

Report No. 43946-IN

# Climate Change Impacts in Drought and Flood Affected Areas: Case Studies in India

June 1, 2008

South Asia Region  
India Country Management Unit  
Sustainable Development Department  
Social, Environment and Water Resources Management Unit



Document of the World Bank

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## Abbreviations and Acronyms

EGS	Employment Guarantee Scheme
HH	households
HadRM	Hadley Centre regional climate model
IMS	integrated modeling system
IPCC	Intergovernmental Panel on Climate Change
NREGS	National Rural Employment Guarantee Scheme
UNFCCC	United Nations Framework Convention on Climate Change
WUA	water user association
MSP	minimum support price

## Conversions

### Units of measurement

1 lakh	100,000
1 crore (100 lakh)	10 million
1 hectare (ha)	2.47 acres or 10,000 m <sup>2</sup>
1 km <sup>2</sup>	0.4 sq. mile
1 cumec	1 m <sup>3</sup> /second
°C to °F or °F to °C	$(F - 32)/9 = C/5$

### Effective exchange rate (May 20, 2007)

US\$1	Rs (rupees) 40.76
Re (rupee) 1	US\$ 0.0245

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## Acknowledgments

This report is the product of a collaborative effort between the World Bank and the Government of India under the overall leadership of the Ministry of Environment and Forests (MoEF). The report has also received significant support from several ministries and agencies of the Government of India; and the state governments of Andhra Pradesh, Maharashtra, and Orissa. Special gratitude is extended to the following government officials: Dr. Prodipto Ghosh, Former Secretary, J.M. Mauskar, Additional Secretary, Rajshree Ray, Deputy Secretary, MoEF, Mr. J.C. Saharia, Former Secretary and Dr. K.S. Vatsa, Former Secretary, both from the Department of Rural Development and Water Conservation, Government of Maharashtra (GoM); and Mr. Aurobindo Behera, Principal Secretary, Department of Water Resources, Government of Orissa (GoO). Significant contributions from various representatives from Non-Government Organizations (NGOs), central and state sectoral agencies during meetings and workshops held at various stages of the study and their technical support to the study consultants through data and information, are gratefully acknowledged. This report has received funding from the U.K. Department for International Development (DFID), although the views expressed within do not necessarily reflect official policy.

We would like to especially thank the Technical Advisory Group (TAG) members that participated in the consultative process and guided the design of the study: The TAG members include Dr R. K. Pachauri, The Energy and Resources Institute, Dr. A. Patwardhan, Technology Information Forecasting and Assessment Council (TIFAC), Delhi; Dr. P. K. Aggarwal, Indian Agricultural Research Institute, Delhi; Dr. K. S. Kavikumar, Madras School of Economics, Chennai; Dr. Rupa Kohli, Indian Institute for Tropical Meteorology, Pune; Dr. Santosh Kumar, National Institute of Disaster Management, Delhi; Prof. A. K. Gossain, Indian Institute of Technology, Delhi; and Dr. Ajay Mathur, Bureau of Energy Efficiency, Ministry of Power, Delhi. Our gratitude is extended to Dr. David Radcliffe, Senior Rural Livelihoods Advisor from DFID, Government of U.K., for his continuous support to this activity.

The contributions and written comments received from a number of experts deserve special mention and are gratefully acknowledged, especially Dr. K. S. Kavikumar from the Madras School of Economics for detailed comments and advice. Gratitude is also extended for comments, data and inputs from: Dr. Charles Batchelor, Dr. Stephen Foster, Dr. V. P. Dimri and Dr. D. Muralidharan from the National Geophysical Research Institute, Hyderabad; Mr. A. K. Jain and Mr. Pradeep Raj from the Groundwater Department, Government of Andhra Pradesh; Dr. Himanshu Kulkarni from the Advanced Centre for Water Resources and Development and Management, Pune; Dr. S. P. Bagde, Groundwater Survey and Development Agency, GoM; and finally, Dr. S. Umarikar, Department of Water Supply and Sanitation, GoM.

The World Bank team was initially led by Bilal Rahill and in the subsequent phase by Richard Damania with Priti Kumar as co-task-team-leader. The team included Suphachol Suphachalasai, Carla Vale and Kumudni Choudhary. Other Bank staff who contributed to the production of this report were Sanjay Pahuja, Ranjan Samantaray, Bela Varma, Rachel Susan Palmer and Vinod Ghosh. Technical background reports were produced by a team of consultants from the Risk Management Solutions India (RMSI) Pvt. Ltd. led by Satya Priya and Murthy Bachu; The Energy and Resources Institute (TERI) led by Preety Bhandari and Suruchi Bhadwal with

support from Sreeja Nair, Souvik Bhattacharya, Meena Sehgal and Kadambari Anantram; and Pragmatix Research and Advisory Services Pvt. Ltd. led by A. J. James.

Peer reviewers are Gretel Gambarelli, Chandrasekar Govindarajalu and Willem Janssen of the World Bank. Helpful comments and contributions were received from World Bank staff representing several sectors and regions, including Ernesto Sanchez-Triana, Michel Pommier, Siet Meijer, Charles Cormier, Malcolm Jansen, Martien Van Nieuwkoop and Winston Yu. Special thanks are due to Kseniya Lvovsky and Karin Kemper for detailed and insightful comments on the draft report and for their support. The support and contribution of Robert Watson for his guidance on scoping out the study; and Ian Noble for guiding the overall climate modeling exercise are also acknowledged. Finally, we would like to express our sincere appreciation to Michael Carter, Former Country Director for India, Jeffrey Racki, Former Acting Sector Director, South Asia Environment and Social Development Unit, and Fayez Omar, Senior Manager, India Program, for their overall guidance and support to this activity.

Thanks are due to John Dawson and Allison Russell for their meticulous contributions in editing the report and appendices, respectively.

The opinions presented here and any errors are the sole responsibility of the authors and should not be attributed to the individuals or institutions acknowledged above.

## Glossary

**aquaculture.** Breeding and rearing fish, shellfish, etc. or growing plants for food in special ponds.

**adaptation.** A process by which strategies to moderate, cope with, and take advantage of the consequences of climatic events are enhanced, developed, and implemented. Types of adaptation include anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation.

**adaptive measures or responses.** Actions taken that result in building the capacity of communities and boosting their long-term resilience to climatic shocks or stress. See also *coping measures*.

**adaptation strategy.** A broad plan of action that is implemented through policies and measures. Strategies can be comprehensive, focusing on national, cross-sectoral scales; or targeted, focusing on specific sectors, regions, or measures.

**adaptability.** The degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes of climate (IPCC 1995, Working Group II).

**adaptive capacity.** The ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, and to cope with the consequences. Adaptive capacity is limited by existing information, technology, and the resources of the system under consideration (IPCC 2001, Working Group II).

**adaptive potential.** A theoretical upper boundary of responses based on global expertise and anticipated developments within the planning horizon of the assessment (UNDP 2004b).

**basin.** The drainage area of a stream, river, or lake.

**biophysical vulnerability.** Sensitivity of a natural system to an exposure to a hazard.

**block or mandal.** An administrative subdivision of a district, which in turn is a subdivision of a state.

**C4 plant.** A land plant that uses a so-called C4 fixation method to transform carbon dioxide into sugar. Chemically speaking, the method allows for binding the gaseous molecules to dissolved compounds inside the plant for sugar production through photosynthesis. C4 fixation is an improvement over the simpler and more ancient C3 carbon fixation strategy used by most plants. The intermediate compounds of the process contain four carbon atoms, hence the name C4.

**climate change.** Following the Intergovernmental Panel on Climate Change (IPCC), any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), which defines climate change as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.” See also *climate variability*.

**climate prediction or climate forecast.** The result of an attempt to produce a most likely description or estimate of the actual evolution of the climate in the future.

**climate projection.** A forecast of the response of the climate system to emission or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections differ from climate predictions in that they depend upon the emission, concentration, or radiative forcing scenario used, which are based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty.

**climate variability.** The variation in the mean state and other statistics (such as standard deviations and the occurrence of extremes) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may result from natural internal processes within the climate system (internal variability) or from variations in natural or human-induced external forcing (external variability) (IPCC 2001).

**coping measures or responses.** Actions taken in the short term by households and communities that result in diminishing the impacts of climatic shocks or stress on them temporarily and which help to tide them over the stress period.

**drought.** It is defined in many ways and includes the phenomenon that results when precipitation is significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems. In the case of India, the definition of what is considered “precipitation below normal” varies from agency to agency.

**event or impact year.** The year in which an event such as a drought or flood takes place.

**emission scenario.** A plausible representation of the future development of emissions of greenhouse gases and aerosols based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development and technological change) and their key relationships. In 1992, the IPCC presented a set of emission scenarios that were used as a basis for the climate projections in the Second Assessment Report (IPCC 1995). These emission scenarios are referred to as the IS92 scenarios. For the Third Assessment Report (IPCC 2001) new emission scenarios, namely the SRES scenarios (Special Report on Emission Scenarios of the IPCC), were published. These are known as the A1, A2, B1, and B2 scenarios and were also utilized in the preparation of the Fourth Assessment Report (IPCC 2007a, 2007b, 2007c; final report in preparation).

**evapotranspiration.** The combined process of evaporation from the Earth’s surface and transpiration from vegetation.

**extreme weather event.** An event that is rare within its statistical reference distribution in a particular place. Definitions of “rare” vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile. By definition, the characteristics of what is called extreme weather may vary from place to place. An extreme climate event occurs when the same considerations apply to an average of a number of weather events over a certain period of time (e.g. rainfall over a season).

**flood.** A phenomenon that occurs when an increase in precipitation, which is above normal recorded levels in a specific timeframe, leads to the volume of water within a body of water, such as a river or lake, to surpass the total holding capacity of that body. As a result, some of the water flows sit outside their normal perimeter, potentially causing serious damage and adversely affecting people and land resource production systems.

**impact of climate.** Consequences of climate change on natural and human systems that usually affect people and communities in a negative way (though they could also have beneficial effects).

**(climate) impact assessment.** The practice of identifying and evaluating the detrimental and beneficial consequences of climate change on natural and human systems.

**intensity.** A measure of the physical strength of a damage-causing event, such as a flood.

**irrigation.** A method of purposely providing land with water, other than rainwater, by artificial means.

**normal year.** Any year in which an extreme event, such as drought or flood, does not impact a geographic area.

**policies and measures.** Means of addressing the need of climate adaptation in distinct but sometimes overlapping ways. Policies typically refer to the courses of action that governments can adopt to change economic and other behaviors through, for example, such instruments as taxation, command-control regulations, market mechanisms, incentives, and information gathering or dissemination. Measures are usually specific actions amenable to implementation, such as reengineering irrigation systems, planting different crops, or initiating a new industry. Many projects can also be termed measures.

**resilience.** The ability to exploit opportunities, and to resist as well as recover from negative shocks. It is also defined as the amount of change a system can undergo without changing its state.

**risk (climate related).** The result of the interaction of physically defined hazards with the properties of the exposed systems in terms of their sensitivity or (social) vulnerability. Risk can also be considered as the combination of an event, its likelihood, and its consequences; that is, risk equals the probability of a climate hazard multiplied by a given system's vulnerability (Lim *et al.* 2005).

**runoff.** Surface flow occurring when the precipitation rate exceeds the infiltration rate of the soil or other surface material.

**sensitivity.** The degree to which a system will respond, either adversely or beneficially, to a given change in climate (or other external pressures).

**socioeconomic vulnerability.** An aggregate measure of human welfare that integrates environmental, social, economic, and political exposure to a range of harmful perturbations. Can also be defined as the sensitivity of the human system to an exposure to a hazard.

**stakeholders.** Any persons with interest in a particular decision, either as individuals or as representatives of a group. This includes people who influence a decision or can influence it, as well as those who are affected by it.

**thermal expansion.** In connection with sea level rise, this refers to the increase in volume (and decrease in density) that results from the warming of water. A warming of the ocean leads to an expansion of the ocean volume and hence an increase in sea level.

**vulnerability.** See appendix B

## **Executive Summary**

### **A. Background to the Study**

#### **A.I Climate Variability and Change**

1. With alpine conditions, arid deserts and tropical regions, India's climate is as varied as its landscape. The summer monsoon marks the most important event in the economic calendar of rural India. Over 70% of the annual precipitation falls between the months of June and September and a good monsoon heralds a bountiful harvest and financial security. But when monsoons fail, or are excessive, suffering and economic loss can be widespread. Climate variability has been the source of both misery and prosperity for much of rural India. India is already experiencing the effects of climate variability. It is at risk of considerably deeper impacts if climate projections are indicative of what may actually happen.
2. Recognizing the significance of climate variability on growth and development, the Government of India has established a range of programs, policies and institutions to moderate the impacts of climate-related risks. These long-standing programs have done much to unleash the development potential of agriculture and have helped build resilience to climate shocks. India's disaster management programs rank among the most comprehensive in the world and have achieved considerable success in countering the most severe effects of extreme events. When floods or drought descend, an elaborate relief machinery springs into operation, with rapidly arranged protective policies that include employment schemes, cash and food disbursements, and emergency health care.

#### ***Fiscal Burden of Climate Extremes***

3. The extensive relief systems have come at a substantial price on the public purse. Several state governments spend significantly more on relief and damages than on core rural development programs. In the state of Maharashtra, a single drought (2003) and flood (2005) absorbed more of the budget (Rs 175 billion), than the entire planned expenditure (Rs 152 billion) on irrigation, agriculture, and rural development from 2002–2007. Climate change is expected to increase the frequency of extreme events in ways that are outside the realm of experience, so relief measures and their financing may not be sustainable, particularly if droughts and floods concomitantly become more severe. This is already beginning to compromise the effectiveness of many development programs. Though relief can be strengthened and will continue to remain a vital part of the defense against climate extremes, in the long term there is a clear fiscal and development imperative to strengthen climate resilience of the rural economy by addressing the root causes of vulnerability.

#### ***Vulnerability of Agriculture***

4. With an emerging gap between the languishing performance of agriculture and the accelerating growth of industry, the Government of India has assigned the highest priority to supporting development in the agriculture sector in the Eleventh Five Year Plan period (2007–2012), with targeted growth of 4%. However, delivering on the promise of faster agricultural growth will be difficult, given the multiple constraints facing the sector including, fragmented landholdings, inadequate market access and

rapidly depleting natural resources. This will be made more challenging by the impacts and consequences of ongoing and future climate change. For the poor and marginal<sup>1</sup> farmers clustered along the poverty line, even small climatic shocks could impose large and irreversible losses, triggering poverty and destitution. Reaching development targets will therefore require priority investments in building the climate resilience of vulnerable rural communities with a portfolio of adaptation options that can address climate risks.<sup>2</sup>

### ***Geographic Diversity: A Further Challenge for Adaptation***

5. India's immense geographic diversity adds to the complexity of developing an adaptation strategy. Projections indicate that climate variations in India will be varied and heterogeneous, with some regions experiencing more intense precipitation and increased flood risks, while others encounter sparser rainfall and prolonged droughts. The impacts will vary across sectors, locations and populations. The implication for a country so diverse is that broad generalizations on ways to promote adaptation to climate change will be misleading. Consequently, there can be no one-size-fits-all approach to developing a climate risk management strategy: approaches will need to be tailored to fit local vulnerabilities and conditions. All of this renders adaptation policy making complex and difficult.

### **A.II Objectives of the Study**

6. It is in this context that the Government of India has acknowledged the need to develop adaptation strategies to deal with the possible human toll and economic costs of climate variability and change. The aim of this study is to assist the government in this endeavor by focusing on selected priorities. The overarching objective of this report is to promote the mainstreaming and integration of climate related risks in India's development policies and processes, where this is appropriate. The objectives and scope of work were developed in close consultation with the Ministry of Environment and Forests as the primary counterpart, a cross-section of concerned ministries and departments in the central government and in three selected states, and scientific experts from academic, policy and research institutions. In the states, the Department of Water Resources, Government of Orissa, and the Department of Rural Development and Water Conservation, Government of Maharashtra, supported these assessments, reflecting a multisectoral interest in and demand for adaptation solutions.
7. The focus of this report is on vulnerabilities in natural resources and rural livelihoods, which stand at the front line of climate change impacts.<sup>3</sup> The approach was dictated by government priorities, which indicated the need to (a) assess climate risks to agriculture and livelihoods in areas facing elevated and increasing exposure to droughts and floods; (b) generate better information on current coping and climate risk management strategies in response to droughts and floods; (c) develop and demonstrate the use of a climate

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<sup>1</sup> Marginal farmers are defined as those who own less than 1 acre of land.

<sup>2</sup> These concerns have been echoed in the Planning Commission's working documents for the Eleventh Five Year Plan.

<sup>3</sup> The study builds upon and takes forward many of the recommendations of an earlier World Bank assessment of the impacts of droughts in the state of Andhra Pradesh (World Bank 2006f).



modeling framework that could be used to identify future climate risks and (d) use the information to assist in developing the key elements of a forward-looking adaptation plan that can help improve climate resilience and adaptive capacity.

### A.III The Approach

8. Responding to these needs, the assessment is focused on drought-prone regions of Andhra Pradesh and Maharashtra, and select flood-prone districts in Orissa. The study adopts multiple approaches to meet its objectives:
  - First, it **learns lessons from the past and present** by gathering statistical information to understand how rural communities in the study areas cope with and build resilience to extreme climate events.
  - This is complemented by a **review of governmental programs and institutions**, which identifies policy and administrative gaps and strengths in addressing climate risks.
  - The impacts of climate variability and change are projected to differ in kind and magnitude from current climate patterns. So lessons from the past may be of limited relevance in guiding future policy. Looking forward, the study builds an **integrated modeling system (IMS)** to assess future climate risks and vulnerabilities in the study regions.
  - Finally, the report synthesizes the results and articulates a way forward for promoting adaptation and building climate resilience of rural communities in the study areas.
9. The modeling framework used in this study is a complex but powerful tool that generates information on future climate scenarios and the likely impacts on agriculture. The system integrates a climate model with a hydrological water balance model. Together these feed information (on temperature, precipitation, and soil moisture) into an agronomic (crop growth) model that simulates the impacts on crop yields. A custom-built farm-level economic model assesses the financial consequences for farmers and determines cost-effective adaptation strategies. The development of the farm economic model represents an innovation of this study and provides a tool that can be used to assess the financial effects of different policies and scenarios.
10. Before delving into the main results, a number of *caveats* and qualifications are in order. First, neither the issues, nor the locations, examined in this report are intended to provide an exhaustive account of adaptation to climate variability and change in a country as large and varied as India. With a focus on droughts and floods, the case studies are indicative of “hotspots” and regions at the edge of climate tolerance limits. These zones constitute about one-third of the country comprising many of the “lagging regions” with a large population, who are disproportionately poor, and most at risk from climate change. There are other regions such as the fragile Himalayas, the biodiverse Western Ghats, the vast coastal areas, and the prolific agricultural lands of the Gangetic plains that are not covered in this study and need to be considered in subsequent work.
11. Second, as in all matters relating to climate change, there are long and uncertain time frames. Forecasting climate events, or the economy, even a few years into the future remains an imprecise and hazardous exercise. By its nature the analysis of climate change

must look ahead many decades. The model projections should be interpreted with caution and viewed as indications of the possible direction and magnitude of changes rather than as precise forecasts. Despite these uncertainties, policy makers are compelled to respond to climate risks and make decisions on matters that will be affected by future climate events. Modeling exercises can help policy makers to generate informed decisions based on scientific assessments of risks, outcomes, and policy impacts. Nevertheless, it needs to be emphasized that model simulations are not predictions but scenarios based on a host of assumptions.

## **B. Coping with and Adapting to Drought Conditions**

### **B.I Consequences of and Responses to Drought**

12. India has a long history of addressing droughts, so the study begins by exploring how farmers in selected drought-prone areas of Andhra Pradesh and Maharashtra are affected by and respond to droughts. The immediate consequence of drought is a predictable and often precipitous decline in agricultural production and income. This ignites an ominous chain of events – indebtedness, distress sales, asset depletion, and deteriorating health – all of which perpetuate poverty and deprivation. However, in any community certain households are less affected by drought than others, irrespective of landholding, wealth, or location.
13. What explains why some exhibit greater resilience to drought than others? The answer lies in the interplay of key factors: the availability of water, a critical farm input; economic incentives that shape the way farmers react to climate risks; and the opportunities created by policy and circumstance. Among these the following variables are found to have a disproportionate bearing on vulnerability to droughts:
  - **Reliable irrigation supplies**, in particular groundwater, can provide insurance against income losses due to meager rainfall. Beyond this self-evident link, the assessment finds more nuanced impacts. The availability of irrigation supplies tends to promote greater reliance on lucrative and water-intensive crops such as rice and sugarcane. If irrigation supplies are assured through a drought, then agricultural incomes are protected. Conversely, when water sources become depleted there is a more dramatic fall in incomes, with debilitating consequences. In broad terms, holding other factors constant, a household with access to irrigation during a drought year in Andhra Pradesh earns about 50% more income. The clear implication is that judicious and sustainable water use can provide an indispensable buffer against deficient rainfall. For this to occur there is an overwhelming need to tackle the unrestrained competition for groundwater.
  - **Household indebtedness** is another major consequence of drought in communities facing heightened climate risks in areas with degraded and scarce natural resources. The assessment finds that once encumbered by high debt, households are locked into agriculture and remain more exposed to climate risks. Obvious remedies such as debt-forgiveness schemes may help to appease suffering, but they do not address one of the root causes of the problem – an overreliance on rainfall-dependent sources of income. This suggests scope for

introducing cost-effective policy instruments that simultaneously tackle the problem of indebtedness and provide incentives for job mobility.

- Finally, the provision of **local public goods**, notably infrastructure and education, provide opportunities for income diversification, thereby limiting the exposure to drought risks. Infrastructure and education in climate-vulnerable communities yields a double dividend – they generate well-recognized development benefits in the near term and simultaneously build resilience to drought in the longer term. In particular education exhibits increasing returns in building climate resilience, whereas infrastructure stimulates economic activity and enhances employment and business opportunity. The policy implication is that climate vulnerabilities need to be integrated into decisions that guide the location and design of public investments and infrastructure.

## **B.II Future Prospects for Drought-Prone Regions under Climate Change**

14. What does future climate change hold for these regions? The modeling framework developed in this study is used to generate projections of climate events based on two commonly used emission scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) for the period 2070-2100.<sup>4</sup> The assessment distinguishes between the influence of climate on agriculture, from other possible shifts in the economy (such as prices, economic structure and technology).<sup>5</sup> The projections find considerable variability of impacts across regions and crops. In dry areas most crops respond favorably to higher precipitation and elevated levels of carbon dioxide (termed carbon fertilization). But these can be offset by higher temperatures. The net effect is determined by the magnitude of changes and baseline conditions.

### ***Drought-Prone Districts of Andhra Pradesh***

15. In the arid study regions of Andhra Pradesh the climate projections indicate substantially higher temperatures (2.3°C –3.4°C, on average) and a modest but more erratic increase in rainfall (of about 4% to 8% at the basin level). With high prevailing baseline temperatures these changes generate deteriorating agroclimatic conditions, with declining yields for the major crops (rice, groundnut, and jowar). Though all yields decline, conditions are more favorable to groundnut, which is already prevalent in the area, reflecting farm-level adjustments to arid conditions. Despite groundnut's suitability to these harsh conditions there are well-recognized risks that prolonged monocropping brings: pests, disease, and fertility loss. Projections suggest that declining yields of major dryland crops are mirrored in lower agriculture incomes. In the harsher climate change scenarios, farm incomes could decline substantially (by over 20%), suggesting that agriculture as currently practiced may not be capable of sustaining large populations on

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<sup>4</sup> The first (termed A2) depicts a gloomy and pessimistic world where high greenhouse gas emissions result in severe climate change. The other (termed B2) emphasizes sustainability, global cooperation, and lower greenhouse gas emissions.

<sup>5</sup> Damages due to changes in climate would call for different remedies from impacts due to variations in economic conditions. Hence the study presents results for key climate change scenarios, holding economic and technical factors constant. It then tests the limits and sensitivity of the projections by allowing for wide changes in economic and technical variables. The report focuses on results that appear robust to substantial variations in parameters.

small rain-fed farms. Recognizing these limits the Government of Andhra Pradesh has initiated numerous programs to encourage agricultural and occupational diversification and a forward-looking drought adaptation program supported by the World Bank.

### ***Drought-Prone Districts of Maharashtra***

16. The drought-prone belt in Maharashtra (specifically Nashik and Ahmednagar districts) offers a striking contrast. The climate projections suggest a significant, though more variable, increase in rainfall (approximately 20% to 30% at the basin level) accompanied by higher temperatures of about 2.4°C to 3.8°C, on average. As a result the yield of several dryland crops (including the millet varieties of jowar and bajra) exhibit small improvements and provide a measure of relief to rain-fed farmers with a boost of about 8% to 15% in incomes. Prospects for other crops are less certain. Sugarcane is widely grown on irrigated farms in arid regions of the state. Under the climate change scenarios sugarcane yields are expected to decline considerably (by nearly 30%) as a result of increased heat stress caused by the warmer climate.
17. Negative trends in sugarcane production are already visible across the state. Sugarcane is generously subsidized and has been implicated in the overabstraction of groundwater. There is mounting evidence of a significant reduction in the output and yields, due in part to increasing levels of environmental degradation. Climate change pressures would reinforce the many current benefits from encouraging a shift from sugarcane to less water intensive crops.

### **C. Elements of a Strategy for Adaptation to Drought Conditions**

18. Is there a need for additional policy and public investments to promote adaptation to climate change? Vulnerabilities to climate extremes and change are often related to poverty. So it may be argued that as India grows more prosperous, it will inevitably build greater resilience to climate risks. The myriad government programs that deal with education, infrastructure, and job creation also serve a complementary objective of reducing community exposure to climate risks. In this context, adaptation policy can be viewed as an adjunct to good development policies that promote equitable growth. All of this might suggest that adaptation to climate change requires no additional policy priority or interventions.
19. There are, however, high risks associated with complacency that could magnify the costs of climate variability and change. The projections in this report suggest a considerable and mounting human toll from climate change and highlight the need and urgency for mitigating the avoidable costs, particularly among the vulnerable sections of society. Incomes on the small rain-fed farms in Andhra Pradesh could decline by 5% under modest climate change and by over 20% under harsher conditions, bringing farmers closer to, and in many cases under, the poverty line. The escalating fiscal strain of the current drought relief system reinforces the need to tackle the root causes of drought vulnerability as a priority in the development process.
20. This report suggests that building greater climate resilience requires a combination of measures packaged with the right incentives and implemented at multiple levels of government (local, state, and national). Reactive or singular approaches to droughts, such as relief and emergency assistance or debt relief alone for that matter, are essential to

appease suffering, but could generate perverse incentives that perpetuate climate risks and impede appropriate adaptation. Consequently these should be complemented with a combination of other initiatives that promote longer-term climate resilience.

## **C.I Policy Approaches**

### **Policies to Build Adaptive Capacity and Resilience to Climate Risks**

21. A strategy to build climate resilience and ignite growth needs to take account of a region's comparative advantage, resource constraints, and the impending changes brought about by climate. The exact policies and interventions will differ by location and circumstance, with emphasis given to four overarching strategies: (a) the need for policy and investment decisions to be based on sound scientific knowledge of risks, calling for the use of diagnostic risk assessment tools to generate policy-relevant information; (b) innovations and reforms in agriculture and water management that promote more climate resilient cropping systems; (c) cost-effective and efficient management of climate risks to promote income diversification through economic instruments; and (d) institutional structures to facilitate these changes. These strategies are formulated on the basis of the study findings in combination with a review of the literature and a consultative process with government officials and NGOs, and are discussed below.

### **Strengthening Climate Risk Information and Tools to Match Needs**

22. Climate change will have heterogeneous and spatially variable impacts. The first step in building adaptation policy is to identify vulnerabilities and risks to determine priorities for investment and policy. A recent Bank assessment has also emphasized the need for such informed decision making (World Bank 2006f).
23. There are two immediate areas where climate risk information is required:
  - First, climate change could have important ramifications for assets with long lead times and long design lives. The location, construction and refurbishment of these will need to incorporate climate risk information. This is particularly important for arid regions where changing water flows or rainfall patterns could require modification or relocation of vital irrigation infrastructure.
  - Second, the assessment finds that local public goods (notably education and infrastructure) play a powerful role in enhancing climate resilience. Consequently climate risks need to be integrated into policy decisions in these sectors, calling for the use of diagnostic risk assessment tools to determine how much to invest and where to invest.
24. The capacity to generate this information rests with national research centers, while the need and demand for the information lie with affected communities and the government. This argues in favor of a recent suggestion by the Planning Commission to build a climate information system at the national level to disseminate information for planning and management to end users (Planning Commission 2007). This initiative will also need to be supported by improved meteorological information at the subbasin and local levels (blocks and subblocks) to improve forecasting and monitoring capabilities.

## **Innovation and Reforms in Agriculture**

### ***Water Management***

25. In drought-prone areas water scarcity is the limiting factor of production and plays a key role in shaping the fortunes of agriculture. Much has been done across the country to address water shortages, with a particular focus on supply-side remedies, including large infrastructure, watershed, rainwater harvesting and water conservation programs, and a host of community initiatives. However, water management still remains a formidable challenge. The climate change projections indicate that even when farmers have largely adapted to arid cropping patterns, increased demand and consequent water stress could severely jeopardize livelihoods and diminish agricultural productivity. There is an overwhelming case for more aggressively pursuing water conservation in semi-arid and arid regions. Greater attention must be given to hybrid approaches that emphasize the efficiency of groundwater use and increase the effectiveness of watershed activities to conserve soil moisture and harvest water. Such measures are not a substitute for pricing policies and water policy reform, which would need to focus on the demand side, for example by strengthening incentives and controlling groundwater demand at the wider geographic scale necessary for effective management. However, they provide interim and feasible measures for reducing vulnerabilities (DFID 2005a).

### ***Research and Extension***

26. The study makes a strong case for a shift in agricultural systems in order to overcome future climate change pressures. It is clear that small and medium farmers in dryland areas will need greater support with knowledge and policy assistance to make this transition work on a large scale. Much is already occurring across the country and there is research in dryland farming for rice, horticulture and numerous other crops. Strengthened support for agricultural research and extension is essential to promote more sustainable modes of dryland farming. This could include looking at opportunities in farm services associated with low costs of production and intensifying agro-forestry and livestock-based production systems suitable to dryland areas, among others.

### ***“Smart Subsidies” and Incentives***

27. In the medium to near term, alternative mechanisms are needed to deliver support to farmers more effectively, with the resulting savings being used to increase public investment in ways that reduce the exposure to climate risks. This would also require complementary measures that address the farm-level incentives (including subsidies and regulations) that have implicitly encouraged the production of water-intensive crops (such as sugarcane) in arid regions. Experience elsewhere suggests that the use of interim smart subsidies may offer a pragmatic way to shift incentives and, thus, cropping patterns to modes that are better suited to agroclimatic conditions. Smart subsidies recognize that there are costs to altering cropping patterns and provide incentives to change the crop mix by shifting support from environmentally degrading activities to more benign forms of production. As an example, moving price support from water-intensive agriculture to dryland crops could help counteract the current incentives to cultivate water-thirsty crops.

### **Financial and Economic Instruments to Promote Income Diversification**

28. In semi-arid and arid areas where the natural productivity of agriculture is low and threatened by droughts, income diversification remains the most obvious and effective way of reducing exposure to climate risks. This brings new and unfamiliar transition risks to farmers that can be tackled through a variety of financial incentives that facilitate the shift to nonfarm activities and promote job diversification.

### ***Debt Relief Coupled with Other Instruments***

29. Farmer indebtedness is among the major impediments to occupational mobility. An important priority and challenge for policy is to find cost-effective ways of reaching poorer farmers to help reduce their risk exposure. Coupling debt relief with new risk mitigation instruments is an obvious way to prevent a debt-induced poverty trap. Two innovations merit further policy consideration and scrutiny:
- The relief of old debt could be coupled with the provision of capital for a new business. This would simultaneously reduce indebtedness and lower the transaction costs of occupational shifts by providing new opportunities. The myriad ongoing micro-credit schemes provide a vehicle to pilot such schemes.
  - A variant of this approach would have debt relief coupled with insurance to cover the initial risks of shifting from farming to other businesses and provide protection against new and unfamiliar sources of risk.<sup>6</sup>

### **Institutional Change: Convergence and Synergy between Programs**

30. There are a large number of central- and state-sponsored programs for addressing drought risks that are implemented under different guidelines and by various implementing and coordinating agencies. Synergies between these programs could be enhanced through an integrated approach to coordinate priorities and fill gaps in these programs. This remains a challenging task, as it requires considerable institutional dexterity to synchronize diverse programs managed at different levels of government within a common framework. There are several institutions at the central level, including the National Rainfed Area Authority and National Disaster Management Authority, that are capable of assuming the role of an apex coordinating agency whose convening power could be harnessed to coordinate the different planning and implementation processes. Furthermore, enlarging existing schemes, such as the state Employment Guarantee Scheme (EGS) and the National Rural Employment Guarantee Scheme (NREGS) to include resilience-building activities would be a fruitful policy measure to encourage sustainable farming systems in rain-fed areas. Finally states could build in a adaptation/climate change dimension into the district agricultural plans<sup>7</sup> which would go a long way in mainstreaming the climate risk management agenda as well as creating

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<sup>6</sup> Variants of both approaches are suggested in World Bank 2006f.

<sup>7</sup> The National Development Council Resolution of May 2007 under the chairmanship of the Prime Minister of India gives high priority to incentivising states to develop comprehensive district agricultural plans that will include livestock, fishing, minor irrigation, rural development works and other schemes for water harvesting and conservation.

enabling conditions for translating the recommendations of the report into actions on the ground.

## **D. Climate Change and Vulnerability to Floods**

### **D.I Consequences of and Responses to Floods**

31. Floods are a natural feature of India's river basins. They replenish groundwater, deliver topsoil and nutrients to support agriculture in otherwise infertile regions, and sustain valuable ecosystems. Excessive flooding poses risks to human life and is a major contributor to the poverty and vulnerability of marginalized communities. It is estimated that the flood-affected area has more than doubled in size from about 5% (19 million hectares) to about 12% (40 million hectares) of India's geographic area in the past five decades. This has occurred despite generous and rising government spending on a multitude of flood protection programs.
32. Orissa is among the most flood-affected states in the country. Frequently it has coped with simultaneous droughts in one part of the state and extensive floods in another, as well as with cyclones and other natural calamities. Two flood-prone districts – Puri and Jagatsinghpur – are the focus of this study. Households in the study areas endure harsh conditions. Villagers are accustomed to moving homes and losing crops and property because of flood. Livelihoods and occupations have responded and adjusted to the predictable risks of flood damage. Rice, which is among the most flood-resistant of crops, dominates agriculture. There is also an emphasis on cultivation in the dry rabi months, when flooding can often improve yields by delivering nutrients and soil moisture.
33. The communities have diversified into a range of more flood-resilient activities, such as aquaculture, fishing, dairy, and petty business, though the scale of these activities is still minor. Despite significant levels of adaptation, floods continue to disrupt and devastate communities, with the impact bearing disproportionately upon the poorer segments of the community (the small farmers and the landless). Even when the poor diversify into nonagricultural activities, they remain more vulnerable to floods. While the nonagricultural income of the large landholders falls by a meager 5% in a flood, that of the landless declines by about 14%, reflecting their fragile economic status as unskilled, casual workers.

