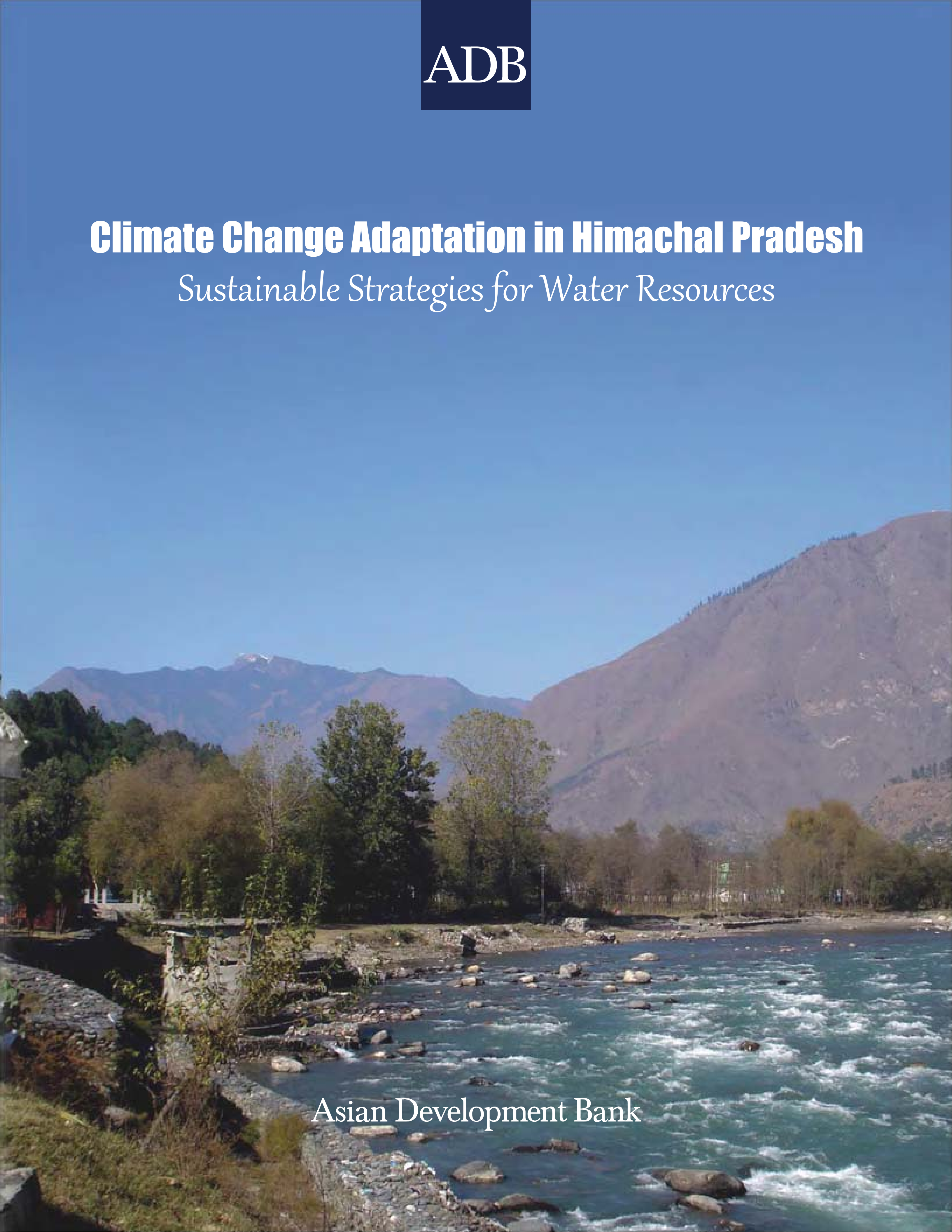
ADB

Climate Change Adaptation in Himachal Pradesh

Sustainable Strategies for Water Resources



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Message

I am pleased to introduce the final report of the study for Sustainable Strategies for Resources; the study forms a key component of the initiatives for Climate Change Adaptation for Himachal Pradesh. The report builds on various State and National programmes to address the impacts of climate change on water resources including; the National Action Plan for Climate Change, the agreements of the recent Himalayan Conclave, the proposed establishment of a state councils and a centre and for climate change and the preparation of a state environment action plan. Establishment of an integrated approach to water resource management is an essential part of the strategy; the recently formed State Water Management Board will play a key role in ensuring effective cross sectoral integration of the various water sectors.

Himachal Pradesh features a great diversity of climates, hydrological and ecological systems, as well as a diversity of cultures and communities. All of these natural and social systems depend on the region's glaciers, snowpack, rivers, soils, and monsoons. The river systems provide immense freshwater and hydroelectricity resources, and the mountains generate valuable tourism revenue and hold great spiritual value. The state water resources play an important role in the national hydrological cycle, atmospheric circulation, biological and cultural diversity. The mountain areas of India have been identified to be especially sensitive to climate change, with water resources likely to be the major area of climate impact on the largely rural Himachal communities as well as water resources investments.

No-one can predict the consequences of climate change with complete certainty; sufficient information is however now known to broadly understand the risks. Evidence shows that ignoring climate change will eventually damage economic growth and result in extensive impacts on vulnerable families; especially with low income groups and communities with lower capacities for adaptation. Timely and effective action for climate adaptation is a key pro-growth strategy and essential for long term sustainability. Early actions will be less costly as well as provide better levels of protection from the risk of economic and social loss, especially to the most vulnerable communities. Effective measures to support the Himachal population to meet the impacts of climate change are essential.

The output of water resources strategy study provides the direction to plan the way forward; moving from ideas and concepts to actions on the ground. The strategy identifies approaches for the effective development of state wide programmes to create robust water resources systems adequate to meet future climate impacts as well as the long term needs of sustainable water resources development.

Yours sincerely

(Ram Subhag Singh)

PREFACE

India, with 2.4% of the world's total area and 16% of the world's total population, accounts for only 4% of the total available fresh water. Sustainable and efficient management of water resources in the context of a growing economy, increasing population size, fast urbanization, and a relatively backward agriculture sector which consumes more than 80% of the available water, is daunting in itself. When the huge uncertainty in water availability due to climate change is factored in, the need for urgent and concerted action for "conserving water, minimizing wastage, and ensuring equitable distribution both, across and within States (and sectors) through Integrated Water Resources Management (IWRM) and development", as emphasized by the National Water Mission, becomes amply clear.

The threat of climate change is now regarded as an established fact. Most climate change models predict that global warming will disrupt the hydrological cycle, and intensify the temporal and spatial variation in precipitation, snow melt, and water availability. The Intergovernmental Panel on Climate Change observes that despite this impending crisis, water resource issues are yet to be systematically factored into climate change analyses and policy formulations, especially in developing countries. Likewise, climate change problems have not been adequately dealt with in water resources assessments, management, and policy formulation.

As part of the Himalayan mountain ecosystem, Himachal Pradesh is home to a wide range of natural water resources. However, as explained in the study, this bounty notwithstanding, the Himalayan ecosystem and therefore, states such as Himachal Pradesh, are particularly sensitive to climate change, and all its attendant adverse effects. Regional changes in climate have already affected a number of physical and biological systems in the mountains. Analysis of temperature trends in the Himalayas and its vicinities shows that temperature increases are greater in the uplands than that in the lowlands. The study, *Climate Change Adaptation Focused Sustainable Water Resources Strategy for Himachal Pradesh*, undertaken by ADB at the request of the Department of Economic Affairs and the state government of Himachal Pradesh, and in full consultation with all relevant stakeholders, is therefore, very timely.

The study examines the status of water resources in Himachal Pradesh, including the present and planned water utilization across sectors and uses, within a framework of environment, conservation and sustainability. It also examines the present institutional arrangements for water resources management and assesses the requirements for institutional development, improvement in data collection and analysis, catchment and agriculture planning, and other reforms required to ensure sustainable water resources management.

The strategic framework presented in this study builds on the broad principles of Integrated Water Resources Management, environmentally sustainable development, and participative planning and management. The approach is designed to generate net social and economic benefits irrespective of whether or not, or how anthropogenic climate changes occur. The strategy is also designed to build on the important initiatives being taken the Government of Himachal Pradesh and is complimentary to the recommendations of the National Action Plan for Climate Change (NAPCC) and the conclusions of the Himalayan Conclave and the Shimla Declaration (October 2009).

Increasing assistance for climate change adaptation and mitigation is a core focus of ADB's Strategy 2020. We are therefore, very happy to have supported this important study which fits in very well with the priorities of India's National Water Mission. We hope this study will help the Government of Himachal Pradesh in setting up and operationalizing a robust institutional framework for integrated water resources so that it can adapt to climate change related uncertainties, and sustainably manage this critical resource for the long term development of the state and its people.

Hun Kim

Country Director

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ABBREVIATIONS

ACCA	Advancing Capacity to Support Climate Change Adaptation
AEZ	Agro-ecological Zones
BBMB	Bhakhra Beas Management Board
CAD	Common Area Development
CAT	Catchment Area Treatment
CBOs	Community Based Organisations
CWC	Central Water Commission
DEST	Department of Environment, Science and Technology
DIPH	Department of Irrigation and Public Health
DOA	Department of Agriculture
DST	Department of Science and Technology
EIRR	Economic Internal Rate of Return
EMP	Environment Master Plan
GHG	Greenhouse Gas
GLOF	Glacial lake outburst flood
GOHP	Government of Himachal Pradesh
GOI	Government of India
GSDP	Gross State Domestic Product
HIMURJA	Himachal Pradesh Energy Development Agency
HPPCL	Himachal Pradesh Power Corporation Limited
HPPF	Hydro Power Producers' Forum
HPSEB	Himachal Pradesh State Electricity Board
HSHEB	Himachal Pradesh State Hydro-Electric Board
HYV	High Yielding Variety
ICAR	Indian Council of Agricultural Research
IMD	India Meteorological Department
IHR	Indian Himalayan Region
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resources Management
JFM	Joint Forest Management
JFMC	Joint Forest Management Committees
JICA	Japan International Cooperation Agency
NGOs	Non-Governmental Organisations
NTPC	National Thermal Power Corporation

NHPC	National Hydro Power Corporation
MOEF	Ministry of Environment and Forests
MOWR	Ministry of Water Resources
NAPCC	National Action Plan on Climate Change
NREGA	National Rural Employment Guarantee Act
NREGS	National Rural Employment Guarantee Scheme
NWM	National Water Mission
O&M	Operation and Maintenance
PRI	Panchayati Raj Institutions
RBOs	River Basic Organisations
RMB	River Management Board
SJVNL	Satluj Jal Vidyut Nigam Limited
SoER	State of the Environment Report
SUDS	Sustainable Urban Drainage System
ULB	Urban local bodies
UNITAR	United Nations Institute for Training & Research
WUA	Water Users Association

EXECUTIVE SUMMARY

The preparation of a Climate Change Adaptation Focused Sustainable Water Resources Strategy was requested by the Department of Economic Affairs and the State Government of Himachal Pradesh. The study was funded under ADB's Water Financing Program through the Multi-Donor Trust Fund under the Water Financing Partnership Facility. The study was carried out in Himachal Pradesh during late 2009 and early 2010, and involved extensive discussions and consultations with the various water-related departments and agencies, as well as field visits and meetings with communities and stakeholders. The draft final report proposals were discussed with the key water resources departments and agencies at a workshop held on 26 February 2010 under the chairmanship of the Chief Secretary to the Government of Himachal Pradesh. Comments and recommendations received at the workshop and subsequently are incorporated into this final report. Support studies were provided by the CSK, Himachal Pradesh Agricultural University of Palampur.

The broad objective of the study is to develop a climate change adaptation-focused sustainable water resources strategy and appropriate institutional framework for Himachal Pradesh. Adaptation in this context is an ongoing and flexible process designed to reduce the exposure of society to risks arising from climate variability. The strategy identifies and presents a broad framework for integrated water resources planning and management to increase the level of resilience to climate change. It is based on an assessment of the status of water resources in the state, including the present and planned water utilization examined within a framework of environment, conservation and sustainability. The strategy also examines the present institutional arrangements for water resources management and assesses the requirements for institutional development, strengthening and necessary reform measures to support the development of robust and sustainable water resources management.

Although the understanding of the impact of climate change continues to improve, it is as yet difficult to project and identify the specific regional impacts with any precision. This uncertainty remains a key constraint and major challenge, both, in formulating and implementing policies related to adaptation. Climate change represents a loss of information; the value of historical data in guiding water resources decision-making is degraded and future conditions are subject to a high level of uncertainty. With the very high variations of topography and rainfall, prediction of future climate trends will be especially difficult for Himachal Pradesh. It is evident that farmers are already feeling impacts of climate change. Observed parameters include movement of apple orchards to higher altitudes, loss of various tree species, drying of traditional water sources, changes in bird types and populations, reduction in crop yields, and increased vulnerability of winter cropping due to changes in rainfall patterns and planting dates.

The mountain ecosystems harbour a wide range of natural resources and are particularly sensitive to change. Regional changes in climate have already affected many of the physical and biological systems in the mountains. Analysis of temperature trends in the Himalayas and vicinities shows that temperature increases are greater in the uplands than the lowlands. Climate change impacts on water resources will likely include; (i) increased frequency of heavy precipita-tion; (ii) increase in extreme rainfall intensity; (iii) increased variability in rainfall patterns; (iv) increased likelihood of water shortages/drought (v) reduced levels of precipitation as snow; (vi) loss of glacier volumes; (vii) earlier snow melt; and (viii) increased temperature.

A seven point strategic framework for water resources adaptation has been developed. It sets out the approach and strategies required for achieving long term sustainable water resources management and adaptation to climate change. It is proposed to apply IWRM as a management tool since it would open up important opportunities to position water, as a resource at the centre of the policy making arena an important facility to initiate proactive actions to increase the resilience of water resource systems to climate change. The strategic framework has been designed to build on the recommendations of the National Action Plan for Climate Change (NAPCC). The three most relevant parts of the NAPCC from the perspective of this study are; the National Missions for Water, Sustaining the Himalayan Ecosystem, and for Sustainable Agriculture. The strategy also builds on the recommendations of the recent conclave of the five Indian Himalayan states.

(cont'd overleaf)

A road map to move forward from ideas and concepts to actions has been prepared. It compares the present status and identifies the main outputs and activities to meet the needs of climate change adaptation. A summary of the seven strategies and proposed projects is given below.

1. Effective Institutions and IWRM
   - o Establishment of effective institutions for IWRM.
   - o Finance and resource strategies to meet the needs of climate change.
   - o Strengthen Interstate Water Management.
   - o Strengthen the linkages between State and National agencies.
   - o Capacity Building for awareness. understanding and, management of water resources and climate change.
2. Water resources Data and Information Systems
   - o Establish a Water Resource Data and Information Centre.
   - o Development of tools, methods and capacities to analyse climate information.
   - o Strategies for effective research to meet needs of climate adaptation.
3. Catchment and Agricultural Planning
   - o Framework plans for four selected sub catchments.
   - o Detailed studies and designs for follow up investments.
4. Integrated Water Resource Planning
   - o Preparation of IRWM Plan for Sutlej River in Himachal Pradesh and Punjab.
   - o Ensuring environmentally sustainable water resources management.
   - o Detailed studies and designs for follow up investments.
5. Disaster Preparedness
   - o Preparation of Disaster Preparedness and Management Plans to meet needs of climate change.
6. Rural Employment and Diversification
   - o Strategies for rural employment and diversification.
7. Projects and Investments
   - o Integrated soil and water conservation.
   - o New initiatives in precision agriculture.
   - o Upgrading performance of irrigation schemes.
   - o Upgrading levels of service delivery and sustainability of potable water.
   - o Integrated hydroelectric projects to improve performance and reduce social and environmental impacts.
   - o Other investment projects to be defined.

1

INTRODUCTION

The development of a climate change adaptation focused water resources strategy has been undertaken at the request of the Government of India, through the Department of Economic Affairs and the Government of Himachal Pradesh (GoHP). This study is designed to review and assess the requirements for efficient and sustainable water resources management in Himachal Pradesh.[1]

Its broad objective is to develop a climate change adaptation focused sustainable water resources strategy for Himachal Pradesh. The strategy identifies and presents a broad framework for integrated water resources planning and management. It is based on a rapid assessment of the status of water resources in the state, including the present and planned levels of water utilization, as well as issues of environment, conservation, and sustainability. The strategy also examines the present institutional arrangements for water resources management and assesses the requirements for institutional development, strengthening, and necessary reform measures. It presents the outline framework for future water resources planning and management in the face of climate change, and proposes a preliminary road map setting out the broad measures required for adaptation.

It is estimated that climate change will affect people primarily through unpredictable changes in water ecosystems and the water related economies. While projections of future temperatures are becoming better understood, the overall impact on the water resources is still not clearly defined. Irrespective of the scale and viabilities of climate mitigation measures, realistic, and effective adaptation measures are necessary.[2] Of major issue for water resources are the non-linear effects where changes in climate can be amplified in the water environment. For example, small temperature changes of a few degrees might possibly result in both, increases and decreases of water resources, of up to 30 per cent or more. Water sector planners and managers require guidance on directions for future strategies and priorities for investment to meet the challenges of climate change.

The Intergovernmental Panel on Climate Change (IPCC) concludes that so far, water resource issues have not been adequately addressed in climate change analyses and climate policy formulations.[3] Likewise, in most cases, climate change problems have not been adequately dealt with in water resources analyses, management, and policy formulation. According to many experts, water and its availability and quality will be the main pressures on, and issues for, societies and the environment under climate change; hence, the necessity to improve the understanding of the problems and inter linkages involved.

India's position on climate change issues and Government of India (GoI) response:[4] India has been and will continue to be severely impacted by climate variability precisely at a time when it is confronted with huge development imperatives. The focus of climate change action cannot just be on emissions but must equally address the important issue of adaptation. India is already subject to a high degree of climate variability that is manifest in droughts, floods, and other extreme weather events. The government's 11th Five Year Plan (FYP; 2007-2012) clearly articulates the impact and implications of climate change noted in the IPCC Assessment Reports. In an address to the National Conference of Ministers of Environment and Forests in August 2009, the Prime Minister, Dr Manmohan Singh, encouraged state gov-

[1] The study was funded under ADB RETA 6498. 2008. *Knowledge and Innovation Support for ADB's Water Financing Program - Preparation of Climate Change Adaptation-Focused Sustainable Water Use Strategy.* Manila.

[2] Intergovernmental Panel on Climate Change (IPCC). 2001. *Climate Change Impacts, Adaptation and Vulnerability.* Switzerland.

[3] IPCC. 2008. *Climate Change and Water.* Switzerland.

[4] Government of India, Public Diplomacy Division, Ministry of External Affairs. 2009. *The Road to Copenhagen: India's position on climate change issues.* http://www.meaindia.nic.in.

ernments to create state level action plans on climate change consistent with the strategies of the National Action Plan on Climate Change (NAPCC) which had been launched on 30 June 2008. Based on the recommendations of the NAPCC, eight National Missions have been established; each of the Missions will be managed by the respective Ministries and line agencies through inter-sectoral groups including related Ministries, Ministry of Finance, Planning Commission, and experts from industry, academia, and civil society.[5] Each Mission is preparing detailed implementation plans under the 11th FYP and 12th FYP (2012-2017). In this context, measures for the conservation of mountains have been specifically envisaged. Of the eight National Missions, the National Missions for Himalayan Ecosystems under the Ministry of Science and Technology, the National Water Mission under the Ministry of Water Resources, and the National Mission for Agriculture under the Ministry of Agriculture are of special relevance to the study.

Himachal Pradesh

Himachal Pradesh is a relatively young state, having been granted full statehood in 1971. It is a relatively small state both, in terms of population and size. With a population of 6.6 million, it represents well under 1 per cent of India's total. About 90 per cent of the population resides in rural areas. Himachal Pradesh is largely mountainous with the exception of small pockets bordering Punjab and Haryana. The state comprises hilly terrain, perennial rivers, and significant forest cover. The state offers many opportunities, given its abundant water resources, hydropower, mineral resources, horticulture, agriculture, and potential for tourism. It is however, facing significant challenges arising from its elevation, topography, and ecological vulnerability. Since the 1990s, Himachal Pradesh has grown faster than the national average and is ahead in terms of most indicators of human development. It is performing better than several more developed states on the plains in terms of social and economic progress. Supportive government policies have invested in infrastructure and given high priority to expenditures in the social sectors; Himachal Pradesh has achieved per capita social expenditures which are approximately double of the all-states average for India. Investments in infrastructure is gradually creating a facilitating environment for growth, but much of the economy remains dependant on public spending financed borrowing and central assistance. Employment opportunities outside the public sector remain scarce and opportunities for the now well educated younger generation in the state remain limited. Himachal Pradesh is one of eleven special category states with eligibility for special central assistance. The state and its rivers are shown in *Figure 1*.[6]

Figure 1 Himachal Pradesh showing rivers

Population

From the 2001 census, the population of the state is esti-mated at 6.1 million; the decadal growth 1991-2001 was 17.5 per cent, a slight downward trend over the previous ten years of growth of 20.6 per cent. Himachal Pradesh has the highest percentage of rural population in the country with 90 per cent of the population recorded as rural. Urban growth is higher than that in the rural areas. The urban population has increased by 1 per cent more than the rural over the last decade. An estimated 26 per cent of the population is below the poverty line; there are however, substantial disparities in wealth in the rural population. Over 29 per cent of Himachal Pradesh's population are scheduled castes and scheduled tribes; of whom 45 per cent are below the poverty line. The population density in the state is shown in *Figure 2*.[7]

Livelihoods

The predominately rural population is primarily dependant on agriculture. Almost every family owns land and is engaged in agriculture or horticulture for their day to day requirements. Over the years, the state has become known for its production of off-season vegetables and flowers. The average land holdings are very small and less than a hectare per family, with many fields being on steep land that do

[5] These include the following: (i) National Solar Mission; (ii) National Mission for Enhanced Energy Efficiency; (iii) National Mission on Sustainable Habitat; (iv) National Water Mission; (v) National Mission for Sustaining the Himalayan Ecosystem; (vi) National Mission for a "Green India"; (vii) National Mission for Sustainable Agriculture and (viii) National Mission on Strategic Knowledge for Climate Change.

[6] Government of Himachal Pradesh, CSK Himachal Pradesh Agricultural University, Centre for Geo-informatics, Palampur.

[7] ibid.

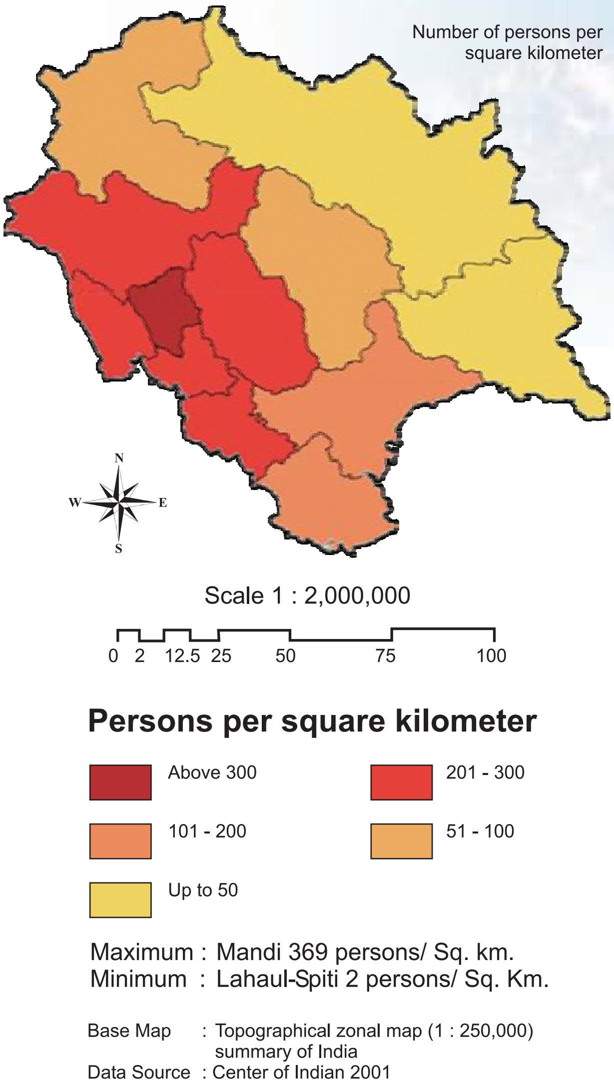

Figure 2 Population Density

not lend themselves to mechanisation. Most agriculture is of the subsistence type and depends on suitable climate for good yields. The agricultural based economy is therefore, inadequate to fulfil the total livelihood requirement for most of the families. Increasingly, most rural families have access to off-farm incomes to supplement the shortfall from agriculture. Many families have one or more member working in urban centres out of the state, or in the military. Tourism and craft industries provide some supplementary income.

