impacts? What are the gaps?
   a. No land use policy for hilly regions
   b. Flood zonation maps (with return period analysis) are lacking.
   c. Building-buy laws are lacking
2. What is currently being done to overcome the challenges around regulations and policies?
   a. Preparation of master plan. Dehradun Mussoorie, Nainital and Haldwani regions have a master plan but it is lacking for high-altitude regions.
   b. A flood zonation map of the whole of Uttarakhand is currently being prepared.
   c. Watershed management plans are updated
   d. Several water-related missions are being currently implemented in the region such as JAL JIVAN MISSION, GHAR GHAR NAL, Prime Minister Kisan Sichai Yojana and NAMAMI GANGE PROJECT.
   e. Environmental and ecological issues are being monitored and new laws and policies are being prepared.
3. Are there new policies and regulations that will need to be introduced? Are there other developments related to governance and climate adaptation that need to be strengthened?
   a. High-resolution mapping of hilly areas
   b. A waste management policy needs to be introduced. Plastic ban in the region. Discussions are ongoing with big business enterprises such as Haldiram or Aquafina
   c. A springshed management policy is required to rejuvenate the springs.
   d. Climate change mitigation and adaptation policy is required
   e. Policy to increase awareness of the community. For instance inclusion of climate change in the curriculum of school students.
   f. Climate audit reports should be made and available in the public domain.

Team 3: Institutional and Infrastructural aspects

1. How climate change is impacting the institutional arrangement around water resources? How it is affecting water resources infrastructure?
   a. Decrease in reservoir capacity due to sedimentation.
   b. Increase in water-related hazards risk (landslide, cloud outburst flood, GLOF) the safety of the reservoir
   c. Forest wildfire and wildlife conflicts
   d. Irrigation and water supply system malfunction
   e. Glacier change affecting water level in the reservoirs

2. What type of responses and investments are currently being done to overcome the challenges?
   a. Mandatory river basin study and cloud burst events for the hydropower projects
   b. Hydromet data monitoring density has been increased.
   c. Glacier mapping and water quality studies are going on in several Himalayan basins.
   d. Community involvement
   e. Air quality monitoring from Srinagar to Badrinath is being done by Uttaranchal University
   f. Microplastic and water metal disposal impacts and management studies
3. What additional measures and investments need to be done to strengthen the climate resilience of the institutions and infrastructure in the region?
   a. Strengthen the data monitoring network
   b. Climate resilient infrastructure development
   c. Use of technology (AI, ML, and large data integration)
   d. Capacity building of departments

Team 4: Technological, research, data and capacity building

1. What are the research gaps?
   a. Lack of observational data (precipitation, snow, rainfall, snow depth, SWE, black carbon deposition, glaciers retreat, high-resolution DEMs etc)
   b. especially in high altitudes.
   c. Lack of measuring instruments. Operation and maintenance of the instruments.
   d. Lack of simple tools and methods for modelling high mountain processes. All the models and methods should have an interface with GIS.
   e. Climate change projections are not representative in high mountains so it needs bias correction and better downscaling techniques.
   f. Limited knowledge and database of springs
2. What can be done to improve data sharing?
   a. Open data and common open web-based data information systems for the different government departments to share the data.
   b. Acknowledgment of the data source
   c. Training programs (short and long term) for the institutional capacity building
   d. Increase in awareness of the community

3. What type of capacity building is required in the region?
   a. Technology transfers to the future generation. Training in schools and colleges
   b. Integration of traditional knowledge with new state-of-the-art modelling techniques
   c. Para-hydrologist training (sampling, field data collection, analysis, and storage)
   d. Training on socio-economic impacts of climate change

Annex 3 Governance analysis methodology

The methodology for governance analysis included: (i) a desk-based review focused on water resources management in the Bhagirathi basin; (ii) consultation with 41 stakeholders including targeted semi-structured interviews (on-line, telephone and face-to-face) and one workshop. The desk-based review included grey literature, scientific publications, reports, newspapers, or websites providing relevant information. The review, in turn, served as a preliminary identification of relevant stakeholders for the interviews. Interviewees were also identified through the Swiss Development Cooperation (SDC) expert consultation and the governance analysis. The 41 consulted stakeholders included: (i) 34 attending the project inception workshop on May 18, 2021; (ii) 7 interviewees contacted between October 12, 2021 and February 2, 2022. These stakeholders represented different sectors and administrative levels, as well as non-governmental entities involved in the water management, including e.g., the Planning Commission of Uttarakhand, the Watershed Management Directorate, the Indian Forest Office, the BAIF Institute for Sustainable Livelihoods and Development (BISLD), the National Institute of Hydrology (Roorkee), and the Springshed Management Consortium of Uttarakhand.