### **D.II Future Prospects for Flood-Prone Areas under Climate Change**

34. Adding to these already high risks, the climate projections suggest that temperatures, precipitation, and flooding are likely to increase, with adverse impacts on crop yields and farm incomes. Among the more substantial effects is a spatial shift in the pattern of rainfall towards the already flood-prone coastal areas. Climate change is also projected to bring a dramatic increase in the incidence of flooding. As an example of the implied magnitudes, the probability that the discharge might exceed 25,000 cubic meters per second (cumecs) (at the measuring station at Naraj on the Mahanadi River in Orissa), is currently low – about 2%. But under climate change, this is projected to rise dramatically to over 10%. This suggests a clear need for improved and accurate forecasting tools to guide the appropriate location and design for flood protection infrastructure and other high-value assets.



35. In the study districts of Puri and Jagatsinghpur, the assessment finds that rice yields could decline by 5% to 12% and profits by 6% to 8% under climate change. With the dominance of rice and high levels of preadaptation to floods, there is little that can be done to build flood resilience through adjustments in cropping patterns and farming practices. There is a need to further strengthen current flood protection initiatives and develop a proactive, comprehensive, and anticipatory flood management strategy.
36. Orissa has established a wide-ranging flood management policy with an emphasis on relief and protection. When floods strike, an elaborate relief machinery provides employment, cash, food, health care, and shelter. There is also a comprehensive action plan that envisions a host of structural measures such as a cascade of reservoirs, dams, raising and strengthening of embankments, and interbasin transfer of water. Despite the substantial fiscal burden of the flood relief and protection system floods continue to encumber livelihoods and impede development. With the prospect of much more severe and intense flooding under climate change, it is necessary to ask how the system could be strengthened to build greater flood resilience in communities.
37. There is no single remedy for mitigating flood damage and site-specific measures are required to address particular vulnerabilities. Experience suggests the need to integrate hard and soft engineering approaches through three components:
  - Advanced systems for **the detection and forecasting** of floods;
  - **Anticipatory and proactive** actions designed to minimize flood risks and build capacity to withstand flood events;
  - **Reactive actions** that deal with the aftermath of floods and include compensation and relief.

## **E. Elements of a Strategy for Building Flood Resilience**

### **E.I Strengthening Systems for Detection and Forecasting Floods**

38. With the projected future changes in the spatial distribution, intensity, and frequency of floods more advanced forecasting and risk diagnostic tools will be needed to guide the location of high-value investments and the engineering design of flood protection structures. The system's effectiveness could be enhanced by combining data collection, telemetry, flood forecasting, and flood warning elements into one integrated flood management and information system for a basin.<sup>8</sup> Flood inundation mapping is another important planning tool that is needed to guide zoning and investment decisions, but its use across India is limited. There is growing recognition in Government of India that generating such information should be a high policy priority.

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<sup>8</sup> As an example the Hirakud Dam, which is the main control structure on the Mahanadi, was originally designed for a flood of 42,500 cumecs, whereas more recent calculations indicate that the maximum probable flood is 69,500 cumecs. Floods need to be partially regulated by advance reservoir depletion, which may have impacts on water availability for irrigation, and this in turn calls for a basinwide flood forecasting and management system.

## **E.II Strengthening Anticipatory Measures**

39. Although technology can help detect and even forecast floods in a timely way, the information needs to be integrated into planning and policy for longer-term measures that reduce (a) the magnitude of the flood; and (b) vulnerability to a flood of any given magnitude.

### ***The Assault on Floods: Importance of Structural Protection***

40. Structural defenses are an indispensable tool in controlling flood damage, but with prohibitive costs and design limits they cannot offer full protection. Economic considerations argue for an emphasis towards the protection of the higher-value assets (for example urban areas, infrastructure), with greater importance given to building adaptability and flood resilience elsewhere. It is unlikely that floods can be totally subdued, so careful monitoring and planning of new settlements in these flood-prone areas must remain a priority for government authorities. This has been recognized in a number of reports<sup>9</sup>. There is a need to strengthen incentives and institutional systems for strategic asset management so that infrastructure investments are rendered more sustainable. This must be accompanied by changes in budget priorities to enhance community resilience to floods.

### ***The Accommodation of Floods: Importance of Nonstructural Resilience Building***

41. **Building flood resilience in agriculture.** Flood-resilient agriculture provides a way to insulate incomes against flood damage. Numerous pilots have been attempted with more rainfall-tolerant or short-duration varieties of certain crops to minimize flood-related losses. Though economically viable solutions remain elusive, these initiatives have potential and warrant continuing support and dissemination. A further shift in agriculture to the dry (rabi) season could be promoted by increasing access to irrigation in the dry months.
42. **Income diversification.** Income diversification provides a robust way of mitigating flood risks. The economic instruments that are relevant for encouraging income diversification for drought management – such as credit and insurance schemes linked to job diversification – are equally pertinent in the context of floods. The spread of self-help groups in Orissa provides a potential community base for launching such schemes.
43. **Adapting to floods.** There are already numerous and successful pilots in Orissa that aim to promote flood-based livelihoods. This is the quintessential form of flood adaptation. With the escalating demand for fish in India, aquaculture has considerable promise for unleashing rural growth. To further develop this potential there is a need to address supply chain obstacles to improve the marketing of a highly perishable commodity.
44. **Primacy of planning and zoning.** The combined pressures of rapid population growth, land scarcity, and intensifying flood risks call for strengthened and more careful planning and flood zoning. Land use planning and water management need to be combined into a synthesized plan with coordination between various departments and levels of

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<sup>9</sup> These include a World Bank report on the Northeast (World Bank 2007a) and numerous government documents including: Planning Commission 2002; Planning Commission 2001; and Shukla 1997.

government. A greater challenge is the implementation of a plan that would affect many interests and would need processes that involve public participation and stakeholder engagement.

## **F. Conclusions and Recommendations:**

45. With an ambitious growth target of 8% to 10% for the medium term, the Government of India recognizes that accelerating the productivity and sustainability of the agricultural sector will be a prerequisite to achieving its poverty reduction and development goals. The challenges are substantial and will call not only for the familiar investments in agriculture (such as price stability, connectivity, marketability and irrigation), but also for addressing the new and unprecedented risks emerging from climate change. This report demonstrates that climate change will continue to affect the lives and production systems of the millions in India who reside in high-risk rural areas, with a mounting human toll that falls disproportionately upon the poor. Consequently there is an urgent need for action now to avoid higher future costs and missed opportunities associated with a development path that compromises on climate risk management. Fostering a shared vision of the nature of climate change and the implications for the country's development prospects will be critical in catalyzing a policy commitment and also helping to integrate climate risks in development programs over the coming decades.
46. Fortunately, many of the policy actions required to build resilience to the impending changes in climate are wholly consistent with, and supportive of, current development objectives. Adaptation actions and investments provide a cost-effective way of addressing future climate risks. India has considerable technical and scientific expertise to understand, analyze and act upon climate risks. There are many encouraging initiatives and policy reforms that are moving in the right direction. These provide an ideal foundation for developing a comprehensive strategy for promoting adaptation to climate change and building systemic resilience in vulnerable communities. The table on the next page summarizes the policy actions and interventions suggested by the study.

Summary Recommendations for Adaptation <sup>10</sup>	Expected Outcomes
<p><b>Strengthening publicly accessible climate information systems/mechanisms and related management tools to match needs</b></p> <ul style="list-style-type: none"> <li>• Establish a climate information management system at central level for developing climate diagnostic and risk assessment tools with feedback mechanisms to end users. This would include: enhanced data collection systems at local level, hydrogeological data collection, information for groundwater management, and systems for improved detection and forecasting of floods.</li> <li>• Build climate risk assessment as a requirement for all relevant high value and long-lived infrastructure projects.</li> </ul>	<p>Baseline information for the integration of climate risks into policy, planning and investment decisions</p>
<p><b>Fostering climate-resilient reforms in agriculture and water resource management</b></p> <ul style="list-style-type: none"> <li>• Promote agricultural research and extension services towards systems and cultivars better suited to local climate and its variability</li> <li>• Targeted implementation and development of basin level water resource management integrating groundwater resources and applying instruments that deliver economic, social and legal incentives to increase water productivity, using participatory approaches where appropriate</li> </ul>	<p>Promote climate resilience of agriculture and reduce risks</p>
<p><b>Supporting the management of climate risks through economic mechanisms and instruments that promote efficiency</b></p> <ul style="list-style-type: none"> <li>• Explore new innovative financial instruments to promote income diversification, such as <ul style="list-style-type: none"> <li>➢ debt relief instruments coupled with credit for job diversification</li> <li>➢ debt relief coupled with insurance for new business risks</li> <li>➢ community-based risk financing schemes</li> </ul> </li> <li>• Introduce interim smart farm subsidies to encourage switch to more suitable and climate resilient cropping practices</li> </ul>	<p>Promote income and job diversification to reduce climate vulnerability</p>

<sup>10</sup>A number of recent projects supported by the World Bank have incorporated some elements of these recommendations in operations. Examples include: the Hydrology I (1995 – 2003), which focused on nine states including Andhra Pradesh, Maharashtra and Orissa), Hydrology II (2004 – 2010), which currently covers five new states. These include enhanced information systems as project components. The National Agriculture Innovation Project (2006 – 2012) and the National Agriculture Competitiveness Project (under preparation at the time of writing) recognize and build in elements of climate risk.

Summary Recommendations for Adaptation <sup>10</sup>	Expected Outcomes
<p data-bbox="245 296 886 373"><b>Improving institutional capacities and linkages among sectoral programs</b></p> <ul data-bbox="245 384 886 657" style="list-style-type: none"> <li data-bbox="245 384 886 548">• Establish capacities and strengthen role of central bodies in order to enhance coordination and operational linkages between departments at all levels of government. This could include establishing convergence committees for management of drought and flood.</li> <li data-bbox="245 558 886 657">• Integrate measures targeted towards management of future climate risks in the planning process including at the local level in district agriculture plans.<sup>11</sup></li> </ul>	<p data-bbox="894 296 1357 373">Promote policy synergy, identify needs and fill gaps.</p>

47. Moving ahead the first priority is to implement and mainstream the actions proposed in the table. In addition to this climate change will also have wider impacts that go beyond the flood- and drought- affected areas that are the focus of this report. Consequently future work will be needed to fill knowledge and policy gaps. Most notably further analytical work is needed in three priority areas of high development significance. First, the effects of climate change on the rice and grain production regions of India need to be assessed in considerably greater detail to determine impacts on food security goals and growth targets. Second, glacial melt remains the most dramatic threat to water supplies, food production and life-sustaining ecosystems in the country. Further work on the likely consequences remains an urgent priority. Similarly, the threats from sea level rise on coastal communities and cities is another important issue. On the policy front, agricultural trade distortions in the developed world increase climate risks and vulnerability in developing countries, suggesting the need for integrating adaptation and climate change issues in global trade negotiations.

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<sup>11</sup> GoI's National Development Council Resolution of May 2007 gives high priority to building comprehensive district agricultural plans.

# 1. Introduction, Context, and Objectives

## 1.1 Introduction

1. Adapting to climate variability and change has long been part of the human development agenda. Countries and dynasties have risen and fallen because of climate-related issues, particularly those associated with the scarcity of natural resources.<sup>12</sup> However, the current pace of change in the world's climate is unprecedented in recent human history and experiences accumulated to date are unlikely to be sufficient to provide a clear way forward. The challenges will be particularly acute in developing countries, where large and still growing populations live in high-risk areas or rely on rain-fed lands for their livelihoods.
2. Recognizing the significance of climate variability for growth and development, the Government of India has established a range of programs, policies, and institutions that have reduced the exposure of rural populations to climate risks. These long-standing programs have done much to unleash the development potential of agriculture. India has achieved its food security goals, produced a food surplus and developed much prosperous farming communities. Policies have also helped to build resilience to extreme climate events over the years: when floods or droughts descend, the numerous relief programs provide a safety net for the poor and assure a more rapid recovery. India's disaster management programs rank among the most comprehensive and effective in the world. However, accelerating climate change is expected to increase the frequency of extreme climate events in ways that are outside the realm of experience. Therefore, there is a need to address the costs associated with climate change, emphasizing complementary policies and actions that can integrate climate resilience and enhance the sustainability of rural livelihoods.
3. It is in this context that the Government of India has acknowledged the need to develop a strengthened information base to assist in planning and mitigating the consequences of increased climate variability and change. India's Ministry of Environment and Forests is preparing its second formal communication on climate change, reflecting its commitment to the United Nations Framework Convention on Climate Change (UNFCCC).<sup>13</sup> Further, in articulating its Eleventh Five Year Plan, the Planning Commission of India has recognized the need for proactive adaptation, particularly in the agricultural sector, which stands to be most affected by climate change (Planning Commission 2007). The objective of this study is to assist the Government of India in these endeavors. The study focuses on three particularly vulnerable states – Andhra Pradesh, Maharashtra, and Orissa. The main audience for the study is therefore the Government of India and the three state governments involved in the process.
4. The focus of this report is on vulnerable rural communities that face current and future risks from extreme and frequent droughts and floods. The study aims to develop the elements of an adaptation strategy that would assist in a better integration of climate risk

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<sup>12</sup> See Diamond 2005.

<sup>13</sup> This is the Second National Communication on Climate Change to the UNFCCC.

management into India’s development efforts. Scaling up the study approach and refining the methodological framework presented in this report, would allow India to assess, and where necessary act upon, the threats and opportunities that result from both existing and future climate variability in vulnerable areas. As a prelude to these issues, the report begins with a brief description of the current scientific consensus on climate change and the challenges in developing an adaptation strategy.

## 1.2 Context: Climate Variability, a Development Challenge

### 1.2.1 Climate Change and the Development Impacts

5. The Earth’s climate has changed and will continue to change in the foreseeable future, regardless of potential mitigation actions, with consequent impacts and implications for development and growth. On a global scale, the Earth’s climate has warmed, precipitation patterns have altered, sea levels have risen, and most nonpolar mountain glaciers are in retreat. Table 1.1 highlights the trends in global changes in the last decades. These observed changes in climate have, in large measure, been attributed to human activities that have increased atmospheric concentrations of greenhouse gases through the use of fossil fuels and large-scale changes in land use.
6. In the 1990s, climate-related disasters negatively affected about 2 billion people in developing nations, representing about 40% of the total population in the affected countries.<sup>14</sup> Looking forward, climate model projections indicate that there will be more frequent warm spells, heavier rainfall in some areas and more frequent droughts in others, tropical cyclones will gain in intensity, and extreme high tides will be more common. Climate models project that the next two decades will see a warming of about 0.2°C per decade.

**Table 1.1 Selected Indicators of Changes in the Earth’s Climate in the 20th and early 21st Century**

Indicator	Observed change(s) (typically after 1960)
Global mean surface temperature	Eleven of the last 12 years (1995–2006) rank among the warmest years in the record of global surface temperature. Increased by an average of 0.74°C (0.56°C to 0.92°C) during the 1906–2005 period.
Hot days/heat index	Increased in number and frequency over most land areas along with number of hot and warmer nights.
Cold days/frost days	Decreased in number and intensity over most land areas.
Heavy precipitation events	Increased over most land areas. Significantly increased in eastern parts of North and South America, northern Europe, and northern and central Asia. <sup>a</sup>
Frequency and severity of droughts	Increased summer drying and associated incidence of drought in some areas. In parts of Asia and Africa, the frequency and intensity of droughts have increased.
Global ocean average temperature	Increased to depths of at least 3,000 m (ocean has been absorbing about 80% of the heat added to the climate system).
Global mean sea level	Rose at an average rate of 1.8 mm (1.3 mm to 2.3 mm) per year between 1961

<sup>14</sup> EM-DAT: The International Disaster Data Base, <http://www.em-dat.net/>.

and 2003. The rate was faster between 1993 and 2003 at about 3.1 mm/year. The highest contribution to sea level rise has been from retreat of glaciers and melting of icecaps.

Mountain glaciers/  
snow cover Declined, on average, in both hemispheres.

a. This is a long-term trend observed from 1900–2005.

Source: IPCC 2007a.

7. Globally, a significant amount of modeling and research has been done by experts on the impacts of climate variability and change, with an emerging consensus that climate change will have a negative impact on development patterns and growth potential. The most recent findings of Working Group II of the Intergovernmental Panel on Climate Change (IPCC)<sup>15</sup> reinforce these broad conclusions and express “high confidence” (implying a probability of 90%) that the predictions of the major climate change models are consistent with observed warming at regional and global scales. Box 1.1 provides an overview of the key findings of the IPCC’s Working Group II report (IPCC 2007b).

### Box 1.1 Working Group II of IPCC: Summary of Rural Impacts

The report concludes with high confidence (90% probability) that “climate change is projected to impinge on the sustainable development of most developing countries of Asia, as it compounds the pressures placed on natural resources and the environment that are associated with rapid urbanization, industrialization, and economic development”.

#### South Asia

(concluded with medium to high confidence)<sup>a</sup>

- Crop yields could decrease up to 30% in central and South Asia by the mid-21st century.
- Endemic morbidity and mortality are expected to rise due to diarrheal disease primarily associated with floods and droughts. Increases in coastal water temperature would exacerbate the abundance and toxicity of cholera in South Asia.
- The largest number of people affected by sea level rise will be in the heavily populated large

#### Agriculture/food supply

(concluded with medium to high confidence)<sup>a</sup>

- At mid- to high latitudes, and where local average temperature increases anywhere from 1°C to 3°C, crop productivity is projected to increase slightly depending on the crop. Past that point, crops will see declines in yield in some regions.
- At lower latitudes, especially seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1–2°C), which would increase risk of hunger.

#### Freshwater resources

(concluded with either high or very high confidence)<sup>a</sup>

- By mid-century, while average river runoff and water availability at high latitudes and in some wet tropical areas are projected to increase by 10–40%, at mid-latitudes and in the dry tropics they will decrease by 10–30%. Some of these dry regions are already water-stressed areas.
- The extent of drought-affected areas will likely increase.
- Heavy precipitation events, which are very likely to increase in frequency, will augment flood

<sup>15</sup> The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization and the United Nations Environment Programme in 1988 to assess scientific, technical, and socioeconomic information relevant for the understanding of climate change, its potential impacts, and options for adaptation and mitigation. It comprises three Working Groups and a Task Force, which meet regularly to review the globally published scientific/technical literature on climate change and to issue official assessments on the situation.



- deltas of Asia (and Africa).
- Glacier melt in the Himalayas is projected to increase flooding and rock avalanches from destabilized slopes, and affect water resources within the next two to three decades. This will be followed by decreased river flows as glaciers recede.
- Freshwater availability, particularly in large river basins, is projected to decrease, which, along with population growth and increasing demand arising from higher standards of living, could adversely affect more than a billion people by 2050.
- Globally, the potential for food production is projected to go up as long as local average temperature rise does not exceed 3°C; above this, it is projected to decrease.
- Increases in the frequency of droughts and floods are projected to affect local production negatively, especially in subsistence sectors at low latitudes.
- In the course of the century, water supplies stored in glaciers and snow coverage are projected to decline. This will reduce water availability in regions supplied by meltwater from major mountain ranges, which are home to more than 1 billion people.
- Sea level rise is expected to exacerbate inundation, storm surge, erosion, and other coastal hazards, thus threatening vital infrastructure, settlements, and facilities that support the livelihood of island communities.

a. Very high confidence implies that the statement has at least a 9 out of 10 chance of being correct; high confidence implies an 8 out of 10 chance; and medium confidence a 5 out of 10 chance.

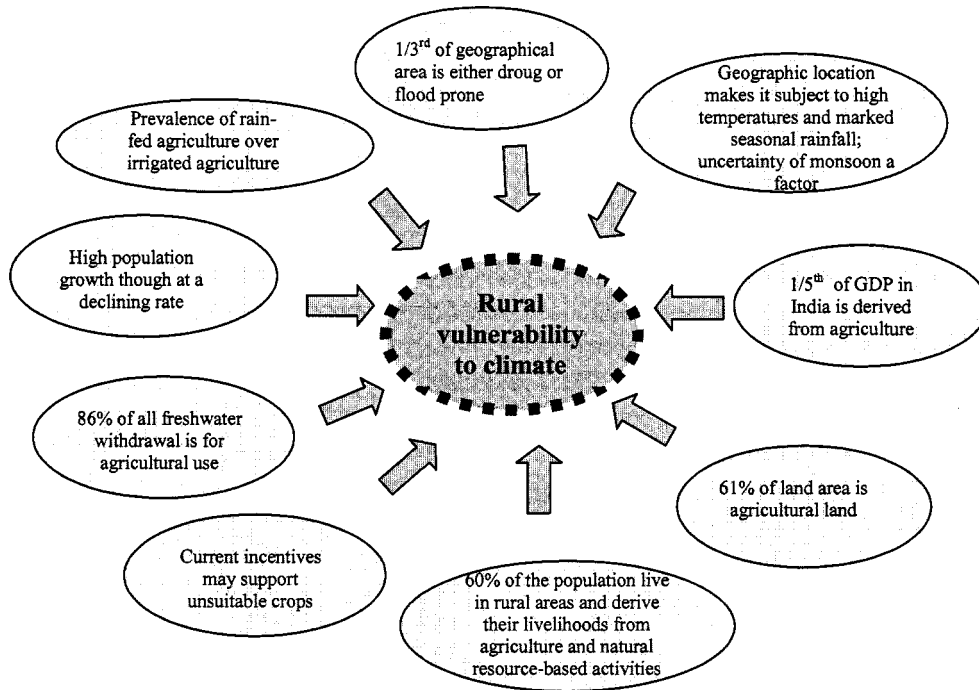
### 1.2.2 Local Variability: A Challenge for Adaptation in India

8. For India, climate change poses particular challenges due to its vast geographic diversity. Climate projections for India suggest that impacts are likely to be varied and heterogeneous, with some regions experiencing more intense rainfall and flood risks, while others encounter sparser rainfall and prolonged droughts (see chapter 2 for details).<sup>16</sup> Even though a vast body of knowledge exists on the impacts of climate variability and change, little is known about the impacts at the meso (district/subdistrict) and micro (revenue village) levels or about specific adaptation strategies at the local levels that can diminish the risks associated with climate variability and change.
9. There is growing recognition that the impact of climate change is highly disaggregated and will vary across sectors, locations, and populations. In India, the climate vulnerability of agriculture and livelihoods depends on a suite of interconnected factors that vary locally, including (a) physical factors such as differences in soil conditions, water supplies and infrastructure; (b) economic factors such as local prices and technology that determine cropping patterns and farm management strategies; and (c) policies (for example taxes, price support, subsidies) and institutions (figure 1.1). The implication for a country as vast and varied as India is that broad generalizations on ways to promote adaptation will be misleading if they neglect local conditions. Consequently, there can be no “one-size-fits-all” approach to developing a climate risk management strategy; approaches will need to be tailored to fit local conditions.

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<sup>16</sup> The climate projections are summarized in India’s official Initial National Communication on Climate Change to the UNFCCC.

**Figure 1.1 Elements of Vulnerability to Climate in Rural Areas of India**



### 1.2.3 Preparing for an Adaptation Strategy

- Adaptation to climate change is analogous to many other forms of risk management. It requires an assessment of possible threats and opportunities arising from climate variability and, where necessary, incorporating these into policy through the appropriate institutional mechanisms. This calls for local-level information on current and future climate vulnerabilities to identify risks and potential impacts. However, the provision of better information is just the first step in promoting more climate-resilient outcomes. For an adaptation strategy to be effective, it must result in climate factors being integrated as a normal part of policy making and risk management. This requires systems to translate scientific results into practical policy information and an institutional framework that allows for the integration and mainstreaming of climate risks into policy making where this is relevant. This report strengthens the knowledge base to facilitate the development of a strategy to build climate resilience in agriculture and, more broadly, to support India's development pathway.

## 1.3 Objectives, Process, and Approach

### 1.3.1 Objectives

- The overarching objective of this study is to mainstream and integrate climate risk management into development policy by enhancing the understanding of climate and

climate-related issues in the agricultural sector. The scope of the study and choice of sector was dictated by government priorities, which indicated the need to assess the climate risks in regions where vulnerability was high and potentially increasing. The recommended focus was on areas facing greater exposure to droughts and floods. The study responds to the following specific needs that were determined in consultation with the Government of India:

- To generate better information and understanding on the current coping and climate risk management strategies in response to droughts and floods;
- To understand government responses and their effectiveness in supporting both coping and adaptation measures;
- To develop and demonstrate the use of a climate modeling framework to identify future climate risks in selected areas of India;
- To use this information to assist in identifying the key elements of an adaptation plan that can help improve climate resilience and adaptive capacity in selected areas of India;
- To further raise awareness of the problem and effective solutions among all actors and stakeholders.

### **1.3.2 Approach**

12. To achieve these objectives the study has adopted multiple approaches:
  - (a) First, it gathers information from selected areas of India on current coping and adaptation measures to learn lessons from the past and present to understand (i) how rural communities cope with and build resilience to extreme climate events; and (ii) to identify the key determinants of vulnerabilities to climate risks among farmers.
  - (b) This is complemented by a review of governmental programs and institutions and climate-related risk management strategies in the case study states. The review identifies policy and administrative gaps and strengths in addressing climate risks and suggests ways to complement existing approaches to deal more effectively with climate risks.
  - (c) Looking forward, the study builds a modeling framework to assess future climate risks and vulnerabilities in the study regions.
  - (d) Finally, the study synthesizes the results of the modeling framework and the other components to suggest a framework for policy options and actions to address adaptation in India.
13. The assessment is focused on regions in the states of Andhra Pradesh, Maharashtra, and Orissa, where a countrywide vulnerability assessment found climate risks of droughts or floods to be high and increasing (appendix A). The case study areas are typical of many parts of Indian agriculture at the edge of climate tolerance limits, but cannot be representative of the vast geographic and climatic variability across the entire country. For example, other important areas of vulnerability include the fragile mountain

ecosystems in the Himalayan ranges and the Western Ghats, coastal zones, and urban areas of India.

### **1.3.3 Process**

14. The primary counterpart in the study has been the Ministry of Environment and Forests of the Government of India. The scope and objectives were developed in close consultation with the Ministry and a wider cross-section of other concerned ministries and departments in both the central government and in selected states. This included consultation in Andhra Pradesh, Maharashtra, and Orissa with relevant departments. A panel of scientific experts from academic, policy, and research institutions in India provided guidance on the study approach and acted as a quality filter to review the technical results. This was complemented by extensive discussions and workshops at the state level with various government agencies, culminating in an international conference on adaptation to climate variability and change held in New Delhi in December 2006 (see appendix C for details).
15. A key feature of this study has been extensive consultations in the states on the methodology and emerging findings. The focus states for deepening the engagement were Maharashtra and Orissa, as the Bank's involvement in Andhra Pradesh was recognized to be on strong grounds through a separate pilot initiative on drought adaptation. As a result of the consultations, the state governments of Maharashtra and Orissa requested rapid assessments of government programs focused on climate-related issues in general, and drought and flood relief management in particular, which were supported by the study. The Department of Water Resources, Government of Orissa, and the Department of Rural Development and Water Conservation, Government of Maharashtra, provided full cooperation and support to these assessments. Further, the study developed a conceptual framework for a drought adaptation program in collaboration with senior officials from the Department of Rural Development and Water Conservation as an example of an operational program on adaptation. Appendix F presents the conceptual framework for a drought adaptation initiative.

### **1.3.4 Operational Context**

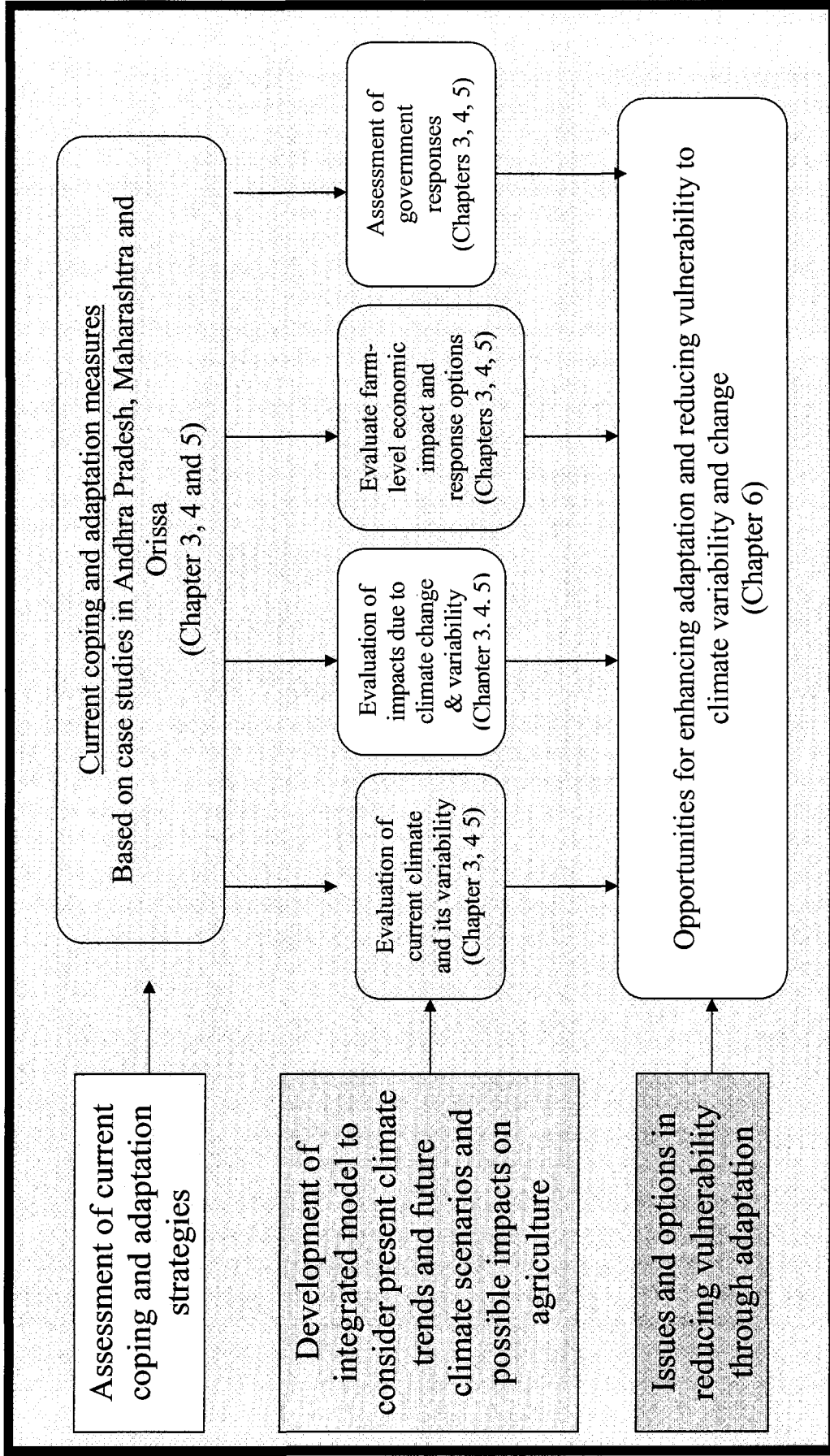
16. The report is part of a wider program of engagement on climate change being undertaken by the World Bank. Recognizing the development significance of promoting adaptation to climate change, a significant portfolio of activities are planned and under way, especially in Latin America, Africa and China. A bulk of the portfolio focuses on technical assistance and knowledge management activities. In Africa, pilot projects to mainstream adaptation into the Bank operations are being developed in Burkina Faso, Kenya, and Tanzania, while in China an adaptation project associated with the irrigation sector is under preparation. In Latin America, a pilot project in coastal areas of some islands in the Caribbean is being implemented and another pilot, which aims to address glacier retreat in the Andean region, is under preparation. This study is most closely related to and extends the modeling framework and approach developed in an earlier study on drought adaptation strategies for Andhra Pradesh, India (World Bank 2006f). The Andhra Pradesh study has led to a pilot drought adaptation initiative in Andhra Pradesh, which is testing innovative approaches related to farming systems and

management of natural resources to promote greater resilience in arid conditions (see chapter 3 for details).

### **1.3.5 Report Structure**

17. This report is arranged in six chapters. Figure 1.2 summarizes the study framework and organization of the report. Chapter 2 provides a snapshot of India's current climate and a review of climate modeling projections of future changes. It also describes the study methodology and design framework used for the analysis. Chapters 3 and 4 present detailed study results for droughts in Andhra Pradesh and Maharashtra, respectively, while chapter 5 presents study results for two flood-prone districts in Orissa. The final chapter summarizes the key findings of this work and proposes some opportunities for action to strengthen adaptation measures.

Figure 1.2 Study Framework



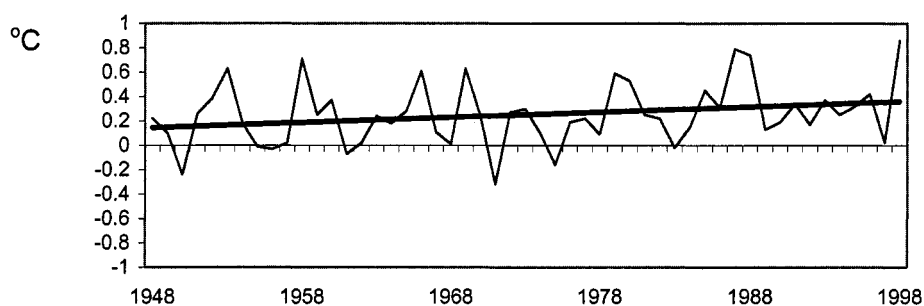
## 2. India's Climate: Background, Trends, and Projection Tools

1. Has India's climate changed? What do climate projections suggest about future shifts in the country's climate and what impacts might these have on agriculture? This chapter attempts to answer these fundamental questions. It begins with an overview of India's climate, which establishes the baseline against which future changes are compared. It proceeds to highlight the possible impacts of climate change on the agricultural sector, based on the scientific literature. This provides the context for describing the methodological approach developed in this study and its contribution to a greater understanding of climate change. The study methodology is presented, supplemented by a description of technical issues in appendices A and G.

### 2.1 India's Current Climate, Its Variability, and Trends

2. **Temperature changes.** Much of India is warming. The mean annual surface-air temperature has risen by an average of  $0.4^{\circ}\text{C}$  in the last 50 years (Rupa Kumar et al. 2002). Figure 2.1 shows the observed changes in mean temperature, which exhibit considerable annual variation, with an upward trend.

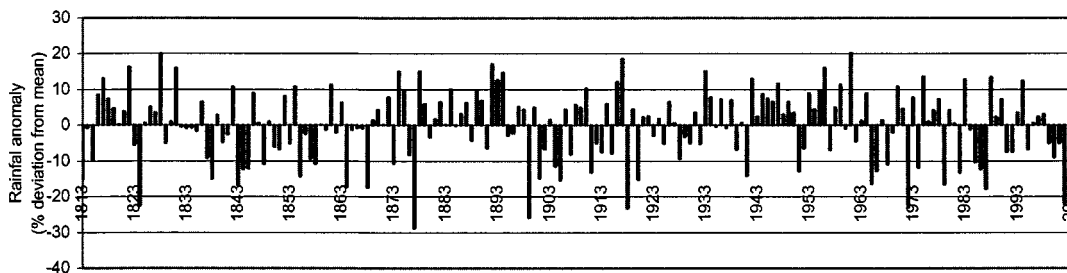
**Figure 2.1 All-India Average Surface Temperature 1948–1998**



Source: Data from Indian Institute of Tropical Meteorology, <http://www.tropmet.res.in/>

3. **Variable rainfall patterns.** The most important climatic feature of the Indian subcontinent is the summer monsoon. As much as 70% of the annual aggregate precipitation is received in a short period from June to September during the southwest monsoon. Fragments of the southeastern states receive rainfall during the winter months. Meteorological records confirm that the monsoon exhibits considerable random (and unexplained) variation, but nevertheless has a relatively stable core (figure 2.2).

**Figure 2.2 Variation of All-India Monsoon Rainfall 1813–2003**



*Source:* Data up to 2000 from Indian Institute of Tropical Meteorology, <http://www.tropmet.res.in/>. Subsequent data from newspaper reports of rainfall.