Animal husbandry is another source of income; almost every family raises livestock for its day to day requirements for subsistence as well as for generating cash income. Owing to the very small land holdings, families rely heavily on natural fodder resources including the forest areas to feed their livestock. Livestock kept by tribal communities are subject to transhumance (seasonal movement to new areas) to get the best pastures. Economically vulnerable groups including the scheduled tribes and castes have high dependence on the forest resources including collection of fodder, medicinal plants, and firewood.

Development Priorities

The 11th FYP seeks to achieve the twin objectives of faster growth and inclusive development including provision of essential social services, especially to disadvantaged groups, increasing farm incomes, developing vital infrastructure, protecting the environment, and improving governance. A vital thrust area identified by the government is the need to tackle unemployment as well as seeking to improve living standards, with priority for disadvantaged sections and remote areas. Himachal Pradesh's development priorities are a function of its unique socio-economic characteristics where it has natural advantages.

There are sectors with high potential that can contribute to more rapid growth. However, there remain sub-sectors like forestry and hospitality that have grown slower despite the state's natural advantages. Sub-sectors like manufacturing have been growth drivers in the recent past, helped by historical tax incentives and other benefits which have attracted new industries, especially in the districts bordering Punjab and Haryana. It will be important to sustain this good performance, and retain the new industries after the financial incentives are phased out in 2010.

The state government aims to achieve continued growth during the 11th FYP by capitalizing on its comparative advantage, increasing the productivity and economic value of its natural assets, and specializing in sectors where it can compete effectively in a globalized economy. Agriculture accounts for almost 70 per cent of employment, but generates less than 22 per cent of the gross state domestic product. Not only are productivity and incomes from this sector low, they are also likely to be more volatile, increasing vulnerability to climate impacts. There is a very high dependence on agriculture especially for rural female workers with 95 per cent being employed in this sector. The state is promoting a shift to higher return vegetable crops. There is a need to transition workers out of subsistence agriculture to more productive employment either, in more modern agriculture or by creating suitable opportunities in the non-farm sector. To some extent, the transition is already happening, with increasing deployment of incremental workers in construction, manufacturing, and sectors associated with tourism, while agricultural jobs are on the decline. The slow pace of the process is, however, troubling. In the rural areas in particular, more jobs are being lost in agriculture than are being created elsewhere.

Even though less than 10 per cent of the population is classified as poor, the state faces issues in terms of vulnerability of the population. It is estimated that one fifth of the population could slip into absolute poverty if the state's good economic performance is not maintained, a situation that might occur if severe climatic problems were to affect the agricultural sector.

2

WATER RESOURCES

The Indian Himalayas

Himachal Pradesh forms a key and central part of the Indian Himalayan region (IHR). The IHR region covers vast areas, with about 17 per cent of the region being under permanent snow cover and glaciers, and about 30-40 per cent under seasonal snow cover, forming a unique water reservoir. This feeds important perennial rivers that provide water for drinking, irrigation, and hydropower. Every year, about 1,200,000 million m^3 of water flows from Himalayan Rivers. The IHR is home to nearly 4 per cent of the country's population, and provides directly or indirectly for their livelihoods. However, the Himalayan ecosystem is highly vulnerable due to geological reasons, stress caused by increased pressure of population, exploitation of natural resources, and other related challenges. These effects are likely to be exacerbated due to the impact of climate change, which may adversely impact the Himalayan ecosystem through increased temperature, altered precipitation patterns, episodes of drought, and biotic influences. This would not only impact the very sustenance of the indigenous communities in uplands but also the life of downstream dwellers across the country and beyond. Therefore, there is an urgent need for giving special attention to sustain the Himalayan Ecosystem.

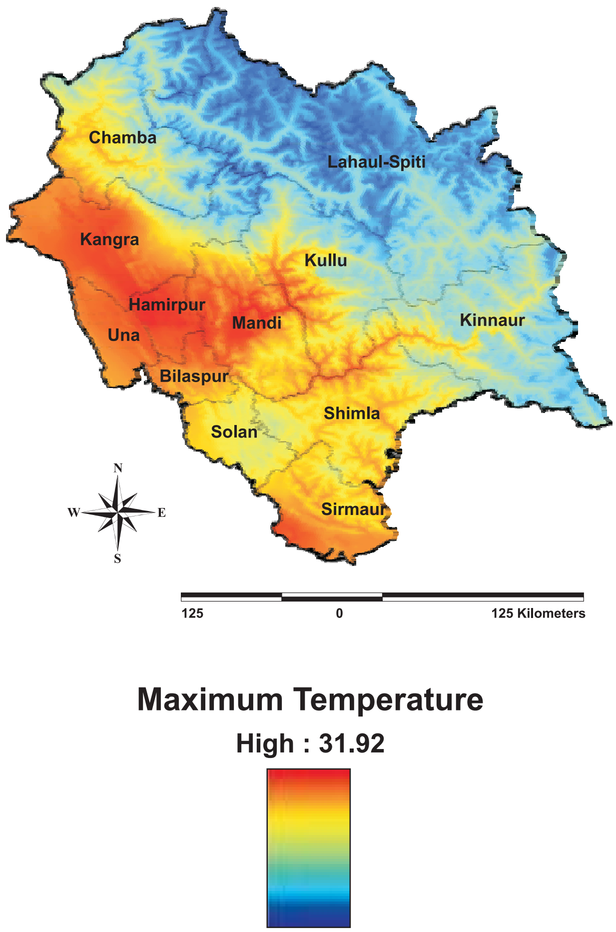

Figure 3 Maximum Temperatures

Climate

The state exhibits considerable variation in the distribution of temperature and rainfall due to the varying aspects and altitudes as shown in *Figure 3* and *Figure 4*.[8]

Agro-ecological Zones

The state has been divided into nine agro-ecological zones (AEZ) which separate the areas with similar sets of potentials and constraints. The demarcation has been based on

[8] ibid.

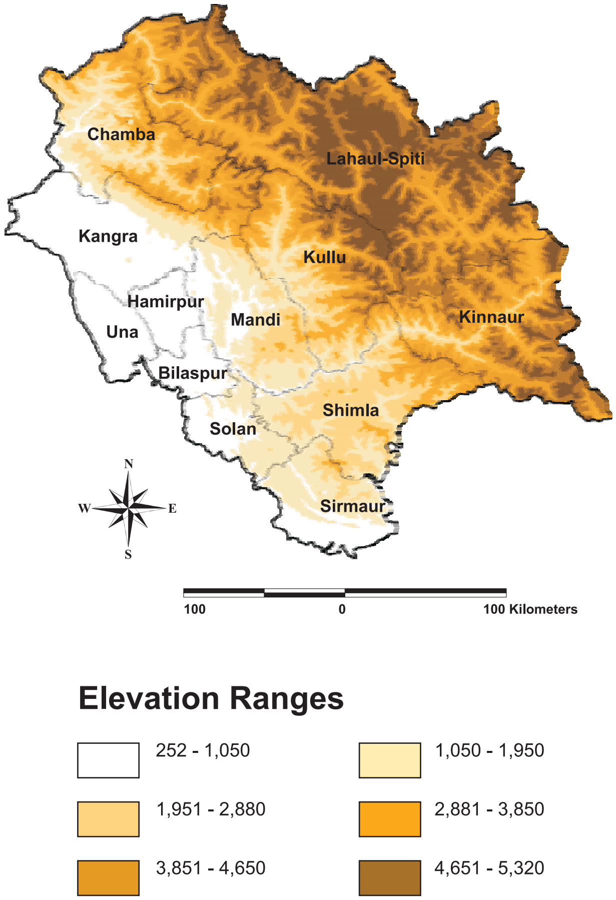

Figure 4 Himachal Pradesh Elevations

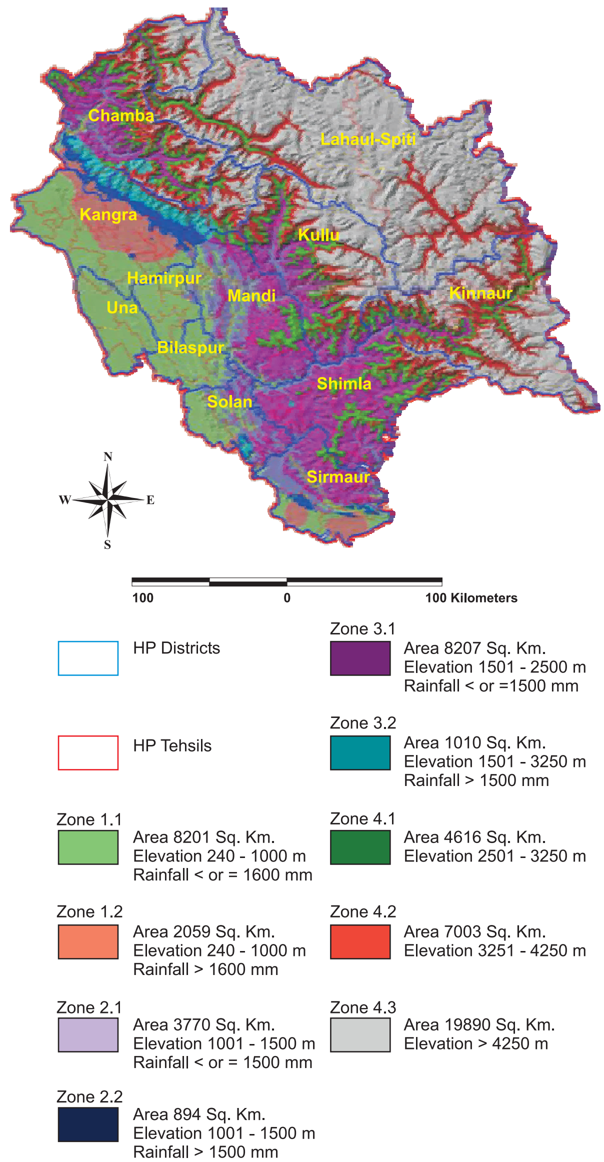

Figure 5 Himachal Pradesh Agro-ecological Zones

two major determinants namely, elevation and precipitation, based on which, the nine AEZs have been defined. The use of the AEZ can form a useful base for agricultural planning and sustainable natural resources management (*Figure 5*).[9]

Precipitation declines from west to the east, and south to the north. The average rainfall in Himachal Pradesh is 1,111 mm, varying from 450 mm in Lahaul and Spiti to over 3,400 mm in Dharamsala, the headquarters of Kangra district. Winter precipitation occurs as snow at elevations above 1800 m. An average of three metres of snow is experienced between December and March. Areas above 4500 m remain under perpetual snow cover. There are three marked seasons: (i) summer season (April to June); (ii) rainy season (July to September) and (iii) winter season (October to March). Pan evaporation generally exceeds rainfall over a period of six months during October to December and April to mid June. Rainfall is shown in *Figure 6*.[10]

Snow and Glaciers

Various studies and estimates of the state of the glaciers have been prepared. One of the most recent studies for Himachal Pradesh in 2004 has documented that there are 2,554 glaciers in the state.[11] Covering an area of 4160 km^2, these high frozen reservoirs release their water at the top of the watersheds. The glaciers plus the seasonal snow cover serve as the perennial sources of rivers that wind their way through

[9] ibid.

[10] ibid.

[11] *Inventory of Glaciers and Glacial Lakes and the Identification of Potential Glacial Lake Outburst Floods (GLOF) affected by Global Warming in the Mountains of the Himalayan Region* CSK Himachal Pradesh University; International Centre for Integrated Mountain Development, Asia Pacific Network for Global Change Research Global Change System for Analysis Research and Training United Nations Environment Programme Resources Centre Asia Pacific.

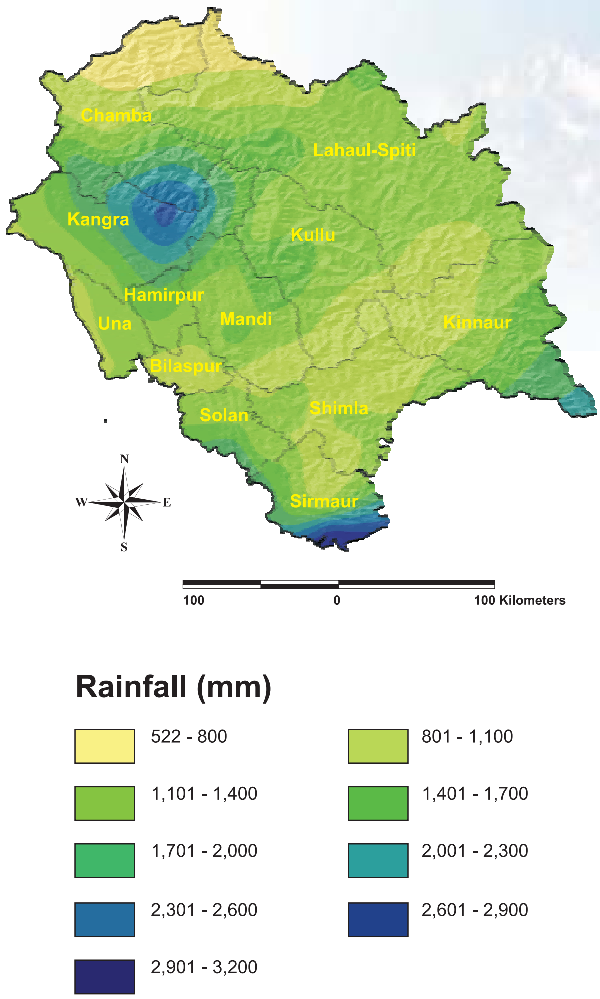

Figure 6 Annual Rainfall

grazing, agricultural, and forest lands, and are used as renewable sources of irrigation, drinking water, energy, and industry for Himachal Pradesh as well as the downstream plain states of Punjab, Haryana, and Uttar Pradesh.

Rainfall

The study demonstrates that the glaciers are retreating in the face of accelerated global warming. While it may be difficult to ascertain the precise pace of glacier recession, there is robust scientific evidence that glaciers are being affected by global warming. The glaciers are particularly vulnerable to climate change and the resultant long-term loss of natural fresh water storage will have as yet uncalculated effects on communities downstream. More immediately, as glaciers retreat, glacial lakes form behind some of the now exposed terminal moraines. Rapid accumulation of water in glacial lakes, particularly in those adjacent to receding glaciers, can lead to a sudden breaching of the unstable dam behind which they have formed. The resultant discharges of very large amounts of water and debris - a glacial lake outburst flood or GLOF - often have catastrophic effects downstream. Over the last half century, many glacial lakes are known to have formed in the Hindu Kush Himalaya, and a number of GLOFs have been reported in the region, including in Himachal Pradesh, in the last few decades. Some of these GLOFs have resulted in many deaths as well as the destruction of houses, bridges, fields, forests, and roads. The lakes at risk are situated in remote and inaccessible areas. In Himachal Pradesh, the catastrophic flood events from a GLOF in the Satluj basin in the last few years raised awareness about the problem considerably. The 2004 study identifies 156 glacier lakes in the State, of which 16 were assessed to be potentially dangerous. The bursting of moraine-dammed lakes can be caused by the breaching of the dam, erosion of the dam material as a result of overtopping, or by surging water or piping of dam material. Earthquakes leading to the slumping of dam material may also cause the bursting of the dam. The drainage of ice-dammed lakes may be due to: flotation of the ice dam, pressure deformation, melting of tunnels through or under the ice, and drainage associated with tectonic activity. A key requirement is to establish assessment, monitoring and warning systems, and fast track mechanisms to reduce the burst risk through lowering of water levels or creation of spillways should the moraine dams were to become critically unsafe. A summary of the major glaciers is provided in *Table 1*.[12]

The estimated volume of glaciers is shown in *Table 2*.[13] The area under glaciers is divided into four main basins and four minor basins. No measurement of thickness was carried out and the volumes of the glaciers (the ice reserves) have been based on correlations of thickness and glacial area from studies carried out in the Tianshan Mountains in People's Republic of China.

Surface Water Resources

The state is drained by nine river systems. The catchment areas of the rivers are given in *Table 3* and shown in *Figures 8* and *9*.[14]

The Satluj: The largest river system in the state with a total catchment area of 20,398 km^2, spread over the districts of Lahaul and Spiti, Kinnaur, Shimla, Solan, and Bilaspur before entering Punjab, it enters the large Bhakra dam.

The Beas: Originally known as the 'Vipasa', this is the second most important river with a catchment area of 13,663 km^2. It originates at Beas Kund near the Rohtang pass. It flows from North to South west over a distance of 286 km before entering the Pong Reservoir and into Punjab.

[12] Government of Himachal Pradesh, CSK Himachal Pradesh Agricultural University, Centre for Geo-informatics, Palampur.
[13] ibid.
[14] ibid.

Table 1 *Summary of Glaciers in Himachal Pradesh*

Bara Shigri the largest glacier in Himachal Pradesh. It is located in the Chandra valley of Lahaul and it feeds the river Chenab. Bada Shigri glacier is more than 25 km. long and about 3 km. wide. It lies on the middle slopes of the main Himalayan range. It is fed by many small tributary glaciers. It is said that this glacier formed Chandertal lake which caused major havoc in Chandra valley in 1936. There are a number of prominent glaciers in Chandra valley in Lahaul. Some of them are Chhota Shigri (means Small Glacier), Kulti, Shpting, Pacha, Ding Karmo, Tapn, Gyephang, Bolunag, Shili and Shamundri. Gyephang is the chief deity of Lahaul valley and the Gyephang glacier is named after him. It is full of snow all the year. It is considered as the Manimahesh of Lahaul.

Chandra Glacier falls in the Lahaul - Spiti district. It is located on the slopes of the main Himalaya. It has been separated from Bara Shigri glacier. This glacier is behind the formation of Chandertal lake, which is surrounded by snow and acres of scree. This deep blue-water lake has a circumference of 2.5 km. It is also called the 'Lake of the moon'. It remains completely frozen during winter. Chandertal lake is the source of the river Chandra.

Chandra Nahan Glacier located on the South-Eastern slopes of the main Himalaya in the area to the North-West of Rohru in Himachal Pradesh. Chandra Nahan Glacier is also aided by various small tributary glaciers. The famous Chandra Nahan lake lies in it and it feeds the river Pabbar. The elevation of Chandra Nahan glacier is more than 6,000 meters.

Bhadal Glacier is located on the South-Western slopes of the Pir Panjal range in the Bara Banghal area of Kangra district. It feeds the river Bhadal, which rises from the snowy range of the area lying between the Pir Panjal and Dhauladhar ranges. Bhadal river's catchment is made up of U-shaped valleys, waterfalls, moraines, cirques, and towering peaks. This river is one of the main tributaries of the river Ravi.

Bhaga Glacier is located on the slopes of the main Himalayan range in Lahaul area. This glacier feeds the river Bhaga. U-shaped valleys, waterfalls, glaciers and moraines characterise the upper catchment of the Bhaga river. The discharge of this river increases during the summer months when the snow on the high mountains start melting. Bhaga glacier is 25 km. long. The other important glaciers of Bhaga valley are Lady of Keylong, Mukkila, Milang, and Gangstang.

The Lady of Keylong is situated at an altitude of about 6,061 meters and can be seen clearly from Keylong. It remains covered with snow throughout the year. In the middle, there appears to be a dark bare patch that looks like the figure of a woman, walking with a load on her back. It is therefore, named 'Lady of Keylong' by the geological survey team of India.

Mukkila Glacier: It is situated at a height of about 6,478 meters.
Sonapani: About 6 km. from the confluence of Kulti Nala.
Gora Glacier: It has receded in the recent past due to an unstable mass balance. It lies in the South, facing the main Himalayan range.
Perad Glacier: Small and easily accessible, this glacier is near Putiruni.
Parbati and Dudhon: These glaciers are located in district Kullu. Both glaciers are 15 km long. They feed the Parbati river.
Beas Kund: It feeds the river Beas and is located on the south facing slopes of the towering Pir Panjal near the Rohtang Pass.

Table 2 *Summary of Glaciers in Himachal Pradesh*

	Basin	Number of Glaciers	Area (km^2)	Ice reserve (km^3)
1.	Beas	358	758	76.0
2.	Ravi	198	235	17.0
3.	Chenab	681	1704	187.0
4.	Satluj	945	1217	94.0
5.	Tsarap Chu	250	163	8.0
6.	Taklingla	55	32	1.4
7.	Bhagirathi	43	43	2.4
8.	Pabbar	24	6	0.2
	Total	**2554**	**4160**	**387.0**

The Chenab: Also known as the Chandrabhaga, it is the largest river in terms of water volume. Its catchment area is 7850 km^2. The Chandra and Bhaga originate on opposite sides of the Baralacha at an elevation of 4891 m. It flows north west before entering Kashmir.

The Yamuna: In the south eastern part of Himachal Pradesh, the Yamuna is fed by a number of tributaries before flowing into Uttar Pradesh.

The Ravi: This river originates from an amphitheatre type basin in the Dhauladhar Range, turning southwards cutting a deep gorge through the Dhauladur hills. The Ravi stretches 130 km before leaving the state into Punjab and Pakistan.

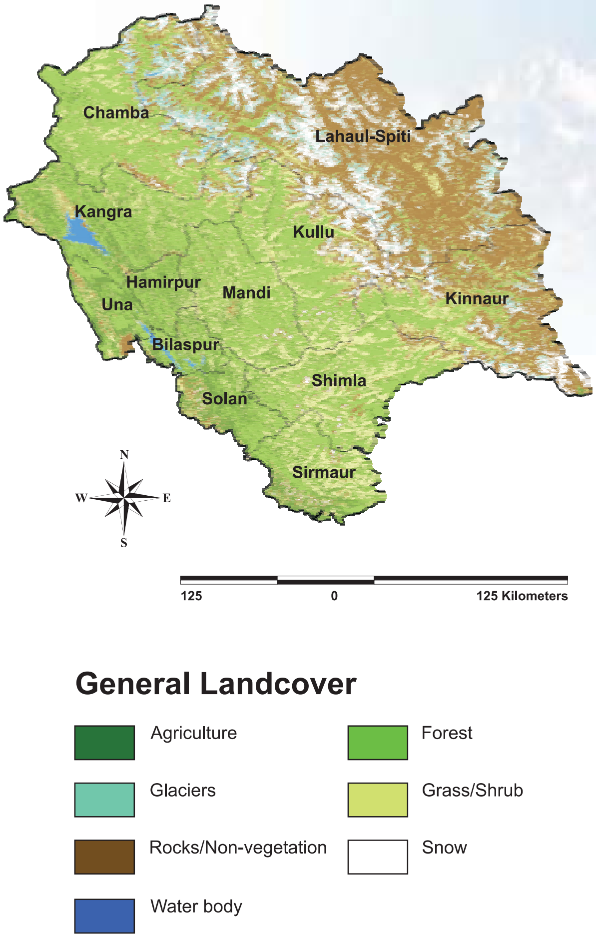

Figure 7 Land Cover

Figure 8 Main River Systems

Water Storage

Water storage in Himachal Pradesh is estimated at around 14,000 million m^3. The two major storages located on the borders of the state are the:

- The Govindsagar Reservoir (Bhakra Dam) in the Satluj River with 6,900 million m^3 live storage, was completed in 1963. The project, located on the border with Punjab, is a major source of hydropower and irrigation.
- Pong Dam located on the border with Punjab in the Beas River with 7,300 million m^3 live storage is primarily used for irrigation in Rajasthan, Haryana and Punjab and also for hydropower
- The Pandoh Dam, a hydroelectric dam on the river Beas upstream of Mandi, has live storage of 18 million m^3. Most of the hydroelectric dams however, only have storage capacity to meet the basic requirements of a few hours.