The analyzed data include the workshop minutes, the interview transcripts and the recordings of interviews and workshop. Interview transcripts and recordings were made anonymous for data analysis, taking into account the Indian national data protection laws. Data and transcripts are available in original language upon request. Data were analyzed using qualitative content analysis and organised according to the conceptual framework described here below.

The topics addressed during the consultations include the key water management issues, needs, barriers and enablers related to IWRM and decision making, e.g., different interests and competing demands concerning water supply, key IWRM priorities and user needs, environmental objectives, impacts of natural hazards on water availability, expected climate-related changes and strategies to address them. More precisely, the conceptual framework used for the interview protocol included over 50 open ended questions, structured around six key thematic areas: (1) Water Management Issues (questions included, e.g., Is climate change a threat for water resources management? If yes, to what extent?); (2) Water Management Options (e.g., What measures should be taken immediately to improve water management issues in the basin?); (3) Decision Making Process: reflection about the past and focus on the future (e.g., Who is included and who is excluded from water management decision making processes?); (4) Information Systems, Decision Support, Training Need Assessment and Capacity Building (e.g., What information systems, information sharing among institutions are needed to support decisions? What are the main information inputs to the water management and are they adequate and tailored to the local needs); (5) Institutional Framework, Policies

and Responsibilities (e.g., Do you think decentralization of management roles to deal with water crisis issues and appropriate adaptation response would improve the situation? If yes, how?); (6) Stakeholders (e.g., Why do stakeholders have different views and opinions about water management solutions?); (7) Finance and Legislation (e.g., How severe have been the financial losses induced from recent water crises or extreme events in the basin?); (8) Concluding Questions. The protocol ended with questions targeted only to some interviewees groups on (depending on interviewee's expertise) about (9) Water Management Measures, (10) Legal and Institutional Aspects, (11) Social Vulnerability and Adaptive Response, as well as (12) Monitoring, data Collection and Dissemination. Developed following the principles of the case study design (Yin, 1989). A better understanding of these key thematic areas is expected to provide the necessary background to kick-start the participatory process for the IWRM plan co-design (for more information about the methodological background see e.g., McDaniels et al., 1999; Videira et al., 2006; Messner et al., 2006; Junker et al., 2007; Paneque Salgado et al., 2009; Kallis et al., 2009; Scolobig and Lilliestam, 2016; Scolobig et al., 2016).

Annex 4 Key governance issues

Natural and climate change-induced disasters

At high elevations in Himalayas the warming of the climate is resulting in the recession of glaciers and formation of glacial lakes that have increased conflict with glacial hazards including moraine dam failures and glacial lake outbursts floods with potentially disastrous effects. The increase in global temperature will cause increased occurrence of GLOFs and will affect the size of the glacial lakes. The State of Uttarakhand is no exception and some glacial lakes have been identified that have the probability of outburst. Last, the area is also prone to extreme events occurring more in the Uttarakhand than in other regions (e.g., Kedarnath 2013 flash floods and Nainital cloud burst in October 2021).

Climate crisis

Disappearance of mountain glaciers (total thickness of the glaciers is reducing) and rise of the snow line altitude, are two common phenomena being reported from Uttarakhand. Precipitations have significantly reduced in the winter season impacting snowfall pattern over time. For example, the Bhagirathi region traditionally received snowfalls from November to December and remained frozen for a long time. Nowadays, maximal snowfall occurs in late January and melt easily due to high temperature, significantly impacting the snow-fed water resources.

Stakeholders involved in the participatory process identify several climate change impacts that pose serious threats to IWRM: (i) decrease in reservoir capacity due to sedimentation; (ii) increase in water-related hazards risk (landslide, cloud outburst flood, GLOF) the safety of the reservoir; (iii) forest wildfires and wildlife conflicts; (iv) irrigation and water supply system malfunction; (v) glacier retreat affecting water level in the reservoirs; (vi) agricultural-related impacts:- changes in cropping patterns, have affected the community and their livelihood.

Migration of population due to water scarcity

While upper regions are currently not impacted due to the availability of glacial melt water, remotely located villages are already facing water shortages as the sources of water for these villages are solely dependent on spring water. This is affecting the living conditions of the local population, who consequently abandon their homeland and migrate to different parts of the country in search of new opportunities. As a result, an increase of population migrations is being observed in the region, as evident by the 250 ghost villages that have been completely abandoned in Uttarakhand due to reduced livelihood availability options.

Urban development and population

The urban population of the Bhagirathi basin is likely to grow considerably and converge towards the basin's largest cities. A greater demand for water resulting from urban expansion and improvement in living standard is therefore expected in the future, while water reserves and availability are already scarce in many districts due to a significant amount of water wasted resulting from excessive or incorrect use. Moreover, unplanned infrastructure development (e.g., road construction) has led to the depletion of water resources, and the population size adds a burden to the water quality issues of the river.