4. **Higher frequency of droughts.** Because of the dominance of the monsoon, India's climate and weather exhibit the heaviest seasonal concentration of precipitation in the world. Almost 20% of India's total land area is drought prone. The frequency of droughts has been increasing over time: there were six droughts between 1900 and 1950 compared to 12 in the following 50 years, and 3 droughts have already occurred since the beginning of the 21st century.<sup>17</sup> Escalating levels of ecological degradation, resulting from such factors as deforestation, receding water tables and overgrazing have increased the vulnerability of ecosystems to drought.
5. **Increased frequency of floods.** The Ganges-Brahmaputra and Indus river systems are highly prone to flooding. The magnitude of flooding has increased in recent decades, from approximately 19 million hectares affected 50 years ago to 40 million hectares in 2003, about 12% of India's geographic area. Floods have occurred almost every year since 1980, and their extent substantially increased in 2003 due to widespread rains, which affected even some of the most drought-prone areas. In recent years an increase in population in vulnerable areas, inadequate drainage and deforestation have all contributed to the rise in flood damage.

## 2.2 Future Climate Change Projections

6. What might the future hold for India's climate? Projecting future climate is a complex and uncertain exercise. The global models that generate projections have technical limitations, such as the level of resolution and data inputs. The inherently uncertain nature of socioeconomic scenarios and responses adds to the challenges of projecting future greenhouse gas emissions and the associated climate impacts. Nevertheless, projections are needed to assess possible future hazards, risks, and opportunities, without which it would be impossible to develop a coherent climate risk management program.
7. The most widely quoted projections for climate change in India are those derived from the Hadley Centre regional climate model (HadRM2), which provides simulated

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<sup>17</sup> EM-DAT: The OFDA/CRED International Disaster Database, <http://www.em-dat.net>, see also Winrock 2005.



outcomes for a range of scenarios. Projections are available for the period 2041–2060 and suggest:<sup>18</sup>

- An increase in average surface temperatures across all seasons, with an increase of 2°C to 4°C south of latitude 25°, and in excess of 4°C in the northern region;
- More variable precipitation during the monsoon season, with a possible decrease towards the west and an increase over the Indian Ocean and the Western Ghats;
- An overall increase in rainfall intensity by 1–4 millimeters per day, accompanied by an increase in the highest one-day rainfall. However, given the country's varied geography, some parts of northwest India could also witness a decrease in extreme rainfall;
- Glacial retreat caused by warming, though the extent remains uncertain;
- A rise in sea level, which would threaten economic assets, coastal cities, and large coast-dwelling populations.

## 2.3 Methodology of the Study

### 2.3.1 Approaches to Measuring Climate Change Impacts on Crop Yields

8. Given the scale and magnitude of these changes, there are concerns that climate change could compromise agricultural productivity in India, threaten food security goals and undermine development efforts. The unease is not without reason: a large and growing rural population live in high-risk areas, agricultural output and water supplies depend on the monsoons, and much farming is on rain-fed lands. Consequently there have been numerous attempts to assess possible impacts of climate variability and change on agricultural productivity.
9. Measuring the impacts of climate change on agriculture is a complex and challenging exercise as there is much uncertainty in moving from climate change to physical impacts on crops and market responses. Two approaches have evolved to determine crop responses to climate change: statistical methods (termed the Ricardian approach) and agronomic crop growth models.

#### *Statistical assessments*

10. The statistical approach examines how farmers in a certain climate scenario perform relative to similar farmers in different climate scenarios. This generates estimates of farm performance across different climate zones that can be used to infer the consequences of climate change. Table 2.1 summarizes the results from the statistical studies of the impacts of climate change in India. These suggest that a temperature increase of 2°C would generate a modest loss of between 3% and 9% of current agricultural income. But for a 3°C rise in temperature, the studies predict a wide range of losses from 3% to 26% of income. These estimates are broad and approximate averages, based on the assumption that temperature and rainfall impacts are uniformly distributed across the country. Furthermore, while statistical approaches capture current and observed farm-level

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<sup>18</sup> Note that the dates do not correspond to particular calendar years, but represent probable climate events that are predicted to emerge within that period.

responses to different climate regimes, they cannot draw inferences on future events and responses.

**Table 2.1 Results of Ricardian Assessments of Climate Change Impacts on Crops in India**

Temperature change	% change in net agricultural revenue per hectare	Source
2°C	-3 to -6	Sanghi, Mendelsohn, and Dinar 1998
2°C	-7 to -9	Kumar and Parikh 1998
2°C	-8	Kumar and Parikh 2001
3.5°C	-20 to -26	Kumar and Parikh 1998
3.5°C	-3 to -8	Sanghi, Mendelsohn, and Dinar 1998

***Agronomic models***

11. Agronomic approaches use a crop model calibrated from controlled experiments that are designed to simulate climate events and different management regimes. Typically these models assume that farmers are “myopic”, in that they do not respond to predictably changing conditions, nor do they learn from past experiences. As a result, estimates of the costs of adapting to climate change are exaggerated. This is a weakness in past studies that have used agronomic models to estimate agricultural impacts of climate change in India. Table 2.2 provides a summary of the key studies. Despite a wide range of simulated impacts the results exhibit a consistent pattern of responses. The assessments show that:
  - Crop yields, are influenced by the interplay of three key climate parameters: (a) the level of carbon dioxide (termed carbon fertilization); (b) the temperature change; and (c) the level and distribution of precipitation. For most crops, elevated levels of carbon dioxide and higher precipitation rates (except where rainfall is excessive) promote crop growth. Since current temperatures throughout much of India are high, these beneficial effects are offset by further warming.
  - The overall impact of climate change on crop yields depends on the baseline conditions of these parameters and the balance of these conflicting forces. In arid locations where crops already suffer heat stress, a small increase in average temperatures can lead to a dramatic decline in yields. The same temperature change in a cooler climate zone could produce an increase in yields.
12. The clear implication is that broad generalizations of crop responses to climate change will be misleading if they do not take account of location-specific baseline climate and soil conditions.

**Table 2.2 Agronomic Assessments of Climate Change Impacts on Agriculture in India (by Source and Region)**

Crop	Yield change (%)	Scenario	Model
<b>Lal et al. 1998: northwest India</b>			
Rice	0	+2°C; doubling CO <sub>2</sub>	CERES-Rice
	-20	+2°C; doubling CO <sub>2</sub> ; water shortage	
Wheat	0	+3°C; doubling CO <sub>2</sub>	CERES-Wheat
<b>Lal et al. 1999: Madhya Pradesh</b>			
Soybean	From -4 to 0	+3°C; doubling CO <sub>2</sub> ; -10% daily rainfall	CROPGRO
<b>Saseendran et al. 2000: Kerala</b>			
Rice	-6	+1.5°C	CERES-Rice
	+12	+1.5°C; +2 mm/day rainfall; 460 ppm CO <sub>2</sub>	
<b>Aggarwal and Mall 2002: parts of northern, eastern, southern, and western India<sup>a</sup></b>			
Rice	From +3.5 to +4.3 (2010) From +13.8 to +22.3 (2070)	Optimistic IPCC scenarios: +0.1°C, 416 ppm CO <sub>2</sub> ; +0.4°C, 755 ppm CO <sub>2</sub> . Both at current crop management level <sup>b</sup>	CERES-Rice
	From +1.3 to +1.9 (2010) From +3.6 to +9 (2070)	Pessimistic IPCC scenarios: +0.3°C, 397 ppm CO <sub>2</sub> ; +2°C, 605 ppm CO <sub>2</sub> . Both at current crop management level	
	From +5.1 to +7.4 (2010) From +16.6 to +25.7 (2070)	Optimistic IPCC scenarios	ORYZAIN
	From +2.5 to +4.1 (2010) From +6.1 to +16.8 (2070)	Pessimistic IPCC scenarios	
<b>Kalra et al. 2007: DEFRA study</b>			
Rice	-5 to -8	+1°C; no change in CO <sub>2</sub>	CERES-Rice
	-10 to -16	+2°C; no change in CO <sub>2</sub>	
	-21 to -30	+4°C	
Maize	-10 to -30	+1°C to +4°C; 350 ppm CO <sub>2</sub>	CERES-Maize
Jowar	-7	+1°C	CERES-Sorghum
	-12	+2°C <sup>c</sup>	
<b>World Bank 2006f</b>			
Rice	-9	Max. temp. +2°C; min. temp. +4°C; annual rainy days -5%; 550 ppm CO <sub>2</sub>	EPIC
Groundnut	+2		
Jowar	+3		
Sunflower	+10		
Maize	+3		
Rice	-8	Max. temp. +2°C; min. temp. +4°C; annual rainy days -5%; 550 ppm CO <sub>2</sub> ; cumulative monsoon rainfall (Jun-Sept) -10%	
Groundnut	0		
Jowar	0		
Sunflower	+9		
Maize	0		

a. Margin of error can be as much as 32%, depending on the uncertainty in climate change scenario and other factors. Sensitivity analyses were run for increases in temperature level of nutrients fed to the crops, and variations in CO<sub>2</sub> levels. These showed that, as long as temperature remains unchanged and CO<sub>2</sub> levels increase, yields will increase; however, with temperature increases, this CO<sub>2</sub> effect is nullified for increases in temperature as low as 0.9°C.

b. "Current crop management level" assumes no change in current nutrient application and irrigation.

c. Further increases in temperature resulted always in lower yields irrespective of increases in CO<sub>2</sub>. The beneficial effect of additional CO<sub>2</sub> up to 700 ppm was nullified by an increase of only 0.9°C.

### 2.3.2 Methodology for Climate Impact Analysis

13. The approach developed in this study incorporates the lessons from these studies and advances the approach to assessing climate change impacts. The agronomic models for India provide a plausible description of crop responses to climate change. However, they fail to capture adaptive responses to climate change at the farm level. Experience shows that farmers can and do adapt to climate variations, which allows them to moderate some of the adverse effects. Consequently, crop losses from past studies that have used agronomic models are likely to be overestimated. The framework developed in this study addresses this problem by linking a farm economic model to the agronomic model to estimate economically prudent responses of farmers to changing climate conditions. Recognizing the country's enormous heterogeneity and the varied climate impacts, it focuses on selected vulnerable areas.
14. **Study areas.** Since droughts and floods are predicted to increase in frequency and intensity, the focus is on districts in drought-affected areas of the Pennar basin in Andhra Pradesh, the Godavari basin in Maharashtra, and the flood-prone area of the lower Mahanadi basin in Orissa. The choice of districts and blocks was determined through a risk mapping exercise (see appendix B), which identified areas where agriculture is already stressed and where current trends indicate worsening conditions. The selection of villages was based on a purposive sampling approach aimed at capturing the impacts of irrigation coverage and infrastructure on adaptive capacity<sup>19</sup>. To assure a representative coverage of the population, household surveys were conducted on samples of households stratified across landholding categories. This approach differs from the Ricardian studies that compare agricultural productivity across a wide spectrum of climate zones. The focus here is on understanding adaptive responses in areas already stressed by droughts or floods. Therefore, the results complement other approaches.
15. **Learning from the past and present.** The study begins by exploring current coping practices and identifying factors that influence the vulnerability of farmers to climate risks in the selected study areas. It uses data from household surveys to explore how farmers respond to current climate risks by comparing outcomes in a "normal" year with those in a drought or flood year. The statistical exercise is useful in illuminating the factors that help communities insulate livelihoods from climate risks and the effectiveness of different coping mechanisms. Complementing the statistical assessment is a review of governmental programs and institutions for managing climate risks. The review identifies the strengths and gaps in addressing climate risks and suggests ways to enhance the synergies and effectiveness of government programs.
16. **Looking to the future.** With its focus on the past, the above approach is limiting, since many of the predicted impacts of climate change are expected to differ in kind and magnitude from current climate patterns. Accordingly, an integrated modeling system (IMS) was developed to generate climate scenarios and assess the impacts on agriculture. The results of the IMS exercise, in conjunction with the above assessments, assist in the development of a framework of appropriate adaptation responses and policies to build climate resilience.

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<sup>19</sup> The study design has intended to take into account two contrasting districts per state and selected villages accordingly from these districts.

17. **Details of modeling using the IMS.** The IMS is based on the two most widely used IPCC scenarios in India, termed A2 and B2 (box 2.1). The former describes a pessimistic world with higher levels of greenhouse gases and more aggressive climate impacts, while the latter depicts a more benign scenario with milder climate change. The system architecture is presented in figure 2.3. The system comprises the following linked subcomponents:

- A regional climate model (HadRM3) provides results for a spatial resolution of 50 km x 50 km and generates climate projections from 2070 to 2100 at the regional level;
- A stochastic weather generator projects these climate impacts to the local (block/mandal) level;
- A hydrological water resource model (SWAT 2000) evaluates the effects of climate change on water resources;
- An agronomic model (EPIC) uses these estimates of temperature, precipitation, and soil moisture and predicts crop yields;
- A custom-built farm-level economic model assesses the financial impacts of climate change on farmers and determines effective adaptation strategies.

**Box 2.1 Emission Scenarios Selected for the Study**

In order to predict future climate change, a projection of how anthropogenic emissions of greenhouse gases (and other constituents) will change in the future is needed. A range of emission scenarios has been developed by the IPCC). In this study, A2 and B2 were selected to run projections<sup>20</sup>. The conditions assumed in the scenarios are as follows: (see the table below for a summary of the main assumptions in each scenario):

- **A2** describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other scenarios.
- **B2** describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with a continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 scenarios. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

**Main Assumptions of Climate Change Scenarios A2 and B2**

Variable	Population (billion)		World GDP (10 <sup>12</sup> 1990 USD/year)		Annual CO <sub>2</sub> (gigatonnes/year)		Cumulative CO <sub>2</sub> (gigatonnes of carbon) (1990 -2100)
	2050	2100	2050	2100	2050	2100	
<b>Scenario</b>							
A2	11.3	15.1	82	243	17.4	29.1	1,862
B2	9.3	10.4	110	235	11	13.3	1,164

Source: IPCC 1998.

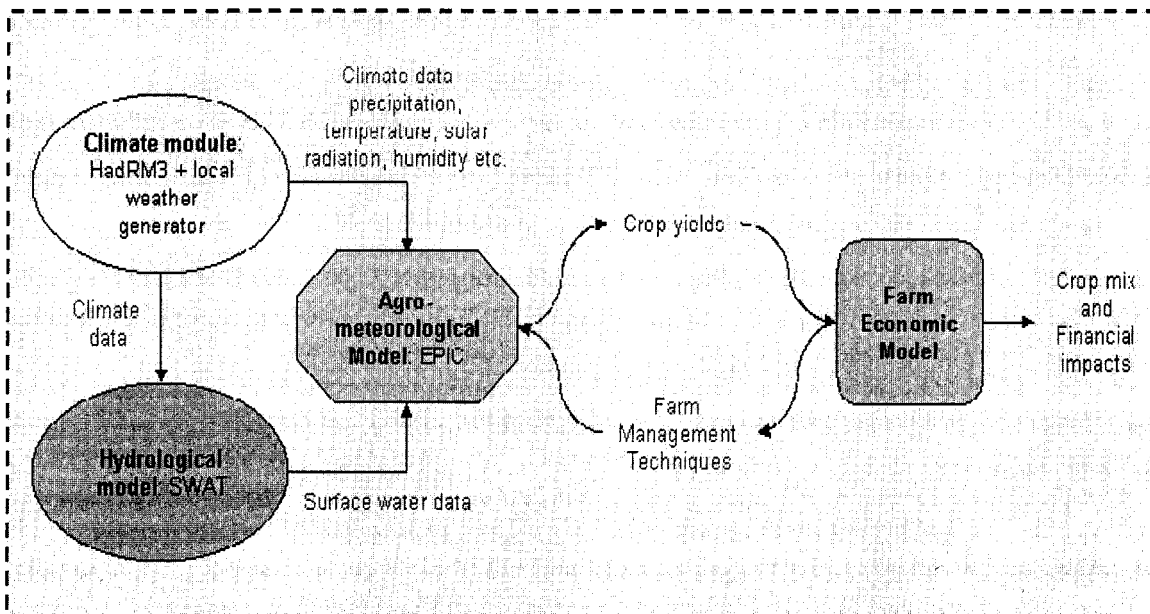
18. The climate projections are from the third-generation Hadley Centre model (HadRM3), produced at a 50-kilometer resolution, and are the most recent simulations available for India. The stochastic weather generator filters these coarse projections down to the block level, while preserving the statistical properties of the regional data. The water resource

<sup>20</sup> Being the first of its kind study for India for which a methodology had to be developed, it was decided to focus on the two future scenarios prescribed by IPCC.

model (SWAT 2000) is widely used in India and simulates the hydrological cycle at a daily time step. It projects runoff and seepage at the basin and subbasin levels. These modules feed data input to the agronomic model (EPIC). Operational links are established through which surface water flows, derived using the SWAT model, are used as inputs for soil moisture in the EPIC crop simulation model.

19. From the wide suite of agronomic models that have been developed, the EPIC model was chosen because of its previous use in one of the study areas (Andhra Pradesh) and presumed suitability for capturing climatic impacts on crop yields in Indian conditions. EPIC is a field-level simulation model that operates on a daily time step to simulate crop growth and yield.<sup>21</sup> For any given set of management inputs (for example fertilizer, irrigation, tillage, date of sowing) and climate events, EPIC predicts yields.
20. EPIC outputs interact with the economic model. The development of a farm-level economic model represents a major innovation of this study. As in all economic assessments, farmers are presumed rational, favoring more lucrative and safer options over less profitable and riskier alternatives. Box 2.2 provides a brief description of the structure of the economic model and full technical details are in appendix H.

**Figure 2.3 IMS System Architecture**



<sup>21</sup> The crop growth model uses radiation-use efficiency in calculating photosynthetic production of biomass. The potential is adjusted daily for stress from water, temperature, nutrients (nitrogen and phosphorous), aeration, and radiation. Crop yields are estimated using the harvest index concept. Harvest index increases as a nonlinear function of heat units from zero at the planting stage to the maximum value at maturity. The harvest index may be reduced by high temperature, low solar radiation, or water stress during critical crop stages.

### **Box 2.2 Structure of the Farm Economic Model**

The economic model replicates the sequence of farming events incorporated in EPIC. It is based on the following structure:

- At the start of the season a farmer determines the cropping mix and the area devoted to each crop. This decision is based on the expected profits from each crop, which depends on prices, input costs, and yields.
- The universe of available crops was determined by resource availability and the data requirements to calibrate the agronomic models. It includes the major crops currently sown in each area. Farmers operate under a series of technical and economic constraints (such as water availability and prices). Once planting decisions have been made, seeding takes place and over time the weather pattern unfolds.
- As in all economic assessments it is presumed that farmers maximize their expected payoffs from cultivation, subject to constraints and attitudes to risk (see below).
- Farmer's respond to the actual weather by adopting management techniques that maximize their payoffs. For instance, in dry years it may be necessary to irrigate some crops (rice) more intensively and reduce water allocations for other crops. If this occurs, it will also be necessary to adjust fertilization rates. The EPIC module predicts yields under different management regimes, while the corresponding economic module computes the associated payoffs.
- Since not all farmers are identical, the analysis distinguishes between three types of cultivators, depending on the availability of land. Subsistence farmers are classified as those with landholdings up to 2 hectares. They are driven by subsistence needs and the imperative to survive takes precedence over commercial considerations. This is modeled as a safety-first constraint, where the primary objective is to earn a threshold amount of Rs 12,000, which is the subsistence threshold defined in India's National Sample Survey. Medium farmers have holdings between 2 and 3.5 hectares and large farmers have holdings in excess of 4.5 hectares. The farmers attempt to maximize the commercial payoffs from farming.
- There are further complexities in assessing how individuals might respond to climate change. Since planting decisions are taken before actual weather is observed, expectations and attitudes to risk are important in determining management techniques on the farm. Large farmers have greater assets that can act as a poverty buffer, so may have less to lose if they gamble on the promise of good rains. Conversely, the poor with fewer assets are more likely to be risk averse, preferring a more secure but lower income, to a riskier but higher rate of return. Hence, attitudes to risk will vary with asset holdings, wealth, and preferences.
- The model allows for different risk-taking behavior by incorporating a risk aversion parameter using the mean-variance method. This implies that more risk-averse farmers incur a greater penalty for choosing options with higher losses (down-side risks), so they select safer strategies even if this means sacrificing some income in a good year.
- The model is solved by backward induction. The second stage of cropping techniques is solved first, yielding optimum payoffs for each crop. Given this information, crop choices and planting areas are determined.
- Simulations are also performed for different climate expectations formation methods including rational expectations (based on the actual distribution of yields) and adaptive expectations (based on learning).

21. **Qualifications.** The IMS system provides a powerful tool for developing alternative climate and economic scenarios that generate information on physical responses of crops and the economic consequences at the farm level. But as with all modeling exercises there are well-known limitations and caveats that need to be recognized when the information is used to guide decisions.
22. **Scenarios are not forecasts.** The model outputs are outcomes of assumed scenarios rather than precise predictions of the future. Unforeseen changes may occur in input prices, technology, land, and labor markets. To predict changes in crop prices requires a global model of demand and supply for each crop and information on the likely trade interventions that might apply in the future. Unfortunately, global crop models generate poor forecasts, so there is no robust and reliable way of determining crop price changes. All of this suggests considerable uncertainty in developing projections and the need for caution when generating and interpreting them<sup>22</sup>.
23. However, uncertainty need not render the assessments useless and can be addressed in various ways. Two approaches were followed in this study. First, sensitivity analysis was performed to test the robustness of various results. This was done for most economic variables (prices, risk aversion parameters, and expectations mechanisms) by testing the limits beyond which the results change significantly. A second more important approach was to create the model in a user-friendly (Excel) interface that would allow other analysts to develop and simulate different economic scenarios.
24. **Assumptions about water.** The hydrological model used in the study includes a simulation of the groundwater component in the hydrological cycle. However, the model makes the assumption that the vegetation cover (including agricultural crops in the winter (rabi) and summer (kharif) seasons) in regions that are not covered by surface irrigation is maintained, and implicitly relies on groundwater storage. Groundwater abstraction is not explicitly modeled. Therefore, the model is likely to underestimate the negative impact of decreasing groundwater availability on the agricultural crop cover, especially in areas where groundwater abstraction exceeds the average annual infiltration.
25. Modeling necessarily entails simplifications that are imposed either by data availability or technical limitations. In this context, assumptions relating to the treatment of irrigation in the model warrant discussion. Water availability for crops in EPIC (the agronomic model) comes from three sources: rainfall as determined by the weather generator; runoff and percolation as simulated by the hydrological model; and an exogenous (predetermined) supply of irrigation water. The agronomic model does not distinguish between the sources of irrigation water, such as groundwater or surface water. In the context of projecting plant growth this is, arguably, a plausible simplification, since crop yields depend on the level of soil moisture rather than the source from which moisture is obtained. But in the context of economics and long-term sustainability, the sources of irrigation do matter. Overabstraction of groundwater could jeopardize water availability and thus lead to different cropping patterns and crop yields. These links have not been developed in the model due to the high complexity and scale of the issues. Accommodating these concerns is beyond the scope of current modeling capacity and must await further understanding.

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<sup>22</sup> At a global and national scale climate change will affect production levels and prices. Determining these impacts is beyond the scope of this report and this is left to future work.



26. **Assumptions about crop mix:** The agronomic analysis is based on the assumption that the crop-mix remains the same and only their proportions may vary under different climate scenarios. This is a limitation caused by the difficulty and inordinate expense of parameterizing the agronomic model and shared in much of the literature. It was not possible within the resource envelope to incorporate more crops in the analysis and hence the focus was on crops that dominate in the chosen areas.
27. **Need for information on climate risks.** As argued in this chapter, the model projections should be interpreted with caution and viewed as indications of the possible direction and magnitude of changes, rather than as precise forecasts. Despite these uncertainties, policy makers are compelled to respond to climate risks and must make routine decisions on matters that will be affected by future climate events, such as investment in infrastructure. Modeling exercises provide the only known way to generate some of the information that is needed to assess risks and policy impacts, and thereby improve decision making.

### **3. Climate Variability and Change: A Case Study in Drought-Prone Andhra Pradesh**

#### **3.1 Introduction and Background**

1. Situated in southern India, Andhra Pradesh is the fifth largest state in the country, both in terms of geography and population. With much of the state lying in the arid parts of the Indian peninsula, the specter of drought is a recurring threat to rural livelihoods. Surface water resources are limited, with modest scope for further increase in supplies. High levels of groundwater abstraction, coupled with low and variable rainfall, have led to sharp declines in the water table in most parts of the state. Consequently, water availability has emerged as one of the binding constraints on farming systems and associated livelihoods in the drought-prone areas.
2. The government of Andhra Pradesh has an impressive array of programs that tackle drought exposure and deficient rainfall in the state. These range from short-term relief schemes to strategic initiatives that include watershed area programs, crop diversification incentives, and water conservation schemes. Yet the human impacts of drought continue to be devastating for affected rural communities, suggesting that the low-hanging fruits of drought policy have been harvested, leaving more complex and intractable problems that take time to address (World Bank 2006f).<sup>23</sup> Climate change has raised concerns that the situation could worsen if droughts become more frequent or intense across the state. Thus the need for an assessment of current and future climate risks and vulnerability in the rural sector has become more urgent.
3. This chapter takes a closer look at how affected communities respond and cope with drought in selected areas of the state. It uses household surveys to investigate the impacts of drought, coping mechanisms and to identify the key factors that promote greater drought resilience among households. The chapter then explores the prospective trends in agriculture and incomes under projected future climate change scenarios. It uses the integrated modeling system (IMS, described in chapter 2) to explore how the yields of key crops and incomes might change under future climate patterns and uncertain water supplies. Finally, it synthesizes the findings to recommend some strategic priorities to address drought adaptation that complement and support the state's development objectives.

#### **3.2 Characteristics of Study Area**

##### **3.2.1 Climate and Geography**

4. The focus of the study is on two districts of Andhra Pradesh – Anantapur and Chittoor. Both districts are arid, especially susceptible to drought, and found to be highly vulnerable to further climate variability because of the limited adaptive capacity of most of its residents, due to low incomes and restricted alternative employment opportunities.

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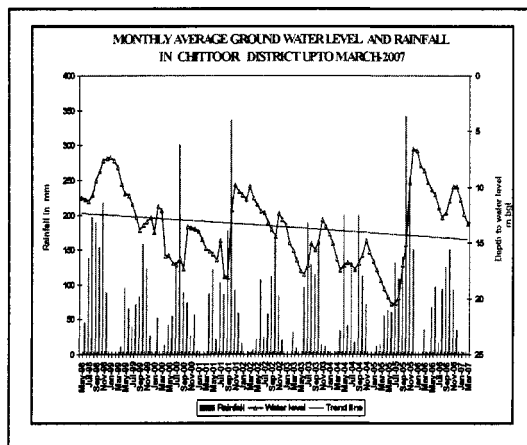
<sup>23</sup> An overview of programs is presented later in this chapter.

### Box 3.1 Groundwater Crisis Looms Large over Anantapur and Chittoor Districts

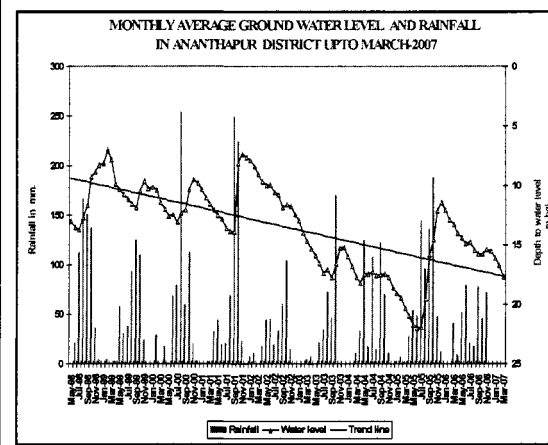
Depleting groundwater resources are threatening the livelihoods of farming communities in Anantapur and Chittoor, calling for greater discipline in water management and land use practices. In the past decade, poor rainfall has led to higher dependency on groundwater for irrigation. According to statistics from the Andhra Pradesh Groundwater Department, a clear declining trend in water table depths is observed in both districts (see figures below). Rates of potential evaporation and transpiration are almost thrice the normal rainfall, with average groundwater recharge of 60 millimeters in Anantapur and 80–90 millimeters in Chittoor per annum. On average, only 5–7% of the rainfall contributes to annual aquifer replenishment, according to studies carried out by the National Geophysical Research Institute, Andhra Pradesh.

A two-storied granite-based aquifer system (the shallow aquifer is in weathered mantle and the deeper aquifer in fracture zone with closely netted sheet joints at different depth levels) persists in the area, with a significantly low storage potential. Good monsoons usually replenish these aquifers though much below optimum levels, and they sustain for a year or a season. As a result, even today in some areas, the shallow dug wells in these areas are performing well with the support of basin development activities. However, the performance of the deeper aquifer system is more complex as it entirely depends on its interconnectivity with the shallow aquifer. During a drought year or successive drought years, a rapid decline of groundwater levels and well yields occurs. The usual reaction of farmers to wells drying up is to make deeper wells in unweathered zones (bedrock), which are unproductive or, if productive, empty the little static resource within that season or even much earlier. Thus, indiscriminate construction of a series of deeper wells has become a key factor leading to declining groundwater levels.

Monthly Average Groundwater Level and Rainfall in Chittoor District to March 2007



Monthly Average Groundwater Level and Rainfall in Anantapur District to March 2007



Source: Groundwater Department, Andhra Pradesh.

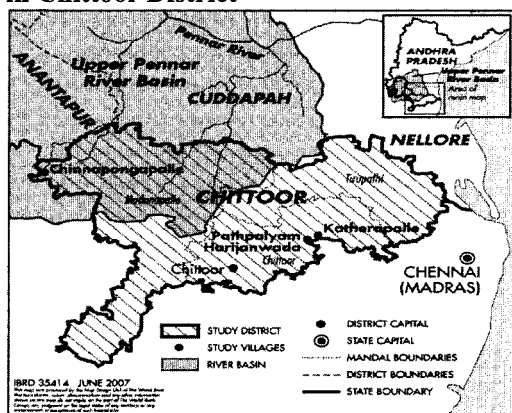
- The districts are located in the Rayalseema region of the state, in the Pennar basin, which extends over a vast flat area of 55,123 square kilometers. Cropped areas occupy about 950,000 hectares of land in Anantapur district, most of which has been classified as highly drought vulnerable over the last decade. About 366,000 hectares in Chittoor district are cropped and nearly half of the total area is highly vulnerable to drought. Though both districts are drought prone, Chittoor is less arid, with an average rainfall of 700–1,000 millimeters per year, compared to an average of 500–750 millimeters per year

for Anantapur, which is the driest district in the state. The geohydrology of these arid zones is characterized by granites that have relatively low groundwater recharge rates, estimated at 5–7% of rainfall. Box 3.1 summarizes the status of groundwater resources in these districts.

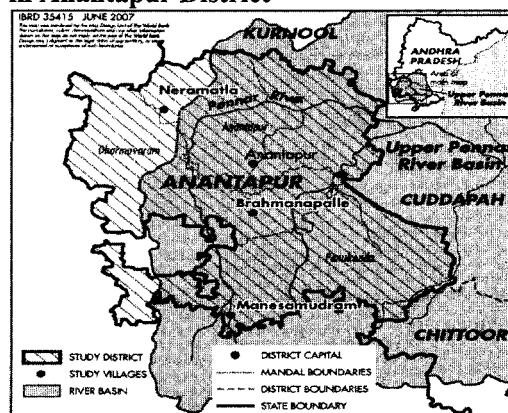
### 3.2.2 Anatomy of the Sample Villages

6. Three villages from each district were chosen for the analysis (figures 3.1 and 3.2). On average, villages in Chittoor are more prosperous, with an average monthly income of Rs 2,686, while in Anantapur the average monthly income is Rs 1,731.<sup>24</sup> Table 3.1 provides a snapshot of the socioeconomic status of households. Predictably the large landholders earn higher incomes and also own more productive and consumptive assets. Educational status and access to health facilities also exhibit some variation with landholding size.
7. **High dependence on agriculture.** Agriculture is the primary source of income in the sampled villages in both districts, with little evidence of income diversification (table 3.2). Large and medium landholders are most heavily dependent on agriculture and obtain approximately 86% of their incomes from farming. It is only the small farmers and landless, with few assets, who are forced into wage employment in both the agricultural and nonagricultural sectors. Diversification into other forms of business or agricultural activities, such as dairying, is minimal, and remittances are low even among the poorest and most drought-vulnerable groups.

**Figure 3.1 Location Map of Study Villages in Chittoor District**



**Figure 3.2 Location Map of Study Villages in Anantapur District**



8. **Limited and unequal access to irrigation.** Despite low and variable rainfall, over 80% of sampled households indicate that they have no access to irrigation facilities. Unlike many other parts of the country, conjunctive uses of ground and surface water are rare in these villages and most groundwater is on farms not covered by surface water.<sup>25</sup> There are considerable inequities in irrigation supplies: larger landholders have greater access to tubewells, whereas canal irrigation is concentrated among the medium landholders, and the bulk of marginal farmers engage in rain-fed agriculture (figure 3.3).

<sup>24</sup> The difference is statistically significant using the Welch t-statistic at the 99% level of confidence.

<sup>25</sup> World Bank 2006f reports a similar finding.

**Table 3.1 Socioeconomic Profile of Sampled Households by Landholding Size**

Landholding size (% of total households)	Ownership of utility assets (%)	Ownership of productive assets (%)	Mean normal monthly income (Rs)	Years of schooling	Access to health facility (%)
Large (14%)	48	59	4,550	10	23
Medium (48%)	33	22	2,428	10	27
Marginal (8%)	24	7	1,479	9	19
Landless (30%)	16	0	1,092	7	10

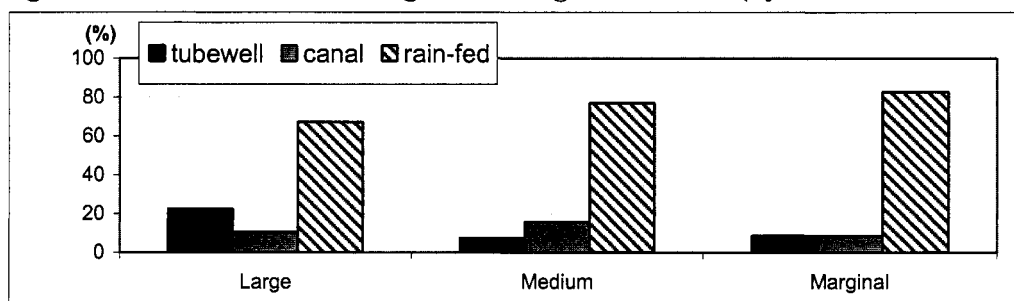
Source: World Bank calculations based on TERI survey data (2003-04).