Satluj Hydrological Budget

A hydrological study carried out in 2008 gives a good summary of the Satluj hydrology and is relevant for improving to better understanding of future climate impacts. The monsoon (June to September) delivers up to 3 m/yr rainfall at the western Himalayan front with a steep gradient to 0.3 m/yr north eastward of the orographic (mountain) barrier.[15] This moisture gradient is inverted during the winter season (December to March) with snowfall amounts of up to 1 m of snow water equivalent mainly derived from 'western disturbances'. These seasonal variations in precipitation have consequences for discharge formation and therefore, influence hillslope processes, sediment flux, and fluvial erosion. The relationships between precipitation, discharge, topography, and sediment flux within the Satluj basin in the western Himalaya were quantified based on an analysis of daily precipitation data of the past 40 years from more than 70 meteorological stations covering large parts of the Satluj catchment and Himachal Pradesh. This unique dataset allowed the reconstruction of the magnitude and frequency of winter and summer storms. A hydrological budget was created to understand the seasonal climate impact on erosion processes on a catchment scale; the analysis was based on satellite imagery, ground observations, glacial mass balance studies, and water-balance modelling. This hydrological budget enabled the quantification of the source contribution

[15] Seasonal Precipitation and its Impact on Discharge and Hillslopes in the Satluj Valley, NW Himalaya, Wulf, H.; Bookhagen,; Scherler; Strecker,, University of Potsdam, University of California December 2008

Table 3 *Catchment Area of River Systems*

	Name of River System	Catchment Area (km²)	Percent
1.	Satluj	20,398	30.7
2.	Beas	13,663	24.5
3.	Chenab	7,850	14.2
4.	Yamuna	5,872	10.6
5.	Ravi	5,528	9.9
6.	Indus	1,450	2.6
7.	Markanda	360	0.6
8.	Ganga	290	0.5
9.	Ghaggar	262	0.5
	Total	**55,673**	**100.0**

of mean annual river discharge along the transition of fluvial to nivo-glacial dominated Satluj tributary catchments. In order to quantify sediment flux along the Satluj, pre-existing discharge and suspended sediment concentration data from Hydropower stations spanning several years to decades at ten locations within the Satluj catchment was collected. The results show that there exists a transitional zone between a lower-elevated rainfall zone and a higher-elevated snowfall dominated zone.

This transitional zone between 1.2 and 1.6 km Satluj-river elevation receives considerable amounts of summer rainfall (~1 m/yr) as well as large amounts of snow and glacier melt. It sustains high melt-derived discharge throughout the ablation season (May to September). In the higher-elevated snowfall zone (upstream of 2 km Satluj-river elevation), snowmelt contributes 80 to 90 per cent of the mean annual discharge in tributary catchments, while glacial melts account for 10 to 20 per cent of their annual budget. The sediment flux in the lower-elevated rainfall zone is highly variable and correlates closely with rainfall events, whereas sediment discharge in the higher-elevated snowfall zone is governed by melt events and less variable. Suspended sediment concentrations within the transition zone rise with increasing rainfall amounts. This trend is mirrored by an increase in vegetation cover, which along with warmer climatic conditions could account for higher soil production rates and therefore, increased sediment availability. The transition zone is likely to be sensitive to climatic variation. This increases the likelihood of future natural hazards such as landslides and floods. By quantifying spatiotemporal patterns of discharge generation, fluvial erosion, and hillslope failure, it is possible to better understand climate driven erosion on short timescales with implications for water management and hazard assessment.

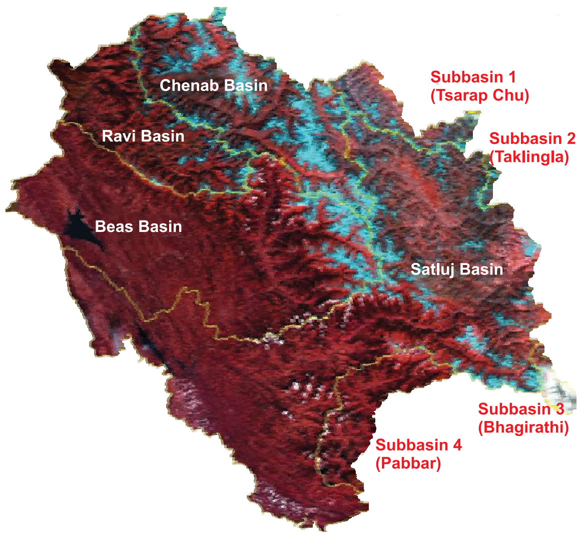

Figure 9 River Basins

Groundwater Resources

Most of the areas of Himachal Pradesh are hilly except for some intermountain valleys. These valleys consist of alluvium, fluvio, and fluvio-glacial deposits. There are five major valley areas covering a total of 120,000 ha. Apart from these, there are numerous valleys with areas so small that no quantitive assessments exist.[16] In the five major valleys, groundwater occurs under unconfined to confined conditions; discharge varies but normally in the range 15-25 l/sec with transmissivity up to 2000 m²/day. Minor aquifers also exist in the rock sedimentary zones or fault zones in hard rock. Groundwater is sourced through either tubewells

[16] Nurpur-Indora valley in Kangra, Bath valley in Mandi, Paonta valley in Sirmaur, Nallagarh valley in Solan and Una Valley in Una. The stage of utilisation is Kangra 35%, Mandi 30%, Simour 17%m, Solan 15% and Una 61%.

or springs. Springs exist in many areas where favourable conditions exist mainly along the structurally weak zones; springs are a major source of water supply in the state. Overall groundwater development is estimated to be 31 per cent of the potential. In district Una, development is however, up to 62 per cent of potential. Estimates by the Central Groundwater Board indicate that in all five valleys, groundwater extraction remain below the maximum sustainable levels. Under climate change conditions, the projection is that the annual rainfall will fall in more intensive storms resulting in increased runoff and lower levels of infiltration to support groundwater recharge. Groundwater in the valleys would however, get recharge from both the rivers and rainfall. Quantities of extraction and groundwater levels require to be monitored carefully. However, the Groundwater Development Board estimates that some further limited expansion of groundwater would be sustainable. The Departments of Agriculture and Rural Development are constructing concrete check dams in some tributary creeks to improve groundwater recharge. Many of the creeks are in fairly impermeable geology which is good for storing water but limit the amount of groundwater recharge. It is understood that there are plans to construct a sub-surface dam in the Beas river in Hamirpur district which could increase the potential for extraction from shallow groundwater in the river bed gravels.

3

CLIMATE CHANGE RISKS

Although the understanding of the impact of climate change continues to improve, it is as yet difficult to identify the specific regional impact with any precision. This uncertainty remains a key constraint and major challenge in both, formulating and implementing policies related to adaptation. Climate change represents a loss of information; the value of historical data in guiding water resources decision-making is degraded and future conditions are subject to a high level of uncertainty. With the very high variations of topography and rainfall, projection of future climate trends will be especially difficult for Himachal Pradesh.

Climate Change and Adaptation

There is a wide range of literature on climate change and pre dictions and scenarios. A summary of the relevant findings from the IPCC is given in *Table 4*.[17]

Observed and Projected Changes as they Relate to Water in Himachal Pradesh

Regional Studies

There are a wide number of regional studies on climate change with somewhat differing outputs. A study, 'Water Resources and Climate Change an India Perspective', shows the complexity due to the extreme variability of the monsoons; both, in terms of the timing and quantity of the rainfall received.[18] The year-to-year variability of the monsoon leads to extreme hydrological events (large scale droughts or floods). The all India summer monsoon rainfall pattern is shown in *Figure 10*.[19] The average rainfall in Himachal Pradesh is 1168 mm, very similar to the average for India of 1170 mm. However, about 66 per cent of the rain falls in the four months from June to September (against 75 per cent for India).

Despite significant advances in climate modelling and gradual convergence between models, there remains significant uncertainty in predicting future rainfall patterns. For India, different climate models vary in their prediction on precipitation changes, ranging from –24 per cent to +15 per cent. Regional changes are likely to be different. At this stage, there is insufficient information to estimate whether or not, there will be long term changes in the total annual rainfall.

For India, various studies on inter-annual and long-term variability of monsoon and annual rainfall have indicated that variation in rainfall for the subcontinent is statistically significant. Somewhat contrary to expectations, an analysis of observed rainfall data for the 131-yr period (1871–2001) suggests no clear role of global warming in the variability of monsoon rainfall over India.[20] Predictions on ice glaciers are more robust. Glaciers are predicted to lose mass due to the dominance of summer melting over precipitation and reduced levels of precipitation as snow. There remain inconsistencies about this rate of loss. There also remains some debate about the snow levels that are very much tied into the annual rainfall variations and possible changes in the percentage of precipitation that falls as snow.

[17] IPCC. 2007. *Fourth Assessment of Climate Change*. Switzerland.

[18] R. K. Mall, Akhilesh Gupta, Ranjeet Singh, R. S. Singh and L. S. Rathore. 2006. *Water resources and climate change: An Indian perspective*.

[19] ibid.

[20] ibid.

Table 4 *Summary of Key Findings from the IPCC*

Robust Findings	Areas of Uncertainty
OBSERVED CHANGES	
Warming of the climate system is unequivocal as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. Many natural systems on all continents and in some oceans are being affected by regional climate changes. Observed changes in many physical and biological systems are consistent with warming. Anthropogenic warming over the last three decades has *likely* had a discernible influence at the global scale on observed changes in many physical and biological systems.	Climate data coverage remains limited in some regions. In many parts, there is a notable lack of data on observed changes in natural and managed systems. Analysing and monitoring changes in extreme events including drought, tropical cyclones, extreme temperatures, the frequency, and intensity of precipitation is more difficult than for climatic averages as longer data time-series of higher spatial and temporal resolutions are required. Effects of climate change on human and natural systems are diffi cult to detect due to ongoing adaptation and non-climatic drivers. Difficulties remain in reliably simulating and attributing observed temperature changes to natural or human causes at smaller than continental scales. At these smaller scales, factors such as land-use change and pollution also complicate the detection of anthropogenic warming influence on physical and biological systems.
PROJECTIONS OF FUTURE CLIMATE CHANGES AND THEIR IMPACTS	
With current climate change mitigation policies and related sustainable development practices, global greenhouse gas (GHG) emissions will continue to grow over the next few decades. For the next two decades, a warming of about 0.2°C per decade is projected. Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century. The pattern of future warming where land warms more than the adjacent oceans, and more in northern high latitudes, is seen in all scenarios. Anthropogenic warming and sea level rise would continue for centuries even if GHG emissions were to be reduced sufficiently for GHG concentrations to stabilise. This is due to the time scales associated with climate processes and feedback. Equilibrium climate sensitivity is *very unlikely* to be at temperature changes of less than 1.5°C. Some systems, sectors, and regions are *likely* to be especially affected by climate change. These include mountain ecosystems, water resources in some dry regions at mid-latitudes and in the dry topics, areas dependent on snow and ice melt, agriculture in low-latitude regions, and human health in areas with low adaptive capacity. Impacts are *very likely* to increase due to increased frequency and intensity of some extreme weather events. Recent events have demonstrated the vulnerability of some sectors and regions, including heat waves, tropical cyclones, floods, and drought.	Models differ considerably in their estimates of the strength of different feedback in the climate system, particularly cloud feedback, oceanic heat uptake, and carbon cycle feedback, although progress has been made in these areas. Also, the confidence in projections is higher for some variables (e.g. temperature) than for others (e.g. precipitation), and it is higher for larger spatial scales and longer time averaging periods. Projections of climate change and its impacts beyond about 2050 are strongly scenario and model dependent. Improved projections would require improved understanding of sources of uncertainty and enhancements in systematic observation networks. Impacts research is hampered by uncertainty surrounding regional projections of climate change, particularly precipitation. Understanding of low-probability but high-impact events, and the cumulative impact of sequences of smaller events, which is required for risk-based approaches to decision-making, is generally limited.
RESPONSES TO CLIMATE CHANGE	
Some planned adaptation is already occurring; however, more extensive adaptation will be required to reduce vulnerability to climate change. Unmitigated climate change would, in the long term, be *likely* to exceed the capacity of natural, managed, and human systems to adapt. Making development more sustainable by changing development paths can make a major contribution to climate change mitigation and adaptation, and to reduce vulnerability.	Understanding of how development planners incorporate information about climate variability and change into their decisions is limited. This limits the integrated assessment of vulnerability. Barriers, limits, and costs of adaptation are not fully understood, partly because effective adaptation measures are highly dependent on specific geographical and climate risk factors as well as institutional, political, and financial constraints.

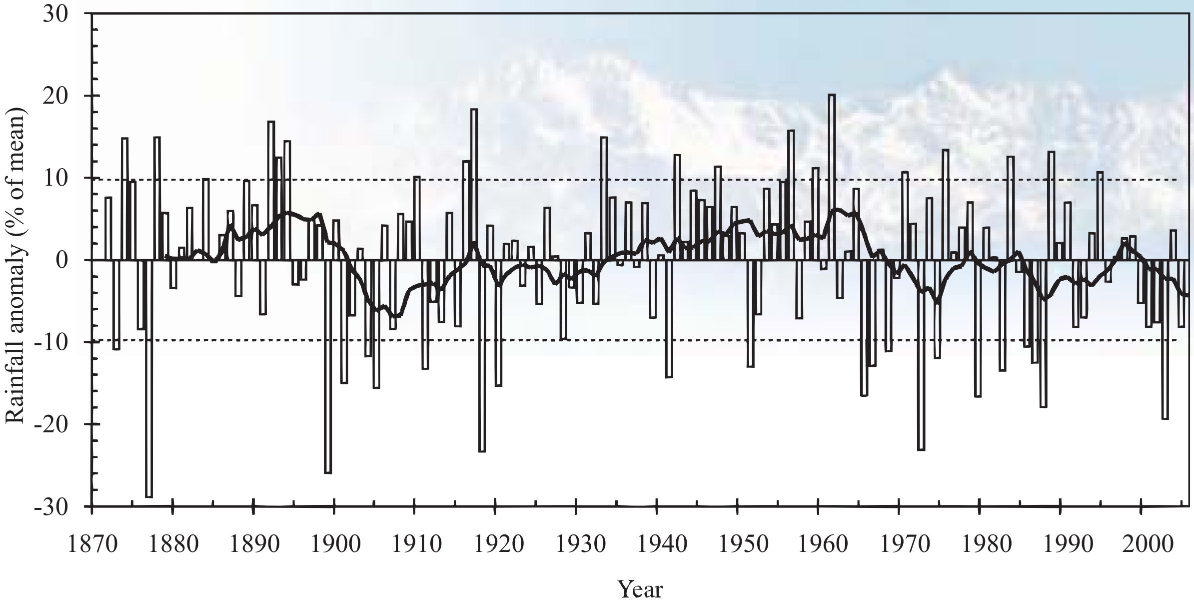

Figure 10 All India Summer Monsoon Rainfall (1871-2004)

Global Observations and Projections

While global projections can give guidance, the specific impact on Himachal Pradesh are however, less clear. Despite significant advances in modelling, different models continue to show some conflicting results and it is not easy to prepare definitive assessments of future climate situations. Climate warming observed over the past several decades is consistently associated with changes in parts of the hydrological cycle and hydrological systems such as changing precipitation patterns, intensity, and extremes; widespread melting of snow and ice; increasing atmospheric water vapour; increasing evaporation; and changes in soil moisture and runoff. There is however, significant natural variability on inter-annual to decadal timescales in all components of the hydrological cycle, often masking or making interpretation of long-term trends quite difficult.

There is still substantial uncertainty in trends of hydrological variables because of large regional differences, and significant limitations in the spatial and temporal coverage of monitoring networks. IPCC reports provide a good overview of the various projections on global climate changes.[21] Most of these would be applicable to Himachal Pradesh. A broad summary is presented below.

Temperature: The best-estimate linear trend in global surface temperature from 1906 to 2005 is a warming of 0.74°C (*likely* range 0.56 to 0.92°C), with a more rapid warming trend over the past 50 years. Future projections depend very much on international actions to reduce emissions, presently targeted at less than 1.5° to 2.0°C.

Average Rainfall: The consensus is that globally, rainfall has and will increase primarily due to increased evaporation due to higher temperatures. There are however, many anomalies. For example, over much of northwest India, the period 1901 to 1925 shows increases of more than 20 per cent over the 100 year period, but the same area has shown significant decreases since 1979. This trend is now apparent in some parts of Himachal Pradesh.

Potential Evaporation: This is projected to increase globally due to increase in the water-holding capacity of the atmosphere from higher temperatures and non-marked change in relative humidity. Water vapour deficit in the atmosphere increases as a result, as does the evaporation rate. Actual evaporation over open water is projected to increase with spatial variations in surface warming. Changes in evapotranspiration over land are controlled by changes in precipitation and radiative forcing, which would in turn, impact on the water balance of runoff, soil moisture, water in reservoirs, and the ground-water table.

Extreme Rainfall Events: Globally, it is considered *very likely* that heavy precipitation events will become more frequent. The intensity of precipitation events is projected to increase especially in areas which experience increases in mean precipitation. In most tropical and mid-latitude areas, it is estimated that extreme precipitation will increase more than mean precipitation. Widespread increases however, in heavy precipitation events (e.g., above the 95th percentile), have been observed even in places where total amounts have decreased. These increases are associated with increased atmospheric water vapour and are consistent with observed warming.

Droughts: There are linkages between intense precipitation and droughts. The projected increase in the risk of intense precipitation and flooding is associated with the risk of drought. Increased precipitation is projected to be concentrated in more

[21] IPCC. 2008. *Climate Change and Water.* Switzerland.

Box 1: Projections for Climate Change

There are now a number of models and projections for climate change in India. One model was prepared by the Indian Institute of Tropical Meteorology (IITM) in collaboration with the Hadley Centre for Climate Prediction and Research UK. The project used the Hadley Centre's, Regional Climate Models to carry out an analysis of climate change scenarios for India. The model also incorporated various socio-economic scenarios associated with the climate projections. The project generated high resolution climate scenarios for different states. For Himachal Pradesh the indicative predictions were that for the period 2070-2100 with reference to the baseline of 1961-1990, the projected increase in summer monsoon rainfall is about 45 per cent over the northern part of the state and 15 per cent in the southern part; temperature rise is estimated at about 4^{o}C across the whole state. The study represents a first step toward understanding the science; the predictions however, still have large uncertainties associated with them. The study specifically recommends additional research to improve the models by removing biases, develop plausible regional scenarios, improve the spatial resolution for regional/local impacts, develop sensitivity studies and develop short and long term predictive models

For water resource planners, a key requirement is how to incorporate climate change projections into strategies. Aspects to be addressed include, (i) What is the level of confidence of the projections? (ii) Who is responsible for verifying the projections? (iii) How should the projections be interpreted? (iv) Whether there is sufficient basis in the projections to justify adaptation investments?.

intense events resulting in longer periods of lower precipitation in between. Intense and heavy episodic rainfall events with high runoff amounts are likely to be interspersed with longer relatively dry periods with increased evapotranspiration, particularly in the sub-tropics. Depending however, on the threshold used to define such events, an increase in the frequency of dry days does not necessarily mean a decrease in the frequency of extreme high-rainfall events. Another aspect of these changes is related to changes in mean precipitation; the projection is that in general, wet extremes will become more severe in areas where mean precipitation increases, and dry extremes, more severe where mean precipitation decreases. Multi-model climate projections for the 21st century show increases in both, precipitation intensity and number of consecutive dry days in many regions. Precipitation intensity will increase almost every where, particularly at mid and high latitudes where mean precipitation also increases.

Changes in Surface Water Resources: There have been many studies globally to assess trends in river flows. However, no homogeneous pattern has been observed. Difficulties were found in assessing trends and differentiating these from increases in abstraction over time and changes in the catchment conditions. At a global scale, there is more coherent evidence of changes in annual runoff with some regions experiencing an increase and others, a decrease. For Himachal Pradesh, the very high levels of hydroelectric and other infrastructure development in rivers and lack of long-term records make estimates of trends difficult.

Glaciers: The linkages between trends in climate and trends in glacier extent (length, area, volume, and melt volumes) are of key concern to the future water resources of Himachal Pradesh as well as of downstream states. The consensus is that glaciers around the world are shrinking primarily because of global warming; the precise rate of melt is still not well researched. Orlove describes that the linkage between glacier extent and temperature is not quite as direct and immediate as many studies suggest.[22] The effects of warming can be influenced by other variables such as topography and cloud cover, both of which affect exposure to sunlight; and the nature of the glacier bed, which can favour or delay the flow of ice. Changes in precipitation associated with climate change can influence accumulation in the upper portions of a glacier and ablation in the lower portions. Moreover, since many glaciers are large, it can take a long time for them to respond to shifts in temperature. Although warming takes place on their surfaces, their interiors can remain cold for some time. Orlove however, concludes that nonetheless, in simple terms, 'the glaciers are melting because temperatures are rising'. It is estimated, that for some areas, a temperature increase in 1°C would require of the order of 25 per cent extra precipitation to offset the increased rate of ice melt.

Effects of Climate Change Seen in Himachal Pradesh

The scope of the study does not allow a full and comprehensive analysis of the water sector parameters under climate variability in Himachal. Some indicators include:

People's Perception

It is evident that farmers are now observing the impact of climate change. Rural knowledge of the changes is in many ways, quite advanced through the day to day seeing and feeling of the changes. Observed parameters include movement to higher altitudes of apple orchards, loss of various tree species, drying of traditional water sources, changing of bird types and populations, reduction of crop yields, and increased vulnerability of crops due to drought and delays in planting. Hopper burn in rice was first reported in the Kangra valley during 2008. Other previously unknown pests are now becoming apparent.

22 B. Orlove; E. Wiegandt, B.H. Luckman; 2008. The place of glaciers in natural and cultural landscapes. In Orlove, B., Wiegandt, E., Luckman, B. H, eds. *Darkening peaks: glacial retreat, science and society*. Berkeley: University of California Press.

Box 2: Vulnerability Assessment Nepal

Recovery from climate related disasters and potential increase in disasters from climate variability is a major challenge to the Nepal Government. Disaster insurance has not been applied as an adaptation mechanism; community-based micro insurance schemes have however, been successfully established in some villages in the livestock and cash crop sectors. Studies indicate that collective or community-based disaster insurance could be one of the options for post-disaster loss sharing measures with potential to contribute to poverty alleviation through distribution of the impacts of disasters more evenly.

Household surveys by the World Food Programme during 2007 showed that almost 94 per cent of households responded that external shocks (drought, hail or rain damage, or illness, etc.) immediately resulted in household food shortages. Surveys in drought-affected areas showed that average household food grain stocks would be depleted within 15 days as compared to 3 months in non-drought-affected areas. The resilience of households to external shocks depends on their socio-economic status; poor and socially excluded groups are less able to absorb climate effects than well-positioned and better-off households.

Almost all households (96 per cent) in the drought-affected areas shifted their consumption to less preferred and expensive food. More than three-quarters had to borrow money for consumption purposes and almost 73 per cent reduced their food intake. Half of the affected population had no meal at all at least one day a week and almost 37 per cent relied on the collection of wild foods as a source of food. More than half of the households have one or more family members who have migrated in search of jobs. Irreversible coping strategies were also widespread, with over one-third of the households selling agricultural and household assets, and a high number of households (18.5 per cent) reporting distress sale of land.

The study showed that vulnerability assessments are a good method to ensure that climate change is taken into account in development planning and the decision making processes. Risks that may be exacerbated by climate change are evaluated. Highlighting the location of key hotspots in a country through a risk assessment is important in identifying areas for intervention and can also inform the insurance process of present and future risks.

Source: UNITAR (United Nations Institute for Training and Research) and ACCA (Advancing Capacity to Support Climate Change Adaptation).