Loss of Biodiversity

The state of Uttarakhand is endowed with rich biodiversity and contains some of the most important species of plants and animals found in the Himalayas. In that respect, the Bhagirathi basin is an eco-sensitive zone. Climate change and urbanization are leading to loss of biodiversity in the state, which will have further influence on water quality and livelihood opportunities for the local communities.

Public health and sanitation

Access to available water resources, water use and availability of clean drinking water are critical issues in the Bhagirathi basin. Anthropogenic activities, including environmentally detrimental practices (such as building roads or unplanned infrastructural development), have often degraded water resources and increased ecosystems vulnerability. Additionally, the major problem in providing safe drinking water are: (1) increased population; (2) industrialization and urbanization; (3) use of chemical fertilizers by the agricultural sector; (4) sewage and sanitation problems;

Energy and infrastructure

Uttarakhand is endowed with numerous water resources that are used, e.g., for activities related to industry and hydro power as demonstrated by the 244 hydroelectric plants (under construction or in operation). Estimated hydro-power potential of Uttarakhand State is approximately 25,000 MW. Poorly planned energy infrastructure development is leading to instability of the fragile mountainous terrain of Uttarakhand, while also destroying the traditional "Naulas".

Annex 5 Decision support systems

To support the implementation of actions and recommendations identified in this plan, a decision Support System (DSS) has been designed. The DSS supports decision making and problem solving with respect to key parameters among a host of options, by analyzing vast amounts of data. These provide insights on the basis of past records, help in predictive analysis and forecasting, and serve as a key platform for constant monitoring. The DSS content will be based on the modelling activities, the needs for the IWRM plan, and its content is strongly stakeholder-demand driven through the stakeholder engagement platform. The DSS consists of a front-end user interface on a web-based dashboard, and its back-end IT architecture.

Front-end with web-based Dashboard

Front-end user interface with an online dashboard, helps the user to interact with the model input and output and analyze the impacts of different climate and socio-economic scenarios for water supply and demand. The key feature is to enable the user to assess different adaptation options. The dashboard features the ability to filter, drilldown and analyze changes in various parameters like sectoral demands and consumption, and spatial changes in other water balance components. The dashboard will feature interactive visual representation in terms of different types of charts like stacked bars, line graphs, pie charts, filtering at different levels and visual cues/insights. The DSS is a key output and will help in widening the outreach and applicability of modelling results of this project. This will facilitate the better usage of IWRM plan by different stakeholders. The DSS will be essential to evaluate scenarios and support water management decisions at the basin level. To develop DSS, Power BI data visualization package, which is a collection of software services, apps, and connector modules that enables to convert structured, formatted data coming from different sources into coherent, relatable, visually appealing, and interactive set, has been used. The Power BI package has built-in machine learning algorithms to assist in trend recognition and extrapolation beyond the available model output. It also has the capability to enable quick information sharing through weblinks and snapshots.

Back-end architecture

The back-end architecture involves the development of a GEO-database, integrating the model outputs as layers and time series, and linking this to the front-end to enable user interaction. The application will be hosted in a secure cloud platform with stable performance, accessibility, robustness and high performance.

DSS framework

Framework for the DSS consists of three main components/ pillars –

1. **Knowledge Base**. It provides access to historical data that has been used for the analysis under the project
2. **Climate Change Projections**. It provides projected results as part of glacio-hydrological modelling and water allocation modelling for the Bhagirathi basin
3. **Adaptation Scenarios**. It represents the alternative pathways to reduce the water issues in the basin

Each major component consists of several sub-components as presented in the Figure 11.

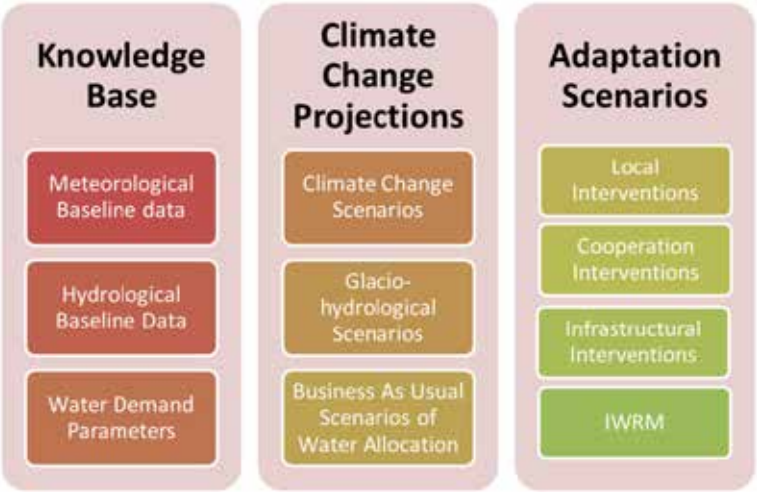


Figure 11 . DSS diagram for IWRM plan