**Table 3.2 Average Share of Sources of Income in Total Income in Sampled Households, 2003-04**

	Agricultural income			Nonagricultural income				
	Cultiv.	Agric. labor	Total	Nonagric. labor	Petty business	Dairy	Remits.	Total
Large	82	4	86	12	1	1	1	14 <sup>a</sup>
Medium	63	24	87	10	1	1	1	13
Marginal	39	34	73	18	5	1	3	27
Landless	0	74	74	20	4	0	2	26

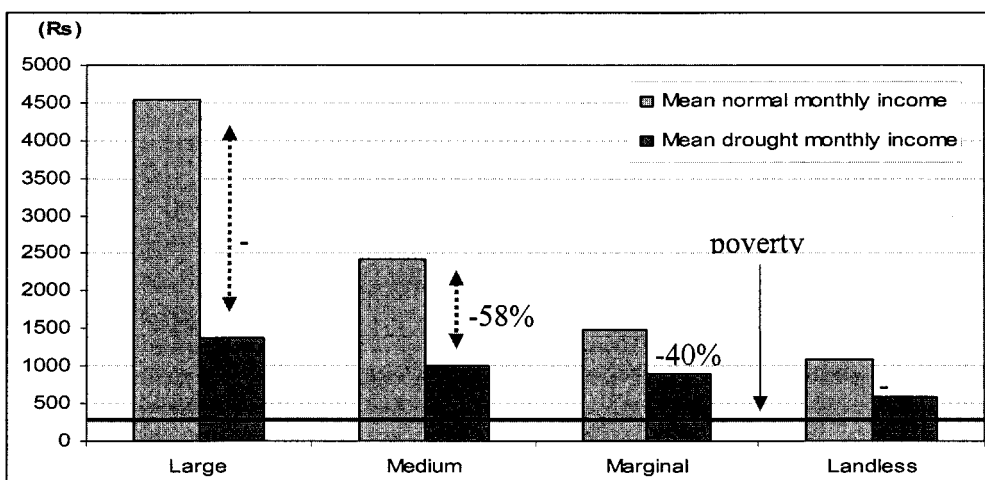
a. Discrepancy in total is due to rounding off of percentages. Source: World Bank calculations based on TERI survey data (2003-04).

**Figure 3.3 Household Percentage with Irrigation Access (by Source & Landholding)**



Source: World Bank calculations based on TERI survey data (2003-04).

**Figure 3.4 Impact of Drought on Income<sup>26</sup>**



### 3.3 Impact of Drought

#### 3.3.1 Effect of Drought on Households

9. The survey compares outcomes in a normal year with a drought year.<sup>27</sup> When drought descends, all households are heavily impacted and face a dramatic decline in their incomes (figure 3.4). Large landholders, being more dependent on agriculture, experience the sharpest (70%) declines in their incomes.
10. Vulnerability to climate shocks is multifaceted and goes beyond income volatility. The ability to stabilize incomes is one, albeit important, dimension of vulnerability that is emphasized in economic assessments. But it fails to capture many of the broader impacts of climate shocks on welfare, including poverty, social disruption, decline in health, dislocation of local markets, and the disruption of public services. Households clustered along the poverty line are most susceptible to hardship and destitution from climate change. Figure 3.4 shows that the incomes of smaller farmers plunge closer to the poverty line during drought. In contrast the large farmers, despite suffering a greater relative drop in their incomes, are still better off due to their higher income levels. This calls for more targeted efforts to build adaptive resilience among smaller farmers. Apart from declining incomes, villages reported that droughts increased health expenditures (12% of the sampled population), led to disruption of education (10%), forced migration to towns in search of alternative sources of employment (17%), and led to distressed sales of land, cattle, and jewelry (34%).

#### 3.3.2 Coping with Drought

11. Household responses to drought have been largely reactive and do little to build long-term drought resilience. Credit remains the most common coping response to drought (68% of sampled households). Large landholders borrow from formal sources (such as

<sup>26</sup> The poverty line in rural Andhra Pradesh is Rs. 263 (Government of India 2001). Source: World Bank calculations on the TERI survey data, drought year (2002-03) and normal year (2003-04)

<sup>27</sup> The survey was for the recent drought year in 2002.

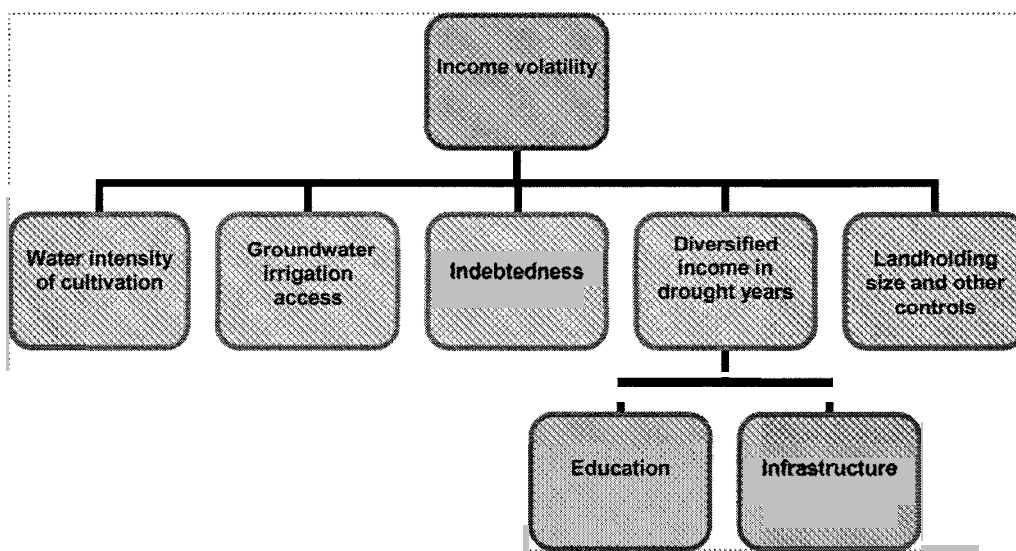
banks), while the landless and small farmers borrow from moneylenders at inflated interest rates. Occupational shifts are another typical response to drought (28% of sampled households). Poorer households (small and landless) move into unskilled, casual employment (construction, mining, and quarrying), while the large and medium landholders shift to temporary salaried employment (clerical jobs and small business). Few households appear to have altered cropping patterns in response to drought and there is a dominance of groundnut across the districts, reflecting a high degree of adjustment to arid agroclimatic conditions.

### Vulnerability to Drought and Its Determinants

In sum, when drought hits, households in these villages suffer a precipitous decline in income. But a closer look at the impacts shows that some are better able to smooth income fluctuations than others, irrespective of landholdings or wealth. What explains the greater resilience of some households to drought over others? To unravel the determinants of vulnerability and identify connections between factors, a detailed statistical assessment was performed using regression techniques. Appendix G reports the technical results. Here the focus is on discussing the results and presenting the implications.

Definitions of vulnerability abound and encompass a variety of dimensions such as social norms, customs, and intrinsic abilities – factors that are difficult to measure.<sup>28</sup> This study adopts a more pragmatic approach and defines vulnerability in economic terms, as a measure of income volatility that is captured through a statistic termed the coefficient of variation. Figure 3.5 summarizes the linkages and pathways through which vulnerability is either amplified or diminished. The analysis identifies links with **economic factors** (debt and occupational mobility), the **resource base** and its management (crop mix and water availability), and certain **initial conditions** (landholdings and location). A brief overview of factors with important policy implications follows.

**Figure 3.5 Determinants of Income Volatility**



### *Water Resources and Use*

- The assessment finds that a greater **dependence on water-intensive crops** increases vulnerability. This reflects a familiar trade-off confronting farmers in areas with unreliable rainfall: gambling on a good monsoon, with water-intensive crops, will pay dividends if there is adequate rainfall. But when drought hits, this also exposes the farmer to greater risks and a deeper fall in income. Consequently income volatility is higher among those farmers who rely on water-intensive crops.
- **Irrigation access** has a large impact on income levels in these arid villages. Consistent with other evidence, the sources of irrigation are also important. Households with access to groundwater typically have higher incomes.<sup>29</sup> But with anemic recharge rates and high levels of abstraction, droughts deplete groundwater reserves, leaving households exposed to the vagaries of rainfall (box 3.1 and table 3.3). Consequently, existing irrigation facilities provide little buffer against drought. In policy terms there needs to be strengthened water management that brings abstraction in line with recharge. This would have to include consideration of changes in cropping patterns, irrigation techniques and job diversification.

**Table 3.3 Percentage of Households with Irrigation Access**

	Normal year		Drought year	
	Tubewell	Canal	Tubewell	Canal
Large	22	11	5	1
Medium	7	16	0	0
Marginal	9	9	0	0
Landless	0	1	0	0

*Source:* World Bank calculations based on TERI survey data, drought year (2002-03) and normal year (2003-04).

### *Economic Factors*

- Households that are heavily **indebted** also experience a greater drop in drought year incomes. Evidently, high levels of debt lock households into agriculture and this lack of flexibility inhibits the poor from seeking remedies that lower their exposure to drought risk. This needs to be tackled through a range of economic instruments that address the root causes of indebtedness, including climate-related risks.

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<sup>28</sup> Appendix A presents a summary of the numerous definitions and approaches that have been used to assess vulnerability.

<sup>29</sup> In a normal year (controlling for other factors), households with access to groundwater earn nearly 50% more than those without any irrigation access and those with access to canal irrigation earn 15% more than those without any irrigation.



- The ability to **diversify income out of agriculture** is an effective strategy for insulating incomes against drought. The analysis finds that there are two key factors that promote income diversification: infrastructure and education.
  - Infrastructure stimulates broader regional development, thus permitting greater income diversification, which reduces income volatility.
  - Education builds human capital and hence provides additional earning capacity to households, as well as the ability to cope with drought.

The implication is that these interventions bring additional cobenefits by building climate resilience. But these investments have a long lead time, so there is a need to develop tools to identify risks and create systems to assure proactive interventions in vulnerable areas.<sup>30</sup>

### 3.4 Future Prospects under Climate Change

14. The assessment so far has focused on the past and has identified the determinants of vulnerability and the common coping responses to drought. Looking forward, many of the predicted effects of climate change are expected to differ in kind and magnitude from current climate patterns. So history may offer only limited guidance on how to mitigate or prepare for these future risks. Accordingly this section uses the IMS to explore future climate scenarios and its impact on agricultural outputs and incomes. It begins with a brief description of climate projections and the resulting crop responses in the study area. It then uses the economic model to ask how these changes might influence farming behavior, cropping patterns, and farm incomes. The following section explores possible strategic interventions that could help ameliorate some of the adverse consequences.

#### 3.4.1 Projections of Climate Change

15. Results are presented for two climate scenarios: A2 and B2 and these are compared to a baseline that describes 30 weather events from 1961 to 1990.<sup>31</sup> The system generates predictions for the Pennar basin in Andhra Pradesh, which includes the districts of Anantapur and Chittoor. Looking to the future the climate model projects:
- An average increase in annual precipitation of about 8% (to approximately 709 millimeters) in the A2 scenario and 4% (to about 683 millimeters) in the B2 scenario.
  - This is accompanied by increases in both the annual and kharif minimum and maximum temperatures. The average increase in the former could range from 2.5°C (B2) to 3.4°C (A2), while the latter could range from 2.3 °C (B2) to 3.1°C (A2).
  - There is also greater variability of rainfall, both within and between years, and this is reflected in more erratic runoff with significantly reduced flows in dry years. Importantly, this greater variability implies a greater frequency of low rainfall years that would be categorized as drought events under current criteria.

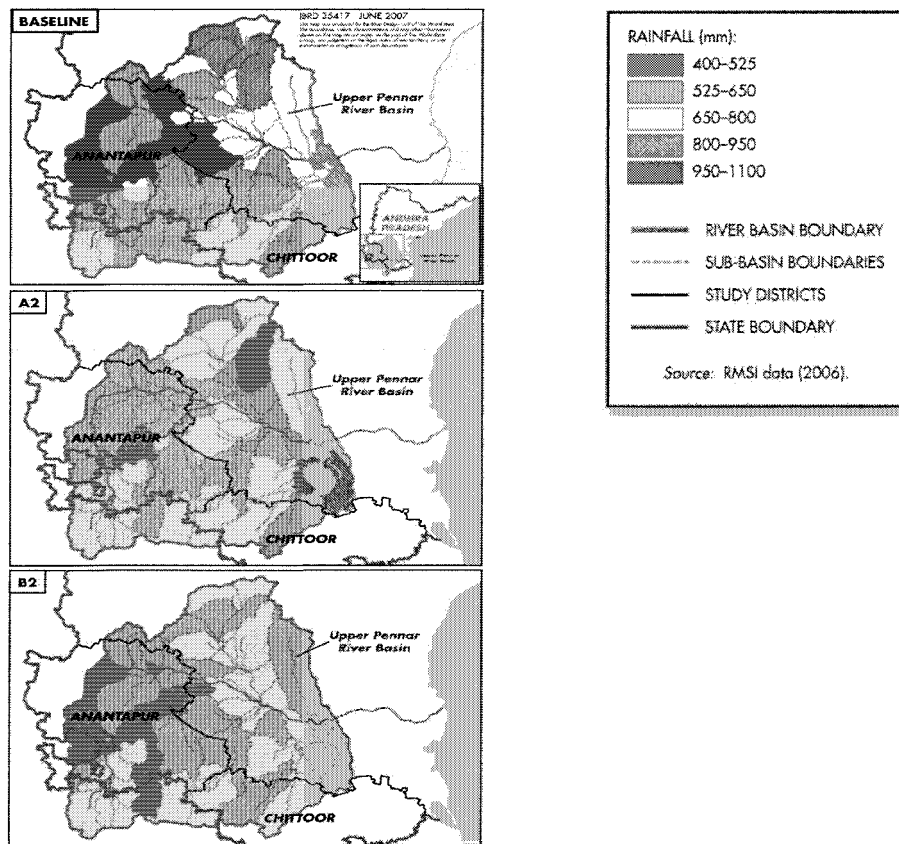
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<sup>30</sup> Other controls include landholding size, village variables, etc. as detailed in the tables in Appendix G.

<sup>31</sup> A2 and B2 are the IPCC scenarios. Projections are from 2071 to 2100. A2 defines a world of high and rising greenhouse gas levels with correspondingly more severe climate change. The B2 world is one with a greater emphasis on sustainability and involves lower emissions (see box 2.2, chapter 2).

- The pattern of rainfall is also expected to change: the traditionally wetter months of June and July are expected to receive less rainfall, while precipitation would increase by a smaller amount in the drier months of May, September, and October.
- A change in the spatial distribution of rainfall is also projected. Figure 3.6 depicts projected changes in average annual precipitation in the basin. It shows that at the basin level the A2 scenario projects rainfall increases in segments of the basin across 50% of the land area.<sup>32</sup> In B2 the changes are more concentrated in the southwest, the north and northwest, and the southeast. The areas that experience a decline in rainfall are in the north, northwest, and a small portion of the southeast. The district-level maps in appendix H show that spatial variation also occurs within districts.

**Figure 3.6 Spatial Distribution of Average Annual Rainfall in the Pennar Basin (Baseline and Climate Change Scenarios)**

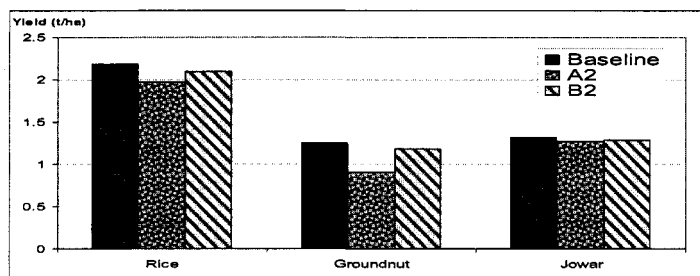


<sup>32</sup> In A2, some parts of the basin towards the northwest and the southeastern boundary, as well as some segments in the central part and the western outer boundary, will see an increase in rainfall. Only one small segment in the north will experience a decline.

### 3.4.2 Crop Responses to Climate Change

16. With projections of this magnitude, there will inevitably be variations in crop yields. The focus is on the impact on three major crops: rice, groundnut, and jowar, which collectively account for approximately 70% of total arable output in these districts. Jowar and groundnut are dryland crops that are well suited to arid conditions and prolonged heat. Though rice is a water-intensive crop, field surveys indicate that farmers devote a small portion of their land (about 0.5 hectares) to rice in order to meet basic household consumption needs and fodder requirements.<sup>33</sup>
17. Deteriorating agroclimatic conditions under climate change are reflected in lower yields. The model finds that despite slightly higher rainfall the average yields of all three crops decline. The reduction is more pronounced under the severe conditions of A2. Figure 3.7 presents results for one block, Talupula in the district of Anantapur, with similar trends elsewhere. Groundnut yields fall dramatically in A2 by 28% and more modestly in B2 by 6%. Jowar exhibits greater resilience with a decline of 4% in A2 and 2% in B2, while average rice yields decline by 10% and 4% in A2 and B2 respectively.<sup>34</sup> The crop responses reflect the complex interplay of three key climate parameters: (a) changes in the level and distribution of rainfall; (b) higher temperatures; and (c) the elevated levels of carbon dioxide. Box 3.2 uses groundnut yields in Anantapur district, Pennar basin, to illustrate these interactions.

**Figure 3.7 Yields of Rice, Groundnut, and Jowar under Different Climate Scenarios, Anantapur**



### 3.4.3 Economic Assessment

18. How might these changes influence farm incomes, crop choices, and farm management regimes? To answer these questions the economic model compares the baseline results (under prevailing conditions), with the A2 and B2 scenarios. In the baseline, groundnut dominates in terms of average profitability per hectare, followed by jowar and rice (figure 3.8a).<sup>35</sup> The economic model estimates the resulting cropping mix, taking account of a

<sup>33</sup> This is imposed as a constraint in the model, details are in Appendix G.

<sup>34</sup> Average yields mask changes in the distribution of crop responses. These are reported in appendix G. Specifically, under climate change the peaks of the distributions are lower, while the tails are thicker. This implies that adverse climate events that (a) generate low yields (bad outcome) become more frequent; (b) the intermediate outcomes are less common; and (c) there is a small increase in the frequency of beneficial outcomes.

<sup>35</sup> Profits from each crop reflect: (a) the yield, (b) the price of the crop and (c) the production costs. Consequently there is no simple one-to-one mapping between yields and per hectare profits. A crop with higher yields may be less profitable if it either sells for less, or costs more to produce.

host of factors including farm size, the volatility of returns, expectations of climate events, and water availability. Prices are based on those that currently prevail and, where relevant, include the Minimum Support Price (MSP). These prices are varied in the simulations. Figure 3.8b shows the predicted cropping pattern in Talupula (a similar pattern holds elsewhere and is not reported).

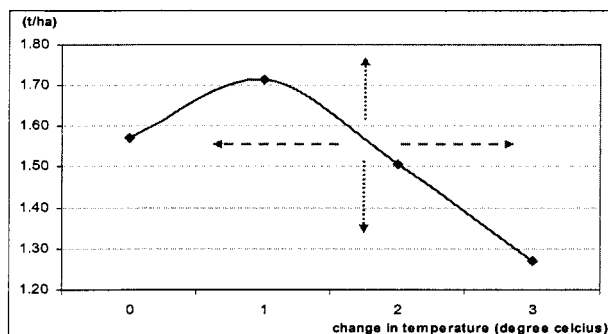
19. The model finds that in the baseline, irrespective of farm size, the bulk of the cropped area is devoted to groundnut. This confirms empirical data that also shows that monocropping of groundnut is common practice in many mandals in Anantapur. Not surprisingly farm management methods have evolved to cope with these harsh arid conditions. However, studies on cropping systems also identify risks with monocropping associated with pest attacks and fertility loss.

### Box 3.2 Illustration of Trends in Crop Responses in the Pennar Basin, Andhra Pradesh

Crop yields are sensitive to a host of weather- and climate-related factors including temperature, the level and distribution of rainfall, and CO<sub>2</sub> concentration. Higher global levels of CO<sub>2</sub> concentrations are associated with more aggressive temperature increases. As an illustration, the figure below tracks the combined impacts of temperature and carbon fertilization on groundnut yields – holding rainfall constant at baseline levels – in the Pennar basin. The simulations are based on higher levels of CO<sub>2</sub> accompanying the higher temperatures. The combination of temperature and CO<sub>2</sub> values are drawn from the HadRM model projections. Groundnut yield increases with temperature from the baseline level up to +1°C, after which the yield starts declining. Underlying this pattern is the assumed relationship between the level of CO<sub>2</sub> concentration and the temperature and also their interaction impact: CO<sub>2</sub> fertilization has a positive impact, while a rise in temperature has a negative impact on yields.

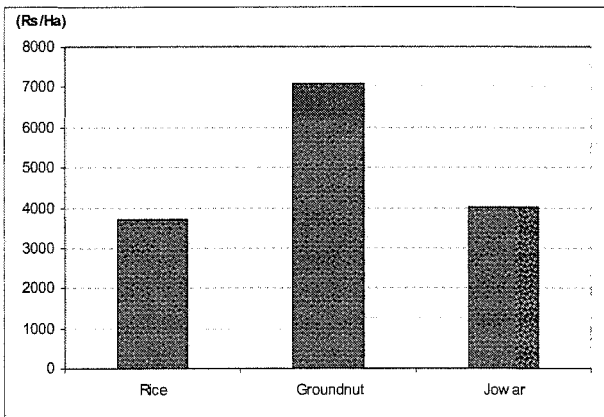
Groundnut yield also depends on the level and pattern (distribution) of rainfall. If the pattern of rainfall is unchanged then higher precipitation will shift the yield curve upward, while less rainfall will shift it downward. Moreover, the change of distribution of rainfall will create a horizontal shift in yield projection. All in all, this illustrates that yield projections are highly sensitive to the set of assumptions underpinning different climate scenarios. These results help explain the differences in yield projections between a previous study (World Bank 2006f) and this study. The earlier study examined the consequences of less aggressive climate scenarios in an earlier period, which placed projections along the rising portion of the yield curve. The projections in this study are based on warming of 2–3°C, which is associated with declining yields.

#### Yield-Temperature Response: EPIC Model Prediction

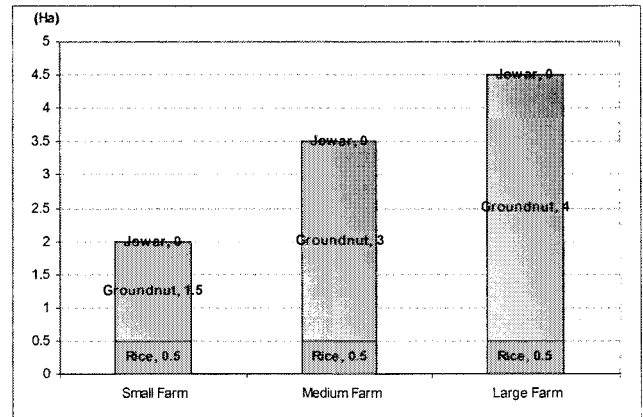


Source: Data from RMSI.

**Figure 3.8a Per Hectare Average Profits in Baseline Scenario, Talupula Block, Anantapur**



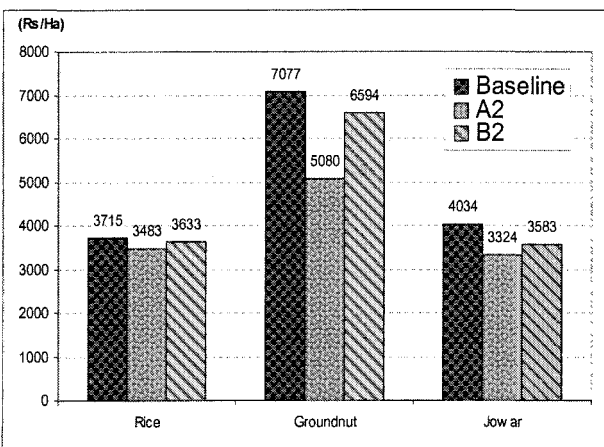
**Figure 3.8b Area Allocation in Baseline Scenario, Talupula Block, Anantapur**



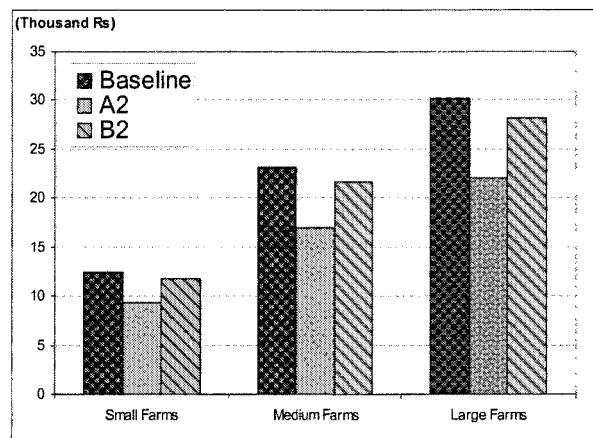
**3.4.4 Projected Consequences of Climate Change**

- 20. With all else equal, under climate change, groundnut still remains by far the most lucrative (profitable) crop (Figure 3.9a). Consequently there is no change in the planting mix (when choosing between the three dominant crops) that would generate more lucrative returns under the climate change scenarios.
- 21. With declining average yields the overall profitability of agriculture declines. The greatest reduction is projected for A2 (approximately 20%) and reflects the impact on yields. There is a more modest and tolerable decline of about 5% in B2. With returns from farming falling (figure 3.9b), the income from agriculture may not be sufficient to sustain the marginal farmers who comprise a large segment of the rural population clustered along the poverty threshold. This finding confirms the conclusion of an earlier World Bank report, which highlights the distributional impacts of drought on the poor and marginal farmers (World Bank 2006f).

**Figure 3.9a Per Hectare Profits in Climate Change Scenarios, Anantapur**



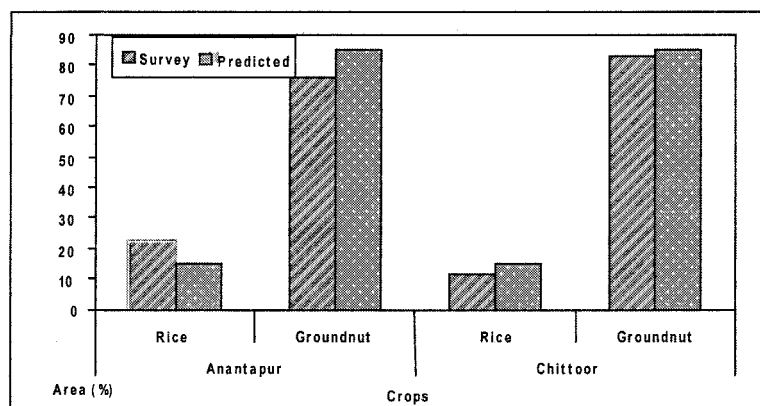
**Figure 3.9b Total Profits in Climate Change Scenarios, Anantapur**



### 3.4.5 Extensions, Validation, and Sensitivity of Results

22. It is important to emphasize that these results are based on a host of assumptions about prices, market structure, and crop availability. In the future, more profitable possibilities for agriculture may emerge, including the creation of drought-resistant crops, alternative crop mixes, and new farm management techniques. The objective of this assessment is not to predict the future, but to identify and isolate the potential effects of climate impacts under particular scenarios. The framework presented here is flexible and can be used to explore a range of policy issues and scenarios.
23. **Validation of results.** An important test of any analytical tool lies in the ability to capture reality. Figure 3.10 compares the predicted outcome in the baseline scenario against the observed crop mix. It demonstrates a remarkable consistency between the model projections and the actual cropping mix and provides some confidence in the model structure and calibration.

**Figure 3.10 Acreage Comparison between Projections of the Farm Economic Model and Data from Household Surveys**



24. **Sensitivity of results.** The conclusions presented here simply illustrate the possible magnitudes of climate impacts under prevailing conditions and assumed scenarios. Predicting future prices and technologies several decades ahead is an impossible exercise. Nevertheless it is still necessary to determine the robustness and sensitivity of results to key assumptions. Appendix G summarizes a host of simulations that test the limits beyond which the key predicted results change. These show that the predicted cropping patterns are robust to significant changes in several parameters, including a variation in the risk aversion parameter in the range of plausible values (from 0-3) and a 20% to 25% change in the price of rice. Results are also presented for the effects of increasing levels of water stress on farms. These show that with less irrigation water available at the farm level there is a predictable decline in cropped area and lower incomes, but this is accompanied by a gradual shift in cropping patterns (towards jowar, which is more heat resilient). Simulations were also conducted for hypothetical changes in water charges. Unsurprisingly since farmers have pre-adapted to arid conditions, higher water charges simply lowers profits but lead to no change in the cropping mix.

### 3.5 Pulling Together the Pieces: Policy Implications

25. Is there a need for additional policy to promote adaptation? The ability to cope with adverse climate events depends on the level of wealth and the economic and social infrastructure of communities. So as Andhra Pradesh grows more prosperous, it will generate more job opportunities and inevitably build greater immunity to climate fluctuations. The myriad government programs that deal with education, infrastructure, and job creation also serve a complementary objective of building climate risk resilience. In this context, adaptation policy can be viewed as an adjunct to good development policies that promote equitable growth. All of this might suggest that adaptation to climate change requires no additional policy priority or interventions.
26. In spite of this, there are high risks associated with complacency that could magnify the costs of climate change. Though the projections in this report are broad, they suggest a considerable and mounting human toll from climate change and highlight the need and urgency for mitigating the avoidable costs, particularly among the vulnerable sections of society.

#### **Box 3.3 Andhra Pradesh Drought Adaptation Initiative: Putting Adaptation into Practice**

A Drought Adaptation Initiative pilot is being implemented in selected villages of Mahabubnagar and Anantapur districts by the Society for the Elimination of Rural Poverty and the Watershed Support Services and Activities Network, in collaboration with district collectors in the pilot districts and under the oversight of the state Department of Rural Development. A state government interdepartmental steering committee and a convergence committee comprising the commissioner for rural development and National Rural Employment Guarantee Scheme representatives have been set up to oversee project implementation. The initiative will be implemented over a period of three years with technical assistance from the World Bank and seeks to (a) identify gaps and missing links in the ongoing drought-related programs and activities in Andhra Pradesh; (b) facilitate institutional integration at state, district, and community levels for delivering drought-related assistance; (c) design and test the innovative methods and instruments for helping selected communities to adapt to drought, targeting different groups within these communities; and (d) improve awareness of drought adaptation options and approaches and disseminate the results of the pilot efforts to build support and demand for wider replication.

The Drought Adaptation Initiative pilot focuses its resources on four areas of interventions: (a) management of common natural resources, dealing with pro-poor water resource (particular groundwater) and common land management; (b) production systems, focusing on diversification and intensification in agriculture, livestock, and horticulture, with technology innovation; (c) economic instruments and marketing, with a focus on improved access to markets, credit, and insurance for new and innovative activities specifically designed for drought adaptation; and (d) institutional support and capacity building, with a focus on institutional strengthening of farmers and other villager organizations, including such community-based organizations as self-help groups, watershed committees, and credit committees. Pending successful outcomes, the pilot is expected to build support and demand for wider replication in Andhra Pradesh and provide lessons to other semiarid states.

27. The Government of Andhra Pradesh assigns a high priority and commitment to strengthening development outcomes, as indicated by its support to robust relief machinery and recent strategies to build long-term resilience to climate risks among rural

communities. Under the oversight of the Department of Rural Development the state is implementing an innovative drought adaptation pilot initiative in dryland areas (box 3.3). In addition, there are a number of sectoral programs in irrigation, agriculture, water conservation, rural development, and forestry that provide a comprehensive and varied platform for strengthening adaptation outcomes on the basis of more effective synergy and coordination (box 3.4). This foundation can be considerably strengthened through additional and complementary initiatives and approaches that would strengthen and harmonize many of the existing initiatives.

28. The focus would be on four priority areas: (a) diagnostic risk assessment tools to generate information for integrating climate risks in policy; (b) management of natural resources – water and agriculture; (c) management of climate risks through economic instruments; and (d) institutional changes to manage climate risks.

**Box 3.4 Andhra Pradesh Sectoral Programs: Comprehensive Base to Build Adaptation Approaches**

Andhra Pradesh has several long-standing governmental programs are currently in operation that address parts of a comprehensive drought adaptation strategy. These government programs are briefly reviewed below.

- **Water resources programs.** Apart from a number of medium irrigation projects that are planned or under way, numerous community tanks (small surface water reservoirs) are being revived and expanded to improve tank system-based livelihoods through the Department of Irrigation. In addition, the state launched a micro-irrigation scheme to promote the use of drips, sprinklers, and rain guns on farmer fields.
- **Watershed programs.** Centrally sponsored watershed programs in drought-prone areas are supplemented by state-sponsored programs, which are sometimes donor assisted. State government watershed programs include the Andhra Pradesh Rural Livelihoods Program, assisted by the Department for International Development, Government of U.K.; the Integrated Watershed Development Program; and the Employment Guarantee Scheme, which uses relief-time labor to construct soil and water conservation structures.
- **Agriculture and forestry.** Special programs on crop diversification and sustainable dryland farming combined with incentives (for example seed subsidies) are underway. The state is considering incentive mechanisms for farmers that adopt the system of rice intensification practices to encourage wider adoption of this water-saving technology, especially in the rabi season. The vana samrakshana samitis in Andhra Pradesh, as part of the Government of India's forestry programs, promote community participation in protecting existing forests and new plantations, supported by bans on open grazing and promotion of stall feeding.
- **Rural livelihoods.** Swarnajayanti Gram Swarozgar Yojana, the centrally sponsored self-employment program for nonfarm-based livelihoods, is complemented by state government programs that support rural livelihoods, including the Andhra Pradesh Rural Livelihoods Program and the Indira Kranti Patham. Both are statewide poverty reduction projects aimed at building strong institutions for the poor and enhancing their livelihood opportunities through community investment funds. Through these programs, the feasibility of strengthening the employment components in the National Rural Employment Guarantee Scheme through the inclusion of innovative activities (for example fodder production, farm composting, and tank desiltation) in rain-fed farming systems is being explored.

**3.5.1 Information on Vulnerabilities and Risks**

29. The impacts of climate change are expected to be heterogeneous and spatially variable, suggesting the need for tools to identify local vulnerabilities, potential impacts, and risks. A recent Bank assessment has also emphasized the need for such assessments (World



Bank 2006f). While there are many uncertainties in projecting future changes, the diagnostic information can provide an indication of their direction and magnitude. The development of such information systems is a first step and common challenge for generating public policy in new and uncertain fields. This study suggests two immediate and urgent areas where diagnostic information is required:

- Tools are needed to identify areas facing increased risks and so build synergies with existing programs and target more effective assistance to vulnerable communities, most notably with regard to investment in local public goods that build climate resilience.
- The economic life of many long-term infrastructure investments will be affected by climate risks that need to be assessed using diagnostic tools. This has important ramifications for assets whose economic lives could be affected by climate change. The location, construction, and refurbishment of these will need to incorporate potential climate-related risks. This is particularly important for Andhra Pradesh, where investments in irrigation can contribute to protecting agriculture against drought.

30. To utilize this information effectively it must be integrated into routine policy decisions, when appropriate. This is a particular challenge that calls for substantial institutional and capacity strengthening, issues that are addressed later in this report.

### **3.5.2 Financial and Economic Instruments to Promote Drought Resilience**

#### ***Debt Relief to Facilitate Income Diversification***

31. In areas where natural productivity is low and agriculture is at the edge of climate limits, income diversification remains the most obvious and effective way of reducing the level of exposure to climate risks. This study has identified indebtedness as an impediment to occupational mobility. Small and poorer farmers who are least able to cope with adverse climate shocks respond to the lack of formal credit by turning to moneylenders. High levels of debt tend to lock households into agriculture and inhibit occupational flexibility. With limited assets and access to start-up capital these groups confront the most systemic climate risks. So an important priority and challenge for policy is to find innovative and cost-effective ways of reaching these poorer farmers to help reduce their risk exposure.
32. Coupling debt relief with new risk mitigation instruments is an obvious way to prevent a debt-induced poverty trap. To prevent debt-induced poverty and occupational lock-in, policy must tackle the root cause of the problem – an overreliance on rainfall-dependent sources of income. To reduce exposure to climate risks, debt relief or subsidized credit could be linked to other incentives that promote occupational mobility and lower dependence on agriculture. Two innovations merit further policy consideration and scrutiny:
- The relief of old debt could be coupled with the provision of capital for a new business. This would simultaneously reduce indebtedness and lower the transaction costs of occupational shifts by providing new opportunities.