Observed Changes

The mountain ecosystems harbour a wide range of natural resources and are particularly sensitive to change. Regional changes in climate have already affected a number of the physical and biological systems in the mountains. Analysis of temperature trends in the Himalayas and its vicinity shows that temperature increases are greater in the uplands than the lowlands.[23]

Glacier and Snow Changes

The glaciers can provide a very useful measure of temperature trends–especially relevant in Himachal Pradesh. There are differing assessments of the rates of retreat and longevity of the glaciers. Further research is very important to make more definitive assessments. Less well defined is the percentage of dry season river flows that is attributable to the glaciers. Nineteen glaciers in the Baspa basin were monitored over a period 1962 to 2001. The investigation showed that all the glaciers were receding and overall, 19 per cent deglaciation was observed in the period. Glaciers at around 5000 m elevation showed 24 per cent loss compared with 14 per cent loss for glaciers above 5400 m. The mean glacier terminus has moved vertically about 88 m.[24] Change in the snowfields is less conclusive and is influenced by the annual cyclical variations of rainfall. An extensive analysis of rainfall and temperature patterns at different elevations is required. Assessments of glacier change are complex and should be based on a study of the mass balance and the location of the equilibrium line.[25]

Climate Assessment in Himachal Pradesh: Studies by the Himachal Pradesh Agricultural University give some indications of higher than average impacts of climate change in the Himachal Pradesh uplands than on the lowlands.[26] From the studies covering over 30 years of records, average air temperatures were found to be 0.7 to 2.4°C higher than that in the 1980s, as against the global average of 0.5°C; the Himachal Pradesh trend indicates an increase of 0.06°C per year. An analysis of rainfall data over the period 1976 to 2006 show increasing trends of rainfall in Lahaul, Spiti, Chamba and Kangra but decreasing trends in Solan and Kinnaur. Other districts showed no significant trends. Crops are showing shorter periods of flowering and maturity.

[23] Government of Himachal Pradesh, Department of Environment, Science, and Technology. 2009. State of the Environment Report. Shimla.

[24] ibid.

[25] Generally, the head-ward part of the glacier has net gain and the lower part has net loss-the equilibrium line is at the point where the net gain or loss equals zero.

[26] Government of Himachal Pradesh, CSK Himachal Pradesh Agricultural University, Centre for Geo-informatics, Palampur.

4

INDICATIVE IMPACTS OF CLIMATE CHANGE

Based on global and Indian projections of climate change, a summary of the key phenomena or trends likely to impact Himachal Pradesh are summarised in *Table 5* below. The extent, frequency and time frames of these events however, remain difficult to quantify.

Table 5 *Indicative Climate Impacts on Water Resources*

Phenomenon and trend direction	Likelihood	Broad impacts on Sectors			
		Water resources	Agriculture/ Irrigation	Other	Adaptation Strategies
Increased frequency of heavy precipitation	Very likely	Increased runoff and higher levels of sediment loading. Reduced groundwater recharge.	Damage to crops and increased soil erosion.	Increased sedimentation will affect hydropower and potable water. Shut-down of hydropower may become more frequent.	Soil and water conservation. Storage to reduce sediment levels. Groundwater management.
Increase in extreme rainfall intensity	Very likely	Increased flood flows.	Damage to crops and severe economic loss for farmers.	Disruption and damage to settlements, roads, infrastructure, and risks to human life.	Soil and water conservation. Insurance. Flood management and protection. Disaster preparedness and management. Changes to design criteria for dam and other water structures. Sustainable urban drainage and land use planning.
Increased variability in rainfall patterns	Very likely	Erratic river flow patterns.	Major impact on non-irrigated crops.	Reduced hydro power production.	Soil and water conservation. Water harvesting, irrigation, and improved agriculture technologies. Improved seed varieties.
Increased likelihood of water shortages/ drought	Very likely	Reduced dry season flows. Drying up of some minor tributaries and springs.	Major impact on rainfed cropping. Some impact on irrigated cropping.	Reduction in water availability for some hydro power, irrigation, and water schemes. Loss of some perennial sources of potable water.	Soil and water conservation. Water harvesting, irrigation, improved agriculture technologies, and new seed varieties. Move from annual to perennial crops including agro-forestry. Improve irrigation and water supply efficiencies.

Phenomenon and trend direction	Likelihood	Broad impacts on Sectors			
		Water resources	Agriculture/ Irrigation	Other	Adaptation Strategies
Reduced levels of precipitation as snow	Likely	Increased winter season runoff. Reduced dry season flows. Drying up of some minor tributaries and springs. Reduced dry season flows to neighbouring states.	Irrigation and potable water schemes in snow-fed rivers and streams would have reduced summer flows.	Loss of some perennial sources of irrigation and potable water. Higher winter rainfall will increase erosion.	Soil and water conservation. Adjustments in cropping schedules.
Loss of glacier volumes	Likely	Initially increased dry season flows. Over the longer term, likely reduced dry season flows-time frame uncertain. Long term reduced dry season flows to neighbouring states.	Uncertainty in supply of irrigation, water and hydropower.	Loss of some perennial sources of potable water. Long term reduced hydroelectric power, irrigation and water supply.	Improvement in irrigation and water supply efficiency. Optimisation of hydropower cascade dams. Storage at selected hydro sites. Change of water sources for potable water.
Earlier snow melt	Very likely	Increased spring flows and reduced summer flows.	Irrigation schemes in snow-fed rivers would have reduced summer flows.	Loss of some perennial sources of potable water and irrigation.	
Increased temperature	Very likely	Increased river and lake temperatures.	Changes in suitability of crops at different altitudes - eg. apples. Possible impact on aquaculture.	Changes in aquatic ecologies- including balance of phytoplankton/ zooplankton balances in rivers and water bodies. Increased bacteria.	Application of land suitability analysis under new climatic conditions. Estimation of temperature changes and impact in rivers and lakes.

Environment

The river and catchments in Himachal Pradesh are under severe stress. Large development projects combined with climate change are clearly affecting the natural ecosystems as well as the runoff characteristics. Water resource strategies will need to carefully balance the development and economic strategies with basic requirements for conservation and for maintaining the environment of the sensitive mountain and river ecologies. Maintenance of environmental flows, though required in the environmental approval process, are neither observed nor enforced in many cases. Assessment of adequate environmental flow is complex and more study is required to ensure that minimum levels of ecological balance are maintained in the rivers. Locations of dams and abstrac tions need to be carefully planned to minimize impact. Most of the rivers are now blocked by dams with major impact on fish migration. There however, remains scope to locate future dams strategically to minimize impact. Consideration should be given to the provision of fish passes. The extremely low environmental flow in the middle Beas River is shown in *Figure 11*.

The Department of Environment, Science and Technology (DEST) has undertaken a number of important initiatives towards sustainable development of water resources. The recently completed State of the

Figure 11 Low Flows in Beas River

Environment Report (SoER)[27] contains a wide range of information on the water and environment conditions. DEST is also supporting the development of a hydrologic model and data system to be implemented on a pilot basis in Himachal Pradesh.

DEST is in the process of formulating an Environment Master Plan (EMP) to address environmental issues. The EMP will be a guiding tool providing strategic direction for encompassing all environmental issues. It is designed as a means to engage the implementing agencies, development departments, and local government to take action on environment priority issues of local concern including community interests. The key objectives of the EMP would include, (i) bringing convergence of the development and environmental aspects in the state; (ii) ensuring closer convergence between all the concerned development departments at the state and central level; (iii) deciding future financing of investments; and (iv) developing suitable institutional arrangements to implement GoHP policies and strategies. The plan would be the first of its type in India. The EMP will be an important tool for the development of adaptation strategies.

[27] Government of Himachal Pradesh, Department of Environment, Science, and Technology. 2009. State of the Environment Report. Shimla, in association with HP Council for Science Technology and Environment and HP State Pollution Board.

5

DEVELOPMENT ISSUES AND OPPORTUNITIES

A number of sectors are directly or indirectly affected by, and in turn affect water resources. For an integrated water resources strategy, it is required to consider all the key water related sectors; the inter-linkages between sectors depend on the specific situation. Water related sectors can be classified as: (i) water use sectors; (ii) sectors affecting, or potentially affecting water resources; (iii) sectors affecting water quality; (iv) sectors affected by changes in water resources; (v) sectors with linkage to water resources development and; (vi) those affecting the river flows regimes, flood levels, etc.

Water Resources Policy

Himachal Pradesh's Water Policy, prepared in 2005, presents a set of general guidelines towards the planning and management of water resources. Key points include:

- The need for an action plan for implementation of the policy. The need for a participatory approach.
- Need for information systems for water related data in its entirety.
- Need for integrated water resources planning based on hydrological units.
- Management through multipurpose and multidiscipline approaches.
- Need for utmost efficiency in water utilisation.
- Financial and physical sustainability through collection of operations and management costs from consumers and a paradigm shift from expansion towards improving performance of existing schemes.
- A client Citizens' Charter to be established to guarantee efficiency and transparency and accountability.

The 2005 Policy provides a good basis for sustainable water resources management, and many of its points are common to this water strategy document. The application of the water resources policy on the ground remains limited and an action plan for implementation (as recommended in the policy) has yet to be put in place. A more specific and directed policy should be prepared to meet the very special needs of the state and climate change. This can be done after some years when the climate adaptation requirements have been more specifically defined. Indicative points include:

- The strategy, mechanisms, and responsibilities for the establishment of IWRM.
- To better address the water issues relating to hydro-power including mitigation measures to protect the fisheries and the environment. The 15 per cent allocation for environmental flows requires to be better defined.
- To mainstream climate change adaptation into the policy, including effective and integrated data systems.
- To more comprehensively address the issues of institutional remits, interstate water management and the need for integration between the agencies and sectors.
- The regulatory frameworks need to be clearly defined, including the need for separate roles for 'implementers' and 'regulators'. The role of independent regulators requires to be addressed. Regulation and control to enforce adaptation may become a critical part of the adaptation strategies.
- To better address issues of 'energy implications' of high head pumping for irrigation and water supply.
- Water conservation including water harvesting and rainwater collection tanks need to be more comprehensively addressed.
- More comprehensive guidance on water rights.

Water Rights

Climate change will likely result in reductions in dry season stream and river flows. Under such circumstances, competition for water may develop and traditional water rights may become important. There are many cases of irrigation and water schemes extracting water from a traditional village

Box 3: Impacts of Climate Change on Small and Marginal Farmers in Non Irrigated Areas.

The vulnerability of rain-fed (non-irrigated) agriculture is not clearly appreciated. Around 80 million hectares, out of India's net sown area of around 143 million hectares lack irrigation facilities. Crop yields are low. Records show that the predominantly rain-fed tracts generally experience three to four droughts every 10 years. Of these, two to three droughts are generally of moderate intensity and one is severe.

Most of the rain-fed agriculture is in arid and semi-arid zones and prolonged dry spells are common even during the monsoon season. This makes crop cultivation highly risk-prone. If the quantum of rainfall in these areas drops further or its pattern undergoes any distinct, albeit unforeseeable change in the coming years, which seems quite likely in view of climate change, crop productivity may dwindle further adding to the woes of rain-fed farmers.

It is estimated by the Indian Council of Agricultural Research (ICAR) that medium-term climate change predictions have projected the likely reduction in crop yields due to climate change at between 4.5 and 9 per cent by 2039, and possibly up to 25 per cent or more by 2099. Though the rainfall records available with the India Meteorological Department (IMD) do not indicate any perceptible trend of change in overall annual monsoon rainfall in the country, noticeable changes have been observed within certain distinct regions.

The National Action Plan on Climate Change (NAPCC), launched in 2008, aims at developing technologies to help rain-fed agriculture adapt to the changing climate patterns. Four of the eight 'National Missions' will have direct or indirect bearing on rain-fed farming. The relevant Missions are on Sustainable Agriculture, Water, Green India and Strategic Knowledge for Climate Change.

The ICAR-led national agricultural research system is also conducting research on specific projects under the umbrella programme on climate change. ICAR identifies that apart from the use of technological advances to combat climate change, there has to be sound policy framework and strong political support. State Agricultural Universities and regional farm research centres, will have to play a major role in developing local situation-specific strategies for adapting the rain-fed farming to emerging climate patterns.

Source : *'Too hot for comfort',* Surinder Sud / New Delhi April 06, 2010

water source and distributing the water to other villages; an acceptable situation until water becomes insufficient to meet all the needs.

Potable Water

Most settlements are supplied with clean water as per government standards. In parallel, sanitation has been provided to most communities. In rural areas, house connections are available for about 50 per cent of households with the remainder depending on standpipes. Future water demand will increase due to the gradual upgrading of levels of supplies and increase in the percentage of house connections. Many rural water schemes are sourced from springs or small rivers located strategically close to, and with adequate elevation to supply settlements by gravity. Increased drought and reduced dry season flows will likely put many smaller river and spring sources at risk of inadequate flow or drying up. The Department of Irrigation and Public Health (DIPH) recognises the problem and is supporting soil water conservation works in the catchments of vulnerable water sources.[28] To meet water shortages and vulnerabilities at some sites, DIPH is in the process of moving towards the development of larger pumped schemes from secured sources supplying multiple villages; a strategy that requires good design, management, and sustainable revenues to meet operation costs.

The use of rainwater tanks is now becoming mandatory in urban areas. There appears to be scope to extend this to the rural areas in conjunction with initiatives in water harvesting for agriculture including small kitchen gardens, supplementary water for domestic use, and helping to reduce storm runoff. Another potential is the re-use of domestic wastewater to support irrigation of small kitchen gardens.

A major policy issue for the potable water is the near zero charging for it. Gravity water schemes have low O&M costs but for pumped schemes, costs are of the order of Rs 6 per cubic meter. DIPH is now initiating a gradual handover of drinking water schemes to the Panchayat Raj Institutions (PRI) or Urban Local Bodies (ULB). There is a need however, to build up the capacities of these institutions to effectively take on the real responsibilities of water supply management including putting effective cost recovery systems in place to meet the basic operation and maintenance costs.

Agriculture

The reported cultivated area of the state is 580,000 ha or about 10 per cent of the total land area. The average holding size is about 1.2 ha with over 92 per cent of holdings classified as small or marginal. Average yields are comparable with other hill states but are lower than that in the states in the plains. Fertilizer use is about half of the national average. Crop cul-

[28] This reinforces the need to coordinate soil and water conservation works between sector agencies to meet specific problems.

tivation is mainly on terraces as many land slopes between 5 to 30 percent. Cropping is closely linked to elevation as shown in *Figure 12*.[29] Double cropping without irrigation is possible in parts of the state where there is adequate level of non-monsoon rainfall. The second season winter cropping is however, very vulnerable to rainfall irregularities.

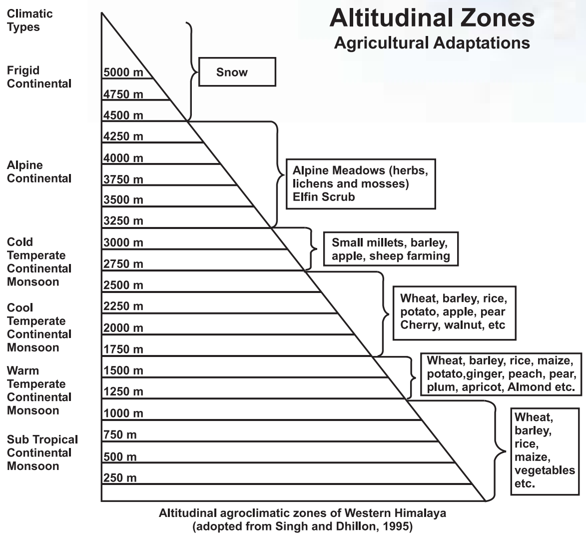

Figure 12 Agricultural Crops by Altitudinal Zones

Although staple food production remains the main priority, over the last decade, a major shift to vegetables and horticulture has occurred. The temperate climate in the state opens opportunities to market and develop high grade and off-season vegetables.[30] The shift to vegetables is primarily in areas with irrigation and where farmers have been able to adjust from subsistence food production to higher risk but better return cash crops. The University of Palampur has prepared comprehensive district level agricultural development plans for the eleven districts. The plans based on extensive farmer consultation propose a wide range of efforts to increase yields and efficiencies as well as a major expansion of vegetable production supported by irrigation and water harvesting. Feedback from stakeholders demonstrates how climate variability is already beginning to affect all crops, especially vegetables. Irrigation and rainwater harvesting are important for coping with rainfall irregularities.

The switch to vegetable production is supported in the State's 11th FYP (2007/08 - 2011/12). The state government has put high priority on diversification from traditional crops to commercial ones. Department of Agriculture (DoA) has formulated a fifteen year "Master Plan and Action Plan on Rural Development" under the technical assistance provided by Japan International Cooperation Agency (JICA) in 2009. Follow up studies have been completed and agreement has now been made with JICA to fund a Rs 267 crore ($ 58 million) program of crop diversification primarily for vegetable production under irrigation.[31] The five year program will start initially in Hamirpur but later include four other districts.[32] JICA will fund a parallel Technical Assistance (TA) to support vegetable production. The scope of the proposed JICA work is currently under finalization with an aim to start in 2010.

National Mission on Sustainable Agriculture

The recently released findings of the National Mission on Sustainable Agriculture are very relevant to Himachal Pradesh. The strategies most relevant for the state for minimising the adverse effects of climate change include:

- **Strategic research** including the application of biotechnology, development of crop varieties, soil and water management, design and development of systems for scientific knowledge management and disease mitigation strategies.
- **Sustained increase in food grain production** through improved distribution of seeds, strengthening of seed banks, improved public and private distribution systems, and expanded production of bio-fertiliser, compost, and micro-nutrients.
- **Improvement of water use efficiency** through the application of water and liquid fertilisers using micro irrigation and prefabricated water conveyance systems. Strengthening of rainwater harvesting systems.
- **Strengthening of risk management systems** including innovative insurance and improved weather forecasting, pest and pathogen management, and disaster risk management through appropriate seed varieties. Insurance would include scaling down of the basic insurance unit to the level of Panchayat.
- **Capacity Building** including financial incentives for farmers to take on climate change adaptation such as use of new seed varieties and cultivation practices (minimum tillage, organic farming etc). Capacity building to be extended including training workshops, strengthening of self help groups, and strategic alliances between the government and research organisations. Information systems and data management to be strengthened.

Aquaculture and Fisheries

Aquaculture and fisheries is a small but important sector. River fisheries have been severely affected by the hydropower projects that have blocked migration routes. The limited quantities of environmental flow from the hydropower proj-

29 Government of Himachal Pradesh, CSK Himachal Pradesh Agricultural University, Centre for Geo-informatics, Palampur.

30 Off-season vegetables are grown in Himachal Pradesh during the periods when vegetables cannot be grown in the lower elevation areas in neighbouring states.

31 JICA: "Diversified Agriculture for Enhanced Farm Income in the State of Himachal Pradesh". Tokyo. The proposed project targets agricultural diversification through conversion from food grains to diversified crops, especially to vegetables for enhanced farm income of small and marginal farmers.

32 Planning studies by JICA have been completed for Bilaspur, Kangra, Una and Mandi.

Box 4: Master Plan for Diversified Agriculture.

Agriculture in the state is growing and remains the largest employer. Its share in the GDP however, recently fell to below 20 per cent of Gross State Domestic Product (GSDP). The 15 year Master Plan for Diversified Agriculture, prepared in 2008 by DoA with JICA's support, considers a basic strategy to maximise the special agro-climatic advantage of the state for diversification from food to value added produce, especially vegetables.

The strategy would in parallel improve productivity of food grains to sustain food security for the estimated 84 per cent of farm households who are marginal and small farmers. The plan estimates that food security could be ensured by increasing yields of food crops which would leave surplus capacity for vegetable production. Present production of vegetables is 1 million tons; the 2018 vegetable demand is estimated to be 1.6 million tons rising to 1.9 million tons by 2023. To meet this demand would require change of 51,000 ha of land presently under food grain production to switch to vegetable production including the provision of irrigation. The plan proposes additional irrigation development over 15 years of 21,000 ha, consisting of 16,000 ha of minor irrigation and 4,900 ha of supplementary irrigation. Provision of improved farm roads is an essential component and 1,330 km of additional roads is proposed under the master plan.

An initial year 10 year action plan was prepared in detail including support components for institutional development, farmer support for production and marketing, and infrastructure development (irrigation and farm roads). The estimated cost of the 10 year programme is Rs 943 crore ($ 200 million). The benefit to cost ratio of the investment is 1.11 with an Economic Internal Rate of Return (EIRR) of 13.5 percent.

ects have also affected the river fisheries. Aquaculture in the lower elevation areas is focused around small ponds (rain-fed or irrigation fed) for growing a mix of Indian Carps and catfish. Higher elevation areas, where water temperatures never exceed 15°C, are suitable for trout cultivation. Trout cultivation is expanding in the higher elevation rivers and can achieve good returns. Cultivation is presently limited to medium sized commercial organisations using concrete raceways; there would appear to be potential for smaller low intensity systems in ponds.[33] Sport fishing in the higher elevation rivers is becoming popular; trout fishing is popular and are stocked in the rivers. Some native species are also highly prized for sport and can reach large sizes. Fish ponds can provide excellent retention of storm runoff.

The Gobindsagar (elevation 560 m) and Pong (elevation 436 m) are the two largest reservoirs in the state for fish production. Fish landings from Gobindsagar account for 58 to 60 per cent of the total fish production in Himachal Pradesh. Directly receiving cold water from the mountains, both reservoirs, in spite of being situated at a relatively low altitude, contain stocks of coldwater fish. The gradual but continuous increase in fish catches through stocking from these two reservoirs has led to a stable commercial fishery, which provides full employment to over 4000 fishermen, traders, retailers, and some other professions. During 1996-97, over 1400 tonnes of fish were landed from both reservoirs, of which about 400 tonnes came from Pong reservoir. Climate change will increase the flood flows, turbidity levels, and temperature of the rivers. Water temperatures in the upper catchments normally never exceed 12°C, while the water temperatures in the lower level Pong reservoir are in the range 9-21°C. The increased temperatures from climate change will affect the river temperatures. However, as many rivers are fed from glacier melt, the impact of air temperature changes may be less significant. Water temperatures downstream of dams are reported to be higher due to the reduced flows and depths. Monitoring, research, and modelling of projected future water temperatures along the main rivers is an important requirement to support planning and management of aquaculture and fisheries.

The gradual expansion of high mountain glacial lakes, with their oligotrophic character and low water temperatures, have limited potential to become productive fishery water bodies but may offer opportunities for sport fishing.[34] Where deemed realistic, stocks of brown trout and/or schizothoracines (a part of the cyprinid-carp family) could be maintained through stocking. Lakes holding already self-sustaining stocks should be carefully managed to avoid overfishing; some of these water bodies could be selected as fish sanctuaries.

Major Challenges for Agriculture

Small holdings have, over time, become gradually unprofitable. The reasons are primarily the unviable size, with about 64 per cent of holdings being less than 1 ha, and the relatively high costs of inputs. The viability of holdings is gradually becoming more critical due to the progressive fragmentation of holdings through inheritance. The rural society is gradually changing as traditional and communal farming systems are breaking down. Many family members now have off-farm employment which causes increased labour shortages and costs. Hired labour from Bihar or other states from the plains is often relatively expensive resulting in narrow margins for many crops, and sometimes insufficient profitability to justify planting. The changes in climate are now

[33] Trout cultivation in ponds is practiced in some farms in Europe, a part of the food source is natural from the pond and lower stocking densities allow more natural growth and less risk of disease.

[34] Lakes with low levels of nutrition and high oxygen.

affecting farmers. Low rainfall and reduced snowfall are affecting crops. Planting of winter crops is frequently delayed and affected by erratic rainfall. Horticultural crops suffer stress at the fruiting stage, adversely affecting the quality and quantity of the produce. There is lack of systematic planning for agriculture. Resource surveys can better support the selection of the crops and help assess the need for inputs and marketing support.

The Government is offering major subsidies in agriculture including financial support for the capital costs of irrigation systems, and polyhouses.[35] At present, only wealthy farmers are able to source the necessary funds and take advantage of the schemes on offer.

Most farmers are gradually moving towards mixed farming including agriculture, horticulture, vegetables, and livestock. Mixed farming uses the available farm resources to the maximum possible levels and provides good returns to the grower. Government extension services and support services are specialised in one area or another, and there is lack of an integrated extension support.