- A variant of this approach would have debt relief coupled with insurance to cover the initial risks of shifting from farming to other businesses and provide protection against new and unfamiliar sources of risk.<sup>36</sup>

### **Box 3.5 Weather-Indexed Insurance for Agriculture in India**

The insurance company ICICI Lombard, in collaboration with the Hyderabad-based microfinance institution BASIX, piloted a rainfall-indexed insurance to protect farmers from drought during the groundnut and castor growing season. This was the first weather insurance initiative in the developing world. It was sold to 230 farmers, mostly small, in Mahabubnagar district, Andhra Pradesh, in 2003. In 2004, the program was significantly modified in terms of geography, product design, and scope, and was further improved in 2005 by adding new features recommended by farmers. Within three years, the small pilot has graduated into a large-scale operation in which 7,685 policies were sold in 36 locations in six states. Similar products are also being offered by the Agricultural Insurance Company of India, and the scheme has achieved wide acceptance among the farmers.

Weather-indexed insurance is less susceptible to the problems intrinsic to traditional multiperil crop insurance. The publicly available weather indicators are easily measured and transparent and the automatic trigger and low-cost weather-monitoring stations reduce insurer's administrative costs, which in turn makes products more affordable to farmers. Moreover, the exogenous nature of the weather indicators helps prevent both adverse selection and moral hazards.

A major challenge in designing weather-indexed insurance is minimizing basis risk: the potential mismatch between payouts and actual losses. Since indemnities are triggered by weather variables, policyholders may experience yield loss in specific locations and not receive payments. Some farmers may be paid without losses. The effectiveness depends on how well farm yield losses are captured by the index used. Weather insurance contracts essentially trade off basis risks for transaction costs, and the insurance will not be attractive if the basis risk becomes too high. A low correlation between yield and rainfall projected by the EPIC agronomic model for the study districts suggests that the implementation of rainfall index insurance may encounter future difficulties.

*Sources:* World Bank 2005b; Skees, Hazell, and Miranda 1999; Hess 2003.

### ***Rainfall Insurance: A Challenge***

33. Crop insurance schemes are frequently promoted as a cost-effective way of reducing and pooling climate risks and, when linked to particular cropping systems, can be used to promote adaptation. A variety of crop insurance programs are available across the country, but there is an emerging consensus that these have failed to adequately protect many vulnerable sections of society. This has led to the creation of a new generation of weather-indexed insurance products (box 3.5). A common feature of these instruments is that payment to the farmer is triggered when rainfall falls below some prespecified limit. A clear advantage is that weather indicators are observable, verifiable, and transparent, making false claims less likely.
34. The framework developed in this study can be used to assess the feasibility and potential impacts of various insurance schemes on cropping patterns and incomes. A prior World Bank study identified the high and rising costs of drought insurance as a major

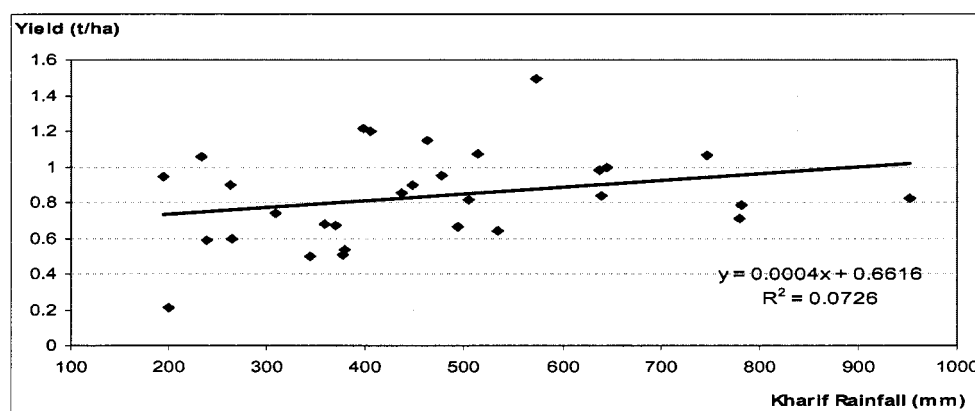
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<sup>36</sup> Variants of both approaches are suggested in World Bank 2006f.

impediment to scaling up (World Bank 2006f). This study suggests a further challenge that could limit the effectiveness of such schemes.

35. Weather-indexed insurance will only help mitigate risks and smooth incomes if there is a stable correlation between the selected weather indicator and crop yields. Figure 3.11 plots rainfall against crop yields in the A2 scenario. It shows that there is no simple correlation between these variables.<sup>37</sup> Consequently rainfall-based insurance would trigger payments in years when incomes are high and withhold payment in years when yields and incomes decline. While this conclusion is preliminary, it cautions against the use of insurance to pool climate risks. A greater concern is that even when climate risk insurance helps appease suffering, it may prolong agricultural dependence in situations that call for diversification into less water-reliant forms of economic activity.

**Figure 3.11 Yield-Rainfall Correlation in Anantapur in A2 Scenario**



### 3.5.3 Management of Natural Resources and Agriculture

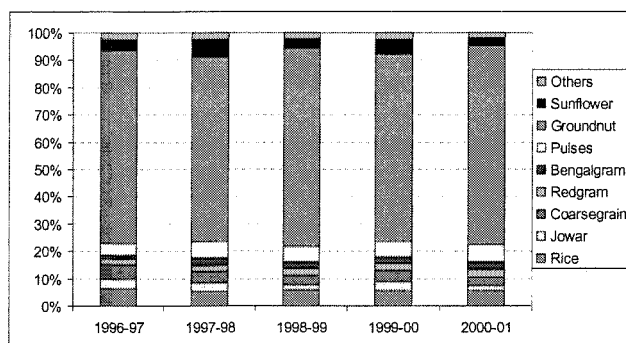
36. **Water conservation and management.** The government of Andhra Pradesh recognizes that there is an overwhelming case for more aggressively pursuing water conservation across the state, as evidenced by its commitment and support to the Andhra Pradesh Water and Land Trees Act. The projections indicate that even when farmers have largely adapted to arid cropping patterns, increased demand and consequent water stress could severely jeopardize livelihoods and render agriculture less viable in these regions. But there are no easy solutions. Community-based strategies to address groundwater overconsumption face significant challenges as customary rights have at times created strong disincentives for sustainable collective management. But this does not mean that these strategies are without benefits and potential. Greater attention should be given to processes that increase the efficiency of groundwater use; support the adaptation of households, communities, and regions to less water-intensive forms of livelihood; and increase the effectiveness of watershed activities to conserve soil moisture and harvest rainwater. Such adaptive measures are not a substitute for the much needed water policy

<sup>37</sup> It is recognized that simple plots and linear regressions are inadequate for capturing these complex relationships. The figure is therefore illustrative. A more extensive statistical search failed to unravel significant and robust relationships between any of the climate parameters (including second and third moments of the distribution) and crop yields. Some of these results are reported in RMSI 2006b.

reform that would likely enable the control of groundwater demand at the wider geographic scale necessary for effective management. However, they provide feasible interim measures for reducing vulnerabilities.

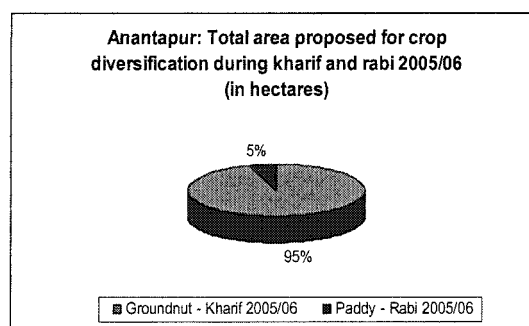
37. **Agriculture diversification.** There is already much evidence that farmers in Anantapur and Chittoor have adjusted to arid conditions by growing groundnut. Though groundnut is well suited to arid conditions, increased monocropping and declining diversity can increase vulnerability to disease and pests, unreliable rainfall, and price fluctuations. This suggests the need for extension of support systems in rain-fed areas that promote alternative and equally profitable dryland cropping systems. Recognizing these risks, the government of Andhra Pradesh has initiated a pilot scheme to encourage diversification into less water intensive crops, such as maize, oilseeds, soybean, Bengal gram, and pulses. Figure 3.12 and 3.13 illustrate the current cultivation patterns and the government's diversification target for Anantapur.
38. Water-intensive rice, currently grown in these areas, serves an essential subsistence need for food and fodder. Research and extension on various forms of dry paddy irrigation are warranted. Emerging methods of rice cultivation, such as the system of rice intensification (SRI) currently being piloted in the state, are innovative and hold promise for scaling up. Indigenous inputs and community-managed support systems for services and inputs appropriate for dryland farming also offer further potential for promoting climate resilience in agriculture. Ongoing nonpesticide management practices supported by the government and the maintenance of community seed buffers for diverse crops are additional strategies that would reduce the cost of cultivation and consequently also the debt burden of farmers. In addition, the importance of livestock to rural livelihoods in marginal cropping systems is increasingly being recognized as a short term response, but it comes with risks (box 3.6).

**Figure 3.12 Cropping Pattern in Anantapur**



Source: Department of Agriculture.

**Figure 3.13 Proposed Crop Diversification**



Source: Department of Agriculture

### Box 3.6 Livestock Systems

Ownership of livestock, especially in arid, semiarid and other noncongenial rain-fed settings, is a critical component of livelihood security. Being more drought resistant than crops, livestock can provide a safety net against drought, spreading the risks and providing a more even stream of income to eliminate seasonal hunger. But there is mounting evidence that increased reliance on livestock dryland pastures could be counterproductive if it leads to further overgrazing and land

degradation.

International experience points out that on arid lands rainfall fluctuations occur (a) from year to year; and (b) in cycles of dry years followed by wetter years. This makes it difficult to devise strategies and grazing management plans to cope with such variability. The light stocking required to match average rainfall can reduce the risk of forage deficit and financial loss due to death and starvation of animals in low rainfall years. But this implies lower incomes in good years, although conserving forage may produce healthier animals that command higher prices. Instead, livestock policies in arid areas should facilitate rapid destocking in bad years through opportunistic herding strategies that rapidly adjust grazing pressures to ecological conditions, instead of assuming that a single stocking rate will be appropriate for all years. But the larger message is that sustainability of livestock management must be enhanced in volatile environments by developing support systems for water-resilient livestock systems and paying close attention to ecosystem productivity and sustainability.

In areas such as Anantapur, farmers tend to have a large number of small ruminants, which, though drought resilient, can be more damaging to pastures. However, the market for this produce is growing. Sheep and goats comprise roughly 70% of the livestock population in these areas, with the remainder as milch animals. There is much global evidence of the pasture damage that can occur with an overreliance on goats. The strategy used by the smallholder mixed (crop-livestock) communities is to purchase animals during the rainy season, when fodder is available, and sell them during the summer season when there is a shortage of fodder. But the greater incidence of drought in recent years has contributed to a sharp decline in livestock populations. There is a need for biomass intensification targeting small ruminants in these rain-fed areas for more secure and productive livestock systems. Other solutions include promoting the production of fodder-yielding crops, the development of fodder banks, and the chopping of fodder by farmers under rain-fed or irrigated conditions to overcome the shortage of green fodder during rabi, when the rainy season ends. Agriculture-embedded livestock systems have a strategic advantage and yield multiple benefits.

#### **3.5.4 Institutional Needs and Priorities**

39. There are a large number of central- and state-sponsored programs for addressing drought in Andhra Pradesh that are being implemented under different guidelines and by various implementing and coordinating agencies. These include the watershed and river basin programs under the Drought-Prone Areas Programme, rural livelihood projects, and farmer schools under the Department of Agriculture. Since natural boundaries seldom coincide with administrative borders, synergies are lost and these fragmented and uncoordinated approaches have rendered strategic management of river basins and natural resources difficult. Programmatic approaches to drought adaptation are needed to coordinate priorities and fill gaps in these programs. This remains a challenging task as it requires integration of diverse programs within a common framework, not only with respect to financial allocation but also with institutions that operate at different levels of government. While the foundation of empowering community-based institutions (for example mandal samakhayas) has been promoted by a number of rural livelihood programs in the state, further building their adaptive capacity to manage climate risks would only strengthen them in the right direction. The state's current efforts to explore opportunities to strengthen the labor dimensions in the National Rural Employment Guarantee Scheme and its linkages with other programs holds great potential to catalyze sustainable development in rain-fed areas and set an example for other semiarid states of India.

## **4. Climate Variability and Change: A Case Study in Drought-Prone Maharashtra**

### **4.1 Introduction and Background**

1. About a quarter of India's drought-prone districts are in Maharashtra, with 73% of its geographic area classified as semiarid. The state is the second most populous in India with 98 million people. It has a large urban population, a literacy rate of 77% (compared to the national average of 65%), and an economy that contributes 20% of the country's manufacturing sector output and 13% of its gross domestic product. Industry and services are well developed and the state remains the financial hub of the country. But paradoxically, almost 47% of its population lives below the poverty line. Acute poverty has largely retreated to the rural areas and reflects the low productivity of the rural economy, on which 56 million people still depend for employment and income.
2. Several factors account for the languishing state of agriculture in Maharashtra: heavy monocropping in some areas, limited value addition to support agribusinesses, a degrading resource base, excessive withdrawal of groundwater, and unfavorable market conditions. Furthermore, irrigation, which covers only 16% of the total agricultural area, is accessible mainly to larger farmers that have access to power and is widely used for the cultivation of sugarcane, a water-intensive cash crop (World Bank 2002a).
3. The drought proneness of the state is a critical additional stress factor that adversely affects productivity, livelihoods, and the rural economy. Ironically, the cultivated areas lie predominantly in drought-affected districts (Ahmednagar, Solapur, Nashik, Pune, Sangli, Satara, Aurangabad, Beed, Osmanabad, Dhule, Jalgaon, and Buldhana), which account for 60% of the net sown area. These areas lie in the rain shadow region east of the Sahayadri mountain ranges in Maharashtra and the adjacent Marathwada region. Aridity appears to be encroaching upon adjacent areas: districts that previously had moderately assured rainfall, such as Vidarbha, have been afflicted by declining and unpredictable rainfall with debilitating impacts on the local economy (box 4.1). Maharashtra experienced severe and successive years of drought in 1970–1974 and 2000–2004.<sup>38</sup> The state Employment Guarantee Scheme (EGS), a relief and rehabilitation program of state support, was introduced in 1972 in response to a devastating drought.
4. Large tracts of rain-fed agricultural land in the state have become unremunerative. The agrarian crisis has become acute, with signs of a breakdown of coping mechanisms among vulnerable groups whose exposure to drought appear to be increasing. For these reasons Maharashtra represents an important case for assessing the coping capacities of communities and the underlying vulnerabilities associated with droughts.

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<sup>38</sup> These periods refer to the fiscal years 1970/1, 1971/2, 1972/3, and 1973/4, and 2000/1, 2001/2, 2002/3, and 2003/4, respectively.

#### **Box 4.1 Rainfall Distribution in Maharashtra**

Maharashtra is divided into 35 districts split among five regions: Vidarbha (in the northeast), Marathwada (in the south-central region), Khandesh (in the northwest), the rain shadow region (extending from the northeast to the southeast between the coastal districts and Marathwada), and Konkan/Western Ghats (in the southwest, on the coast). There is a wide variation in the distribution of rainfall across the state, with the coastal belt, the Konkan region, receiving more than 2,000 millimeters annually, with the second highest rainfall being recorded in the Vidarbha region. Overall, rainfall in Maharashtra increases steadily towards the east and average rainfall in the easternmost districts is about 1,400 millimeters. The rain shadow and Marathwada regions are the drought-prone areas of the state, with an annual average rainfall of less than 600 millimeters. These regions are generally characterized by extreme aridity, hot climate, and acute deficiency in water availability. More recently areas in Vidarbha, which usually have reliable rainfall, have experienced variable and reduced precipitation (Planning Commission 2006).

## **4.2 Characteristics of Study Area**

### **4.2.1 Climate and Geography**

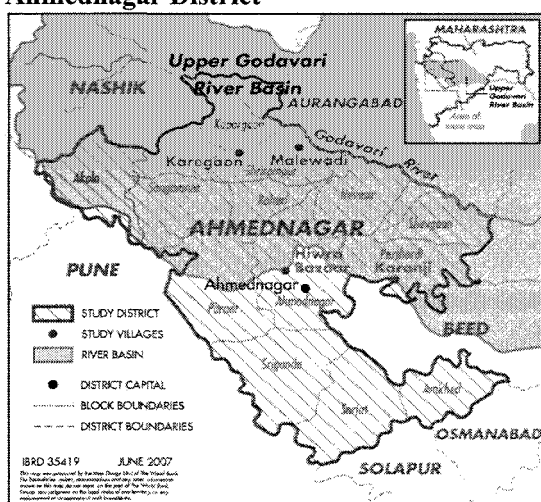
5. The two drought-prone districts of Nashik and Ahmednagar, located in the Godavari basin, were chosen for the case study based on a vulnerability profiling exercise (see appendix B for details). Five villages from the drought-prone belts of the Ahmednagar and Nashik districts were identified for the study (figures 4.1 and 4.2), and a total of 420 households were selected within these villages. Though both districts are located in drought-prone zones, they are substantially different: Nashik is located closer to the higher rainfall Western Ghat region and is the more fertile and moist area. It receives an average annual rainfall of about 1,000 millimeters, and only 25% of its area is fully affected by drought. In contrast, the district of Ahmednagar is arid and lies in the scarce rainfall zone. The district is hot and dry with an average annual rainfall of 579 millimeters, the lowest in the state. All 14 blocks of the district are partially or fully affected by drought. Around 25% of the cultivated area is irrigated. The major food crops include wheat, millets (jowar and bajra), and pulses. Commercial crops grown in certain areas include sugarcane, groundnut, and cotton.

### **4.2.2 Anatomy of the Sample Villages**

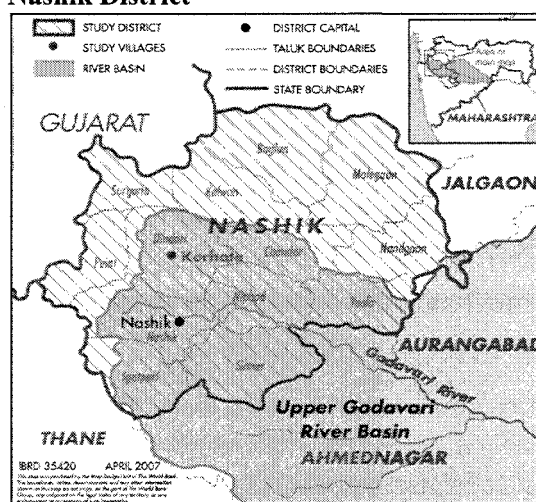
6. In both districts agriculture is the primary source of income. Reflecting agroclimatic conditions, there are great differences in average incomes between the districts: sampled villages in Nashik are much more prosperous with an average monthly income of Rs 22,500, whereas in the arid Ahmednagar villages the average monthly income is Rs 3,455. Large and medium farmer households are more dependent on agricultural sources of income, draw much higher incomes, and own more assets than their marginal and landless counterparts (table 4.1). The standard of education and accessibility to health facilities are similar among most households, except for many of the landless households. There is no significant livestock ownership except in one village in Ahmednagar (Karegaon), where all the households owned livestock.
7. Access to irrigation is of considerable importance to agriculturalists in drought-affected areas. In the sampled households, the quantity and quality of irrigation varies with

landholdings. Access to irrigation in the sampled villages in Maharashtra is considerably greater than in Andhra Pradesh. More than 40% of the households in Maharashtra use either tubewells or canal irrigation, compared to 18% in Andhra Pradesh. However, the irrigation pattern in both states is similar, with sharp inequities in the distribution of irrigation facilities. Access to both tubewells and the canal system is strongly correlated with the size of landholdings (figure 4.3a). There are also consistent patterns in the quality and durability of irrigation supplies: in a drought year the irrigation sources of the marginal landholders are more rapidly depleted than for other landholding categories (figure 4.3b). Box 4.2 describes problems associated with overabstraction of groundwater in Ahmednagar and Nashik.

**Figure 4.1 Location Map of Study Villages in Ahmednagar District**



**Figure 4.2 Location Map of Study Villages in Nashik District**

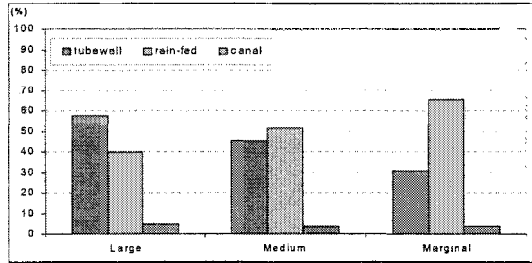


**Table 4.1 Socioeconomic Profile of Surveyed Households in Maharashtra**

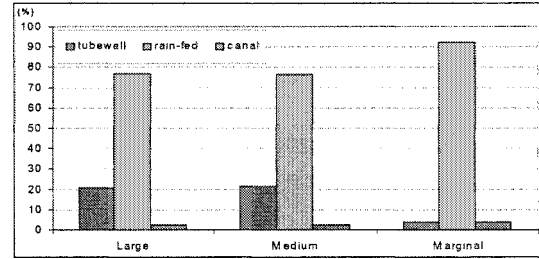
Land category (% of total households)	Ownership of utility assets (%)	Ownership of productive assets (%)	Share of agricultural income (%)	Mean normal income (Rs)	Years of Schooling	Access to health facility (%)
Large (28%)	25	15	86	17,453	6,636	62
Medium (47%)	21	8	78	10,031	11	82
Marginal (6%)	24	3	66	4,611	11	88
Landless (19%)	4	0	67	4,319	9	63



**Figure 4.3a Percentage of Households with Irrigation Access: Normal Year**



**Figure 4.3b Percentage of Households with Irrigation Access: Drought Year**



*Note:* None of the landless households have irrigation access. Conjunctive use of tubewell and canal irrigation, which accounts for under 1% of the households, is included.

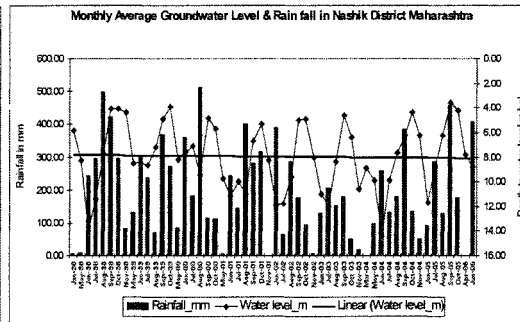
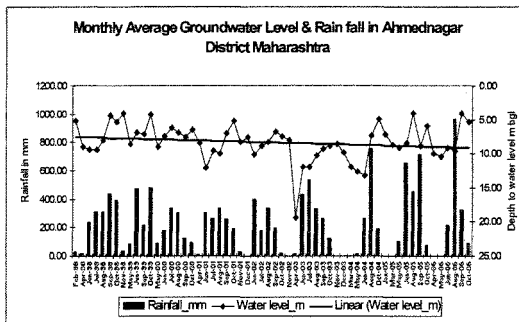
### Box 4.2 Unsustainable Groundwater Development Poses Problems for Ahmednagar and Nashik

Groundwater overdraft in hard rock areas is often self-limiting. Once the weathered layer near the surface is dewatered, abstraction rapidly declines due to falling water levels or water quality problems. This is the case in large parts of western and central Maharashtra, where groundwater abstraction for sugarcane cultivation has reached unsustainable levels.

The most important aquifers in Maharashtra are the Deccan basalts, where groundwater occurs within the shallow weathered and fractured zones extending to depths of 15–20 meters. Deeper aquifers are known to exist within the basaltic lava sequence, but are of limited capacity. The average water table depths in the shallow aquifer range from 5 to 10 meters below ground level during the post-monsoon period and from 15 to 20 meters below ground level during the pre-monsoon period. Recharge rates are low (8–14% of rainfall).

According to state groundwater experts, overuse of groundwater following a poor rainfall season can result in a groundwater drought in the same year, but it more typically happens in subsequent year(s). Much depends on (a) the levels of abstraction and (b) the levels of recharge (i.e. rainfall, run-off and percolation) during the drought and preceding periods. Thus groundwater does in many drought events provide the desired buffer to insulate incomes for a limited period of time, but this is not assured. During a normal monsoon season the shallow aquifers recover through recharge, but increased abstraction and greater incidence of drought have led to cumulative damage (see figures below). During a poor rainfall year, insufficient recharge and overabstraction leads to a progressive decline in water levels. The effect is worsened when pumping of groundwater takes place during the kharif (monsoon) season which is atypical during a good monsoon. The excessive pumping leads to a recession of the water table and consequently wells dry up during the pre-monsoon period (March or April) of the next calendar year. The behavior of the aquifer during drought conditions depends on a number of site-specific factors, such as the intensity of drought, extent of groundwater abstraction, storm pattern and location of the village in the watershed.

Thus, proper enforcement of regulation, planned development of groundwater combined with suitable agricultural practices can greatly reduce the threat to groundwater security in these districts.



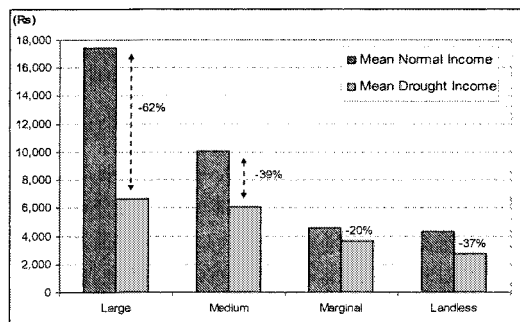
*Sources:* Directorate of Groundwater Surveys and Development Agency and Department of Water Supply and Sanitation, Government of Maharashtra.

## 4.3 Impact of Drought

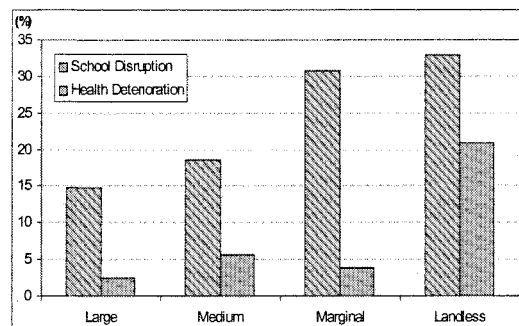
### 4.3.1 Effect of Drought on Households

8. Droughts have a devastating impact on households in these districts. Declining income, in turn, has repercussions on other aspects of household developmental status. Large landholders, with greater dependence on agricultural income, register the largest decline in income (62%). But with greater wealth and assets they also have greater capacity to withstand fluctuations in income (figure 4.4). Non-income indicators show that the poor marginal and landless farmers are worst affected by deficient rainfall (figure 4.5). As many as 33% of the landless households report that drought caused disruption in schooling for children. Drought is also associated with deteriorating health and decreased food consumption, with the landless poor being most severely impacted. A number of short-term strategies have been developed by rural households in Maharashtra to cope with drought. Box 4.3 describes the main strategies used, as indicated by the survey.

**Figure 4.4 Drought Impact on Income**



**Figure 4.5 Nonincome Impacts on Households**



#### **Box 4.3 Short-Term Coping Measures and Responses to Drought in Maharashtra**

When drought descends, households seek alternative sources of income: increased reliance on wage labor, petty business, dairy, and remittance flows. Adjoining villages with good irrigation infrastructure and cities and towns in the immediate vicinity provide alternative options for income generation, particularly for the marginal and landless categories. Opportunities during drought conditions are limited and impacts are significant for farmer households. On average, 89% of the surveyed households responded that they embrace some short-term measures to cope with the crisis of falling income:

- About 50% of households borrow to cover immediate needs; of these 53% borrow from formal sources and 47% from moneylenders, often at high rates of interest. The bulk of the marginal and landless resort to informal sources of borrowing.
- 50% of households temporarily change agricultural practices, reducing fertilizer and seed inputs or growing alternative crops that require less water.
- 50% resort to crop insurance schemes.
- Seasonal migration is high in the rain-fed villages, and among the marginal and landless.

### 4.3.2 Vulnerability and Income Volatility

9. In drought periods, some households are more vulnerable than others. The empirical analysis finds many shared elements of drought vulnerability in two dissimilar, though arid, states – Andhra Pradesh and Maharashtra. This would suggest that the case studies

have identified some of the key drivers of vulnerability among drought-affected populations.<sup>39</sup> Three factors have a disproportionate bearing on vulnerability:

- It is no surprise that income diversification turns out to be a key factor that helps to reduce income volatility among the households. The assessment finds that **indebtedness** locks household into agriculture and increases exposure to climate risks.
- Conversely, **education and infrastructure** bring dual benefits: the usual development gains as well as fostering income diversification into nonagricultural sources, which in turn reduces exposure to drought risk.
- **Access to groundwater** and other sources of water in dry years can provide a buffer against drought and meager rainfall. The analysis shows that access to groundwater in normal years tends to promote reliance on water-intensive cropping systems and so perpetuates water-intensive agriculture (which is also more lucrative). If water supplies are assured through a drought, then climate impacts are ameliorated and drought incomes are stabilized. But for most households groundwater supplies decline substantially during drought. The consequence for these households is a dramatic reduction in incomes during drought years. This highlights the critical role that groundwater could play as a safety net for households in regions with scanty and depleting aquifers (see box 4.2 for a more detailed discussion). It is important to recognize that these results are based on the findings of a single and severe drought. In general, there will be considerable variability in the effect of a drought on aquifer supplies, reflecting the interaction of recharge levels (that depend on current and past rainfall, run-off and percolation) and abstraction rates that partly reflect precipitation levels and water needs (e.g., the crop mix). Consequently, deficit rainfall could produce a drought in the same year or with a lag. In many cases the impact of a drought is felt in subsequent years.

#### 4.4 Future Prospects under Climate Change

10. Turning to the future, the climate change projections indicate that these districts will experience significantly different climate patterns. To assess the likely consequences for agriculture, this section begins with a brief overview of climate change under the two IPCC scenarios A2 and B2. Using the Integrated Modeling System (IMS), it then examines crop responses to climate change and briefly investigates the economic consequences. In the following section, the policy conclusions are summarized.

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<sup>39</sup> Income volatility is measured through the coefficient of variation. Regression analysis is conducted using the ordinary least squares technique with standard errors corrected for heteroskedasticity. The regression includes 409 households and only statistically significant determinants are reported here. All factors reported are stable across specifications and are highly significant. Full technical details are relegated to appendix G. Here, a broad overview is presented that emphasizes the main policy implications.

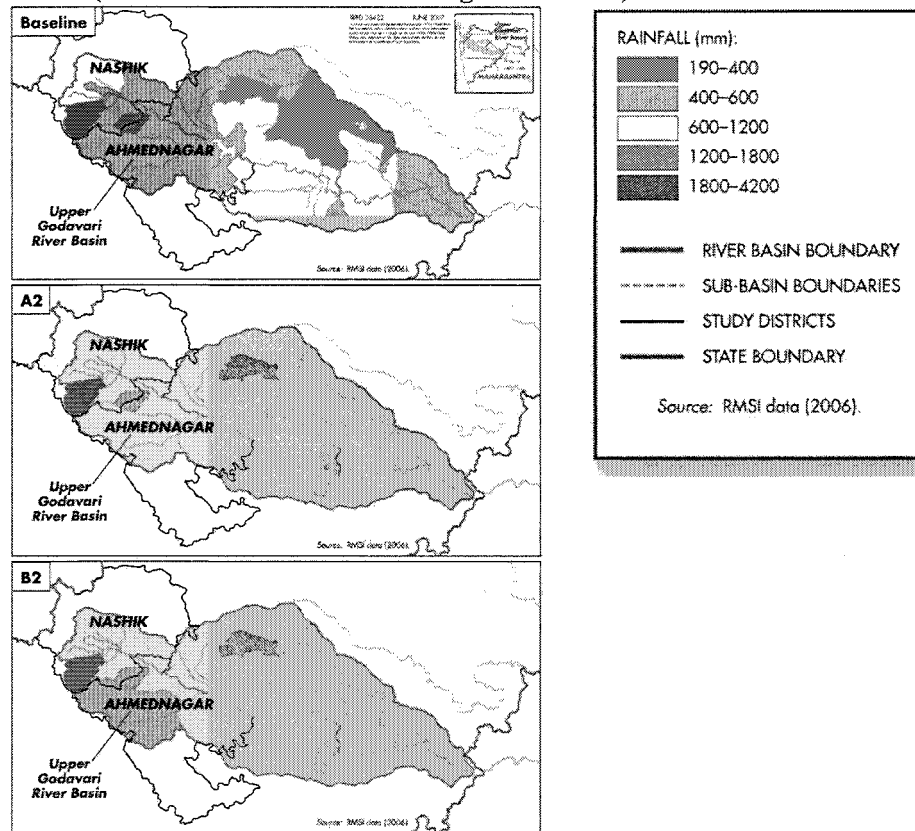
#### 4.4.1 Projections of Climate Change

11. The IMS finds that the following changes may occur across the Godavari basin:<sup>40</sup>
- An increase in precipitation of about 36% (to approximately 840 millimeters) in the A2 scenario and 24% (to about 770 millimeters) in the B2 scenario.
  - This is accompanied by a projected increase in annual maximum temperatures, on average, of 3.8°C in A2 and 2.4°C in B2.
  - Rainfall is found to become more variable but the variation will be very similar in B2 compared to A2; the higher rainfall is expected to increase runoff by 12.5% in B2 and by 13.5% in A2.
  - The monthly rainfall pattern is projected to switch somewhat: while a marginal drop would take place in May and July, an increase would be seen in the already wet months of August and September.
  - In A2 about 50% of the basin's area would see an increase in rainfall and in the remaining 50% rainfall will stay within the current range. The increase would take place in the mid-west, the north, and a small pocket in the south. In B2, about 60% of the basin area will stay within the same range of rainfall while 40% will experience an increase (figure 4.6). At the district level, these changes translate into increases of rainfall for both Nashik and Ahmednagar (see appendix H)

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<sup>40</sup> Projections are for a 30-year period from 2071 to 2100. As noted before, projections for earlier periods at the required level of spatial disaggregation are unavailable.

**Figure 4.6 Spatial Distribution of Average Annual Rainfall in the Godavari Basin (Baseline and Climate Change Scenarios)**



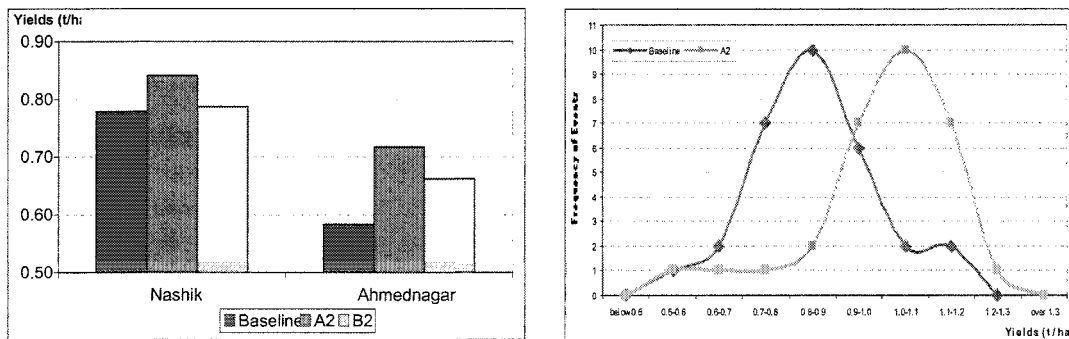
#### 4.4.2 Crop Responses to Climate Change

12. The analysis considers two common millet crops, bajra and jowar, that together account for over 60% of the total cultivated area in Nashik and 40% in Ahmednagar. The other main crop considered in the analysis is sugarcane, which accounts for about 10% of cultivated land in Ahmednagar. While a variety of newer crops have been introduced to these districts, they represent a small proportion of the cropped area. The choice of crops in this study is representative of the majority of farms and has also been guided by the need to examine how crops with different climatic preferences respond to projected climate change. Bajra and jowar are included because they characterize drought-resilient crops that are typically grown on rain-fed farms. In times of stress, these crops are given a survival irrigation if water is available. Sugarcane is included because of its economic significance and because it is a water-intensive cash crop that is grown exclusively on (larger) farms with substantial irrigation supplies.
13. Crop yields and cropping patterns in the baseline scenario are compared with those in the A2 and B2 scenarios. With the rise in temperature and rainfall, the agronomic model finds that average yields of bajra increase dramatically in the more arid district of Ahmednagar (figure 4.7a). In Nashik, bajra exhibits a modest increase in the A2 scenario,

with a negligible impact in B2.<sup>41</sup> Jowar yields also increase by 8% under the A2 scenario, and by 6% under B2.