The move away from grain crops towards vegetable cash cropping is largely based on the attractive financial returns. In terms of climate adaptation, the better returns from vegetables opens the financial viability of providing irrigation, which in turn can provide improved resilience against rainfall uncertainties. Other climate issues such as temperature changes and temperature effects of pests and diseases pose additional issues. Large areas of the agricultural land are of poor quality and provision of irrigation is technically and financially difficult. For these parts, farming will mainly continue under rainfed conditions. Winter grain cropping is very vulnerable to rainfall uncertainties and options for alternative lower risk cropping require to be explored. There are potentials for agro-forestry, grass and other perennial crops. The Forestry department, through the Mid-Himalayan Watershed Development Project, has recently initiated the raising of forests on private and community land. Farmers will be able to earn around Rs 4,000 /ha annually through carbon credit funding over a 30 year period.

Potentials for Precision Agriculture

The development of precision farming is gradually being introduced by DoA. Precision farming involves systems to improve farm management by adjusting cultural practices to take into account the real needs of the crop. These can include seed, efficient water distribution and applications, fertilisers, scheduling, and the use of polyhouses. For the small holder with around 1 ha of land, precision farming allows opportunities to improve efficiency and increase outputs. With a likely worsening of growing conditions under global warming and the high costs of pumped irrigation or the very restricted water availability from water harvesting, precision farming can offer opportunities to maximise the use of scarce irrigation or harvested water. Precision farming is particularly useful where irrigation is expensive and limited, as would be the case of rainwater harvesting, mainly in the higher lands out of the valley bottoms.

DoA have developed a number of models to support precision farming including sprinkler, drip irrigation, polyhouses (polythene green house), polytanks (polythene lined earth tanks), and concrete tanks. More research is required to design and source the most appropriates systems; user acceptability is a key issue. There is also scope for new ideas and technologies that could be applied to widen the scope of options. Many of these new approaches rely on subsidies which are in most cases, a necessary way to meet the upfront costs of many of the new technologies. The approach and modalities of subsidies need to be kept under constant review.

Use of appropriate seed varieties is a key area with major potential to support climate adaptation. DoA has, for many years, been supporting the use of High Yielding Variety of seeds (HYV seeds) to promote increased yields. Under the current and future situations of climate irregularities, it will be necessary to adapt seeds appropriate for the new growing conditions. The agricultural universities are carrying out research into appropriate seeds and there is a need for close liaison between the researchers, DoA, and extension staff. Adequate and flexible seed multiplication is an important requirement. The use of genetically modified seed to combat rainfall irregularities may become a necessary adaptation measure at some stage.

There is good scope for public-private sector participation to support the introduction of precision farming. Agriculture companies can support agricultural intensification by provision of equipment (drip, sprinkler, polyhouses etc), credit, agricultural inputs, knowhow, management, and marketing. Companies could be contracted to provide a complete support package. The use of performance based contracts can be used as a basis with payments made on results (production levels, areas planted etc.).

Irrigation

Irrigation is largely seen as one of the major areas to support improved production of cash and staple crops as well as meeting the impact of increasing variabilities. The reported area of irrigation constructed is 228,000 ha (100,000 ha small scale through Rural Development and Agriculture, 128,000 ha under the Department of Irrigation and Public Health (DIPH); the overall potential irrigated area is estimated to be 335,000 ha.[36 & 37] The actual functional irrigated area appears to be significantly less and is estimated to be about 100,000 ha less than half the constructed area.[38]

35 Polyhouses are based on the greenhouse concept to let in heat and light while preventing the heat from getting out. Instead of the glass on a greenhouse roof, polyhouses are made of cheaper polythene. By reducing evaporation, they also allow farmers to use sprinkler and drip irrigation systems, thus saving water. The National Bank for Agriculture and Rural Development (NABARD) in 2008 sanctioned loans of Rs.155 crore to develop 30,000 polyhouses to be set up over four years to promote off-season farming, particularly in the lower and mid-hills.

36 Of the 128,000 ha, 109,000 ha is classed as minor irrigation and 19,000 ha as medium and major irrigation. The DIPH defines minor irrigation as below 2000ha.

37 Government of Himachal Pradesh, Planning Department, 2009. *State Annual Plan 2009-10*. Shimla.

38 Government of Himachal Pradesh, Irrigation & Public Health Department. *Minor Irrigation Census, 2000/01* and *Annual Plan 2006/07*.

Box 5: New Initiatives in Drip Irrigation for Small Farmers

Modern irrigation systems have largely failed to meet the need for inexpensive and efficient irrigation systems for small farmers. Drip irrigation is widely recognized as one of the most efficient methods of watering crops. However, since its acceptance in the mid-1970s, the hardware has evolved to fit large fields and minimize management and labour requirements. As a result, the standard drip systems now available are sophisticated and expensive. Typical costs of systems installed in Himachal Pradesh are of the order of US$ 2,500 per hectare. In India, two companies provide 80 per cent of the drip systems installed. Despite the high costs, growth in micro irrigation systems over 1999 to 2006 has been 15 per cent per year.

The early drip systems were simple and used holes or micro-tubing instead of sophisticated high cost emitters. These simple designs were later abandoned because they did not fit the needs of modern farming. In fact however, these early system designs were well suited for drip irrigation of small plots. Drip lines can be relatively short and the elevation differences within the plots are typically minimal. Moreover, there is usually sufficient labour to cultivate around the micro tubing and to periodically inspect and clean the simple hole emitters.

New initiatives for simple drip irrigation systems have now been developed, which are appropriate for marginal farmers who need to stretch scarce sources of water. Results from field trials demonstrate that low cost drip systems can stimulate shifts to more intensive agricultural practices by small farmers; cost recovery and the payback period can be quite short. There are indications of enormous demand and scope for growth for low cost drip irrigation. Results from various Indian Research Institutes indicate that drip irrigation can increase yields by an average of 25 per cent with reduction in water use of 40 per cent. Simple drip systems costs are indicatively of the order of $700/ha to $1000/ha, about 40 per cent of the modern emitter systems.

Affordable drip systems are now being installed in the hills of Nepal and northern India where water from community tanks is scarce, and cropland are terraced and prone to erosion. In these areas, very labour and capital intensive efforts go into capturing and storing rainwater runoff through check dams or tanks. Water is often then applied very inefficiently to fields. Affordable drip systems can markedly raise the productivity of this harvested rainwater, thereby, making watershed projects more economical. Low-cost drip systems also have the potential to raise the productivity and incomes of canal system “tail-enders,” whose supplies are often insufficient to irrigate their entire plot of land.

Summarised with adaptations from: Drip Irrigation for Small Farmers: A New Initiative to Alleviate Hunger and Poverty IWRA, Water International, Volume 26, Number 1, March 2001 Postel, P. Polak, F. Gonzales, and J. Keller.

Command Area Development (CAD) activities have been established to bridge the gap between potential irrigated area created and utilized. The program covers both medium and minor irrigation schemes. The CAD program was initiated under a central sponsorship with the objective of fast utilization of created irrigation potential and optimum agriculture production from irrigable land. To date, up to 22,300 ha of field channels and 21,734 ha of Warabandi have been completed in the state.[39] This is however, only about 17 per cent of the irrigation area under DIPH.

Wherever possible, gravity irrigation is given priority over lift irrigation; of the 7,506 irrigation projects in the State, 1,232 were lift (16 per cent) and 181 (3 per cent) were tubewells schemes, while the remaining (81 per cent) were gravity. The lack of suitable sites and demand for irrigation is now creating a situation requiring more extensive use of lift irrigation. The available water sources, topography and soil types all make irrigation difficult and of high cost. The use of lift irrigation is frequently problematic, and has a very poor track record. While DoA and DIPH are both developing lift irrigation schemes, their approach is however, different. DoA provides financial subsidies and support for pumps, tanks and sprinklers or drip distribution for schemes up to 50 ha. Completed schemes are handed over to farmers. DIPH is constructing and directly operating the larger schemes where distribution is mainly by open channel and flood irrigation. A number of sprinkler and drip schemes are however, being constructed. Despite efforts to establish water user associations, schemes remain largely operated by DIPH staff. The potential for high value vegetable crops and good availability of hydropower in the state supports the strategies for lift irrigation. There is however, concern over the costs, sustainability, and environmental impact of some of the high head lift irrigation currently being planned and developed (lifts are often up to 100-150 m, and with some schemes going up to 300 m). Through the DIPH program, capital and operational costs are fully or highly subsidized. Comprehensive economic and social assessments are required to clearly assess the viability and sustainability of irrigation projects together

[39] *Warabandi* is defined as rotation or scheduling of water allocations.

with requirements for increased stakeholder participation in scheme planning and management. Initiatives to improve efficiencies are essential for lift schemes. These are required to reduce the energy waste from excessive water losses and to expand the command area to maximise the beneficiary farmers. Targets for irrigation efficiency should be linked to the pumping head; gravity or low pumping heads could have lower efficiencies with high head schemes to be supported through drip or other appropriate methods.

Climate change will affect the dry season flows and many smaller schemes may have reduced water availabilities as a result. The extent and seriousness will vary depending on the catchment conditions and the source of dry season flows. To compensate, critical schemes will require investments to improve the catchment conditions as well improvements in distribution efficiencies. The NAPCC target is a 20 per cent increase in irrigation efficiency, which is a reasonably appropriate and viable target. DIPH requires to prepare inventories and assessments of stream flows and water demands to identify and inventory the most vulnerable schemes.

The limited take up of irrigation is one of the major challenges facing the irrigation sector. The exact causes require to be identified and appropriate approaches developed to ensure the full potential of irrigation investments is realized. High levels of off-farm employment in the rural areas requires the recruitment of external labour and resultant reduction of the financial viabilities of some crops. Other reported issues include frequent pump breakdowns resulting in farmer reluctance to risk planting. Putting the existing irrigation schemes into order and maximizing their potentials should be one of the top priorities for the irrigation sector. Establishment of robust and sustainable irrigated farming systems is a fundamental requirement towards climate resilience in the irrigated areas.

Major Irrigation Projects

Himachal Pradesh does not have many large developed irrigation systems. The Shah Nehar project is the largest irrigation project in the state. It is located in the Kangra district on the river Beas and irrigates 15,287 ha. Other irrigation projects include the Balh valley project, located in the Mandi district which utilizes the water of Baggi channel of Beas Satluj Link project. The existing potential of the Balh valley project is 2,410 ha. The Bhabour Sahib project utilizes the water of Nangal dam reservoir and irrigates an area of 2,640 ha. Phase II of this project will irrigate a further 2,440 ha. Giri irrigation project in Sirmour district irrigates an estimated area of 5263 ha. The Sidhata scheme is situated in Jawali tehsil of Kangra district with a total irrigation potential of 3,150 ha.

Water Harvesting for Irrigation

Water harvesting is widely seen as a major area to support agriculture and address the variabilities of rainfall.[40] The technologies and approaches require more research to increase the viability. To be financially viable, water harvesting require access to low cost storage and high efficiency distribution systems. Capital costs can be high and net water volumes limited, but with the steep topography in Himachal Pradesh, water harvesting can offer scope for gravity irrigation and the only option for supplementary water in areas high above the river sources where high head lift irrigation is not financially viable. Water harvesting reduces runoff which is an important side benefit.

Costs of water storage are high. Water harvesting to be cost effective, must be developed as a supplementary water source using very high application efficiencies; examples are water harvesting to support irrigation for a polyhouse or as an emergency 'life saving' irrigation.

Studies into alternative storage systems indicate that the polythene lined tanks (polytanks) can provide lower unit costs of storage than concrete; sustainability appears good ,although there are some reservations from farmers.[41] Further research to identify appropriate low cost storage systems and efficient water distribution is recommended. Butyl tanks, ferrocement, corrugated iron/butyl lined tanks are a number of options that could be considered and tried on a pilot basis. Comparison and assessment of the relative advantages and disadvantages of water harvesting and lift irrigation at various pumping heads should be carried out. Household roof harvesting has many advantages and can reduce storm runoff and support potable water needs and irrigation for small kitchen gardens. There is scope to reuse potable water for irrigation. Basic treatment for 'domestic waste water' could be provided in reed beds and used for irrigation after treatment.

Soil and Water Conservation

Soils vary according to aspect, slope, and climatic conditions. They are very vulnerable to sheet and gully erosion. It is estimated that of the cultivated area of 7.6 lakh ha, nearly 43 per cent are prone to very high intensity of erosion.[42] Soil and water conservation forms a major part of the investment by the Departments of Agriculture, Rural Development and Forestry. For Himachal Pradesh, water resources are fundamentally linked to the catchments, and catchment management is seen as a fundamental part of any water resource strategy. From the list of likely impacts of global warming described in *Table 5*, it can be seen that soil and water conservation is one of the main adaptation measures identified.

A number of interventions are presently being implemented including gabion/stone check dams, concrete check dams, planting of berms, trench cum berms, and planting of catchments. The agricultural areas are largely terraced although some parts remain un-terraced or require further levelling. Assistance for terracing was stopped in 1992. With the increased levels of protection required to meet the

[40] In this study, water harvesting refers to the capture and storage of rainwater or runoff for water use-mainly agriculture or water supply.

[41] Estimated unit storage costs from the Department of Agriculture are about Rs 500-1000 /m^3 (poly-lining and brick), higher than unlined tanks (Rs 170 /m^3) but significantly lower than concrete about Rs 2000 /m^3.

[42] Government of Himachal Pradesh, Department of Environment, Science, and Technology. 2009. *State of the Environment Report.* Shimla.

Box 6: Integrated Agriculture, Soil and Water Conservation (SWC)

In Hamirpur District, the DoA and the Department of Rural Development have undertaken an extensive program of SWC works to reduce runoff, create irrigation sources, and promote groundwater recharge. The project covering 7,400 ha over 133 villages constructed soil and water conservation and water harvesting works at a cost of Rs 6,200 /ha ($ 235 /ha).

In Sirmour district, DoA and CSK Himachal University have demonstrated the potentialof integrate agricultural development through a pilot project in the 850 ha Sarahan Watershed. The project promoted the use of SWC, improved agricultural technologies, water harvesting to improve agricultural productivity. Agronomic and SWC measures included land preparation, contour farming, renovation and grassing of waterways, check dams, trench cum bunding, tanks and ponds, spring protection, and storage. Storage for water harvesting was from concrete tanks, and brick lined polythene ponds. Improved irrigation was applied through sprinkler and drip systems. Crop diversification included spice crops, grassland and pasture crops, and livestock management. The project demonstrated increases of cultivated area of 39 per cent and yield increases of 38 per cent. Storage costs were about Rs 2,000 /m3 for concrete tanks fed from springs. Capture of land runoff catchment was achieved using ponds lined with 200 gsm polythene at a cost Rs 1000 /m3, typically irrigating 0.24 ha. Roof rainwater collection tanks, each of 8 m, cost about Rs 1,500 /m3. Concrete tanks suffered from problems of cracking unless filled with permanent water. It was concluded that individual tanks/ponds were more successful than communal systems. The concept of 'high efficiency life saving irrigation' was developed and applied as a part of the project design. The overall investment costs of the project was about Rs 10,500 /ha ($ 235 /ha).

The Himachal Pradesh Mid-Himalayan Watershed Development Project aims to reverse the process of degradation of natural resources and improve the productive potential of natural resources and incomes of rural households. The project also supports policy and institutional development to harmonize watershed development projects and policies across the state in accordance with best practices. There are three components: (i) institutional strengthening and capacity buildings of communities and local governments to effectively manage watershed development; (ii) watershed development and management, financing of soil and water conservation, non-arable land treatments, crop and livestock production, and rural infrastructure; and (iii) enhancing mountain livelihoods, and promotion of value added in agriculture and income-generating activities, particularly for tribal and vulnerable groups.

impact of increased rainfall, there maybe justification to restart this important activity. Terracing provides benefits of water retention to the farmer as well as to downhill areas. Terracing programs could include new terracing or improve the quality of some partially terraced lands. Costs of soil and water conservation are high and the present approaches and technologies require to be reviewed and assessed to ensure that the maximum benefits from investment are being achieved. The different departments must better coordinate and target their investments to ensure that these meet specific and well defined targets with maximum financial returns.

The state is providing a strong emphasis on water conservation. Water conservation works are directed at (i) reducing runoff to reduce soil erosion; (ii) improving infiltration into the soil to increase the percentage of rainfall stored in the soil and (iii) allowing retention of rain water or water in drains to enable slow infiltration into the soil with the objective of supporting groundwater regeneration. Further studies to assess the financial and technical viability of artificial groundwater recharge are suggested. Presently, different departments are working independently within a general framework of soil and water conservation but without a strategic plan with clearly identified site specific objectives. Wherever possible, priority should be given to water conservation that in parallel provides potential economic or social benefits. These include improvement and expansion of terracing, household rainwater tanks, vegetative protection, and water retaining check dams (that can be taken up for irrigation).

For much of the very steep farm lands and high erosion risk areas, agriculture is very marginal and unsuitable for many crops, and vulnerability to erratic rainfall is high. A move from food crops to perennial agro-forestry or perennial grass crops could potentially provide reasonable economic returns with significantly increased resilience to climate change conditions. These crops would, in addition, provide improved levels of erosion protection. Financial incentives could be offered to farmers to take on this important role of soil and water conservation. Precision farming using polyhouses could be implemented in parallel using 10-20 per cent of the landholding.

Forestry

The forests and other natural ecosystems constitute two-thirds of the geographical area of the state and are crucial for its environment, especially water resources. The extent of actual forested land is however, only 26 per cent. The state has 32 per cent of its land under national parks with 32 wild life sanctuaries. Forests, beside the ecological functions, provide fuel wood, fodder, and timber. Under the Forest Policy of 1988, at least 66 per cent of geographic area should be under forest. Since 20 per cent of the forestry land is inaccessible, this target is not achievable. The department aims at expanding forest cover to 35 per cent of the state's geographical area, which includes about 5 per cent under horticulture or farm forestry. Watershed modelling studies show that the Himalayan forests play a crucial role in sustaining river base flows.

In 2001, the participatory forest management notification came into place with the objectives of involving the Panchayats and other community organisations in the management of the forests. In 2005, the State's forest department issued a new sector policy and strategy.[43] The new policy builds on the concepts from the participatory forest management notification and introduces a forest sector policy which encompasses the entire biophysical and environmental components of forests. The new policy is directed at balancing between the needs of the local people and environmental concerns. Areas where forestry can contribute to the local economy include growing of medicinal plants and improving pasture and firewood.

The new policy opens the way for forestry to evolve from management for timber production to multifunctional management and integrated land use planning to support the regularisation of water supplies and other watershed functions. In relation to water resources, effective watershed management is a critical area, especially important as 66 per cent of the geographical area is classified as forest land. The new policy and strategy document identifies the need for a watershed approach involving synergies between concerned government agencies, *Panchayat Raj*, Community Based Organisations (CBOs), and Non-Governmental Organisations (NGOs), all to be coordinated through a nodal agency (to be established). The strategy includes incentives and regulatory administrative measures for promotion of rainfall conservation and harvesting. Within the forestry program, there are already initiatives to create water sanctuaries for wildlife and water conservation. Possible extensions of this programme could be to use some water from these reservoirs to support water harvesting for agriculture. The forest area has available land and in many cases, good topography to allow gravity irrigation. The increased likelihood of intense rainfall may require some review of the adequacy of existing forest tree species to meet the incremental needs of rainfall retention and soil conservation.

Payment for Forestry Ecosystem Services

Moving from timber production to multifunctional management is not an easy transition and requires the development of market mechanisms and incentives to promote and implement forest management. Financing this transition requires new approaches recognising the economic value of eco-services to the state, the nation, as well as to beneficiaries. Forest management to meet the needs of conservation of water and environment requires integrating and extending the concept and practice of payment for ecosystem services.

Hydropower projects in the state are required to provide funds (not less than 2.5 per cent of the investment costs) towards Catchment Area Treatment plans (CAT). The activities under CAT plans include afforestation, fuel, fodder, plantation, soil and water conservation, erosion control, and awareness. CAT plans should cover not less than 15 per cent of the catchment. 1 per cent should be earmarked for ecotourism and protection of wildlife. CAT plans do not cover rural infrastructure which is under the land area development fund. The Forest Department is now moving away from CAT planning (focused around specific hydropower projects) towards river basin works, which is a more holistic approach and conducive to livelihood support and participative community actions.

Hydropower

Hydropower is providing major economic and social benefits to the state. The total hydropower potential of the state is estimated at 20,500 MW, of which about 6,400 MW has been currently tapped. It is estimated that up to 50 per cent of the potential will be in place in the next 3 to 4 years through major ongoing construction of projects in the state. Hydropower development is based on the 2006 Hydropower Policy, which covers the commercial approach as well as initiatives to support local companies and labour. The Policy defines the royalty fee as 12 per cent of power generated to be free of cost for twelve years, rising to 18 per cent for the next 18 years, and 30 per cent after 30 years. After 40 years, the projects revert back to the Government. The policy also defines the requirement for environmental flow at 15 per cent.There is however, evidence that environmental flows are not well adhered to.

The state has followed a mixed model of development. Hydropower is being developed through (i) the state sector directly through Himachal Pradesh State Electricity Board (HPSEB) and the Himachal Pradesh Power Corporation Limited (HPPCL); (ii) Central Government Corporations such as National Hydro Power Corporation (NHPC) and National Thermal Power Corporation (NTPC); (iii) Joint venture of Central and State Government; such as SJVNL (Satluj Jal Vidyut Nigam Ltd.) (iv) private sector participants and (v) mini and micro hydro (below 5 MW) development through the private sector and organized by HIMURJA (Himachal Pradesh Energy Development Agency).

The state is now facing major dilemmas to balance the development of hydropower with increasing pressures to maintain a sustainable environment. A key part of the water strategy will be to identify the possible directions to assess and plan hydropower development in a more integrated approach. This would include assessment of possible multipurpose uses of some of the hydropower dams as well as examining ways to

[43] Government of Himachal Pradesh, Forest Department, 2005. Himachal Forest Sector Policy and Strategy 2005. Shimla.

improve efficiency, sustainability, and reduce environmental impacts. Climate change is affecting and will continue to affect hydropower. Presently, increased glacier melt is providing some additional flows but this will likely be offset by reduced contribution from snow fall in the medium term and by likely reductions in glacier melt flow in the longer term. Silt in the rivers is a major problem (silt levels during flood in the Satluj river exceed 100,000 ppm) and will become more serious as rainfall intensity increases. Many hydropower projects run at low load factors which may reduce further under future climatic conditions. Hydroelectric plants have to close when silt levels get too high. The hydro schemes are currently only required to provide a few hours storage and only a few include specific provision of storage beyond this. Development of storage at selected hydro dam sites as well as multipurpose use is a possible strategy to meet climate adaptation. Storage could also offset some part of the future loss of dry season flows, which is a critical issue for the lower plain states.

The Government of Himachal Pradesh is the only state to have a legal requirement for environmental water releases. Environmental flow requirement is defined as being not less than 15 per cent of the minimum flow observed in the lean season. The interpretation of this requirement has been applied variously; from the minimum flow at one single point in time in any one lean season (i.e., 15 per cent of an absolute minimum flow ever recorded) or the average flow over the lean season. The varying interpretation of the required environmental flow and the difficulty in monitoring compliance is a key issue to be addressed. The Himachal Pradesh Government has recently developed new attractive relief and rehabilitation support packages for projects being implemented in the state sector.

Hydropower Optimisation Study

A recent World Bank study in Himachal Pradesh and Uttarakhand provides good insight into some of the issues of hydropower development.[44] The study identifies shortcomings in the planning and coordination of hydropower development, which is currently based on individual units as well as the lack of coordination among developers and concerned agencies, which works against capturing the full benefits of a cascade system. The main points of the study include:

- There are substantial hydrological and geological risks associated with hydropower development. Much of the risk is due to lack of data and inadequate data sharing.
- Methodologies for determining design floods are not consistent and could lead to under or over designing of spillway capacities for various projects in a cascade. There is no provision for failure of one dam on downstream dams.
- Silt is a major obstacle to hydropower development and threatens to undermine the viability of the hydropower investments unless more effective measures for silt management are developed.
- Simple modelling shows that optimisation of a cascade of hydropower projects results in greater energy output and less physical footprint than the currently planned designs and operational plans.
- An upstream storage will bring benefits to existing and planned downstream projects via regulated flow releases, flood control, and sediment trapping. Studies for the possible Khab storage dam in the upper Satluj river basin show good economic returns with good potential to reduce silt loads.
- There are a multitude of developers which has created some confusion and a lack of coordination and understanding of the regulations. Many of the developers are new to hydropower with limited understanding of the issues including the requirements for environmental flow.
- Development of hydropower puts stresses on the roads and other infrastructure as well as on the fragile Himalayan ecosystems.
- There are often gaps and variable success in the environmental and social plans as well as well as the CAT plans. Funds for CAT plans are often reallocated to other catchments.
- It is recommended that strategic environmental assessments based on river basins are carried out to address issues of environment and development.