14. Accompanying the improving yields is a change in the pattern (distribution) of outcomes. The distribution of yields across 30 climate events in the baseline and in A2 is illustrated in figure 4.7b. Bajra yields are higher across the entire distribution in Nashik, which implies that beneficial climate outcomes occur with greater frequency, while adverse climate events, which generate low yields, become less common. Ahmednagar exhibits a similar pattern.

**Figure 4.7a Bajra: Average Yields, Nashik**      **Figure 4.7b Bajra: Distribution of Yields, Nashik**



15. Sugarcane displays a starkly contrasting pattern of responses. Sugarcane yields are expected to decline considerably (by nearly 30%, figure 4.8a). The decrease in yields is attributed to increased moisture stress caused by the warmer climate, coupled with the low responsiveness of sugarcane to carbon dioxide levels. Similar outcomes are reported for sugarcane under climate change scenarios in other regions, such as the Caribbean islands, Mauritius, and Australia.<sup>42</sup> Box 4.4 provides a concise explanation of the complex interplay of changing climate patterns on sugarcane yields under simulated conditions. Looking more closely at the distribution of yields, Figure 4.8b shows that there is a uniform deterioration in outcomes. In particular, climate events that generate low yields are more frequent, whereas high-yield outcomes become less common.

<sup>41</sup> The EPIC model predicts that bajra yield in these regions increases with both temperature and rainfall. In B2 there is an almost imperceptible change of about 1% in average yields.

<sup>42</sup> For a summary of studies in other countries see IPCC 2001, Working Group II: Impacts, Adaptation and Vulnerability, section 17.2.8, food security. Available online at [http://grida.no/climate/ipcc\\_tar/wg2/633.htm](http://grida.no/climate/ipcc_tar/wg2/633.htm).

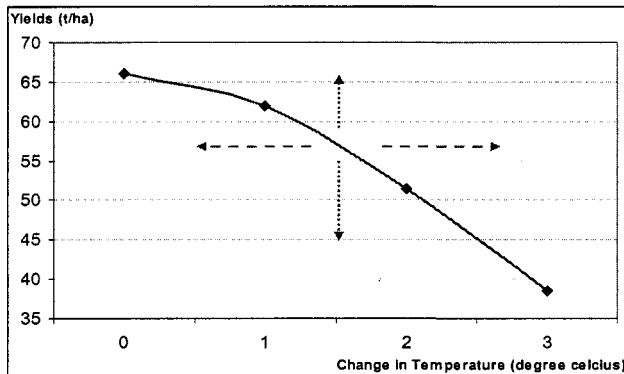
### Box 4.4 Sugarcane Yield and Climate Change in Ahmednagar: EPIC Model Projections

The response of sugarcane yield to climate change is rather complex. The impact takes place through several channels, including temperature, water stress, and the level and distribution of rainfall. A C4 plant (see glossary) such as sugarcane does not benefit from CO<sub>2</sub> fertilization. Interestingly, the EPIC model predicts that increasing CO<sub>2</sub> concentration from 420 ppm to 550 ppm will cause approximately a 13% yield drop in the crop.

The figure below shows that sugarcane yield responds negatively to hotter conditions. Sugarcane yield drops by 6% with a 1°C temperature rise. The damage is even greater when the warming intensifies: sugarcane farms will experience 22% yield loss with a temperature rise of 2°C, and as much as 40% loss with a rise of 3°C. The level and distribution of rainfall also affect yields. Higher precipitation will shift the yield curve upward, while less rainfall will shift it in the opposite direction (green arrows). Furthermore, the change of rainfall pattern will move the curve horizontally (orange arrows).

Although increased rainfall leads to a positive yield response, the EPIC model predicts that this is more than offset by other forces that overall cause yield losses for sugarcane under the A2 and B2 scenarios.

#### Sugarcane Yield-Temperature Response



Source: Data from RMSI.

Figure 4.8a Sugarcane: Average Yields

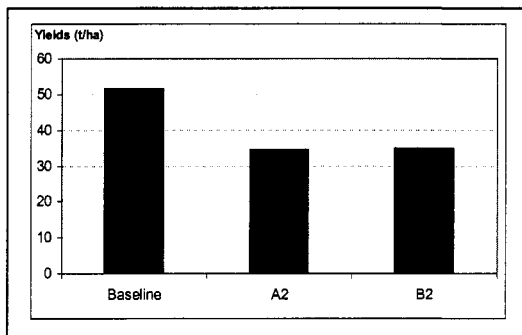
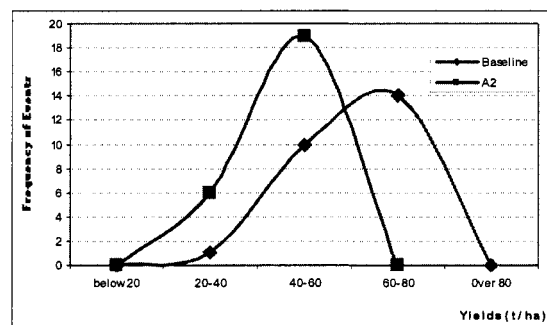


Figure 4.8b Sugarcane: Distribution of Yields



#### 4.4.3 Economic Assessment

16. The economic module estimates the expected profitability of different crops and the resulting cropping mix. Starting first with the baseline, the model finds that under current climate conditions sugarcane is vastly more profitable than either bajra or jowar. The per hectare profits of sugarcane are approximately Rs 19,000 (based on current prices and input costs), while those from bajra are Rs 1,300 in Ahmednagar and Rs 2,300 in Nashik. Consequently, on farms where there is adequate water, sugarcane is projected as the dominant crop. Elsewhere, for millet growers the crop mix is determined by water availability; the model finds that there is a gradual shift from bajra towards jowar as farm water supply declines.<sup>43</sup>

#### 4.4.4 Projected Consequences of Climate Change

17. Under the A2 scenario, the higher yields of bajra and jowar translate into moderately higher profits of 15% and 8% per hectare, respectively. Conversely, the profitability of sugarcane declines dramatically by nearly 30% per hectare in A2 and by 25% in B2. But at current prices sugarcane still remains considerably more profitable, so there is little incentive to switch cropping patterns from sugarcane to either bajra or jowar. The returns per hectare from bajra would need to rise dramatically (eightfold, from Rs 2,337 to Rs 19,165 per hectare) for it to become a competitive alternative to sugarcane.<sup>44</sup> This suggests that despite improving millet yields and declining sugarcane output, a shift to a more less water-intensive cropping pattern may not eventuate without a change in current economic policies.
18. As before, these results are based on the assumption that product prices and all other economic conditions remain at (or close to) prevailing levels. While this approach is useful in isolating the impacts of projected climate factors from other future drivers of change (such as prices and market structure), there still remains a need to examine the robustness of the projections. These are reported in appendix G. For instance, the appendix shows that if water charges were raised from a baseline of Rs. 1.2/mm to about Rs. 40/mm the entire farm area allocated to sugarcane would shift to other less water-intensive crops. The change across this trajectory is linear.

### 4.5 Pulling Together the Pieces: Policy Implications

19. **The fiscal burden.** A review of existing government and civil society measures for drought adaptation suggests that Maharashtra's drought relief mechanism has no parallels within India, and the government has developed a well-structured response to address coping and distress associated with drought years. Appendix D provides a summary of these initiatives. The fiscal and administrative burden on the state machinery is very high. During the Tenth Five Year Plan (2002–2007), the Government of Maharashtra had a planned sectoral allocation of about Rs 152 billion. However, a single drought (2003/4)

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<sup>43</sup> The higher average profitability of bajra depends on there being sufficient water for survival irrigation in hot and dry spells to counter the impacts of heat stress. As the availability of water declines there is a steady shift towards jowar, which is found to be more resilient in the simulations.

<sup>44</sup> Note that the price of sugarcane, when the study was undertaken, was Rs 387 per tonne, while that of bajra was Rs 2,958 per tonne. Sugarcane's productivity was at 50 tonnes per hectare, while that of bajra was 0.8 tonnes per hectare.



and flood (2005/6) cost the government Rs 175 billion (table 4.2). If other drought years are included the gap widens further, with expenditure on relief much greater than the amount allocated to development programs. The fiscal burden underscores the urgency of enhancing climate resilience and considering long-term adaptive measures that can be linked to sectoral programs.

**Table 4.2 Outlays and Expenditures for Drought Relief and Sectoral Programs,**

<b>Tenth Five Year Plan (2002–2007) total outlay</b>	<b>Amount (Rs billion)</b>	<b>Drought and flood damages and relief</b>	<b>Amount (Rs billion)</b>
Agriculture and allied services	45.97	Drought damages and relief (2003/4)	57.21
Rural development <sup>a</sup>	61.99	Flood damages and relief (2005/6)	90.30
Irrigation and flood control works	44.89	Planned EGS outlay (2202/7)	27.98
<b>Total</b>	<b>152.75</b>		<b>175.49</b>

a. Since the Employment Guarantee Scheme (EGS) also acts as a drought relief program, the planned EGS outlay for 2003–04 has been taken out of the rural development component of the Tenth Five Year Plan outlay and added to the relief expenditure and is an underestimate of true expenditures which are higher.

Source: Government of Maharashtra 2006. *Annual Plan 2006-07: Maharashtra State Part II*, Planning Department, Government of Maharashtra, Mumbai.

20. **Policy implications.** The assessment in this chapter suggests many shared policy themes that would help build climate resilience in Maharashtra and Andhra Pradesh.
- In both states local public goods (infrastructure and schooling) not only bring well-recognized development gains, but also have an additional benefit of reducing long-term exposure to climate risks. These risk mitigation benefits need to be factored into investment decisions and so require the development of diagnostic tools and institutional approaches to integrate climate vulnerabilities in policy.
  - Likewise, indebtedness is known to create a poverty trap, but it also emerges in Maharashtra as a constraint on income diversification that amplifies climate risk exposure. Consequently the policy framework suggested for Andhra Pradesh would apply, with appropriate modifications, to Maharashtra. In particular there is considerable scope in Maharashtra for coupling debt relief with new business capital or insurance for the start-up risks of a new business.
21. In addition to these there are two additional policy priorities that warrant special attention in Maharashtra – the reliance on sugarcane and the implications for water use and groundwater supplies.

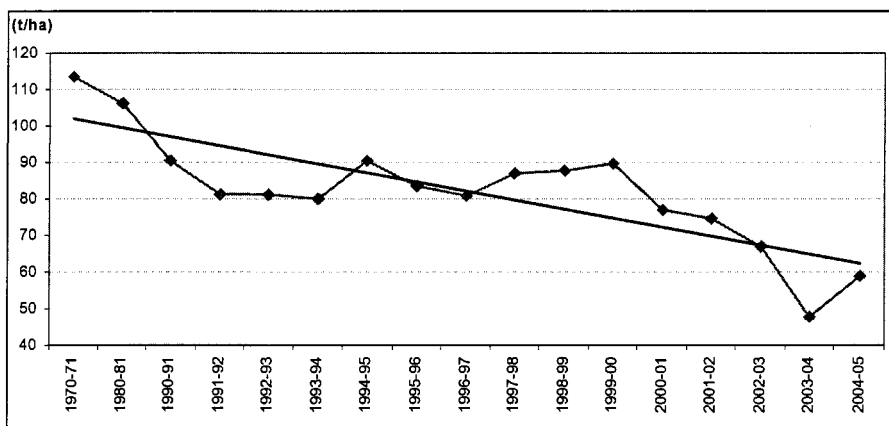
#### **4.5.1 Policy Assistance to Facilitate a Shift from Sugarcane Farming in Dryland Areas**

22. Sugarcane is generously subsidized and has done much to fuel rural prosperity among growers in Maharashtra. But its cultivation is also implicated in the overabstraction of groundwater. Though sugarcane is highly water intensive, requiring about 2,500 millimeters of water per hectare, it is grown on a vast scale in a region that is arid and has an average annual rainfall of 600 millimeters. Strong political support has seen the extension of irrigation command but these regions continue to need drinking water

tankers during droughts. The support policies for sugarcane are complex and include administered prices, a proposed export subsidy, and implicit support through negligible user charges for water abstraction. With much of the sugarcane being cultivated on large irrigated farms, the subsidy is regressive, accruing disproportionately to the larger farmers. Climate change projections suggest a sharp decline in future sugarcane yields, which will bring intense pressure on the government to increase or maintain current subsidies, with undesirable fiscal consequences.

23. There is evidence that natural resource degradation is beginning to undermine the short-term benefits of unsustainable irrigation practices. Increased shortage of water and soil degradation have led to a significant reduction in the output and yields of the crop. Throughout the state sugarcane output has fallen sharply since 1999, despite a marginal increase in the area under production. Yields per hectare have also fallen, a trend clearly visible in drought-prone districts such as Ahmednagar (figure 4.9). Farmers with limited water supplies have experienced declines in yield from 80 tonnes per hectare to 25–40 tonnes per hectare. A handful of forward-looking farmers and community-based organizations in western Maharashtra have begun to abandon cane cultivation in favor of rain-fed traditional crops and intercropping practices for soil regeneration.
24. Looking forward, climate change would reinforce the many benefits from encouraging a shift from sugarcane to less water-intensive crop choices. But this will require concerted policy action. Targeted research and extension is needed to explore the possibility of equally lucrative alternatives to sugarcane as well as to help farmers to minimize the risks of changes in cropping patterns. However, the outcomes of research are always uncertain, so there is no assurance that a profitable substitute to sugarcane can be found. The elimination or modification of subsidies may be required to induce the required shift in cropping patterns. But as elsewhere this would inevitably provoke considerable resistance from the current beneficiaries. So the use of interim smart subsidies may be needed to shift incentives and cropping patterns in ways that are better suited to the state's agroclimatic conditions. Experience elsewhere, including in the European Union, Australia, and New Zealand, has shown that gradual changes are more acceptable and reforms can be accelerated when accompanied by other forms of support that target more benign activities.

**Figure 4.9 Sugarcane Productivity Trend in Ahmednagar (Tonnes per Hectare)**



#### 4.5.2 Managing Groundwater Resources

25. As in Andhra Pradesh, integrated water management remains an overarching priority both for current and future agricultural development. Despite the projected increase in rainfall and runoff it is unlikely that water availability for agriculture will increase in the future with the growing demands of industry, demography, and expanding urban centers. Groundwater could play a major role in fueling sustainable rural economic growth. But for this to occur, abstractions need to be brought in line with recharge. The analysis in this report has shown that contrary to intent, groundwater dependence has failed to provide a buffer to many farmers in times of deficit rainfall. Unrestrained competition for groundwater has promoted water-intensive agriculture, leading to overabstraction and increased vulnerability to drought risks. For agriculture to become sustainable and drought resistant there is an urgent need to promote judicious water management, emphasizing both demand- and supply-side options.

#### **Box 4.5 Role of Community Institutions and Participatory Water Resource Management in Drought Adaptation**

Several landmark examples can be cited from Maharashtra of community-managed water resource management initiatives that have resulted in significant local benefits to communities, including improved natural resource management and livelihoods in low rainfall environments.

Located in Ahmednagar district, the village of Hiwre Bazaar is not covered by any major irrigation program; years ago, it was similar to thousands of other villages in the same block without access to any irrigation. However, effective watershed development and management over the last 15 years have transformed the earlier conditions and reaped positive developments in terms of ecosystem restoration (for example improved soil moisture content) and assured incomes from agriculture even during drought years. This has also reduced outward migration. The village has developed its own water regulations linked to its crop plans, which promote a mix of vegetable and millet crops. Annual decisions on cropping intensity ensure efficient management of the resource and its equitable distribution for crop growth.

In Korhate village in Nashik, water user associations (WUAs) administer water resource sharing for irrigation in major projects. Water allocations are entirely based on cropping patterns and associated volumetric allocations. The WUAs have been found to function effectively and to distribute water equitably, ensuring allocations to small and marginal farmers. Drip irrigation for horticulture crops is promoted. The government of Maharashtra further strengthened local bodies during 2005, empowering WUAs with full legal authority to manage water distribution, maintain irrigation channels, and resolve conflicts.

Initiated in the 1970s, the Pani Panchayat initiative in Pune district prioritized drinking water in the village and restricted the cultivation of water-intensive crops. There are currently 25 pani panchayat schemes in Maharashtra, based on either a groundwater or surface water communal source. Within a pani panchayat village, nearly a third of the village land is typically brought under the scheme, which is managed under the principles of delinking land and water rights and cultivation of only seasonal crops. Hydrological parameters, such as groundwater level or rainfall, are used to assess the amount of water that can be used during the year for crop irrigation. These schemes have survived several droughts successfully, but more recently there is evidence that some of these initiatives may be endangered by gradual overabstraction in the surrounding areas.

*Sources:* TERI 2007; DFID 2005a.

26. Solutions to the problem of groundwater overdraft are difficult to design and implement, as there are significant technical and institutional challenges in the management of groundwater at the higher aquifer or watershed levels where community-based management might occur. These include:
- Monitoring data are lacking and there are limitations in technical ability to quantify hydrological parameters such as flows, recharge, and water balance, which impede effective groundwater management. A wide array of watershed programs is in place across the country but their long-term impacts are poorly documented, including with respect to their ability to reverse the problem of groundwater overdraft.
  - The creation of institutions and organizations capable of functioning at the level necessary for aquifer management remains a challenge, and financing models for these local management institutions still remain elusive.
  - Despite fairly robust groundwater regulations, system managers have limited power to enforce regulations or penalties for violating the rules. So incentives for enforcing sustainability remain weak.
27. Recognizing these problems, numerous attempts are being piloted in Maharashtra to promote livelihood-focused adaptive approaches that provide community incentives to directly manage resources (box 4.5).

#### **4.5.3 Strengthened Integration with Ongoing State Programs**

28. There is potential in Maharashtra to build upon a wide range of relevant programs (box 4.6). But adaptive remedies and programs must endeavor to strengthen convergence with these ongoing programs to focus the impact of these programs on drought adaptation. For instance, the state has close to ten different watershed programs, each of which are implemented under a different set of guidelines and by different agencies. There is scope to integrate these guidelines into a unified framework for implementation to enhance outcomes with respect to financial allocation and institutions at various levels. The implementation of such programs can be encouraged by a consortium of organizations that have established models for scaling up innovative experiences in the states. Further, there is scope for enhancing synergies with the state Employment Guarantee Scheme (EGS) and the National Rural Employment Guarantee Scheme (NREGS) by integrating into the schemes a range of allied drought-proofing activities, including public works, the repair of tanks and community water storage facilities, land development, soil and water conservation, crop planning, and agroforestry.
29. Credit availability and poor marketing systems are crucial impediments to progress in drought-affected areas of Maharashtra. The small farmers remain dependent on moneylenders for routine credit required for inputs such as seeds, fertilizers, and pesticides. Efforts are needed to strengthen the availability of credit from public and private microfinance institutions to ensure effective access to credit. It is recognized, however, that several administrative bottlenecks impede effective access, as demonstrated in the low disbursement of the drought relief credit package announced by the government of Maharashtra for farmers in the Vidarbha region. But as suggested in the previous chapter, debt relief does little to tackle the root causes of the problem and needs to be accompanied by complementary mechanisms that provide incentives for income

diversification. So there remains scope to pilot schemes that lower the costs of job mobility and income diversification, especially among the poor and vulnerable.

#### **Box 4.6 Snapshot of Sectoral Programs in Maharashtra**

##### **Water Resource Programs**

Investment in irrigation infrastructure is large and growing, yet the irrigated area has stagnated at 16%. In addition, while irrigation potential has increased, actual reservoir storage has declined significantly, from 71% in 2000/1 to 59% during the peak drought year of 2003/4, primarily due to siltation, poor maintenance, and low rainfall. Funding is from a variety of sources, including through state government funds and centrally sponsored schemes, such as the Accelerated Irrigation Benefits Programme, the Command Area Development Programme, and the Rural Infrastructure Development Fund. The ongoing Maharashtra Water Sector Improvement Project is assisted by the World Bank.

##### **Watershed Programs**

There are close to ten central and state-sponsored watershed programs in the state, many of which operate in drought-prone areas. In addition, the newly formed Marathwada and Vidarbha Watershed Missions in Maharashtra aim to develop fallow and underdeveloped land and groundwater tables in rain-fed areas. In addition, a number of nongovernmental organizations, including the Water Organizations Trust, the Bharatiya Agro Industries Foundation, Marathwada Sheti Sahyog Mandal, and Action for Agricultural Renewal in Maharashtra run their own watershed programs in limited pockets. The watershed programs include measures such as improved surface runoff collection structures, better groundwater recharge, drainage line treatment, and increases in vegetation cover.

##### **Agriculture**

Developing drought-resistant varieties has not been a major initiative of the Department of Agriculture. However, dryland horticulture (fruit crops requiring less water) has been promoted with some success by the Horticulture Development Programme and is linked with the state Employment Guarantee Scheme. Since 2005/6 this state-sponsored scheme has been merged with the National Horticulture Mission, with funding being shared with the central and state funds. The district-level agricultural technology management agencies responsible for decentralized program planning provide a useful vehicle for linkages and promotion of innovative activities.

##### **Rural Livelihoods**

Swarnajayanti Gram Swarozgar Yojana is the single unified centrally sponsored self-employment program for nonfarm-based livelihoods. It aims to establish a large number of sustainable micro-enterprises. The program targets families in rural areas that live below the poverty line, providing them with income-generating assets through a mix of bank credit and governmental subsidy.

## **5. Climate Variability and Change: A Case Study in Flood-Prone Orissa**

### **5.1 Introduction and Background**

1. Floods are a natural feature of India's river basins. Seasonal floods are necessary to support agriculture, deliver topsoil and nutrients to farmland in otherwise infertile regions, sustain valuable ecosystems, and contribute to groundwater replenishment. But excessive flooding comes at a considerable cost and causes great havoc and damage. Floods are a major contributor to the poverty and vulnerability of communities.
2. It is estimated that about 12% of India's geographic area (40 million hectares) is affected by floods.<sup>45</sup> This is almost double the estimated 19 million hectares affected by floods in India about five decades ago. This has occurred despite rising government spending on flood protection, which has increased dramatically from Rs 0.13 million in the First Five Year Plan (1951–1956) to Rs 106 billion in the Tenth Five Year Plan (2002–2007), while 39% (15.8 million hectares) of flood-prone land is protected with embankments, drainage channels, bunds, and similar structures (Sekhar 2007; Planning Commission 2002). Yet frequent breaches of embankments and other protective structures are a common occurrence.
3. Orissa is among the most flood-affected states in the country and is the focus of this chapter.<sup>46</sup> The chapter examines the impact of floods on selected districts in Orissa and explores the consequences of climate change and variability for agriculture. The assessment is in two districts: Jagatsinghpur and Puri. The analysis draws upon field surveys and future climate projections derived using the IMS described in chapter 2 and appendix A.

### **5.2 Characteristics of Study Area**

#### **5.2.1 Climate and Geography**

4. Orissa is located in eastern India, with a coastline that extends over 480 kilometers. Its geography has rendered it highly vulnerable to natural calamities and extreme weather events such as cyclones, droughts, floods, and storm surges. Between 1965 and 2006, the state experienced about 17 droughts, over 20 floods, 8 cyclones, and a super cyclone in 1999, which had devastating consequences.<sup>47</sup> To compound these problems, there are years in which the state simultaneously endures droughts and extensive floods.
5. The state's population of 37 million resides mainly in rural areas (85%), with a large population of marginal farmers. The average size of landholdings is less than 1 acre (0.4 hectare). The main crop is rice, often grown in a two-crop combination with oilseeds,

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<sup>45</sup> According to the National Flood Commission (Rashtriya Barh Ayog) this estimate reflects the maximum flood-affected area.

<sup>46</sup> The focus on floods and not on other natural disasters such as cyclonic storms, which are also frequent in this state, emanated from the consultative process, as noted in chapter 1. After all, cyclones tend to lead to flooding and are, therefore, regarded as being part of the flood dimension rather than separate from it.

<sup>47</sup> Data compiled from the International Disaster Database (<http://www.em-dat.net/>) and TERI 2006.

pulses, groundnut and jute. The state is located within the Mahanadi basin, which drains about 42% of its total area. Large tracts of cultivated land in the state have no access to irrigation, with 75% of the cultivated area being rainfall dependent. Of the state's territory, 21% (3.34 million hectares) is considered flood prone (Government of Orissa 2006c).<sup>48</sup> The population most affected by floods is in the diara lands of the deltaic region and other low-lying areas.

6. Assessing the full impact of floods on communities is a challenging exercise. There are both direct and indirect costs associated with flooding. The direct costs are closely connected to a flood event: the magnitude, extent, and duration determine the resulting physical damage. By contrast, indirect costs are incurred over an extended time period in the aftermath of a flood. They include loss of opportunity, reduction in property values, foregone tax revenue, and disturbance to ecosystems. Measuring these is more difficult.<sup>49</sup> The focus here is on the direct costs, but even for these more visible impacts accurate measurements remain elusive and are difficult to verify against actual expenditures and losses.
7. Table 5.1 shows that the extent of flood damage in Orissa has varied greatly from year to year. A feature of the flood damage is that public property losses are far greater than either agricultural or private property losses. This suggests scope for better protection of public assets through improved planning and climate risk assessments, an issue that is addressed later in this chapter.

### **5.2.2 Anatomy of the Sample Villages**

8. The choice of districts selected for this case study is based on a vulnerability profile developed for the state, which found the districts of Puri and Jagatsinghpur to be especially susceptible to the impacts of climate change because of the regular occurrence of floods (see appendix B for details). The districts are located on the state's eastern coast. Puri has a long coastline of 155 kilometers, which is almost twice that of Jagatsinghpur. Both districts are very similar in terms of socioeconomic indicators (table 5.2). Puri has an average annual rainfall of 1,449 millimeters per year compared to Jagatsinghpur's slightly higher average of 1,501 millimeters per year. For the purposes of this case study, three villages were selected from each district (see figures 5.1 and 5.2 for location).<sup>50</sup>

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<sup>48</sup> Of these flood-prone areas, 75% spread across eight coastal districts; Cuttack, Kendrapara, Jagatsinghpur, Puri, Balasore, Bhadrak, Jeypore, and Ganjam.

<sup>49</sup> This is because it requires modeling hypothetical scenarios that would have eventuated in the absence of floods.

<sup>50</sup> The villages are Naugaon, Tarasahi, and Sunadiakandha in Jagatsinghpur; and Raibidhar, Gadasampat, and Deipur in Puri. In these villages surveys using stratified sampling were conducted to inventory the existing coping strategies and to assess adapting capacities and vulnerability of communities across villages and landholding categories.

**Table 5.1 Floods and Resulting Damage in Orissa 2001–2007**

	Year				
	2001/2	2003/4	2004/5	2005/6	2006/7 <sup>a</sup>
<b>Administrative areas/population affected</b>					
Number of districts	24	27	5	14	–
Number of blocks	219	230	20	72	–
Number of villages	18,790	13,404	564	4,318	22,381
Population affected (million)	9.68	7.62	0.31	1.91	8.06
<b>Physical losses and damages</b>					
Number of human lives lost	102	93	10	10	90
Number of livestock lost	18,149	2,956	–	–	1,656
Crop area affected ('000 ha)	799	1,490	37	94	309
Number of houses damaged	187,575	185,483	2,097	18,099	120,446
<b>Financial loss (Rs million)</b>					
Crop loss	667	2,538	79	–	–
Private property loss	564	633	5	–	–
Public property loss	8,834	11,937	662	2,434	–
<b>Total</b>	<b>10,065</b>	<b>15,108</b>	<b>746</b>	<b>2,434</b>	<b>–</b>

– Not available.

a. At the time of writing no figures were available for several of the categories in the 2006/7 period.

*Sources:* Memoranda on floods for various years submitted by Government of Orissa to Government of India, and annual reports on natural calamities of the special relief commissioner for the years cited.

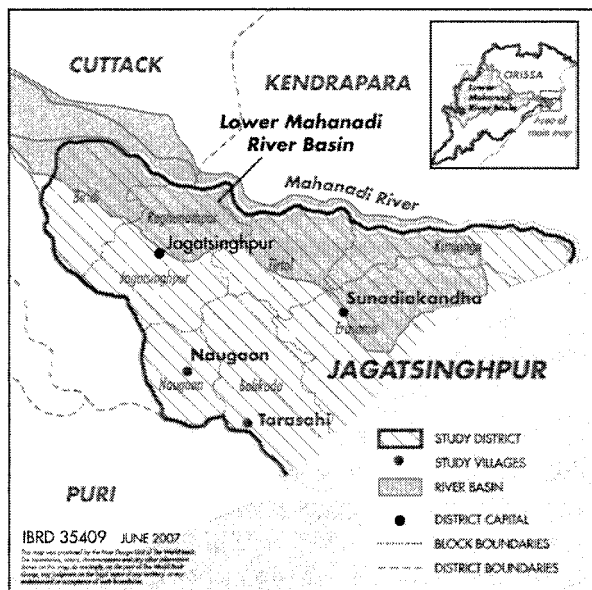
**Table 5.2 Socioeconomic Characteristics of Puri and Jagatsinghpur Districts Compared to Orissa State**

Indicator	Orissa	Jagatsinghpur	Puri
Total area (million ha)	15.6	0.19	0.14
Total population (million)	36.8	1.1	1.5
Rural population (as % of total)	85	86	87
Population growth rate (% , 1991–2001)	15.94	13.15	14.8
Literacy rate (% of total)	63	79	78
Normal rainfall (mm/yr)	1,482	1,501	1,449
Gross irrigated area (% , 2004/5)	34.5	52	40
Main crops grown	Rice, pulses, oilseeds	Rice, pulses, groundnut	Rice, groundnut, millets

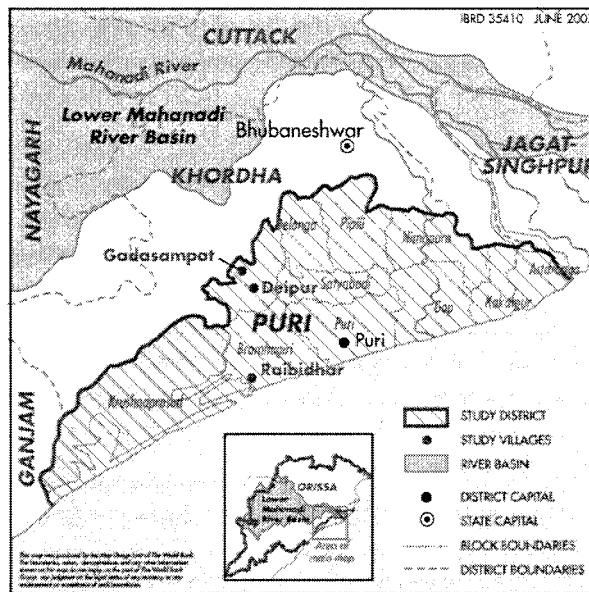
*Sources:* Government of Orissa 2001a, 2002a, 2005a; Government of India 2004.



**Figure 5.1 Location of Study Villages in Jagatsinghpur District**



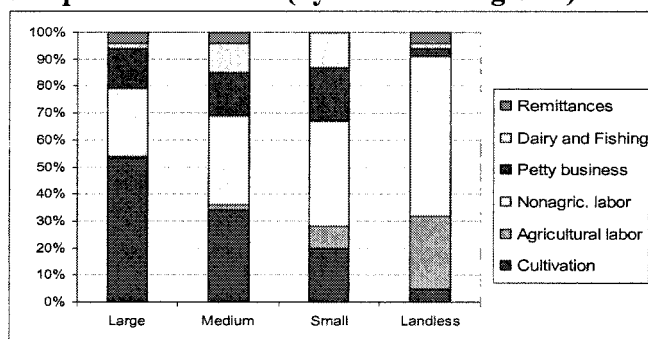
**Figure 5.2 Location of Study Villages in Puri District**



### 5.3 Impacts of Floods

9. **Evidence of preadaptation to floods.** Households in these villages are accustomed to floods. Contrary to what is observed in most rural districts, agriculture is not the primary source of income in the study area. Livelihoods and occupations have responded and adjusted to the predictability of floods. In Puri 54% of income is derived from nonagricultural sources, and in Jagatsinghpur the figure is higher at 70%. In addition to casual nonskilled labor, aquaculture, fishing, dairy, and petty business are the main nonagricultural activities in which households engage. Many of these initiatives have flourished because of the proactive interventions of community groups (including self-help groups) and the state government, but the scale of these activities is still minor. Figure 5.3 summarizes the sources of income. Large landholders remain the most dependent on agricultural sources of income, mostly from cultivation. The landless and marginal farmers earn the bulk of their income from casual labor.

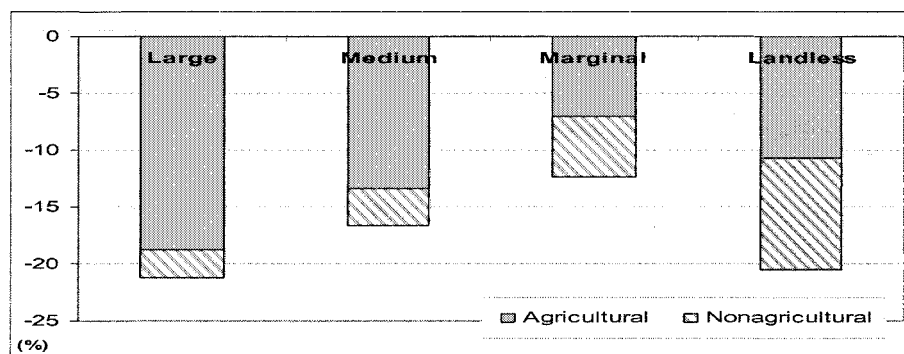
**Figure 5.3 Average Percentage of Sources of Income in Total Monthly Income in Sampled Households (by Landholding Size)**



Source: World Bank calculations from TERI survey data.  
Sample size: 552

10. **Volatility of incomes.** Figure 5.4 depicts the impact of the 2003/4 flood on households, illustrating vulnerabilities across sources of income. Large farmers and the landless suffer the greatest reduction in their incomes. For the large farmers, this reflects their heavy reliance on agriculture and rainfall-dependent sources of income. There are also differences in the impact of floods on nonagricultural incomes across landholding size. The nonagricultural incomes of the marginal farmers and the landless register the largest decline after a flood, reflecting their fragile economic status, typically as unskilled casual laborers with little job security. In policy terms, it suggests the need for greater attention to these vulnerable groups.

**Figure 5.4 Changes in Agricultural and Nonagricultural Incomes as a Result of a Flood Event**



Source: World Bank calculations from survey data. Sample size: 552

11. **Impacts on agriculture.** Looking more closely at damage to agriculture, rice in the flood-prone kharif season is hit hard by inundation; production declined by 67% in the flood year (table 5.3). A direct consequence of the drop in agricultural output is that agricultural incomes in the surveyed households are reduced, on average, by about 20%. However, floods boost productivity in the rabi season as a result of increased soil moisture and fertility; consequently, there is a growing emphasis towards more intensive cultivation during the rabi season.

**Table 5.3 Average Seasonal Crop Production in the Surveyed Households**

Season	Crop	Normal year (2005/6)		Flood year (2003/4)	% Change in average production
		Average (kg)	production	Average production (kg)	
Kharif (June–October)	Rice	2,739		893	-67
Rabi (November–April)	Rice	4,863		4,580	-6
	Groundnut	1,211		1,381	14
	Black gram	273		215	-21
	Parbal	1,380		1,560	13
	Vegetables	930		975	4
	Green gram	317		350	10

Note: Total production (kg) = number of bags x size of bags (kg). Sample size: 552

Source: TERI 2006.

12. **Broader impacts of flood.** The effects of floods go beyond economic and financial hardship. Data from both districts show that the health of the population is considerably affected by floods: a large number of households (59%) report a higher incidence of sickness due to water-borne diseases as a result of flooding. The incidence is reported to be higher in Jagatsinghpur (67%), which is more prone to waterlogging because of its low-lying geography, than in Puri (59%). As a result, health expenditures increase by 15%, with the medium farmers and the landless being worst affected. With lower incomes, it is unsurprising that expenditure on food declines, on average, by 6%.
13. Education is also disrupted by floods in two ways: children are either forced out of school to engage in work to supplement the household income or they cannot attend because school facilities suffer damages. Of the population surveyed, 27% reported that their children drop out of school following a flood event. In addition, flooding forces people to abandon their homes (48%). Forced migration to towns in search of alternative sources of employment is another consequence of natural disasters (9% of the sampled population). Box 5.1 describes strategies followed in the study areas to cope with floods.

#### **Box 5.1 Flood Coping Strategies in Study Area**

**Income diversification** away from agriculture appears to provide a robust way of ameliorating flood impacts. But in addition to this, households adopt a host of strategies to ameliorate the effects of floods:

**Proactive approaches**, which anticipate future costs and are designed to avoid or prevent damages. Strategies reported by the surveyed households include:

- Safe storage of food grains in houses or public shelters (37% of households);
- Construction of special facilities for grain storage, for example high shelves (22% of households);
- Crop insurance, largely concentrated among large landholders, reflecting their greater purchasing power and need to protect assets of higher value (20% of households);
- Floodproofing dwellings (16% of households).

**Reactive measures** attempt to ease the immediate impact and cost of flood damage:

- The most common measure reported was borrowing of money through credit or loans (reported by 54% of sampled households). Of these, 48% come from formal credit sources such as banks and cooperatives. This is likely a consequence of the existence of farmers' cooperatives and government programs that have been established to address rural poverty and disaster management in Orissa. The success of these initiatives is further indicated by the fact that access to credit is relatively evenly distributed across all landholdings (see table below). The fact that 53% of large farmers do not borrow, compared to about 34% of medium, marginal, and landless, speaks to the fact that large farmers have more assets and a wider set of options to rely on in times of crisis than do their less fortunate counterparts.
- Distress sales of cattle and jewelry (15% of households) constituted another reactive measure and was largely concentrated among the landless and medium farmers.

<b>Distribution of Credit across Landholding Size</b>					
<b>Source of credit</b>	<b>Large</b>	<b>Medium</b>	<b>Small</b>	<b>Marginal</b>	<b>Total (% of households)</b>
Informal (%)	6.4	6.0	3.9	3.9	7.1
Formal (%)	40.0	57.3	62.7	62.7	49.1
No loan (%)	53.6	36.7	33.3	33.3	43.8

Sample size: 552

## **5.4 Future Prospects under Climate Change**

14. Turning to the future, the IMS projects the impacts that a changing climate may have on the agricultural sector. The projections are for the lower Mahanadi basin in the A2 and B2 scenarios. The basin-level projections are illustrated in figure 5.4.

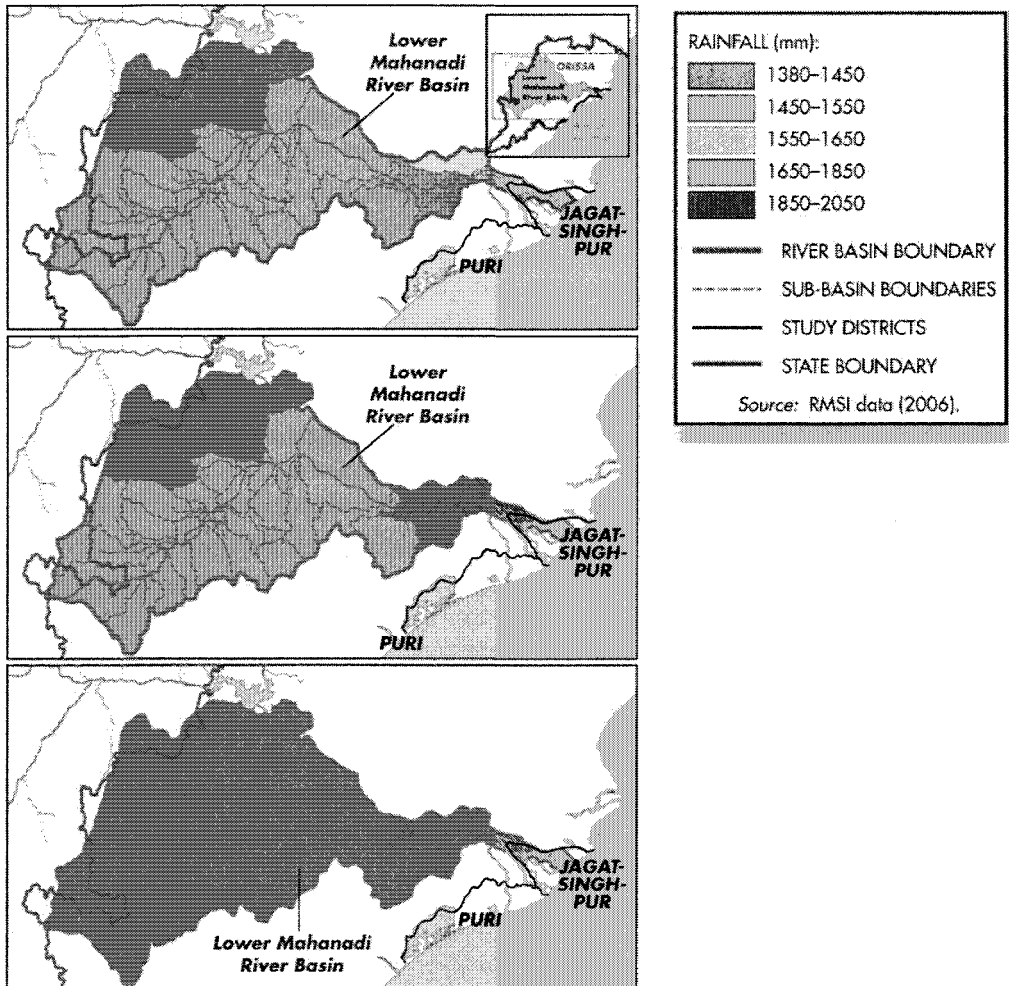
### **5.4.1 Projections of Climate Change**

15. The model projections indicate:

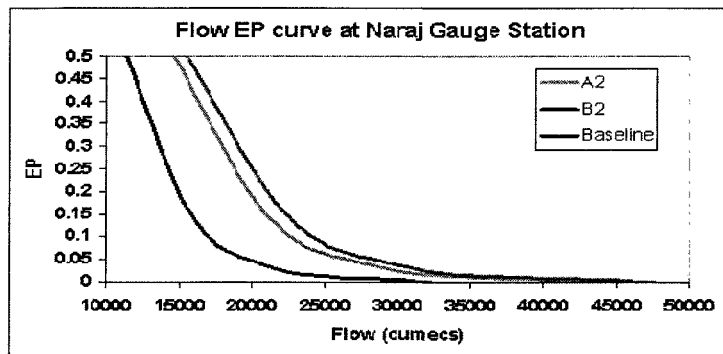
- In the coastal districts located on the deltaic area the model projects a 23% increase, on average, in the annual mean rainfall in A2 and 19% in B2 (see appendix H).
- A projected shift in the monthly rainfall patterns, with more rainfall in the already wetter months of May and July (kharif planting season), and less rainfall from October to December (rabi). The implication is clear – heightened flood risks in the kharif season in the six districts studied.
- There are also important changes in the spatial distribution of rainfall, as the central section of the basin becomes somewhat drier but the already flood-prone areas on the coast will receive more rain.
- At the district level, average annual maximum temperatures are expected to increase in both scenarios by between 2.4°C and 3.7°C, but in A2 the increase is more pronounced than in B2. Minimum temperatures are projected to increase by an even greater amount – as much as 4.2°C in A2.

16. The assessment suggests that the probability of flood frequency and its intensity could increase dramatically. The hydrological model projects daily outflow discharges at a gauge station (located in Naraj northwest of Jagatsinghpur and Puri). The results show that in the A2 and B2 scenarios, the probability of flooding will increase substantially. As an example of the implied magnitudes, the probability that the discharge might exceed, say, 25,000 cumecs (cubic meters per second) is low (about two to three times in 100 events) in the baseline. But under climate change, this is projected to rise to about ten times in every 100 events (figure 5.6). Changes of this scale will have significant implications for the type and location of hydrological infrastructure that will be needed to protect communities and their assets and highlight the need for better forecasting tools to identify priorities for structural interventions.

**Figure 5.5 Spatial Distribution of Average Annual Rainfall in Lower Mahanadi Basin (Baseline and Climate Change Scenarios)**



**Figure 5.6 Exceedance Probability Curves for Annual Peak Flows at Naraj Gauge Station**

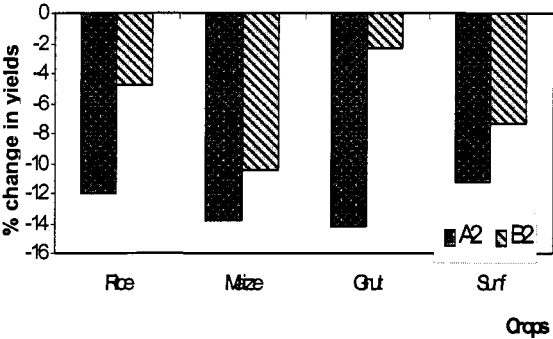


Source: RMSI calculations, 2006.

**5.4.2 Crop Responses to Climate Change**

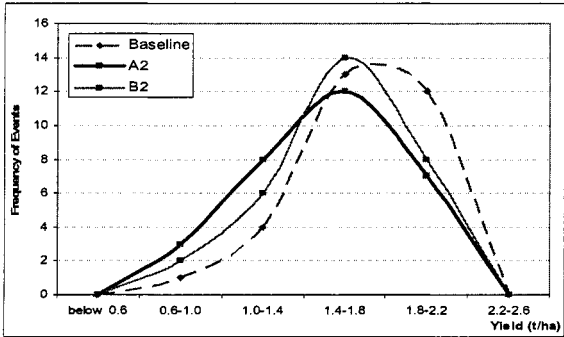
- 17. To determine how climate change may affect agriculture it is instructive to distinguish the influence of climate (the flood event) from other possible changes in the economy and in agricultural practices. Increases in flood damage due to changes in climate might require different remedies from damage due to changes in economic activity. Accordingly the results presented in this section investigate scenarios with changes in climate, holding economic and technological factors at their baseline levels.
- 18. To compare future impacts on agriculture, four crops were selected: rice, groundnut, maize, and sunflower. These crops collectively account for almost 70% of the agricultural output in six coastal districts, with rice accounting for the largest proportion. Projections were run to predict yields for these crops in both districts. For brevity, the focus is on Puri, as the pattern is very similar to that in other areas in the study.
- 19. In the baseline the typical farm grows rice because of its suitability to the climate. Under climate change the results show that yields of all crops suffer a decline in both the A2 and B2 scenarios, but the extent of the decline is less in B2 than in A2, given the milder nature of the changes in temperature and rainfall (figure 5.7a). Figure 5.7b illustrates the distribution of rice yields under climate change. It shows that climate scenarios that are unfavorable to rice yields emerge more frequently, whereas climate events that generate high yields become less common.

**Figure 5.7a Yield Changes in A2 and B2 by Crop, Puri District**



Source: RMSI 2006b.

**Figure 5.7b Distribution of Yields under Climate Change, Puri District**

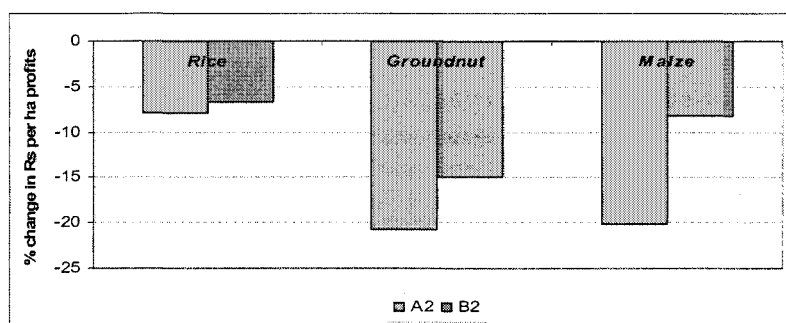


Source: World Bank calculations.

**5.4.3 Projected Consequences of Climate Change**

- 20. Overall, groundnut, a crop that is usually grown in arid regions, is expected to be hit hardest, followed by maize (which is dependent on soil moisture, but also needs time to dry), rice, and sunflower (which needs moist soil, but also full sun to grow optimally). The economic model estimates that the decline in yields leads to a reduction in farmer profits, as illustrated in figure 5.8. Since the area is dominated by rice, which is among the most flood resistant of crops, there is little that farmers can do to shift planting patterns, suggesting that the prospects for agriculture in the region may deteriorate under climate change. Climate change consequently reinforces the benefits that would accrue from further income diversification.

**Figure 5.8 Impact of Climate Change on Farmer Profits Derived from Selected Crops, Puri District**



## 5.5 Policy Implications

21. Against a background of more intense and frequent flood risks, it is necessary to ask whether current policies and institutional structures will provide effective protection to vulnerable communities. Orissa, like other states in India, has achieved remarkable success in countering the most extreme effects of floods (Dreze and Sen 1989). When floods strike, an elaborate relief machinery comes into operation with rapidly arranged protective polices, including employment schemes, cash and food disbursements, health care, and shelter (box 5.2).

### 5.5.1 Fiscal burden

22. Disaster relief is a high policy priority for the state government, but it comes at a substantial price on the public purse. With the frequency of natural disasters, Orissa spends more on relief and damages than on planned sectoral and departmental schemes in the rural sector (GoO 2003a-c, 2004, 2005a-b 2006a). Tables 5.4a and 5.4b show that the cost of relief in just four years exceeded that of development expenditures for selected major sectoral programs delivered through the Tenth Five Year Plan. The fiscal strain is substantial since central government reimbursements against flood relief are usually lower than the requests for assistance.

### 5.5.2 Flood management system

23. Reflecting the importance given to climate disasters, administrative oversight resides in the highest political office in the state – the chief minister and the ministerial cabinet. Implementation is left to various departments under an elaborate organizational structure. The main thrust of the flood management system is on two issues: relief and protection. The relief mechanisms are comprehensive and are judged effective. Similarly, there is a wide-ranging action plan prepared by the Water Resources Department envisioning a host of structural measures, including dam construction, raising and strengthening of embankments, and interbasin transfer of water. Though most state government resources are spent on structural measures, there are also nonstructural initiatives for flood management either planned or under way in Orissa. These include legal measures, flood plain zoning, institutional coordination, drainage plans, and the use of satellite maps (box 5.2). However, as tables 5.4 a and b show, the state is not fully utilizing its outlays planned for either sectoral programs or relief. These funds could therefore be earmarked for adaptation programs.

### **Box 5.2 Flood Management in Orissa**

Orissa has a complex flood management system. The state Flood Management Organization in Orissa is headed by the revenue minister, who controls statewide flood management and relief operations. The Orissa State Disaster Management Agency oversees relief operations and the special relief commissioner, Revenue Department, is in charge of coordinating flood relief activities in the state. The Revenue Department coordinates with a host of other state departments. The district-level heads, the collectors, directly monitor and operate the flood management system and relief works. Likewise there are complex flood reporting protocols involving numerous agencies.

#### **Relief**

The relief system is comprehensive and comprises: (a) evacuation services; (b) the assessment of crop loss and other damages; (c) housing and the provision of other financial assistance in specially deserving cases; (d) health services; (e) drinking water supply; (f) employment; (g) the provision of free food, polythene, and kerosene; (h) emergency facilities to preserve animal welfare, such as cattle camps, provision of fodder, veterinary treatment, and vaccination; and (g) furnishment of daily situation reports to the regional divisional commissioner and the special relief commissioner until the danger is over.

#### **Nonstructural Measures for Flood Management in Orissa**

- **Legal measures.** The oldest form of nonstructural flood management measures is the legislation that has been enacted over the years, from the Bengal Embankment Act of 1882, which provided for the construction, maintenance, and management of embankments and watercourses and gave powers to the collector to move any obstruction to general drainage or flood drainage in any tract of land, to the Orissa Gram Panchayat Act of 1965, which requires gram panchayats to construct, maintain, and clean drains and drainage works.
- **Flood plain zoning.** Recognizing zoning as an important strategy for flood management, the Government of Orissa has constituted a subcommittee to finalize a draft flood plain zoning bill.
- **Institutional coordination.** The Orissa State Disaster Management Agency, as the nodal agency for coordination and preparedness, coordinates across government agencies during flood preparation, forms community disaster management committees at village, block, and district levels, promotes community-based disaster preparedness through participatory planning, roles and responsibility distribution, and coordination with different departments at different levels, maintains communication networks, keeps ready the Orissa Disaster Rapid Action Force, and develops and maintains rescue, shelter, and storage infrastructure at village level.
- **Watershed programs.** Watershed development programs are currently not focused on flood management but rather may achieve some part of this as a by-product. The Orissa Watershed Development Mission, an independent agency under the Department of Agriculture, is responsible for planning, implementing, and monitoring all programs in the state.
- **Master plan for drainage clearance** in 17 doabs of Orissa's coastal belt has been prepared.
- **Satellite imagery.** The Orissa State Remote Sensing Application Centre has several satellite-based images and maps, but basic flood inundation maps are still not available.



**Table 5.4a Orissa: Outlays and Expenditures for Sectoral Programs 2002–2007 (Rs billion)****Table 5.4b Orissa: Allocation and Expenditures for Drought and Flood Relief 2002–2006 (Rs billion)**

Tenth Five Year Plan (2002–2007)	Outlay	Expenditure	Drought and flood relief (by year)	Allocation	Expenditure <sup>a</sup>
Agriculture and allied activities, forest	7.98	2.69	2002/3	20.34	18.02
Rural development	8.98	7.96	2003/4	27.41	21.49
Special area programs	16.92	18.80	2004/5	26.41	23.60
Irrigation, flood control	39.92	24.42	2005/6	31.80	3.65
<b>Total</b>	<b>73.79</b>	<b>53.87</b>		<b>105.96</b>	<b>66.77</b>

a. Figures for 2002/3 and 2003/4 are actual expenditures; for 2004/5, the figure is provisional; for 2005/6 it is an average estimate.

Sources: 5.4a: Economic Survey of Orissa, 2004/5 and 2005/6; 5.4b: GoO, 2006a.

24. The current emphasis on relief and structural solutions is necessary, but not sufficient to build flood resilience. Relief is an essential part of flood policy and is needed to alleviate suffering and distress. But it is limited in its effectiveness, as it does not address one of the root causes of vulnerability – the exposure to climate risks. With climate change projected to bring far greater flood risk, the already high costs of relief could rise dramatically. More importantly, an overemphasis on relief could blunt incentives to shift to more climate-resilient activities and prolong dependence on flood-sensitive livelihoods.
25. Structural solutions are also necessary, but are seldom sufficient to assure full protection. History shows that the public (rather than decision makers) tends to become complacent about the level of protection that any engineering solution can provide. Structural measures can never offer complete safety, for all possible events, so residual risks on the community will remain. With climate change and the expectation of more extreme events, these risks will increase over time. This suggests that there is a need to complement structural and relief solutions with policies that build community resilience to floods.
26. Experience elsewhere suggests that a comprehensive and effective flood management strategy must include a suitable combination of reactive measures (relief), proactive interventions (both structural and nonstructural measures), and economic policies designed to build flood resilience and lower exposure to flood risks. Countries such as Argentina, China, Poland, and Turkey have struggled for decades with recurrent floods and have addressed the problem by undertaking a systematic series of investments in all these areas (box 5.3).

### **Box 5.3 Poland Flood Emergency Project (1997–2005): Good Practice in Nonstructural Measures for Flood Management**

The Flood Emergency Project was implemented following the 1997 flood in the Odra River basin, which entailed costs of US\$2.3 billion and the loss of 57 lives. The project's main objective was to increase flood preparedness and management in Poland through the modernization and expansion of the country's flood forecasting and warning system which, after the completion of the project, became one of the most modern in the world.

A subcomponent on basin flood management planning calls for updating and developing new basin management strategies and plans, with an emphasis on economic assessment of flood hazard and formulation of alternatives for different levels of protection, including structural and nonstructural options. Three regional coordination and information centers were established at Krakow, Wroclaw, and Gliwiceby, and an advanced database, using remote sensing data, enabled hydraulic modeling of flood plains and the generation of flood hazard maps, contributing to the development of early warning systems and the preparation of flood protection measures.

Local flood loss reduction and flood prevention plans, including postdisaster components, were also prepared and implemented in 12 territorial self-government units by local governments and residents, with the support of technical support units. Cofinancing for reconstruction of hydraulic structures was provided to eight municipalities.

The project included elements that were (a) proactive, including restrictions on flood plain development, preparation of a handbook on flood mitigation measures, and refinement of early warning systems; and (b) reactive, including the putting in place of rescue and evacuation plans.

A basin approach to water management, consistent with the European Union's Water Framework Directive, was strengthened under the project. The Odra River Basin Flood Protection Project (2007–2014), which aims to protect over 2.5 million people against loss of life or damage to property caused by severe flooding, will build on the achievements and experience of its predecessor.

*Source:* World Bank 2006a.

#### **5.5.3 Elements of a Strengthened Strategy**

27. The current system in Orissa provide a strong foundation upon which to build a strengthened flood management strategy that is capable of meeting the challenge of more frequent and intensifying floods. There would be three components, all designed to build flood resilience and mitigate damage through an integrated flood management plan. The components are:

- Advanced systems for **the detection and forecasting** of floods;
- **Anticipatory and proactive** actions designed to minimize flood risks and build capacity to withstand flood events;
- **Reactive actions** that deal with the aftermath of floods and include compensation and relief.

#### ***Strengthening Systems for Detection and Forecasting***

28. Climate change projections suggest that there will be changes in the spatial distribution, intensity, and frequency of floods. Advanced forecasting and risk diagnostic tools will be needed to guide investments in high-value flood protection assets. The current forecasting system for the seven flood-prone basins of the state are in need of upgrading and

improvement to match the scale of risks that climate change could bring. The forecasting authority (Central Water Commission) employs a single hydrograph for a very large basin and uses an insufficient number of forecast points. The system's effectiveness could be enhanced by combining data collection, telemetry, flood forecasting, and flood warning elements into one integrated flood management and information system for the basin.<sup>51</sup> Flood inundation mapping is another important planning tool and provides local authorities with important information for emergency flood responses. Generating such data for the Mahanadi delta area should be a priority for the Government of Orissa.

### ***Strengthening Anticipatory Measures***

29. Although technology can help detect and even forecast floods in a timely way, the information needs to be integrated into planning and policy for longer-term measures that reduce (a) the magnitude of the flood; and (b) vulnerability to a flood of any given magnitude.
30. **The assault on floods: importance of structural protection.** Any improvements made to existing facilities, or construction of new ones, will need to take into account the prospect of more intense flooding and spatial shifts in flood incidence. Improvements (where needed) and expansion (where possible) of flood control infrastructure are vital in reducing flood damage. The Government of Orissa has been prudent in recognizing that absolute protection to all flood areas, for all magnitudes of floods and for different probabilities of occurrence, is neither possible nor economic. Economic considerations argue for an emphasis towards the protection of the higher-value assets (for example urban areas, infrastructure), with greater importance given to building adaptability and flood resilience elsewhere. So careful monitoring and planning of new settlements in these flood-prone areas needs to remain a priority for government authorities.
31. **The accommodation of floods: Importance of nonstructural resilience building.**<sup>52</sup> A number of measures may be considered within this context:
  - **Agricultural adaptation.** Flood-resilient agriculture provides a way to insulate incomes against flood damage. Numerous pilots have been attempted with more rainfall-tolerant or short-duration varieties of certain crops to minimize flood-related losses. Though economically viable solutions remain elusive, these initiatives have potential and warrant continued support, as the benefits from research and extension are always uncertain and take time to produce results. A greater emphasis on *rabi* cultivation could be further facilitated by improving irrigation access in the drier months.
  - **Economic instruments.** For those with few or no assets, who depend on agricultural wages, the situation is more challenging. The economic instruments that are relevant for encouraging income diversification for drought management – such as credit and insurance schemes linked to job diversification – are equally

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<sup>51</sup> As an example the Hirakud Dam, which is the main control structure on the Mahanadi, was originally designed for a flood of 42,500 cumecs, whereas more recent calculations indicate that the maximum probable flood is 69,500 cumecs. Therefore, floods need to be partially regulated by advance reservoir depletion, which in turn calls for a basinwide flood forecasting system.

<sup>52</sup> Many of the arguments presented here echo and extend those in World Bank 2007a.

pertinent in the context of floods. The spread of self-help groups in Orissa provides a potential community base for launching such schemes.

- **Income diversification.** There are already numerous and successful pilots in Orissa that aim to promote flood-based livelihoods. This is the quintessential form of flood adaptation. Aquaculture is one option with considerable promise for unleashing rural growth. With the escalating demand for fish in India, and across the world, there is scope to increase aquaculture production in flood-prone areas. But for this to eventuate, two obstacles need to be addressed. First, research and extension on biological sustainability, environmental impacts (externalities), fish productivity, and the choice of species is in its infancy and requires considerable further investment. A second and more important constraint arises from the outdated marketing system for perishables. Investments in addressing both the research and supply chain obstacles are obvious policy priorities for the flood-prone regions.
- **The primacy of planning and zoning.** With the pressures of rapid population growth and land scarcity coupled with intensifying flood risks there is a need for better and more careful planning and flood zoning. Land use planning and water management need to be combined into a synthesized plan and call for coordination between various departments and levels of government. A greater challenge is the implementation of a plan that would affect many interests and would need processes that involve public participation and stakeholder engagement.
- **Improved watershed programs.** Watershed development programs should take into account flood management as an explicit design practice. International experience shows that planning watersheds upstream in the river basin can significantly contribute to improved flood management.

#### 5.5.4 Reactive Strategies

32. In terms of reactive policies, India has established disaster relief systems that are among the most comprehensive in the world (box 5.2). Their effectiveness could be improved through further fine tuning. But ultimately adapting to floods remains the most sustainable and effective way to protect communities and harness rural growth. Improvements in the relief system might include the following:

- Improved training of panchayats and communities in flood preparedness. Community contingency plans for relief have been prepared through government initiatives but in many cases the plans have not been updated and have lost their relevance as circumstances change.
- There is a gap between what is being planned for relief and what is being implemented on the ground (for example, what medical facilities are provided), largely due to poor accountability and monitoring of relief work.
- The protection of critical infrastructure and shelters, surprisingly, does not figure in the list of disaster preparedness actions at the state, district, or subdistrict levels. Safe shelters have been constructed in the coastal belt primarily to protect the coastal communities against cyclones, not floods. The maintenance and effectiveness of these shelters are therefore a concern.

## 6. A Way Forward

1. India has achieved impressive economic growth in the past decade but its farm sector has languished, with stagnating yields, low productivity, and pockets of poverty and indebtedness. Aware of the growing disparity between agrarian and industrial India, the government has assigned the highest priority to revitalize the farm sector to its fullest potential in the Eleventh Five Year Plan period (2007–2012). Targeted growth of 4% per year in the agricultural sector is deemed necessary to achieve the aims of poverty reduction, inclusiveness, and increased income opportunities, with a special focus on rain-fed areas. But this is a challenging task and is made more so by the impacts and consequences of ongoing and future climate variability and change.
2. There is a litany of factors that account for agriculture's slow growth. These include fragmented landholdings, prevalence of subsistence and marginal farming, inadequate levels of technology, poor market access, and a shrinking natural resource base, endangering agricultural productivity and farm livelihoods across India. Added to this, projections indicate that climate variability and change will be characterized by more frequent and severe droughts and floods, posing significant economic, environmental, and social risks. Since 60% of India's workforce depends on agriculture and natural resources for livelihood, employment, and income, they are highly vulnerable to future climate risks and have limited adaptive capacity to effectively deal with the increasing unpredictability of climate change.
3. Delivering on the promise of faster and more inclusive growth will therefore require investment strategies that more effectively capture the potential effects of future climate trends and are accompanied by a portfolio of adaptation options that can diminish the associated risks. Living up to this commitment will require proactive and integrated tools, and interventions and policy measures, that are specifically targeted and tailored to the high-risk and vulnerable areas. Improvements in institutional capacities must also be met at an equal pace to facilitate adaptation.
4. This report suggests that adaptation to climate variability and change can be tackled through a comprehensive climate risk management approach, starting with the most severe vulnerabilities arising in regions that are subjected to frequent, intense and damaging climate events. Using this approach, the report makes a strong case for moving towards integrated risk management solutions for enhancing the resilience and adaptive capabilities of rural residents in selected areas of semiarid India. The report emphasizes that there is no single adaptation solution. Effective and sustainable adaptation to climate variability and change requires a combination of measures that must be implemented at multiple levels (national, regional, local, and community).
5. The study findings and recommendations coupled with a rigorous review of the literature and consultations with government officials and NGOs suggest four interrelated strategies that would help lower the exposure to climate risks and build adaptive resilience:
  - Strengthening climate information systems and mechanisms and related management tools to match current and future needs;
  - Fostering climate-resilient reforms in agriculture and water resource management;

- Supporting the management of climate risks with economic mechanisms and instruments;
- Improving institutional capacities and linkages among sectoral programs.

## **6.1 Strengthening Climate Information Systems and Mechanisms**

6. The study has shown that climate change projections are characterized by a high degree of spatial variability in rainfall and temperature trends, which translates into spatial heterogeneity in drought and flood incidence. Generating high-resolution climate information is an important first step to factor climate risk into development decisions in the states. This can be done with more localized meteorological data and climate models, which can help to better identify areas at risk.
7. In dealing with floods, there is an overwhelming case for strengthening the current flood forecasting system to guide investments in high-value flood protection assets and to support more effective development and targeting of nonstructural approaches. The effectiveness of such a system can be strengthened by combining data collection, telemetry, flood forecasting, and flood warning elements into an integrated flood management and information system for the basin. Developing more robust flood inundation maps for planning and use by local authorities is another important priority that would facilitate risk assessment in zoning and planning decisions.
8. However, climate and meteorological data processing is complex and lies at the frontiers of climate change research. The capacity to generate climate information rests with research centers, while the need and demand for such information and products lies with local communities in risky areas. This argues in favor of a climate information system at the national or state level to disseminate information for planning and management to end users, such as irrigation or farm sector managers. This is also recognized in the Planning Commission's working documents for the Eleventh Five Year Plan.

## **6.2 Fostering Climate-Resilient Reforms in Agriculture and Water Resource Management**

9. There is a strong case for more aggressively pursuing water conservation across drought-prone states. The projections indicate that even when farmers have largely adapted to arid cropping patterns, increased demand and consequent water stress could severely jeopardize livelihoods and render agriculture less viable in these regions. Reliance on supply-side approaches does little to curb the escalating and unsustainable demand for groundwater. Greater attention must therefore be given to hybrid approaches that emphasize the efficiency of groundwater use and increase the effectiveness of watershed activities to conserve soil moisture and harvest rainwater. Such adaptive measures are not a substitute for much needed economic incentives to enhance the productivity of water and water policy reform aimed at, the control of groundwater demand at the wider geographical scale necessary for effective management. However, they provide interim and feasible measures for reducing vulnerabilities.
10. The study makes a strong case for a shift in agriculture systems in order to overcome future climate change pressures. It recognizes that there are many needs and opportunities related to farming systems. The use of interim smart subsidies may help shift incentives and cropping patterns to modes that are better suited to state-level agroclimatic

conditions. Additional measures, including strengthened support for agricultural research and extension and opportunities for reduction in costs of production, are essential to promote more sustainable modes of dryland farming, for example, water-efficient processes for paddy cultivation, promotion of millets, oilseeds, and pulses and use of low-external inputs in agriculture.

11. There are other ways in which rain-fed farming systems can be made more sustainable in semiarid areas. It is not within the scope of this report to examine these in detail, but some innovative methods include non-pesticide management, intensification of biomass used by small ruminants, water-saving composting methods, seed production, livelihood opportunities associated with agro-forestry and livestock-based production systems, and pooling of farm bore wells, packaged with appropriate incentives.
12. In the case of floods, solutions in the water sector would involve a combination of infrastructure and nonstructural approaches such as flood plain zoning, institutional and community coordination, and drainage planning measures. This is not to diminish the importance of structural measures, but as indicated earlier, flood forecasting systems can guide such investments to maintain long-term performance and efficacy.

### **6.3 Economic Mechanisms and Instruments to Promote Income Diversification**

13. This study has emphasized the need for innovative and cost-effective ways of reaching poorer farmers to help reduce their risk exposure. Indebtedness has been identified as one of the major impediments to occupational mobility. Debt instruments offer the potential to protect many vulnerable sections of society and overcome the limitations of crop insurance schemes. The study has also suggested caution in the design of insurance schemes arising from the potential mismatch between payouts and actual losses. Coupling debt relief with new business start-up capital provides a way of encouraging income diversification by lowering risks and transaction costs. These initiatives could be channeled through public and private microfinance institutions.

### **6.4 Improving Institutional Capacities and Program Linkages**

14. Several government programs provide a rich and varied platform upon which to build comprehensive adaptation strategies. But the programs are largely uncoordinated and operate in isolation. Integration is needed to harmonize the essential ingredients of drought adaptation by building upon and facilitating synergy with ongoing programs, for example those run by the state departments of water conservation, rural development, agriculture, and water resources.
15. Apex bodies, such as the National Rainfed Area Authority and the National Disaster Management Authority, could play a strong role in coordination, planning, and identifying gaps and synergies in programs. The panchayati raj institutions and community-based organizations have an important role to play in harnessing opportunities and building appropriate capacities for employment security and asset building, while ensuring the effective use of such assets in reducing the adverse impacts of droughts and floods.

16. Numerous opportunities exist to build climate resilience within current programs. For example, states could build in an adaptation/climate change dimension into the district agricultural plans<sup>53</sup> which would go a long way in mainstreaming the climate risk management agenda as well as in enabling conditions for translating the recommendations of the report into actions on the ground. Furthermore, there is scope to introduce innovative activities for rain-fed farming systems in the National Rural Employment Guarantee Scheme. States could also integrate improved agricultural technology into watershed development programs. A number of state and centrally sponsored schemes being implemented under different guidelines and by different agencies can be brought under a common framework with the dual purpose of strengthening development outcomes and building climate resilience.
17. As regards floods, the institutional set-up for relief operations is comprehensive and operational. But adaptation to floods requires greater integration across different sectors, including water resources and irrigation, housing and land development, and forestry and agriculture. Since adaptation is a new and emerging concept, there is a role for creating state-level climate risk management committees as a first step in facilitating synergy and planning for adaptation activities.