The study focused only on hydropower and does not consider other sectors. It also does not consider possible impacts of climate change. Follow up studies should also assess how integrated hydropower can best meet the needs of the downstream states under climate change conditions.

Forum of Hydro Power Producers and other stakeholders of Satluj Basin

A forum of Hydro Power Producers and other stakeholders of Satluj Basin (abbreviated as HPPF) has been recently constituted and the members of the forum have agreed to cooperate under a "Five Point Programme" to achieve common goals and objectives for harnessing the hydro-electric potential of the Satluj Basin in an eco-friendly manner and to ensure the development of the area including the welfare of the people. Members have resolved to (i) join efforts to pursue the goal of eco-friendly energy development and to evolve an integrated CAT plan for the Satluj Basin; (ii) join hands for comprehensive planning of operations of power stations in the Satluj Basin for unhindered operation, optimized utilization of run-off and to pool the expertise to tackle eventualities of operation outages due to floods or mishaps; (iii) create, upgrade, and share facilities to generate data in respect of discharge, silt, and meteorological observations and sharing of common laboratory testing facilities; (iv) jointly develop and implement effective flood forewarning and disaster management systems; and (v) share views and derive a common approach towards implementation of guidelines and statutes of the state and union government and forward constructive suggestions for modifications and improvements.[45] It is hoped that this forum will eventually extend to other basins as well.

[44] Hydro Electric Corporation, Tasmania. 2007. India River Basin Optimisation Study. funded under the Public Private Partnership Advisory Facility of the World Bank (PPIAF), Washington, D.C.

[45] Presently, there are ten members of the Forum namely, the Bhakra Beas Management Board (BBMB), National Thermal Power Corporation (NTPC), Himachal Pradesh State Electricity Board (HPSEB), Jaiprakash Hydro-Power Ltd (JHPL), HPL Socomec (HSPL), NSL, Himachal Pradesh Power Corporation Ltd (HPPCL), Himachal Pradesh Power Corporation Limited (HPPTCL) & YPVL, and the Satluj Jal Vidyat Nigam Ltd (SJVNL).

Hydraulic Rams

A direct use of hydropower to supply water to higher elevations is the hydroram (hydraulic ram) which is a simple impulse pump working on the principles of water hammer. Hydrorams are low maintenance and use power from the river to pump water to higher elevations. The volume of water pumped is small but has potential use for water supply or irrigation to precision type agriculture. HIMURJA has installed 392 hydrorams for various uses.

Urbanisation and Industry

Himachal Pradesh is the least urbanized state in India and remains predominantly a rural region. The urban areas in the state are however, growing fast. Out of the state's population of six million, about 9.8 per cent live in urban areas; the districts with high urban percentages are Shimla (23 per cent), Solan (18 per cent), and Sirmour (10 per cent). Most of the urban centres are under the management of the urban local bodies (ULB) of which there are 49, including the Shimla Municipal Corporation. Urban populations are not large. As per the 2001 census, the largest town is Shimla with a population of 142,000, while the smallest town, Narkanda, has a population of 712. Industrialisation is comparatively new in Himachal Pradesh. Although industrial growth lags behind that of neighbouring states, it is beginning to enter a takeoff stage. Industrialization, in terms of the number of factories per 100,000 population, is highest in Solan (150), Kullu (42), and Hamirpur (39).

Water Challenges from Urban and Industrial Areas.

Water Supplies: Increased demand for urban water is increasing the pressure on water resources. The conditions of many urban water utilities are critical. Most of the water supply sources need augmentation, and distribution systems need major replacement or rehabilitation. There is severe deficiency in water supply in the summer. Of the 56 towns in the state, the water supply of 49 towns remain under DIPH. Urban water supply for six towns is under the Cantonment Board. The fundamental issue of urban water supply is the lack of revenue to support O&M. The present water supply situation is characterized by low tariffs, low revenue, and low levels of service delivery.

Sanitation: The State of the Environment report identifies untreated sewage as the single largest polluter with respect to faecal coliform. In most areas, sewage is characterised by septic tanks, many of which are not designed or maintained properly. Moreover, in areas of shallow bedrock, infiltration is limited and many of the soak pits do not operate in the desired fashion.

Pollution: Pollution control is under the State Pollution Control Board, a state nodal agency, for the planning, promotion, co-ordination and implementation of environmental programs. In future, it is anticipated that the length and frequency of drought will increase, reducing the capacity of the receiving water bodies to accept wastewater. Industry affects water quality through the release of contaminated waste water as well as turbidity of river water from mining, excavations and spoil heaps at hydroelectric sites from increased levels of rainfall intensity will exasperate this situation.

Sustainable Urban Drainage Systems (SUDS): SUDS is a concept that includes the long term and social factors pertaining to drainage. SUDS will become a more critical requirement with the likely increases in rainfall intensity due to climate change. Built up areas need to be drained quickly to remove water. However, the systems developed in the largely impermeable urban areas can lead to problems elsewhere in the catchment. Water quality can also become compromised due to pollutants from the urban areas going into the water courses. In Himachal Pradesh, the steep topography results in very quick and high levels of runoff, and flash flooding becomes a major risk. New concepts in urban drainage are being developed that balance the needs of good drainage with the possible impact on the river systems. The philosophy behind SUDS is that stormwater runoff characteristics from any new development should not exceed the runoff time-discharge values of the undeveloped site. Where possible, infiltration should be used to absorb the extra water. If this is not possible, water should be stored on site and released slowly over time (the UK standard is that release flows should be below 2 l/s/ha). In Himachal Pradesh, the installation of rainwater harvesting systems has been recently made mandatory for all new buildings to be constructed in urban areas of the state and no building plan without rainwater harvesting system can be approved. Construction of rainwater harvesting system has also been made mandatory for all schools, government buildings, new industries, and bus stands. Most of the systems proposed are roof water collection tanks which can provide some initial retention of storm water. However, without consideration of mechanisms to drain the tanks during the monsoon, they will quickly become full and lose their storm retention functions. Further, studies and design of appropriate options for sustainable urban drainage are proposed.

Institutions and Cost Recovery: One of the critical aspects of water supply in the state is that water schemes are mainly operated by DIPH or the Cantonment Boards and not the ULBs. This is despite the constitutional amendment directing the handover of water supplies to the ULBs. The level of tariffs remains extremely low.

Water Caused Disasters: Floods, Landslides, Avalanche, Glacier Lake Outburst Floods and Drought

Himachal Pradesh is a mountainous state comprising large Himalayan ranges with complex geological structures. The topography and climatic conditions make it particularly prone to natural disasters caused by avalanches, floods, cloudbursts/flash floods, and glacial lake bursts etc.

Himachal Pradesh falls in Zone V of seismic activity and has been the epicentre of several earthquakes, which have caused heavy damage and loss of lives.

Increasing frequency of extreme climatic events will likely impact most on low income groups. Innovative engineering and infrastructure construction mechanisms need to be balanced with new approaches to risk assessment, and organizational, institutional and social communication methods (awareness-building, warning measures, hazard specific responses, credit and strategic reserve facilities for recovery). Some innovations are emerging but there is need for research on how they can be better integrated at local levels.

Flooding: Due to the diverse topography, flooding is largely isolated and tends to be flash type flooding of high intensity and short duration. High rainfall in the Shiwalik and mid-Himalayan range can cause extensive floods. In the upper reaches of Beas, Satluj, and other rivers at higher elevations, the main problems are flash floods. Flooding can also be due to blockages from rock falls and landslides. The overall flood prone area of the state is estimated to be about 230,000 ha. The Government through DIPH is working to protect properties through river bank and flood protection. As of 2007, 13,500 ha has been protected. One of the major flood areas is in district Una where the bed of the Swan river has risen due to siltation. Flood works have been implemented by DIPH through flood protection as well as catchment treatment. Flash flooding will be a major concern in the steeper catchments where likely increased rainfall intensity will cause higher risk of flood. Provision of adequate planning and building controls to ensure adequate setback and protection of buildings will be critical.

The Satluj River Flash Flood and Mitigation Project has developed a prototype flash-flood warning system for the upper Satluj. Flow monitoring of the Satluj at Rampur shows the flows to be very bi-model, ranging from 70-130 m^3/sec in winter to 400-1500 m^3/sec in summer. The upper part of the Satluj is not affected by monsoon rains but the lower part is, resulting in extreme peak flows. The estimated peak discharge at Rampur was about 5000 m^3/sec (more than twice any peak measured at the site over 28 years from 1972 to 2000). Sediment concentrations can reach 43,000 mg/l. The Nathpa-Jhakri project with capacity of 1,500 MW has to shut down when concentration exceeds 4,000 mg/l. The flash flood water warning system is designed for local officials to meet emergency response but also to protect the Nathpa-Jhakri project infrastructure.

GLOF will likely become a more serious issue due to the gradual retreat of glaciers and increased melt rates. Landslides due to the steep terrain are and will continue to be major problems. Avalanches are similar to landslides and can occur when the shearing stress of the snow is exceeded due to excessive snow load. Increased intensity of snow fall and variability of temperature all contribute to raising the risk of avalanches. Increased rainfall intensity and runoffs resulting from climate change are likely to increase the risk of floods, landslides, and avalanches. Uncertainty and variations in weather patterns potentially could cause major crop losses. As a first step, it will be necessary to prepare zoning maps of the flood, landslide, avalanche, and drought prone areas.

Based on the National Disaster Management Act 2005, the state has established a Disaster Management Authority as well as a State Executive Committee. Similar authorities will also be set up at the district level. State and District Disaster Management plans have been prepared, consisting of long term mitigation measures as well as short term emergency responses. For water related disasters, a multi-disciplinary approach is needed and there are requirements to address the necessary additional measures to provide additional protection under climate change.

Disaster management is under a number of different departments. DIPH is responsible for flood and river bank protection works. Further study is required to develop integrated strategies for flood and river protection as well as other potential types of disaster. The strategies must incorporate the best available information on extreme meteorological effects of climate change, and help in providing a framework for building professional capacity for disaster management.

6

WATER INSTITUTIONS

The Issues

Sustainable water resources strategies to meet climate change require strong and well coordinated planning and management. Sectors at the state and central levels presently plan, implement, and manage water and catchment programs with fairly minimal levels of integrated or coordinated strategies and planning. Integrated water resources and catchment planning is a key requirement towards sustainable and water resources management. Sector agencies must interact, and there is a requirement for a core cross-sectoral department to coordinate the sector interventions. Planning and management is centralized with scope for significantly increased levels of stakeholder participation. A summary of the government's water institutions is provided in *Table 6*.

River Basin Management

Cross Sectoral Integration: A number of initiatives have been taken to support integration. In August 2009, a State Water Management Board was set up to tap synergies across line departments, as well as coordinate with central ministries. The purpose and constitution of the Board, directly under the Chief Minister, is to improve coordination across all the government departments, and the development of a multidisciplinary approach to the management of water resources. Another initiative is the recently established forum for hydropower producers and other stakeholders in the Satluj basin. The forum has the remit to improve coordination between activities of power producers and other stakeholders, and actively support solving of issues in relation to the management of the Satluj. The hydropower producers' forum, the Board, and other associations may lack the capacity to meet the needs of effective water resources management without good coordination and integrated planning by the line agencies.

Interstate Water Management: This is organized through the Bhakra Beas Management Board (BBMB) which was constituted in 1966. The functions of the Board are to regulate the supply of Satluj, Ravi, and Beas water to the states of Punjab, Haryana, Rajasthan, Delhi, and Chandigarh (Union Territory), and to distribute power from Bhakra-Nangal and Beas Projects to the states of Punjab, Haryana, Rajasthan, Himachal Pradesh, and Chandigarh. Decreases or changes in the flow regimes from Himachal Pradesh will have major impact on the irrigation in these states, and the need for strong and effective interstate water management will become essential. Although river management boards (RMB) are often seen as a precursor to integrated IWRM, the experience in India and other countries indicate that RMBs often fall short of expectations partly due to their lack of real association with the state's decision makers. It is recommended that the role of BBMB is reviewed to examine how it can better serve the needs of interstate water management covering all the main water sectors.

Hydrology

There is limited capacity for hydrology in the state. Two externally funded hydrology initiatives are however, ongoing in the state. Establishing technical capacity to compile and analyse hydrological data is a key requirement for assessing climatic changes and impact. The complexity of climate change requires the development of expertise at the central and state levels. Specialized analysis, relevant to the whole country, can be implemented most cost effectively at the centre with open access to the states. Similarly at the state level, it is not cost effective for all individual departments to maintain and analyse hydrological data. A central state information unit which provides open access to all departments is the most viable approach. If the skills and expertise are not available within the government, then specialist skills and analytical software and appropriate hardware should be sourced from the private sector or institutions.

Table 6 *Government's Water Institutions*

Nr	Sectors	Departments Responsible	Responsibilities/ Issues
A	**SECTORS**		
1.	Agriculture	Department of Agriculture.	Impart latest technologies, provide timely supply of inputs, educate farmers in economic use of irrigation facilities, soil, and water, pest management, diversified farming and marketing, construct minor and tank irrigation (<50ha).
2.	Horticulture	Department of Horticulture.	Support diversification of farming systems, promote environment-friendly farming, create conditions and infrastructure to improve farm incomes, encourage use of technologies for optimal utilization of potential, and facilitate participative planning.
3.	Fisheries	Department of Fisheries.	Increase fish production, develop reservoir fishery, fish breeding for seed stocking in reservoirs and rivers, promote reservoir and lake fish protection, promote game fishery, promote aquaculture including rainbow trout at high altitude, and create employment.
4.	Irrigation and Water Supply	Dept of Irrigation and Public Health (DIPH) (for schemes >50 ha).	Responsible for drinking water systems, sewerage systems, irrigation larger than 50 ha, and flood protection. Management is bureaucratic and centralized; efficient and flexible management is required to ensure sustainability. Handover of operation of schemes is recommended. DIPH lacks parallel support for agriculture in irrigation schemes.
5.	Forestry	Department of Forestry Joint Forest Management (with Panchayats).	Afforestation, timber distribution, grazing, fuel wood, watershed management, and forest harvesting. Now following new directions to support community needs and conservation.
6.	Soil and Water Conservation	Department of Rural Development along with Departments of Agriculture and Forestry described above.	Implementation of different rural development and poverty alleviation programs. Water programs include watershed development, desert development, and integrated wasteland development. Many projects are funded through the Mahatma Gandhi National Rural Employment Guarantee Scheme (NREGA). Soil and water conservation and rainwater harvesting is one of the main adaptation mechanisms. The needs and likely levels of investment required to meet the targets for climate change adaptation are significant. The importance of soil and water conservation would appear to justify the creation of a separate Department or Directorate of Soil and Water Conservation to better coordinate and plan SWC activities.
7.	Hydropower	Himachal State Electricity Board. HIMURJA. Public Sector Developers. Private Sector Developers.	Power generation and execution of hydro projects with a mission for uninterrupted power to all consumers. The Board appears is primarily a development agency and lacks the mandate to control and manage the myriad of hydropower producers. HIMURJA is responsible for all mini and microhydro schemes less than 5 MW.
B	**CROSS CUTTING SECTORS**		
1.	Economic Development and Planning	State Planning Board (apex planning organization chaired by the Chief Minister). State Planning Department, National Planning Commission.	Objective is to determine real priorities, identify development strategy to raise living standards. Compiles 5 year and annual plans Lacks the capacity and mandate to plan and effectively manage water resources and water resources projects.
2.	Surface Water Resources: hydrology, climate, flood risk	State Water Management Board. No defined line departments.	The State Water Management Board is newly established and can potentially be the apex body for integrated water resources management and control. The Board however, without a dedicated nodal department to support the activities, will not achieve the desired result. Capacity in hydrology is presently being developed in DIPH.
3.	Groundwater Resources	Central Groundwater Management Board.	Limited state capacity in groundwater management.
4.	Environment	Department of Environment and Scientific Technologies (includes the State Pollution Control Board).	To improve effectiveness of environmental management, protect vulnerable ecosystems and enhance sustainable development.
5.	Rural Development	Department of Rural Development	The state's Rural Development Department is engaged in the implementation of different rural development and poverty alleviation programs. Development Blocks are the pivot for planning and implementation of various rural development schemes. Projects include soil and water conservation and implementation of NREGA activities.

Hydrology Project

The Hydrology II Project, supported by the World Bank, aims at improving existing systems and developing an integrated and comprehensive data collection and information system for the whole state. The 'Hydrological Information System' is designed for use by all water users. The Hydrology II project, started in 2006, will continue for six years. The project will include river gauging, groundwater observation wells, hydro-meteorological sites, water quality laboratories, data centers, data management, computer packages, and communication facilities. The Hydrology project is working with DIPH as the nodal agency as well as with other line agencies. The lack of skilled technical staff in DIPH and inadequate budget to take on the management after completion of the project poses a risk to the sustainability of the project output. There is a proposal under discussion for the establishment of a 'Hydrologic Information Centre/Data Bank' to be organized through the DIPH and funded by the hydropower producers.

DST Hydrologic Data Model and Information Systems

The Central Government Department of Science and Technology (DST) is sponsoring the development and implementation of a hydrologic model and information system. The model is different from the Hydrology II model as it can predict the future conditions. Himachal Pradesh has been selected for initial application of the model. The DST Hydrologic Data model is working with the Department of Environment.

Independent Regulators

The Government of India is becoming increasingly aware that sole state authority over natural resources is unlikely to achieve sustainability. Strong state control however, remains important for creating legislative and policy frameworks that encourage devolvement of management to community groups and the private sector.

To meet the needs of a fully independent body or bodies to represent the stakeholders and the needs of the environment, it is important to establish independent water and catchment regulators who would support coordination and control of the planning and management of water resources including the catchments. The power sector has established an independent power regulator, which has achieved good success in the fiscal aspects of controlling the various developments but with less involvement in social and environmental aspects.

Outside the hydropower sector, there are some questions on the real need for regulators since most water sources are still maintained under government control. The key issue is whether the government as the planner, developer, and manager of water projects, can realistically also be an independent body to oversee and control, set tariffs, and ensure that consumers receive adequate levels of service delivery.

The present arrangement is in the main characterized by low tariffs, low levels of efficiency, and poor service delivery. An independent regulatory authority can act as a key catalyst to move towards higher levels of efficiency and service delivery, supported by more realistic tariff levels as well as ensuring the environmental integrity of the river systems.

Planning, Management and Regulation of Hydropower

Hydropower is being developed at a fast rate through state and central government corporations and the private sector. The Himachal Pradesh State Hydro Electric Board (HSHEB) is now slated to become a state corporation, a move that appears to leave some gap as to which line agency is responsible for overall planning, management, and control of hydropower.

Community and Traditional Institutions to Meet Climate Change

There is a long history of community and traditional institutions managing water projects in Himachal Pradesh. Of special significance is the *Kuhl* system in the Kangra Valley, one of the largest community-managed irrigation schemes in the world. The *kuhls* have been built, operated and maintained by the user community for generations.[46] Earthquakes and floods have repeatedly destroyed the system and increasing off-farm employment has drawn labor away from farming. Prevailing theories of common property resources would suggest such conditions would cause the *kuhls* to die out. Instead, most remain alive and well. The *kuhl* associations have traditionally utilized networks of interdependence to reduce environmental vulnerability and risk. Networks composed of interlinked *kuhl* provide opportunities for pooling expertise, labor, water sharing, and other support following floods, water scarcity, or other environmental impacts. These management networks can lie latent for most of the time, and move into action within very short time frames and provide a periodic and effective buffer, which can contribute to the endurance of the *kuhls*. State intervention has had mixed effect on the *kuhls*. DIPH, which took over full management responsibility of some of the larger *kuhls*, has inadvertently weakened the *kuhl* system. The handover of responsibilities to the water users' committees also affected adjacent *kuhls* as the watershed network of *kuhls* was lost. The state has attempted to support community managed systems through formalization of the management; this bureaucratization of the *kuhl* management has influenced and affected the local patterns of power. Government support for repairs was largely through male farmers and has resulted in some loss of women's participation and engagement in the irrigation operations.

The example of the *Kuhl* system shows the ability of community management and common property in meeting environmental impacts; the speed and flexibility of communities to adapt to crisis far supersedes any government intervention. Strengthening and reestablishing community

[46] J. Mark Baker. 2005. *The Kuhls of Kangra Community-Managed Irrigation in the Western Himalaya.* University of Washington Press.

institutions to manage water projects is therefore, seen as an important adaptation measure.

Government Sponsored Community Groups

The various departments have established community groups to support the management of water schemes. DIPH has constituted water user associations (WUAs) for all its schemes. The role of the WUAs is to manage the operation and maintenance so that the scheme's benefits are available to the whole command area. DIPH has reported that due to the inactive role of these associations, the department officials continue to manage the schemes. This is reported by DIPH to be the main reason for major differences between potential created and potential realized. The Forest Department has established around 1400 Joint Forest Management Committees (JFMC) as a part of the overall approach. Under Joint Forest Management (JFM), the Forest Department and the village community enter into an agreement to jointly protect and manage forest land adjoining villages and to share responsibilities and benefits. The village community is represented through a body specifically formed for the purpose.

Coordination of Management Functions

Nodal Agency for Water

The need for better coordination between the water agencies has been frequently raised as a pertinent issue by government departments and non-government stakeholders. The need for an apex nodal agency to coordinate water resources planning was widely seen as an important requirement. The government has already taken some important steps in this direction through the establishment of the State Water Management Board. The Board however, has no direct line department to work through. The role of such a nodal agency must be to coordinate and balance resources and issues. It should however, be independent of any regulatory functions. The establishment of an apex water agency requires more consultation and dialogue. A new higher level nodal agency with the remit to coordinate the line agencies may have some difficulties to get effective cooperation and support from them. To bridge the gap of coordination between departments, it is proposed to establish two interim functionary units as below:

- A Water Resources Working Group to coordinate water resources planning including hydrology, irrigation, water supply, and hydropower. The agency would support the State Water Management Board and be the apex unit to support the water aspects of IWRM. The working group would comprise representatives from DIPH, Department of Environment, Himachal Pradesh State Electricity Board, and HIMURJA.
- A separate Catchment and Agriculture Working Group to coordinate all the soil and water conservation, agriculture and forestry – programs. The catchment and agriculture working group would consist of representatives from the Environment, Forestry, Agriculture, Horticulture, and Rural Development Departments.

Coordination of Agricultural and Horticultural Activities

Most farmers have mixed farms, raising food crops, vegetables, orchards, livestock, and dairy. Promotion of mixed farming opens opportunities for better returns and reduces vulnerability to climate and rainfall irregularities, and other agricultural risks. Government support mechanisms would be more effective if agricultural support could be better integrated. This can be achieved by closer integration or merging of the Departments of Agriculture, Horticulture, and Animal Husbandry. This would enable farmers to access integrated extension support through a 'one stop shop'.

Environment

The Department of Environment and Scientific Technologies (DEST) was set up in April 2007 with the objectives of improving effectiveness of environmental management, protecting vulnerable ecosystems, and enhancing sustainability of development. Since its establishment, it has contributed significantly to the protection of the environment.

The mandate of DEST is to exercise all the powers vested under the government acts and rules pertaining to protection of environment and control of pollution. DEST is responsible for the implementation and enforcement of all environment legislation on behalf of the State Government, which cannot be implemented by the State Board or any other agency. This includes water and air pollution prevention and control, control mechanisms for waste including biomedical and hazardous waste, recycled waste, ozone depletion, and noise pollution. It is the nodal agency for environmental clearance.

Greater capacity and autonomy of state level environmental control of water resources is important. Presently, many environmental controls and clearances are handled through the Ministry of Environment and Forest. Follow up control and management is lacking and enforcement of planning conditions including the strict adherence to environmental flows is necessary. The remit of the State Pollution Board could be expanded to include enforcement of environmental flows. Water pollution is intrinsically linked to the flows in the receiving waters. It is understood that initiatives are ongoing to increase the profile of the Department of the Environment in water resources management and controls. These are good initiatives and should be supported. Close coordination and defining the integrated remits with the other water agencies, especially DIPH, is important. The Department of the Environment has nearly completed the formulation of the State Environment Master Plan in assistance with the World Bank. The master plan would incorporate spatial vulnerability assessments and sectoral guidelines for environmental protection formulation etc. The state is continuing to work further in developing the tools and methodologies for 'green accounting' in state planning and budget processes.

Climate Change

The Himachal Pradesh government is taking some important initiatives to tackle climate change. A state level Governing Council and Executive Council on Climate Change to oversee and coordinate work on Climate Change has been set up recently. A State Centre for Climate Change, Disaster Management, and Snow and Glacier Studies will soon be established. The Centre will be responsible for planning climate change mitigation and adaptation strategies, and enhancing the state's preparedness for natural disasters such as earthquakes, landslides, glaciers, lake outbursts, flash floods etc. The center would also serve as a State Resource Information Centre to serve as a central repository for all databases on environment, natural resources and climate change. The ongoing Environment Master Plan will incorporate issues of climate change.

Role of the Private Sector

National and state water policies encourage private sector participation in the implementation and management of water projects. Private sector participation is seen as an effective means to help introduce corporate management approaches to improve service delivery and accountability to users. In the hydroelectric sector, major studies and investments by private and government corporations have made significant contribution to the rapid expansion and efficiency in the sector.

In areas of potable water, irrigation, and catchment management, the role of the private sector is less clear mainly due to the lower and less attractive levels of direct financial returns to investors and the complexity of the social issues. Private sector involvement can come in many possible ways, and lack of financial returns can be balanced as required through government's support packages. The scale and necessary pace to meet climate adaptation will exceed the government's capacity and private sector initiatives in many parts of the adaptation process will be critical.

The use of state corporations potentially offers an alternative to direct government or private sector management. To be effective however, the corporations require a clear remit and defined targets for management and service delivery. They also require an independent body to control and assess their operations and mechanisms with the authority to change or remove the corporation if targets are not achieved. There would appear to be potential for state corporations to work together with private service providers where in-house capacities or skills are lacking.

Efficiency in water resources management is intrinsically linked to water services performance. Identification and establishment of effective water services can lead the way forward to increased water use efficiency, sustainability, and effective delivery to meet the targeted investment objectives. Water services providers in water, sanitation, and irrigation require to significantly enhance performance by effectively providing affordable service coverage coupled with affordability and financial viability. Such improvements must be coupled with institutional reform to allow autonomy and accountability to ensure the long term sustainability of the investments.

Performance Agreements: They form a more commercial based approach to the delivery of public services. Performance agreements can be applied to operationalize performance through the utilization of private sector management principles with a more commercial orientation towards achieving effective service delivery including the effective collection of revenues to support the financing costs. Water supply and sanitation service performance agreements are presently being put into place quite successfully in a number of states in India. In these, a private sector service provider is employed to operate the system based on a performance based management contract for a defined period after scheme completion. In the agriculture and irrigation sectors, there are presently very limited private operations outside the design and construction activities. The move to high return vegetable production however, opens opportunities for investor support to small holders for development and expansion of production. Investment support for high efficiency irrigation and precision agriculture is a key requirement and presently largely beyond the reach of most small holders without external financial support. A cautious approach is desirable. Poorly managed and controlled private sector interventions can lead to inequity, loss of the decision making autonomy for farmers, marginalization of lower income groups, and politicization of issues.

Finance and Resources for Adaptation

Climate change will require heavy investment and institutional support. Estimates of the costs of adaptation should be prepared and a financing plan prepared to meet the necessary costs over the appropriate timeframes. There are now moves to open a significant number of global financing opportunities to meet the needs of climate adaptation. The state government can play a key role in supporting studies and assessments, and preparing proposals for project financing. Initiatives for catchment protection through tree planting may qualify for carbon trading funding.

Human resource planning requires to be addressed. Government staff has limited scope to take on additional work outside the heavy commitments of administration. The appropriate role and capacity of government staff requires to be assessed. The potential for increasing the effectiveness and efficiency of staff should be examined. Shortfalls in capacity or numbers will have to be outsourced from the private sector or through the appropriate handover of management responsibilities to community user groups.

7

STRATEGIC FRAMEWORK

The strategic framework sets out the proposed approach and road-map towards achieving long term sustainable water resources management and adaptation to climate change.

Broad Principles

Integrated Water Resources Management (IWRM)[47]

IWRM is a holistic tool for planning that if applied effectively can deal with the multiple challenges of water resources. IWRM is directed at ensuring sustainable water management. Although it is not designed per se to deal with climate change, it can be tailored to incorporate its impacts, and thereby, help in adapting to climate change. The use of IWRM opens important opportunities to position water as a resource at the centre of the policy making arena.

IWRM strives for effective and reliable delivery of water services by coordinating and balancing the various water-using sectors. This approach, when applied in a planned and strategic manner, can enhance water security and facilitate adaptation to water-related risks. Successful IWRM under climate change conditions requires integration of supply and demand side management and development of strong linkages between research, monitoring, and management. Government of Himachal Pradesh will require considerable support to meet these challenges. The NWM[48] clearly identifies IWRM at the river basin level as the foundation upon which the implementation of adaptation strategies for climate change should be based. In parallel with overall IWRM, the individual water sectors must independently move forward to achieve significantly higher levels of effective and sustainable management. Each sector should develop targets through the broad IWRM umbrella program. Improving efficiency in the water sector is widely seen as being fundamental in working towards climate change adaptation. There are also requirements for basin management, including the incorporation of dialogue and interchange of information on water use with neighboring states. The potential application of River Basin Organizations (RBOs) in this context may be considered.

Environmentally Sustainable Development

The long term sustainability of economic growth in Himachal Pradesh is largely based upon responsible management of its environmental heritage. The State's key growth and revenue drivers in the medium term are critically dependent on its natural resource base. While some environmental degradation inevitably accompanies growth, inaction or failure to balance the environmental costs of development with the benefits will have particularly serious consequences for Himachal Pradesh where opportunities mainly lie in the natural resource sectors, agriculture, horticulture, tourism, and hydropower. Given Himachal Pradesh's unique geographic situation and small resource base, protecting rich natural resources assume greater importance than in other states. Climate change will undoubtedly result in some level of impacts (flood, drought or other natural disasters). In such conditions, expediency to address the problem can result in bypassing of environmental procedures. Well developed strategies for meeting climate change challenges, recognizing environmental needs, and putting in place agreed mechanisms to meet the challenges, will go a long way towards minimizing the environmental impacts.

[47] IWRM has never been formally and unambiguously defined. At the 1992 International Conference on Water and Environment in Dublin, IWRM was defined based on four principles; (i) fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment; (ii) water development and management should be based on a participatory approach involving users, planners and policy makers at all levels; (iii) women play a central role in provision, management and safeguarding of water and (iv) water has economic value in all its competing use and should be recognised as an economic good.

[48] National Water Mission, Government of India

Box 7: Water Resources Tools for policymakers[49]

Government and regulators are required to take the lead in driving specific measures and policy changes for water resources. They also set the context and rules by which participants in the water sector behave. They are also the major capital providers for water solutions. Government must balance the demands and needs of stakeholders, evaluate the scope for additional supply and its benefits, and ensure delivery in the context of political cycles and future climate changes—all with only limited information. Three examples and issues in decision making are shown below.

Example 1: The Impact of Policy Changes On Water Demand. Many Indian farmers rely on groundwater and lift irrigation; groundwater is abstracted from increasing depths or pumped to varying heads using energy intensive pumps. The energy comes at little cost to most farmers but at a significant cost to the state due to energy subsidies (up to 80 per cent of power expenditure in certain states). Energy subsidies hide the true cost of water; farmers face little direct incentive to conserve water. Some estimates show that if some regions of India were to remove these energy subsidies, the demand for water would decrease by almost a third with total crop production decreasing by nearly 15 per cent or less. Such action would reduce India's 2030 projected water supply deficit by 8 per cent The benefits from reducing the deficit would come on top of the fiscal savings from elimination of the subsidy; a part of the reduced costs would require to be offset by initiatives to compensate the reduction in crop production, as well as related loss of economic activity.

By reducing the power subsidies, other water saving strategies such as the introduction of sprinkler irrigation become more attractive. While a reduction in subsidies would negatively impact a farmer's aggregate income, the positive effect on productivity measures could more than compensate for these losses.

Example 2: Assessing implementation challenges of technical measures. Many measures to improve efficiency require to be supported by Government and stakeholder commitments and in many cases, institutional change. There are however, many non-quantitative factors that have to be addressed to ensure successful outcomes. For example, 'better tilling' appears to be a good no-regrets move that can reduce water usage and costs in agriculture and increase productivity. In reality, however, encouraging millions of subsistence farmers in India to adopt new farming techniques is extremely complicated. Conversely, building a large piece of infrastructure may be expensive but it involves much less coordination. Solutions that are in principle, technically feasible, may encounter barriers, which while not easily quantified in financial terms, are nevertheless very real for those charged with implementation.

The McKinsey study (2009) conducted assessments of the relative costs of different measures to reduce water deficit from a public policy perspective. The exercise exposed the reality that solutions made up of only those measures which required the action of a few central decision-makers would in the main come at significantly greater cost than solutions incorporating all available measures, including those where implementation would require significant changed behavior from millions of farmers and industrial or domestic water users. The study estimated that for India, avoiding these "more complex" levers, and applying only the "less complex" levers would require an additional $17 billion a year in capital costs.

Example 3: Quantifying the economics of adoption for end-users. Financial costs that are relevant for policy makers are not necessarily the same as those for households, farmers and businesses which will need to adopt efficiency measures or invest in supply. End-users see costs quite differently from the government. For example, end users may not experience the real capital and operational costs of water due to subsidies or other reasons. Their discount rates may also be higher than what would be legitimate to assume from the perspective of a government. This difference in cost perspective lies at the heart of the water dilemma, and that is why, understanding and quantifying the costs of change is so important. Government needs to be concerned about the economics of adoption: if end-users perceive measures as providing a net benefit, they are more likely to adopt them. One useful way to evaluate when a measure can be considered to have a net benefit is to calculate its payback time.

No-regrets Approach

The proposed adaptation strategy would follow a no-regrets approach in that the strategy would generate net social and economic benefits, irrespective of whether or not anthropogenic climate change occurs, or whether or not the changes follow the projected directions.

Participative Planning and Management

Present water development approaches are top down and largely non-participative. Long term sustainability and access to community and stakeholders' support resources can be significantly improved through effective participation at the planning stages. This also facilitates the handover of

[49] Summarized from McKinsey and Company (2009), Charting our Water Future Economic Frameworks to Inform Decision Making. The 2030 Water Resource Group.

management responsibilities after scheme completion. The additional planning costs and time frames to implement effective participative planning, and institutional development to support handover must be factored into the projects' budgets and schedules.

Building on ongoing initiatives

There are wide number of good ongoing initiatives in the water sector. Unfortunately, many of these are not documented or fully assessed. New adaptation strategies must review, assess, adjust, and build on the experience of the many water programs in the state.

Components of the Strategy

Effective water resources management and development are key requirements. Increasing pressures of hydropower, irrigation, and water supplies are creating issues, and development of robust water management strategies is now urgently required. The new circumstances of climate change will increasingly require improvements and changes in the direction of water resources planning. Seven key areas identified to support the development of a robust water resources strategy are summarized below:

- **Effective institutions to support integrated water resources planning and management:** Water resources planning and management are presently sector driven and with limited institutional mechanisms to undertake integrated water resources planning and management. Institutions include government, communities, and the private sector. Requirements include establishment of wide cross sectional support for IWRM, identification of targets and responsibilities, and establishment of water apex bodies, participatory mechanisms, and regulatory agencies to support long term and effective management of surface and groundwater resources and the catchments. Global predictions are that climate change adaptation will require significant financial resources and effective financial planning will be required to assess, provide, and manage the very large financial, institutional and human resources required to meet the needs of climate adaptation.
- **Establishment of integrated data and information systems**: There is very limited information to support effective water resources planning and management to meet the needs of climate adaptation. Moreover, the available information is spread over a number of departments and institutes both, at state and central level. For Himachal Pradesh, water resources systems are very complex, and an integrated water resource data system is required, including information on rainfall, snow and glacier storages and melt volumes, river flows, groundwater, land use, land conservation (forest, agricultural and other), and climatic parameters (temperature, evapotranspiration etc). The information system must also incorporate key data on water projects and water use, abstractions and return flows, and locations of different types of catchment protection works. The data system should be a GIS based system and will require to be planned and managed on a well-funded and highly professional basis. The information system will build on ongoing Hydrology II and DEST hydrology projects and other sector information systems. The data and information system will form the key information source to assess present and future risks and vulnerability assessments. The information system will be supported by the mechanisms and tools to analyse and apply the climate assessments. Information and knowledge gaps must be supported by research and the development of effective climate adaptation research will be part of this component. A key output should be the preparation of a bi-annual climate adaptation report which assesses the latest information of climate trends and the status and adequacy of adaptation measures.
- **Catchment and Agricultural Planning:** Climate change will have major impact on agriculture, soil, and water conditions in the catchments. A move to integrated catchment planning and management is required to assess the issues and to develop appropriate models for soil and water conservation and robust agricultural systems. Catchment planning must involve all the related organizations including strong and effective community participation. It is proposed that options for climate adaptation are studied on a sample basis in selected sub catchments. Fast track framework planning can be carried out to a lower level to compile information, identify issues and broad opportunities. Framework planning would be multi-sectoral, and would be followed up by more detailed studies and designs to support investments. The planning would build the ongoing programs under the Departments of Agriculture and Forests.
- **Integrated Water Resource Planning:** There is no integrated cross sector water resource planning. Projects are mainly implemented on a piecemeal basis. There is need to establish workable planning processes where projects are identified and planned rationally, incorporating the needs of the various sectors and the environment. Hydropower now forms a major contributor to energy needs and state revenues. Climate change will however, impact the long-term viability and sustainability of hydropower schemes through changing flow regimes and increased silt loadings. In addition, there are the increasing concerns of the social and environmental impacts of projects. Irrigation is seen as a key tool to address increasing rainfall irregularities but most irrigation schemes are performing poorly. Climate change will put many potable water sources at risk. There are good opportunities to increase levels of robustness to climate irregularities, service delivery, and operational efficiencies of schemes through improved planning including optimization of projects, and addressing environmental issues through strategic environmental planning. Planning should be an iterative process with refinements gradually developed as more information becomes available-a key requirement as new and refined climate change and simulation information is developed.
- **Disaster Preparedness:** To meet increased vulnerability of communities to flood, drought, and other water

related disaster impacts. Increased glacier melt increases the risk from bursts of glacier lakes (GLOF). These risks would need to be factored in.

- **Rural Employment and Diversification:** About 70 per cent of the population is presently involved in agriculture. Although reasonable potential exists to improve agriculture and reduce vulnerabilities, it will remain susceptible to climate impacts, market changes, and many risks including those due to pests and diseases. A key part of the water adaptation strategy is to promote diversification in the rural economies.
- **Investments:** Fairly major water development, environmental, and conservation projects will be required to meet the needs of social and economic development, environmental sustainability, and adaptation to climate change.

Strategic Framework

The proposed strategic framework towards water resources planning and climate adaptation is shown in *Table 7*.

Table 7 *Strategic Framework for Water Resources Adaptation*

Nr	Key Areas	Requirements
1.	Effective Institutions for IWRM	• Effective organizational framework. • Clearly defined responsibilities for line agencies. • Effective coordination mechanisms between sectors. • Effective and holistic water resources physical and fiscal planning. • Assessment of costs and financing requirements for climate change adaptation. Review of financing options including state and central government and multilateral funding. • Review of subsidies and fiscal policies to support adaptation looking at all the water sectors. • Incorporation of stakeholder participation in planning and management. • Decentralization of management and handover of appropriate works to community water users' associations. • Strengthening and reestablishment of traditional and community associations. • Strengthening of existing management bodies including the Hydropower Producers Forum. • Decision makers, technical experts, and key stakeholders to have capacity in water resources planning and management. • Strategies to mainstream environmental management and controls. • Develop integrated multi institutional support including government, government corporations, institutes, and private sector partnerships. • Interstate water planning and management.
2.	Water Resources Data and Information Systems	• Establishment of an Integrated Data and Information Unit. • Modern fully computerized information systems building on output of the World Bank's Hydrology II Projects, the DST hydrology project, and the proposed land use information system under the Forest Department. • Compilation of water resource information from state and central bodies, research institutes and international agencies. • Comprehensive information on climate, surface water, temperature, glacier, and snow melt. • Establishment of best possible estimates of future climate conditions and dissemination to sector planners. • Development of climate 'decision support tools' to support water resource planning. • Establishment of updated design parameters to meet likely extreme events under climate change. These would include extreme flood forecasting and better estimates of river yields. • Establishment of strategies for effective climate and water research.
3.	Catchment and Agricultural Planning and Management	• Planning and prefeasibility studies in sample sub-catchments to identify in detail, issues, options, and adaptation approaches, including technical, social, environmental, and economic assessments. • Planning to be integrated based on principles of IWRM. • Sub-catchments to be selected to address core soil, water, agricultural, and climate issues. • Planning to be participatory with stakeholder inputs. • Planning to incorporate best estimates of future climate scenarios and identify priority actions to meet. • Detailed studies for follow up investments in soil and water conservation, precision agriculture, irrigation, and water harvesting.
4.	Water Resources Planning and Management	• Integrated water resources planning based on best possible information on future climate characteristics. • Integration of water resources and catchment planning to define the likely climate impacts on the wider water systems. • Establishment of strong and effective participatory planning mechanisms to assess needs and options. These would include the needs of meeting development targets as well as creation of adequate robustness to climate change. • Review and preparation of proposals for transboundary and interstate water requirements. • Ensuring environmentally sustainable development of water resources. • Detailed studies and designs for water resources investments for adaptation including upgrading of efficiencies of existing projects, new integrated projects, assessments, and planning of increased levels of water storage.

Nr	Key Areas	Requirements
5.	Disaster Preparedness	• Identification of the increased risk and vulnerability to communities though climate change. • Preparation of contingency plans to meet possible water disaster situations. • Monitoring and assessment of Glacier Lake Flood Risk.
6.	Rural Employment and Diversification	• Review issues and opportunities for increasing off-farm incomes in the rural areas. • Carry out planning and feasibility studies to assess specific opportunities. • Develop government and non government approaches to support investments in rural industries including crafts, tourism, rural enterprises.
7.	Investments	• Pilot projects to assess viabilities of new ideas. • Scaled up projects where full feasibility has been established. • Projects to support social and economic water use, environmental sustainability and measures to meet adaptation to climate change.

Linkages to the NAPCC

The strategic framework has been designed to build on the recommendations of the National Action Plan for Climate Change (NAPCC). The three most relevant parts of the NAPCC are the National Water Mission, the National Mission for Sustaining the Himalayan Ecosystem, and the National Mission on Sustainable Agriculture. The key linkage between the NAPCC proposals and strategies for Himachal Pradesh are summarized in *Table 8*.

Table 8 *Linkages to NAPCC*

	Proposals in NAPCC	Linkages to the Proposed Strategy for Water Resources	Road Map Reference
I	NATIONAL WATER MISSION		
1.	Comprehensive Water Database and Assessment of Impact of Climate Change	• Establish Water Resource Data and Information Systems.	2
1.1	Development of Water Resources Information Systems	• Establish Water Resource Data and Information Systems.	2.1
1.2	Modern technologies for measurement	• Modern state of the art computer systems to analyze climate and water data. • Development of tools, methods, and capacities to utilize and apply climate information.	2.1 2.2
1.3	Customizing Climate Change Models for regional water basins	• Establish an initial climate and water simulation model for Himachal Pradesh	2.2
2.	Citizen and State Action		
2.1	Increasing storage capacities	• Preparation of framework plans for four selected sub catchments to assess water retention through soil and water conservation. • Preparation of Integrated Water Management Plan for Satluj River including requirements for storage.	3.1 4.1
2.2	Preparation DEM models	• Establish water resources data and information system.	
2.3	Flood forecasting	• Preparation of Disaster Preparedness Plan includes flood forecasting.	5.1 and 2.2
3.	Focused Attention on Over Exploited Areas		
3.1	Regulation and Control of GW	• Not a major issue-monitoring of groundwater proposed 2.1.	
4.	Increasing Water Use Efficiency by 20 per cent	• To prepare water resource framework plans for 4 sub-basins-will review options for efficiencies including development of precision agriculture. • Proposed investments in precision agriculture. • Upgrading irrigation performance of pumped irrigation schemes. • Upgrading levels of service delivery and sustainability of potable water.	3.1 9.2 9.3 9.4
5.	Promotion of Basin Level Integrated Water Resource Management	• Establishment of Effective Institutions and IWRM. • Strengthen Interstate Water Management. • Strengthen linkages between state and National. Agencies. • Capacity Building for Climate Change.	1.1 1.2 1.3 1.4

	Proposals in NAPCC	Linkages to the Proposed Strategy for Water Resources	Road Map Reference
II	**NATIONAL MISSION FOR SUSTAINING THE HIMALAYAN ECOSYSTEM**		
1.	Management measures to sustain glacier and mountain ecosystem	• Ensuring environmentally sustainable Water Resources Management.	4.1
2.	Understand whether and extent to which glaciers are in recession	• Establish Water Resources Data and Information System.	2.1
3.	Establish observational and monitoring network to assess freshwater resources	• Develop tools, methods, and capacities to apply climate information.	2.2
4.	Promotion of Community based management of Himalayan Ecosystems and incentives for Panchayats to for Protection and Enhancement	• Framework Plans for Four Selected Catchments ensuring environmentally sustainable Water Resources Management. • Strategies for rural employment and diversification. • Integrated Soil and Water Conservation.	3.1 4.1 6.1 9.1
III	**NATIONAL MISSION FOR SUSTAINABLE AGRICULTURE**		
1.	Strategic research including the application of biotechnology tools to increase productivity	• Strategies for effective research to meet the needs of climate adaptation.	2.3
2.	Sustained increase in food grain productivity to counter reduced productivity due to temperature increases.	• Improved seed and more efficient irrigation systems. • Himachal Pradesh is not ideal for food grain production and irrigation of food grains is less viable than that in other states. Cropping strategies need to be developed including balancing needs for adequate crop returns to support irrigation investments and lower risk rainfed cropping and needs of soil and water conservation.	3.1 2.3 and 3.1
3.	Improvement in water use efficiency	• Assessment planning and design of precision agriculture systems including high efficiency irrigation systems. • Integrated Water Resource Planning including proposals to increase service delivery and efficiency of irrigation. • Ensuring environmental sustainable Water Resources-establishing high efficiency pumped irrigation systems to minimize energy needs. • Detailed design for follow on investments-precision agriculture and performance upgrading of existing irrigation systems.	3.1 4.1 4.2 3.3 and 4.4
4.	Strengthening risk management systems to minimize adverse impacts due to climate variability	• Sub-Catchment Framework planning will identify approaches and design pilot programs to reduce vulnerability.	3.1

Linkages with the Himalayan Conclave and the Shimla Declaration

Senior ministers and officials of the five Indian Himalayan States met in Shimla and agreed on 30th October to a 12 point action plan to jointly face the challenges of climate change and sustainable development. The Strategic Framework incorporates many of the points in the Shimla Declaration as summarized in *Table 9*.

Table 9 *Linkages to Himalayan Conclave*

	Actions under the Shimla Declaration	Linkages with Proposed Strategy for Water Resources	Road Map Reference
1.	Establishment of a Himalayan Sustainable Development Forum	• Establishment of effective institutions and IWRM will include support for the Himalayan Forum and used State Councils for climate change.	1.1
2.	Setting up Councils for Climate Change		
3.	Catalysing Research and Policy Actions	• Strategy for effective research to meet the needs of climate adaptation.	2.1
4.	Payment for Eco System Services	• Finance and resource strategy to meet the needs of climate change.	1.2
5.	Managing Water Resources for Sustainable Development	• Water Resources and Data Information Systems. • Catchment and Agricultural Planning. • Integrated Water Resources Planning.	1 2 3
6.	Challenges of Urbanization	• Catchment and Agricultural Planning-studies to support the development of urban sustainable drainage systems.	3.1
7.	Green Transportation	• Not addressed.	
8.	Dealing with impacts of climate change on livelihoods	• Strategies for rural employment and diversif cation.	6.1
9.	Decentralized Energy Security	• Not addressed.	
10.	Managing Growth of Eco-Friendly Tourism and Pilgrimage	• Strategies for rural employment and diversification.	6.1
11.	Green Industry	• Ensuring environmentally sustainable Water Resources Management-strategies for water pollution management including urban and industrial waste water treatment.	4.2
12.	Green Job Creation	• Strategies for rural employment and diversification.	6.1


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8

ROAD MAP FOR CLIMATE CHANGE ADAPTATION

A road map has been prepared to plan the way forward, from ideas and concepts, to actions on the ground. The road map compares the present status with the long term planning targets as well as the likely climate change impacts and how these can be factored into the planning approach, planning targets, and ultimately developed into state wide programs.

At this stage, the road map is a preliminary proposal that has to be refined and developed as new information and understanding of the issues become available. The seven point strategic framework has been packaged into projects which have been designed to be independent but interconnected interventions. The preliminary road map is shown in *Table 10*.

Table 10 *Preliminary Road Map for Climate Change Adaptation*

Nr	Activity/ Project	Present Issues	Main Outputs/ Activities
1.	**EFFECTIVE INSTITUTIONS AND IWRM**		
1.1	Establishment of Effective Institutions for IWRM	• Present institutions are fragmented and major gap in integration of efforts. • No lead institution to guide, coordinate, control, and support IWRM for both surface and groundwater. • Lack of an independent authority for Environmental management and control of all water projects. • Very limited stakeholder participation.	• Detailed assessment of IWRM functions and necessary arrangements for inter-sector coordination. • Assessment and preparation of proposals for institutional changes and reforms. • Clear mandate for one or more institutions to take the lead in planning and management of water resources. • Assessment of requirements for establishment of an independent water regulator, strengthening of surface and groundwater authorities to address issues of policy, tariffs, stakeholder participation, and other regulatory functions. • Clear definition of inter-sector and sector mandates. • Clear strategies for handover of government responsibilities and decentralization of decision making and stakeholder participation. • Strengthening of traditional community associations.
1.2	Finance and Resources Strategies to Meet the Needs of Climate Change	• Climate change will require heavy investment and institutional support including human resources and specialists. • The state has given a high priority to social expenditures which is putting a major strain on the state's finances. • Tariffs and cost recovery from irrigation and water supply are extremely low. • There are many subsidies available to support rural development initiatives- some more successful than others. • The time-frame to meet climate change adaptation is limited.	• Fiscal and resources strategies to meet the needs of water resources adaptation over a five year period. • Estimation of costs to meet climate change adaptation including capital costs, operational costs, cost for studies, data and information systems, design and supervision. • Fiscal strategies to meet proposed subsidies for agriculture and other measures to support the rural economies. • Fiscal strategies to agree to tariffs for water supply, irrigation and other utilities. • Agreed strategies towards cost sharing between central and state government. • Development of insurance mechanisms to support resilience to climate change. • Overall sustainable financing models to meet funding needs of adaptation. • Agreed and appropriate tariffs for water consumers including potable water and irrigation. • Appropriate financing packages to encourage private sector partnerships.

Nr	Activity/ Project	Present Issues	Main Outputs/ Activities
1.3	Strengthen Interstate Water Management	• Many climate issues in the Himachal Pradesh catchments will impact on downstream states. • Water resource strategies of Himachal Pradesh must be coordinated with downstream states.	• Open dialogue with neighboring states. • Assess issues of interstate water. • Review present institutional arrangements including the role of the Bhakra Beas Management Board. • Assess appropriate mechanisms for interstate water planning and management. • Prepare interstate water resources management strategy. • Prepare MoU for interstate water management.
1.4	Strengthen linkages between state and national agencies	• Limited interface in coordinating overall strategies for water resources. • Climate change is a very large problem requiring coordination and pooling of resources at the state and national levels.	• Review of the present arrangements and areas for central Government support. • Review how national and state institutes can better coordinate research and application of research to policies. • Prepare strategies for improving coordination of resources to meet climate change including technical financial and environmental issues. • Coordinate data and information sharing between state and centre, with special reference to sourcing climate projections. • Operationalize improved climate orientated management initiatives. • Open information sharing for international transboundary rivers.
1.5	Capacity building for awareness, understanding and management of water resources and climate change	• Limited capacities for effective planning and management of water resources. • New issues of IWRM and climate change require significant upgrading of skills.	• General awareness and training for government, stakeholders, and general public. • Specialist training for selected personnel. • Upgrading of facilities including new computer technologies, GIS etc to be supported by training. • Development of web sites and other media initiatives.
2.	**WATER RESOURCES DATA AND INFORMATION SYSTEMS**		
2.1	Establish Water Resource Data and Information Center	• Very limited data and information systems to support water resources planning and assessment of climate impacts. • No integrated sharing of information between sectors, State and Central Government and National and International institutes.	• Establish a Water Resources Data and Information Centre for Himachal Pradesh • This Centre would build on existing and ongoing programs at state and centre including World Bank Hydrology II program, the Hydrologic Information System being developed by DEST, as well as the proposed Department of Forest information system. • Modern state of the art computer systems to compile and analyse climate data and other information. • This Centre would identify data gaps and monitoring requirements including rainfall, river, snow, and glacial data as required. • Sourcing data from Himachal Pradesh, central government, national and international institutes. • Sourcing of guaranteed sustainable funding to meet the needs of the centre and agencies responsible for collection of data.
2.2	Development of tools, methods and capacities to utilize and apply climate information	• WR planning has historically relied on estimates of future climatic conditions based on historic data on climatic conditions. • Under climate change, historic information is no longer valid. • Need to develop new tools to support decision making.	• Review mechanisms and strategies to develop or obtain climate and water simulation models for Himachal Pradesh. Models would be based on data compiled by the Water Resources and Data Unit as well as sourcing state-of-the-art information from national and international agencies and institutes. • The models would incorporate best information from national and international research. • Establish mechanisms to update and refine models based on new information. • Establish tools and mechanisms to incorporate simulations into sector planning • Use models to assess and forecast climate events including flood forecasting. • Establish updated design parameters and criteria to meet likely extreme weather events. • Preparation of bi-annual adaptation assessments.

Nr	Activity/ Project	Present Issues	Main Outputs/ Activities
2.3	Strategies for effective research to meet needs of climate adaptation	• Research is not integrated. • Limited sharing of information. • Research does not meet real needs of the state.	• Development of a Strategy for Climate Adaptation Research to meet the needs of Himachal Pradesh. • Defining key areas of necessary research for water resources and climate adaptation for Himachal Pradesh. • Establishment of a committee to coordinate research. • Information sharing between research institutes at the state, national, and international levels. • Coordination and sharing of research outputs sponsored by MoEF, MoWR and others.
3.	**CATCHMENT AND AGRICULTURAL PLANNING**		
3.1	Framework plans for four selected sub- catchments	• Lack of integrated and holistic planning for water resources. • General proposals for climate adaptation (this strategy, NAPCC and others) need to reviewed and assessed based on actual field conditions.	• All water sectors to work together to prepare participatory water resource framework plans for up to 4 sub-catchments to address land and water issues, soil and water conservation, potential to increase water efficiency through precision agriculture, irrigation, and water harvesting. Integrated planning and adaptation to climate change is required. Adaptation of cropping to provide increased resilience to climate change. • Plans would develop GIS mapping and information systems including land and climate suitability analysis for crops. • Plans will incorporate new water initiatives including agriculture, precision agriculture, water harvesting, small scale irrigation using high efficiency distribution systems, soil and water conservation, hydropower, water supply, forestry and off-farm employment opportunities. • Plans will address strategies to improve the risk management systems including availability of appropriate seed, weather advisory systems, innovative crop insurance mechanisms, pest controls, and provision of incentives to farmers to take up climate resilient agriculture. • Studies for agro-forestry on degraded and marginal lands of small farmers. • Studies to include at least one urban area to assess issues of sustainable urban drainage systems in urban areas, sanitation, and issues of urban water supply.
3.2	Detailed studies and designs for follow up investments	• Current planning and design lacks detail. • Economic analysis of options is limited. • Planning is top down with very limited participation by communities and stakeholders.	• Participatory planning and design of catchment and agricultural projects to meet the needs of adaptation. • Projects to build on experience of other state governments and other projects including Mid-Himalayan and proposed JICA projects. • Detailed studies for high efficiency, precision agriculture, irrigation, and cost effective soil and water conservation.
4.	**INTEGRATED WATER RESOURCES PLANNING**		
4.1	Preparation of Integrated Water Resources Management Plan for Satluj River in Himachal Pradesh and Punjab	• Major social and environmental issues of hydropower projects. • Low levels of efficiency and service delivery of water projects. • Water management and sharing between states based on old agreements. • Hydrological conditions have and will change significantly. Climate impacts on water resources in Himachal Pradesh will have significant impacts on Punjab. • Require integrated studies. Existing studies have been directed primarily at hydropower with less consideration of other sectors.	• Integrated water resource plan for Satluj river using latest information sources of project water availabilities. The plan would include all water sectors including hydropower, irrigation, rural and urban water supplies and sanitation. • Build on other existing information and studies including the India River Basin Optimization Study (World Bank PPIAF, 2007), incorporating all water sectors and address interstate issues. • Prepare Strategic Environmental Assessment for the Satluj Basin to assess strategies to meet development needs and minimize environmental impacts. • Planning would be participatory, involving extensive stakeholder consultations. • Assess and prepare water resources development strategies to optimize water resources between the two states including requirements and potential for storage. • Plan would incorporate proposals to improve efficiency of hydropower schemes and levels of service delivery, and efficiency of irrigation and water supply schemes. • Plan would incorporate outputs of strategies for 'Effective Institutions' and 'Catchment Planning' including applications of high efficiency precision agriculture, irrigation, cost effective soil and water conservation.

Nr	Activity/ Project	Present Issues	Main Outputs/ Activities
4.2	Ensuring environmentally sustainable Water Resources Management	• Water resource projects create environmental impacts; major impacts of hydro projects. • No department or organization has adequate capacity to control environment.	• Assessment of environmental issues and present approaches to environmental management. • Incorporate environmental aspects of NAPCC (principally National Water Mission, National Mission for Sustaining the Himalayan Ecosystem, and the National Agricultural Mission) into water resource management in Himachal Pradesh. • Incorporate necessary institutional arrangements. • Review and prepare strategies for water pollution management including urban and industrial water treatment. • Promotion of community institutions to support the natural environment. • Prepare an environmental protection strategy for water resources development including criteria for development controls, and environmental flows etc. • To evolve management measures for sustaining and safeguarding mountain and glacier ecosystems. • Establish high efficiency pumped irrigation systems to minimize energy needs and maximize irrigable areas.
4.3	Detailed studies and designs for follow up investments	• Lack of cohesive planning of projects. • Project designs do not incorporate climate impacts. Technical, financial and economic analysis of options is limited. • Planning is top down with very limited participation by communities and stakeholders.	• Participatory planning and design of hydroelectric, irrigation, and water supply projects. • Performance upgrading of existing irrigation schemes to improve service delivery, productivity, and robustness against climate variability. • Improved service delivery of potable water schemes reducing vulnerability to drought. • Improving power factors and efficiency of future hydro-electric schemes through optimization of cascade dams and storage. Detailed assessment of options to minimize environmental impacts.
5.	**DISASTER PREPAREDNESS**		
5.1	Preparation of Disaster Preparedness and Management Plan to meet needs of climate change	• Present disaster planning in relation to water risks needs to incorporate best information and analysis. • Water related risks-flood, land slide avalanche, drought, and GLOF will increase under future climatic conditions. • IWRM planning and GIS based risk assessment can provide information to support effective disaster management.	• Development of a robust disaster management plan to incorporate increased water risk from climate change. • Building on the existing disaster management planning including 'no water' risks. • The Plan will incorporate up-to-date information from water resource data/ information systems. • Institutional requirements for planning, updating of plans, and management of disaster preparedness to form part of the Plan. • Review requirements and prepare flood forecasting systems. • Improving risk management systems for agriculture to minimize adverse impacts and major crop losses due to climate variability.
6.	**RURAL EMPLOYMENT AND DIVERSIFICATION**		
6.1	Strategies for Rural Employment and Diversification	• Climate change will increase vulnerability of agriculture. • Water adaptation and agriculture measures alone are unlikely to meet the requirements of ensuring full employment. • Promotion of off farm incomes can provide a significant buffer against climate change. • Himachal Pradesh has a well educated work force but limited employment opportunities outside agriculture and government. Many people are therefore, forced to seek employment outside the state. • Estimated 26 per cent of the population is below the poverty line and 29 per cent of Himachal's population are Scheduled Castes and Scheduled Tribes. Of these, 45 per cent are below the poverty line. • Low income families will be most vulnerable to climate impacts.	• Preparation of a strategy for Rural Employment and Diversification. • Strategy to work in parallel with other proposals for adaptation. • It would be state-wide but would involve framework studies in the selected catchments (project 3.1). • The strategy would assess the potential for private sector and possible private sector partnerships to promote employment, including provision of credit for start up. • Opportunities for new livelihoods where climate change has caused loss of income. • The plan would give special attention to backward and tribal communities and other low income groups. • To assess opportunities for communities to protect the environment. • To expand the opportunities of sustainable livelihoods from the forest • Opportunities could include tourism, eco-tourism, agricultural processing and marketing, and industry including cottage industries. • Special support to be directed at employment of women and minority groups and regional employment imbalances in the state.

Nr	Activity/ Project	Present Issues	Main Outputs/ Activities
7.	**PROJECTS AND INVESTMENTS**		
7.1	Integrated soil and water conservation	• Limited coordination of soil and water conservation works under different line agencies. • Of firm objectives and evaluation. • Projects should be targeted, planned programmed, monitored and evaluated.	• New initiatives in soil and water conservation based on Framework Planning Studies. • Integration between different line agencies. • Promotion of community participation in conservation. • Improved institutional coordination.
7.2	New Initiatives in Precision Agriculture	• Present farming is low efficiency with low production and high levels of waste. • Farming in Himachal Pradesh is moving towards a change from subsistence food crops to cash crops. • Irrigation development in most cases is high cost. • Land holdings are very small • Good potential for high return vegetable and other crops.	• Precision agriculture offers potential to reduce costs of inputs such as water, seed, fertilizers etc. • Investment costs are high (rainwater harvesting, pumped irrigation to medium/high heads, and polyhouses require well planned strategies to maximize returns and efficiencies. • High returns through the production of high quality vegetables and other off-season production. • Some progress in place but technologies need to be better defined and assessed through pilot projects.
7.3	Upgrading Performance of Irrigation Schemes	• Irrigation water use efficiency and uptake is quite low-especially critical for pumped irrigation. • Long-term sustainability of pumped irrigation is being questioned. • Many schemes have very high pumping heads, and surface water distribution is inappropriate for steep land.	• Development of strategies to improve the performance and efficiency of irrigation. • Assess the issues and options including technical, social, and financial aspects. • Review the options of surface, drip, sprinkler and low cost hybrid systems. Prepare cost comparison combining capital and operational costs to prepare economic assessments of different systems.
7.4	Upgrading levels of Service Delivery and Sustainability of Potable Water	• Levels of service delivery for water supply schemes is low and cost recovery is negligible. • Climate change will put minor sources at risk. • Long term sustainability of potable water is a key requirement.	• Support for integrated water supply and sanitation. • Secure sustainable water sources under climate variability. • Increase water supply efficiency. • Establishment of effective service delivery including cost recovery. • Establish new initiatives for water reuse and rainwater harvesting. • Capacity building and training for handover.
7.5	Integrated Hydro-electric Projects to improve performance and reduce social and environmental impacts.	• Piecemeal development of hydroelectric sites. • Low power factors. • Increasing concern and resistance by communities and environmental groups to new projects.	• Sites selected and designed based on integrated and optimization studies and strategic environmental assessments. • Prioritization of most efficient sites and development modalities. • Strict environmental controls of construction and enforcement of environmental flows.
7.6	Other investment projects to be defined		

Responsible Agencies for Water Resources Adaptation

Refer to Table 10 (above) for Activity/Project

1. Effective Institutions and IWRM

1.1
- Government of Himachal Pradesh
- All water sector agencies

1.2
- Government of Himachal Pradesh
- State Planning Board
- State Planning Department
- National Planning Commission

1.3
- Government of Himachal Pradesh
- MoWR/Central Water Commission (CWC)
- Bhakra Beas Management Board (BBMB)

1.4.
- Government of Himachal Pradesh
- Planning
- Central government agencies

1.5
- Government of Himachal Pradesh
- Water sector agencies

2. WATER RESOURCES DATA AND INFORMATION SYSTEMS

2.1
- Government of Himachal Pradesh
- Central Govt.
- Institutes
- Consultants

2.2
- To be defined, would involve State and Central Government and research institutes and private sector

2.3
- Government of Himachal Pradesh
- Water Sector Line Agencies
- CWC/ Ministry of Environment and Forests
- Research Institutes

3. CATCHMENT AND AGRICULTURAL PLANNING

3.1
- Government of Himachal Pradesh
- All Water sector agencies

4. INTEGRATED WATER RESOURCES PLANNING

4.1
- Government of Himachal Pradesh
- DEST/DIPH/ HIMURJA and Himachal State Electricity Board
- Government of Punjab
- All Water Sector Agencies
- MoWR/CWC

4.2
- Department of Environment
- All water sector agencies

5. DISASTER PREPAREDNESS

5.1
- Government of Himachal Pradesh
- Disaster Management Authority

6. RURAL EMPLOYMENT AND DIVERSIFICATION

6.1
- Government of Himachal Pradesh
- Department of Rural Development
- Dept of Tourism
- Planning and Economic Affairs

7 PROJECTS AND INVESTMENTS

7.1
- Agriculture
- Rural Development
- Forestry

7.2
- Government of Himachal Pradesh
- Agriculture DIPH

7.3
- DIPH
- MoA

7.4
- DIPH

7.5
- DEST
- Himachal State Electricity Board
- HIMURJA, Corporations and private sector developers.

9

IMPLEMENTATION PLAN

Approach

The adaptation road map is extensive and involves a complex mix of activities to be defined, planned, designed and executed. Water involves a wide number of government institutions and it is important to develop a rational and workable approach to meet the objectives of IWRM. For the long term, some adjustments to the institutional remits and responsibilities will be required, but to meet the needs of a fast track start up, it is proposed to base the program as far as possible on the existing institutional arrangements but requiring the lead departments to work closely together. The proposed approach is described below and summarized in *Table 11*.

Effective Institutions and IWRM: This would form an umbrella organization for all the adaptation activities. Establishment of effective institutions and frameworks to develop IWRM is essential. Implementation of this core component would be through the State Water Management Board working closely with the main water departments and agencies (Environment, HPSEB, HIMURJA, Agriculture, Forestry, Rural Development, Irrigation and Public Health and Fisheries). Consultation and dialogue would be maintained with the other agencies, corporations, and Boards affected by water. The two working groups would be established namely, a Water Resources Working Group' and a 'Catchment and Agriculture Working Group' to support coordination and an integrated approach.

Catchment and Agricultural Planning: This would be implemented primarily through the Departments of Environment, Agriculture, Forestry and Rural Development, while maintaining close liaison with other water departments and agencies. Effective management of the catchments is critical to sustainable agriculture and water resources, and would include planning of minor water projects including small irrigation and water harvesting.

Integrated Water Resources Planning: This would focus on the major water resources and water development while maintaining strong linkages with the catchments and agriculture. The work would be through the key water agencies DIPH, Himachal State Electricity Board, HIMURJA, and the Environment Department.

Cross-Cutting Initiatives: These are multi sector initiatives requiring a fully integrated approach. Cross-cutting initiatives would provide key linkages between the catchment and water planning activities. The development of water resources data and information systems would form a fundamental cross-cutting part of the strategy. A key requirement is the preparation of bi-annual reviews and assessment of climate information and projections and assessments of the adequacy of the measures planned and in place for adaptation.

Program

A five-year program to establish effective climate change adaptation for water resources is proposed; the schedule is shown in *Figure 13.* Tight and intensive time frames are proposed, reflecting the urgency of the need to prepare and put in place, effective climate change adaptation measures. To effectively apply the gradual improvement of information, frequent reviews have been programmed. These will form an important part of the plan.

Table 11 *Proposed Implementation Arrangements*

EFFECTIVE INSTITUTIONS AND IWRM		
• Establishment of effective institutions for IWRM • Fiscal and Other Resources Strategies • Strengthen Interstate Water Management	• Strengthen linkages between central and state institutions • Capacity building for awareness and understanding	
CATCHMENT AND AGRICULTURE PLANNING	**CROSS CUTTING INITIATIVES**	**INTEGRATED WATER RESOURCES PLANNING**
Departments of Agriculture and Forestry Department of Rural Development Catchment and Agricultural Planning • Framework plans for four selected Sub-Catchments • Detailed studies and designs for follow up investments including precision agriculture, irrigation and water harvesting, soil and water conservation	Department of Environment DIPH, Departments of Forestry, Agriculture, Tourism, Disaster Management Authority Water Resources Data and Information Systems • Establish water resources data centre. • Development of tools for analysis of climate information • Strategies for effective research Disaster preparedness Rural Employment and Diversification	DIPH Dept Environment Himachal State Electricity Board, Himurja Integrated Water Resources Planning • Integrated Water Resource Plan and Strategic Environmental Study for Satluj River Basin • Detailed studies and designs for performance upgrading and improved service delivery of irrigation and potable water. • Optimization and reduced environmental impact of hydropower schemes.
INVESTMENTS		
• Integrated soil and water conservation • New initiatives in Precision Agriculture.	• Establishment of fully funded state-of the-art information center. • Investment in adaptation research	• Performance upgrading of medium and major irrigation schemes. • Sustainability and service delivery for potable water. • Sustainable and environmental hydropower.

Figure 13 *Proposed Implementation Schedule*

	Nr	Year 1-preparation				Year 2		Year 3		Year 4		Year 5	
		1	2	3	4	1	2	1	2	1	2	1	2
EFFECTIVE INSTITUTIONS FOR IWRM	1	Define requirements and strategies		Government and stakeholder agreements		Key reforms		Organisation in place		Refine and develop IWRM functions			
DATA & INFORMATION SYSTEMS	2	Assess needs, cost and design		Procurement		Organisation in place		Climate adaptation assessment 1				Climate adaptation assessment 2	
CATCHMENT AND AGRICULTURAL PLANNING	3	Framework Plans for Four Sub Catchments				Design for follow up investments							
INTEGRATED WATER RESOURCES PLANNING	4			Integrated Water Resources and Strategic Environmental Assessment for Sutlej Basin				Design for follow up investments			Planning review and update		
DISASTER PREPAREDNESS	5	Assess Preparedness in Four Sub-Catchments				Prepare State Wide Disaster Plan				Put Disaster Management in place			
RURAL EMPLOYMENT & DIVERSIFICATION	6	Assess Opportunities in Four Sub-Catchments				Expand to State							
INVESTMENTS	7					Pilot Projects			Upscaling				

About the Book

This publication lays out a strategy which identifies and presents a broad framework for integrated water resources planning and management, to increase the level of resilience to climate change in Himachal Pradesh. It is based on an assessment of the status of water resources in the state, including the present and planned water utilization examined within a framework of environment, conservation and sustainability. The strategy also examines the present institutional arrangements for water resources management and assesses the requirements for institutional development, strengthening and necessary reform measures to support the development of robust and sustainable water resources management.

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