## **6.5 Future Work**

18. In conclusion, there is a clear recognition of the need for, and commitment to, moving forward with a development strategy that can take into account future climate risks, as indicated by the many central and state programs that include climate risk components, and the emerging policies embodied in the Eleventh Five Year Plan of the Government of India. This study has developed, through analysis and consultation, a series of adaptation options (with associated time frames) that support the development priorities to build a more climate-resilient and sustainable India. These are summarized in table 6.1.
19. Strategic actions including barrier removal activities are required by the Government of India to implement the recommendations of this report. These would include greater investments in climate forecasting and dissemination activities; economic incentives to promote income diversification in the form of both insurance and credit services in order to give farmers incentives to shift to long-term viable non-farm activities and price stabilization interventions by the government for rain-fed and drought-resistant crop varieties, and finally market-based and demand-driven mechanisms to help farmers with assured sales of their crops and livestock.
20. Climate change will have wider impacts that go beyond the flood- and drought-affected areas that are the focus of this report. Most notably future work is needed in areas of high development significance. First, glacial melt remains the most dramatic risk that could threaten the water supplies, food production and life-sustaining ecosystems upon which millions in the Indo-Gangetic plains depend. There is an urgent need to assess the magnitude of these risks, the economic implications and identify cost-effective adaptation responses. Independent of this, changing rainfall and temperatures will affect the

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<sup>53</sup> The National Development Council Resolution of May 2007 under the chairmanship of the Prime Minister of India gives high priority to incentivizing states to develop comprehensive district agricultural plans that will include livestock, fishing, minor irrigation, rural development works and other schemes for water harvesting and conservation.



productivity of major food supplies in the rice and grain production regions of India suggesting the need to investigate the impacts on food security goals, livelihoods and agricultural growth targets. Similarly, the threats from sea level rise on coastal communities and cities is another important issue that warrants greater investigations. Finally, though seldom recognized, the interplay between climate risks and agricultural trade needs to be explored in greater detail. Distortions from the protectionist policies in developed countries are likely to increase climate risks in developing countries. These are important issues that need to be addressed in future work. .

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Table 6.1 Summary Recommendations for Adaptation<sup>54</sup>

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**Strengthening publicly accessible climate information systems/mechanisms and related management tools to match needs**

- Establish a climate information management system at central level for developing climate diagnostic and risk assessment tools with feedback mechanisms to end users. This would include: enhanced data collection systems at the local level, systems for hydrogeological data collection and information for groundwater management, and systems for improved detection and forecasting of floods.
- Build climate risk assessment as a requirement for all relevant high value and long-lived infrastructure projects.

**Supporting the management of climate risks through economic mechanisms and instruments that promote efficiency**

- Explore new innovative financial instruments to promote income diversification, such as
  - debt relief instruments coupled with credit for job diversification
  - debt relief coupled with insurance for new business risks
  - community-based risk financing schemes
- Introduce interim smart farm subsidies to encourage switch to more suitable and climate resilient cropping practices

**Fostering climate-resilient reforms in agriculture and water resource management**

- Promote agricultural research and extension services towards systems and cultivars better suited to local climate and its variability
- Implement demand-side approaches for management of groundwater resources at watershed and aquifer levels in drought-prone areas
- Promote basin-level irrigation systems in drought- and flood-prone areas designed to take into account climate risks

**Improving institutional capacities and linkages among sectoral programs**

- Establish capacities and strengthen role of a central bodies such as the National Rainfed Authority and National Disaster Management Authority in order to strengthen coordination and operational linkages between departments at all levels of government. This could include establishing convergence committees for management of drought and flood in the states.
  - Integrate measures targeted towards management of future climate risks in the planning process in district agriculture plans<sup>55</sup>
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<sup>54</sup> A number of recent projects supported by the World Bank have incorporated some elements of these recommendations in operations. Examples include: the Hydrology I (1995 – 2003), which focused on nine states including Andhra Pradesh, Maharashtra and Orissa), Hydrology II (2004 – 2010), which currently covers five new states. These include enhanced information systems as project components. The National Agriculture Innovation Project (2006 – 2012) and the National Agriculture Competitiveness Project (under preparation at the time of writing) recognize and build in elements of climate risk.

<sup>55</sup> GoI's National Development Council Resolution of May 2007 gives high priority to building comprehensive district agricultural plans.

## **Appendix A: The Integrated Modeling System - Framework and Approach**

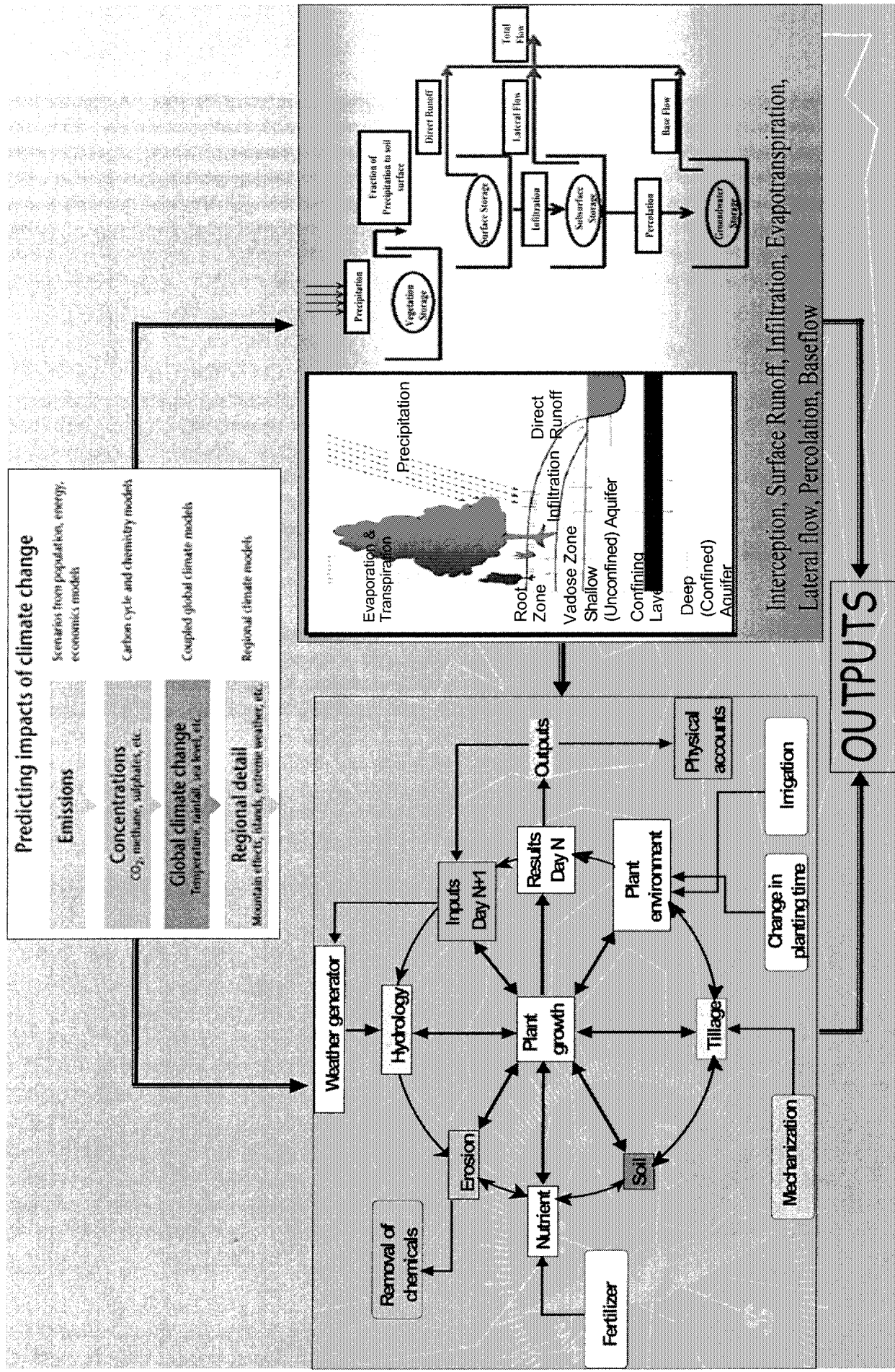
### **Model Structure**

The Integrated Modeling System (IMS) developed for purposes of this study consists of three sub-components – HadRM3 climate data, a hydrological model (SWAT), and an agro-met simulation (EPIC) model – and their functional links. These sub-components are, in turn, linked to the economic model, described in Appendix G. The modeling toolkit and database binds these sub-components into single modeling tool, in a simple and interactive way. The basic components of the integrated modeling system include a control unit, database management, model- and knowledge-base management, and user interface.

The underlying flow of data and information in the Integrated Modeling System is illustrated in figure A.1. The starting point for the IMS is the generation of climate data based on the IPCC emissions scenarios. The resulting climate data is then used in the hydrological model, SWAT, to generate surface water data, which are required as inputs to run the agro-meteorological model, EPIC. The latter integrates water and climate data into an agricultural output estimation framework. Detailed information about SWAT and EPIC is provided later in this annex. Both SWAT and EPIC, are process-based deterministic, each is governed by a set of modeling equations. The spatial resolution used in this study is Mandal/Block resolution. However, calibrations were done with the help of local scientists - to know more about EPIC and its calibration.

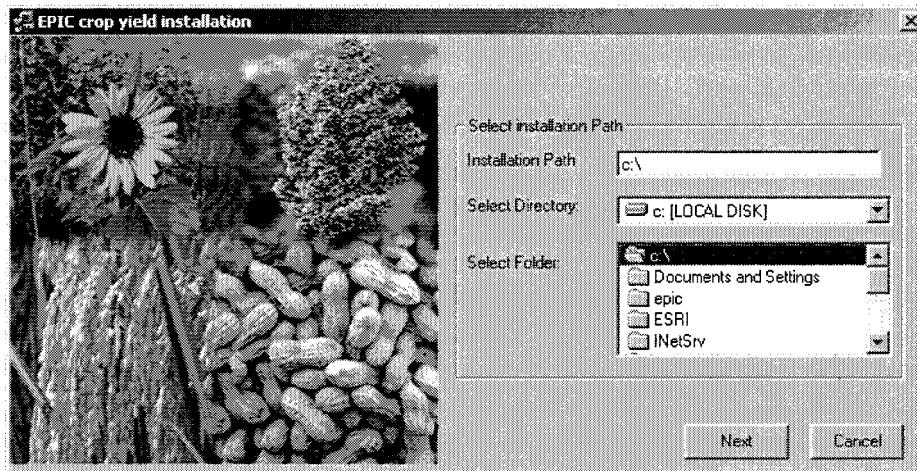
The IMS requires a computer running on, at least, Windows 2000. The minimum platform configuration is a Pentium or equivalent processor running at 100 megahertz with 64 megabytes of memory, at least 500 Mb of free disk space, and a display resolution of at least 1024 x 768. For optimal performance, a Pentium processor running at 400 megahertz, or faster, with at least 128 Mb of memory, 1Gb of free disk, and a display resolution of 1280 x 1024 is recommended.

Figure A.1 Flow of Data and Information in the Integrated Modeling System



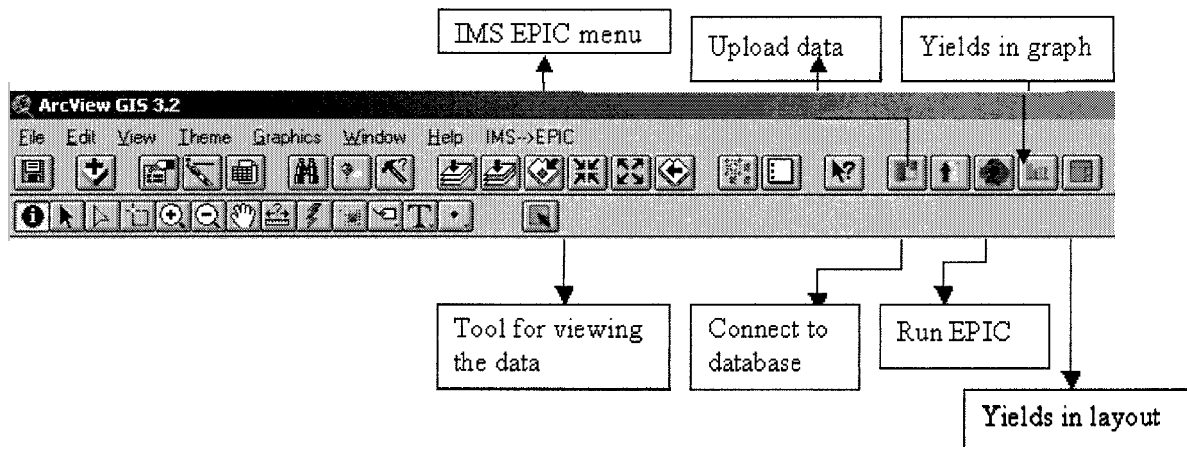
The Graphical User Interface (GUI) for IMS-EPIC is a Windows-based tool that communicates with the internal database for data entry, editing, and data validation. The GUI was designed to overcome most of the significant hurdles faced by EPIC users, particularly the lack of a user-friendly interface. The development environment of the GUI is based on Arc View Avenue and Visual Basic; both applications operate under Microsoft Windows. Figure A.2 provides an example of the appearance of the interface which will pop up during installation.

**Figure A.2 Interface for Installation of the Application**



Once the application is installed on the computer, the Arc View application is launched. Using the toolbar one can open a view to show the regions of interest (figure A.3).

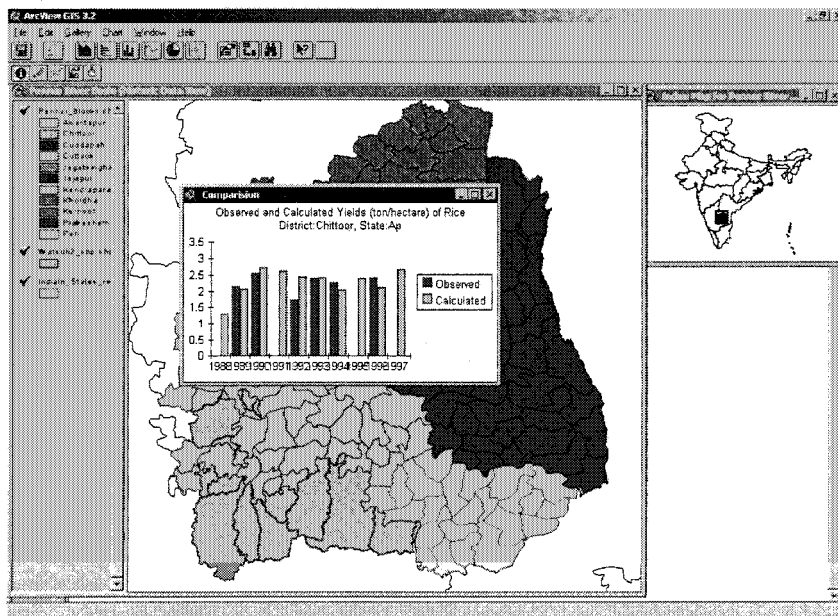
**Figure A.3 IMS Toolbar in Arc View**



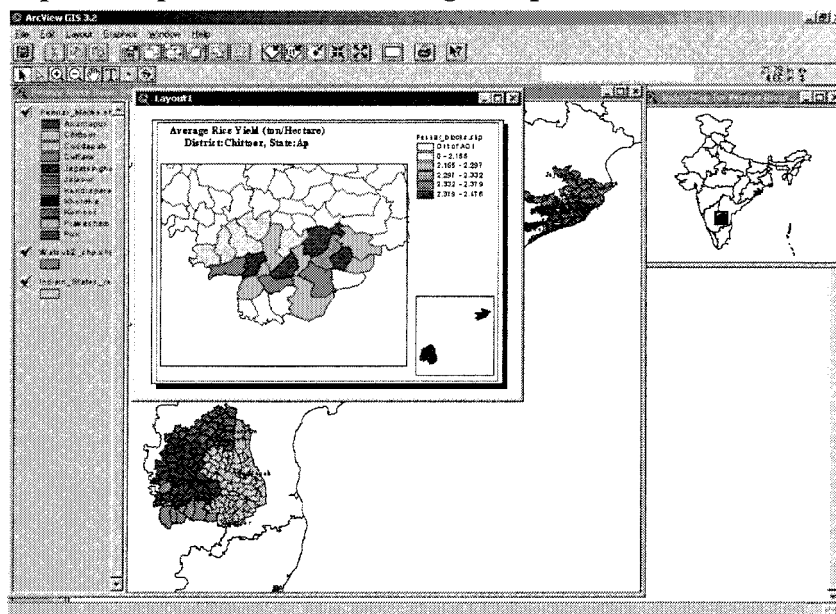
In order to run projections and create charts depicting the projected parameters, one makes a connection to the preferred climate scenario database by choosing the scenario: Baseline, A2, or B2. The dataset is uploaded by the system and the data corresponding to the block or region desired will be displayed in a series of interfaces showing the block, the crop(s) being analyzed,

the type of soil, the weather, and the crop management information. It is also possible for the user to edit such parameters. Finally, crop yields are displayed using bar charts and layouts as shown in figures A.4 and A.5.

**Figure A.4 Crop Yields Shown Using Bar Charts**



**Figure A.5 Spatial Representation of Average Crop Yield in the Chittoor District**



## Hydrological Modeling (SWAT Model)

SWAT, which stands for Soil and Watershed Assessment Tool, was developed to predict the impact of land management practices on large, complex river basins or watersheds. SWAT2000 is capable of performing continuous, long term simulations for watersheds composed of various sub-basins with different soils, land uses, crops, topography, weather, etc. Being a physically-based model, SWAT2000 requires specific inputs to model any river system rather than use of regression equations to describe relationships between the inputs and outputs. The driving force is water balance. Another important characteristic of SWAT2000 is that it provides relative accuracy as well as absolute accuracy. This model is best used to predict long-term outcomes of management practices.

SWAT2000 can handle hundreds of sub-basins. The soil profile for each of these sub-basins can be divided into ten layers. The movement of runoff, sediment, nutrients, and pesticide loadings to the main channel in each sub-basin is simulated considering the effect of several physical processes that influence the basin's hydrology. SWAT2000 requires data relating to daily precipitation, maximum/ minimum air temperature, solar radiation, average daily wind speed, and relative humidity. This information can come from observed data or it may be generated from a weather generator database.

The precipitation may be homogenous for the entire watershed; however, spatial variability may lead to unique climate conditions for the various sub-basins in the model.

### *Box A.1 Stochastic Weather Generator*

A stochastic weather generator allows the generation of synthetic daily weather data for any number of years using the statistical properties of a weather variable. In this study, a stochastic weather generator was used to generate scenarios of future climate at block level from the low-resolution RCM-derived scenarios. The climate scenarios developed from the outputs of the RCM include not only changes in the mean of the climate but also changes in its variability. The historical annual cycle of means, standard deviations, probability of wet/dry days, and number of rainy days at block level were computed using the daily rainfall data at block level and other daily weather data obtained from the India Meteorological Department (IMD). The stochastic weather generator was used to simulate daily weather for 50 years for historical (Baseline), A2, and B2 scenarios in each block of the selected districts of each study region.

The weather generator is designed to preserve the dependence in time, the internal correlation, and the seasonal characteristics that exist in the actual weather data. Precipitation and wind are generated independently of the other variables. Maximum temperature, minimum temperature, and solar radiation are generated subject to whether the day is wet or dry. A first-order Markov chain is used to generate the occurrence of wet or dry days. When a wet day is generated, the precipitation amount is based on a skewed normal distribution. With the first-order Markov chain model the probability of rain on a given day is conditioned on the wet or dry status of the previous day.

The procedure to generate the daily values of maximum and minimum temperature and solar radiation is based on the weekly stationery generating process given by Matalas (1967). The wind component of the model provides for generating daily values of wind speed and direction as described by Richardson (1982a).

*Source: RMSI, 2006b.*

## **Assumptions and Limitations**

A watershed may be broken down into several sub-basins, each consisting of different Hydrologic Response Units (HRUs). The HRU is the primary modeling unit for the SWAT model. Within a sub-basin, an HRU often consists of areas with the same hydrology, soil type, and management practices. The model assumes that the hydrological routing paths are the same for all the areas that belong to the same HRU, even if the areas are distributed in different parts of the sub-basin.

Since the model is designed to simulate and predict the impacts of long-term land management practices in watersheds on the water quality in receiving water bodies, it cannot properly be applied to simulate detailed, single-event flood routing. The stream flow network in SWAT is designed as one directional flow, which routes runoff from upper stream/reach to down stream/reach. It cannot simulate backflows.

The basic model components simulated by SWAT2000 include weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loading, and water transfer.

## **Agrometereological Model (EPIC)**

The EPIC (Erosion Productivity Impact Calculator) model was developed by scientists from the US Department of Agriculture's Agricultural Research Service (ARS), Soil Conservation Service (SCS), and Economic Research Service (ERS). The model was selected for use in the IMS because it provided a more coherent modeling environment and because there was experience available in the application of EPIC in relevant parts of India.

EPIC was originally designed to assess the effect of soil erosion on productivity. It simulates the effects of management decisions on soil, water, nutrient, and pesticide movements, as well as their combined impact on soil loss, water quality, and crop yields for areas with homogeneous soils and management. Some of the important components of EPIC are: weather generator (WXGEN); hydrology, erosion and sedimentation; nutrient cycling; crop growth; tillage; economics; and plant environment control.

## **Model Resolution**

The IMS' model resolution is aimed at "blocks"; results are aggregated at "district" level, since this is the level of resolution of the agro-met model. All efforts are made to collect data at basin/district level and the results are generated at this level. For regional levels, the results can be aggregated from the districts/blocks. Apart from this, one major driver of this study is HadRM3 (a Regional Climate Model), which has a resolution of 0.44 x 0.44 degrees (approximately 50 kilometers cell-size) on ground covering the average size of a typical Indian district/sub-basin.



## Model Validation

The model was validated through rigorous testing involving the comparison of reported crop yields to simulated yields based on similar conditions to those prevailing at the time that the real-world reported data were published. Efforts were made to provide accurate and realistic data-input files to close the gaps between simulated and reported crop yields.

The validation exercise showed that the observed crop yields and those simulated by the IMS were very close.

### **Box A. 2 Regional Climate Models vs. Global Climate Models**

The simulation of seasonal rainfall as well as its spatial and temporal variability over the Indian subcontinent has remained rather poor in most Global Climate Models (GCMs). This is mainly due to the fact that GCMs have coarse horizontal resolution, which restricts the representation of the topography's and coastlines' complexity. It also limits the parameterization of sub-grid scale processes. Therefore, GCM scenarios fail to capture the local details needed for conducting impact assessments at the regional level. In addition, GCMs cannot capture extreme weather events and their intensities such as cyclones or heavy precipitation events. The alternative method to obtain detailed predictions of the future climate is to use a high-resolution version of GCMs known as Regional Climate Models (RCMs).

An RCM has a high resolution (typically 50 kilometers, compared to 300 kilometers in a GCM) and covers a limited area of the globe (typically 5,000 kilometers x 5,000 kilometers; roughly the size of a box around Australia). It is a comprehensive physical model, usually made up of the atmosphere and land surface, containing representations of the important processes in the climate system (e.g. clouds, radiation, rainfall, soil hydrology). At its boundaries, RCM is driven by atmospheric winds, temperature, and humidity output from a GCM. RCM predictions of ideally 30 years (e.g. the period 2071–2100) are needed to provide robust climate statistics, e.g. distributions of daily rainfall or intra-seasonal variability.

The third-generation Hadley Centre RCM (HadRM3) is based on the latest GCM, HadCM3. It has a horizontal resolution of 50 kilometers with 19 levels in the atmosphere (from the surface to 30 kilometers in the stratosphere) and four levels in the soil. In addition to a comprehensive representation of the physical processes in the atmosphere and land surface, it also includes the sulphur cycle. This enables it to estimate the concentration of sulphate aerosol particles produced from SO<sub>2</sub> emissions, which have a cooling effect as they scatter back sunlight and also produce brighter clouds by allowing smaller water droplets to form. Thus, regional models can take account of the effects of much smaller-scale terrain than GCMs.

In spite the RCMs' advantages, their level of resolution is not high enough to assess the impact of climate change on natural resources. In order for this assessment to be as accurate as possible, the resolution would have to be even better, that is, approximately 10 kilometers by 10 kilometers. In an ideal, best case scenario it would be as high as 1 kilometer by 1 kilometer. Thus, there is a mismatch between what climate models can supply and what natural resource impact models require.

Since the technology to create even lower-resolution climate models is not yet available, other alternatives are available to produce a similar effect. These alternatives involve the manipulation of the climate data fed to the models using an approach called "Statistical Downscaling". This means developing high-resolution climate data using the IPCC future climate scenarios and the observed data of rainfall, temperature, solar radiation, relative humidity, and wind speed.

*Source: RMSI, 2006b.*

## Appendix B: Methodology Used for the Design and Analysis of Household Surveys and Data

### Vulnerability: A Complex Term

There is no one single definition for the term “vulnerability” and no one single way of measuring it. Different disciplines define it and measure it differently, but the one common trend among all of them is the idea that the concept is related to levels and types of risks to which people/communities are exposed. Table B.1 summarizes some of the most commonly used definitions.

**Table B.1: Definitions of Vulnerability<sup>56</sup>**

Discipline/ Literature	Definition of Vulnerability	What is Measured How it is Measured	Criticism
Economics <sup>57</sup>	It is an outcome of a process of household responses to risks, given a set of underlying conditions. Often times, the outcome is poverty.	The fall of income beyond the poverty line or changes in consumption are measured.	There is an underlying presumption that all losses can be measured in monetary terms.
Sustainable Livelihoods	It is the probability that “livelihood stress” will occur – with more stress or a higher probability implying increased vulnerability. Also, “the balance between the sensitivity and resilience of a livelihood system.”	The loss of livelihood, continued vulnerability to subsequent shocks and vulnerability changes over time are the subjects of interest. The assessments are specific to population or society. It uses a case study approach.	It tends to use terms and concepts that are unclear or not widely accepted. It is not clear how changes in vulnerability would be evaluated over time when some indicators show a positive change while others a negative one.
Food Security	It is the risk of irreversible physical or mental impairment due to insufficient intake of macro or micronutrients.	Vulnerability mapping and indexes. A number of analytical techniques are used to examine the degree of correspondence between the concept of food security and the indicators chosen to measure it.	It usually lacks a benchmark to which indicators can be compared. It recognizes that vulnerability is made up of different components, but it ignores the specific process by which the components interact to determine overall vulnerability.
Disaster Management	It is the characteristics of a person or group in terms of their capacity to anticipate, cope with, and recover from the impact of a natural disaster. It is an underlying condition separate	Vulnerability = Hazard – Coping Household characteristics are key determinants in that they affect either side of the equation.	There is a lack of precision in the language used, which leads to confusion. At times, it fails to be specific about what constitutes loss or

<sup>56</sup> Alwang, Jorgensen and Siegel. 2001. Vulnerability: A View from Different Disciplines. Washington, DC: World Bank.

<sup>57</sup> Variants of this approach are the “poverty dynamics” and the “asset-based” approaches to vulnerability (see source for details).

	from that of the risky events that may trigger the outcome. It refers to risks as “hazards”.	The use of vulnerability mapping is also widespread.	damage, or whether it matters who endures these.
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The differences between the approaches can be reduced to the tendency of each discipline “to focus on different components of risk, household responses to risk and welfare outcomes”. All approaches have their strengths and weaknesses: some are considered strong in their conceptual framework but weak in their empirical approach (i.e., how it is measured) and vice versa. The definition used in this study is eclectic: it borrows from all of these disciplines.

### **Selection of Study Areas – Vulnerability Mapping**

Vulnerability indices are commonly used in the field as a way to measure vulnerability by different researchers and institutions. Two such indices are the “Food Insecurity and Vulnerability Information and Mapping System” (FIVIMS), developed by the Food and Agriculture Organization of the United Nations (FAO); and the “Vulnerability Analysis and Mapping (VAM)”, produced by the World Food Program in cooperation with FIVIMS.<sup>58</sup>

In this study, a vulnerability index was also developed to guide district selection. Case study sites were identified based on a vulnerability analysis using a “Principles, Criteria and Indicators” (PC&I) framework, together with a Geographic Information System (GIS). Rather than assigning weights and scores on an ad hoc basis, Principal Component Analysis (PCA)<sup>59</sup> was employed to provide a statistical basis for determining the effect of each variable on the target variable, i.e. agricultural vulnerability.<sup>60</sup>

The drought- and flood-prone areas were demarcated and then overlaid with other maps containing information on other biophysical, social, and economic parameters. The basin was used as the geographical unit in the development of the maps. By superimposing maps with the different parameters and showing their fluctuation from one year to another over a reasonable period of time, a map depicting different degrees of variation is produced which serves as the basis for selecting specific sub-areas for analysis.

In this study, the secondary data on biophysical, social, and economic indicators such as gross cropped area, cropping patterns, groundwater availability, and an Infrastructure Development Index (IDI), among others, was compiled over different years spanning a 10-year period, for comparison purposes. The data was collected from various sources including the Survey of India (SOI), the Census of India (COI), the Central Ground Water Control Board (CGWB), the Central

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<sup>58</sup> Aandahl, Guro and Karen O’Brien, *Vulnerability to Climate Change and Economic Changes in Indian Agriculture*.

<sup>59</sup> The statistical basis provided by this methodology provides better results than the conventional practices that “create” weight on an ad hoc basis.

<sup>60</sup> The area of different vulnerable zones in the states selected for the study was estimated using the spatial analyst function of Arc GIS and drawn on GIS-produced maps.

Water Commission (CWC), the National Bureau of Soil Survey and Land-Use Planning (NBSS & LUP), the National Atlas & Thematic Mapping Organization (NATMO), the Center for Monitoring Indian Economy (CMIE), the Indian Agricultural Statistics, Volumes I & II, the Agricultural Census, and the Maharashtra and National Information Center (NIC).

Using PCA, a vulnerability index was created which allocates degrees of vulnerability to districts: low, moderate, high, very high, and extremely high. Districts were classified according to the index and maps were then developed for the states of Andhra Pradesh, Orissa, and Maharashtra. An overlay of different profiles for these states thus forms the basis for the selection of the districts in each state, except for Orissa where official data was not available to allow for a comparison of vulnerability over time. Consequently, the district selection in Orissa was guided by a combination of (a) analysis of secondary data and (b) the extent of the geographical area which is considered to be liable to floods. Based on this analysis, some districts were deemed to face greater threats than others due to a combination of high biophysical and social vulnerability and limited infrastructure development.

The final selection of districts in the selected river basins was made to purposely capture a range of vulnerability patterns given their different socio-economic, technological, and biophysical conditions.

## **Field Surveys**

Despite the fact that more than two districts in each of the three states were selected for climate projection (five in Maharashtra and four Andhra Pradesh), further prioritization of districts was necessary in conducting field surveys due to limits in time and budget. Thus, field surveys were carried out in two districts in each state. In the end, the districts of Anantapur and Chittoor in Andhra Pradesh, Jagatsinghpur and Puri in Orissa, and Ahmednagar and Nashik in Maharashtra were chosen for the study. The objectives of the surveys conducted were the following:

- to assess the coping capacities and vulnerabilities of communities in dealing effectively with droughts and floods; and
- to determine the factors that influence the effective implementation of coping measures at field level.

Institutional surveys were carried out to collect information on the central and state government plans and programs being implemented in the state and to ascertain their efficacy in enhancing the capacities of communities in dealing effectively with climate variability and conditions of extreme weather, including drought and floods. The field surveys sought to collect information on the communities' perceptions on (a) the intensity of droughts/floods, (b) the crops grown in the region, (c) the change in cropping patterns, irrigation, livelihood options and migration, (d) infrastructure, (e) the availability of financial services and schemes, and (f) the importance of insurance. Through these surveys, an attempt is made to undertake a critical review of policy and community-oriented interventions that enhance the capacities of communities to cope during extreme climate situations. In all, 1,640 households were surveyed: 570 households in Andhra Pradesh, 650 households in Orissa, and 420 households in Maharashtra.

## **Development of Tools for Institutional and Field Surveys**

Questionnaires designed for implementation in drought and flood circumstances as well as other Participatory Rural Appraisal (PRA) tools were used. Secondary data including sketch maps, transect walk, collation of time-line information and trend-lines, seasonal cropping calendar mapping, institutional mapping, problem tree analysis, and problem and opportunity ranking was collected. In addition, group discussions, interviews, focus group discussions, and institutional surveys were carried out.

The questionnaires were pre-tested in pilot surveys in Rajasthan (a drought-prone area). It provided insights about the available quantitative information and its usefulness for the purpose of the survey, and it was improved and modified accordingly.

The lack of proper recorded information at the village level posed a major constraint to quantitative/statistical analysis.

## **Selection of Villages in Identified Districts Based on Analyses of Secondary Data**

The selection of villages in each district was based on the screening of village-level secondary data collected from the census office. This data was collected for parameters including village land area, land use, cultivated and irrigated land, and availability of infrastructure including education, bank/credit, society, communication, power facility, and services like health care. The data was used for the preliminary selection of villages within each district. These were later confirmed by discussions with officials in government departments at the district level as well as other localized non-governmental organizations and communities at the village level.

### **Village Classification Based on Irrigation**

All villages lying within a district were classified into one of three levels based on their irrigated area as a percentage of their total agricultural area: low (0-33%), moderate (33-66%), or high (66-100%).

### **Village Classification Based on Infrastructure Development**

An infrastructure index was developed by considering the existence or level of certain facilities and services at the village level including the availability of drinking water, education facilities, medical facilities, electricity, banks, agricultural society, and communication linkages.

The villages were assigned to one of four categories according to their irrigation- and infrastructure-based classification. The purpose of this categorization was to select villages that were representative of different contexts which may further the understanding of the factors underlining the different levels of vulnerabilities. These broad criteria on irrigation and infrastructure are used to classify the villages in a matrix as the one shown here below.

**Figure B.1 Example of the Village Classification in the Infrastructure-Irrigation Matrix**

High Infrastructure	For instance: Korhate in Maharashtra	For instance: Manesaudram in Andhra Pradesh
Low Infrastructure	For instance: Neramatla in Andhra Pradesh	For instance: Brahmanapalle in Andhra Pradesh
	High Irrigation	Low Irrigation

## Sampling

The sample size,  $n$ , for each target population is computed using the formula by Murthy, (1977):

$$n = \frac{N * \tilde{n}}{N + \tilde{n} - 1}$$

Here,  $\tilde{n} = c^2 / e^2$  where  $c$  is the population coefficient of variation and  $e$  is the allowed percentage of error.  $N$  is the target population size (480).

To obtain a representative sample, proportionate sampling based on landholdings were conducted. Records indicating household land category were collected from the Tehsildar<sup>61</sup>. The survey was conducted based on the various landholding categories: >4 acres (large farmers); 1-4 acres (medium farmers); < 1 acre (small farmers)<sup>62</sup>; and landless. After conducting the survey, all the data was coded and entered, and were used for quantitative analysis. A reference manual was also developed to facilitate viewing and referencing.

## Measure of Income Volatility

The Coefficient of Variation (CV) is used to understand the extent to which household incomes are volatile to the impact of drought/floods events<sup>63</sup>. The CV is simply **a measure of the deviation of ‘impact year’ income from ‘normal year’ income.**

CV is defined as the ratio of the Standard Deviation to the Mean ( $\mu$ ) and is defined by the following formula:

$$c_v = \frac{\sigma}{\mu}$$

<sup>61</sup> Person in charge of maintaining land records of villages in a panchayat

<sup>62</sup> 1 ha = 2.5 acres

<sup>63</sup> It is imperative to mention here that income is considered a proxy for well-being, but is not tantamount to well-being. The latter is a holistic concept, encompassing livelihood security, food security, ownership characteristics, and respect in society. Of these, the focus of this study is on livelihood and income security, and hence the nature of employment emerges as an indicator in the status of well-being.

In this formula,  $\sigma$  is standard deviation and  $\mu$  is average income<sup>64</sup>. It is often represented as a percentage by multiplying the above by 100.

An advantage of the CV is that it is free from the units of the variables, and it thus permits comparisons with respect to their variability. The CV is commonly used since it is a quantity without physical units. Although the CV indicates the magnitude of variations, it fails to capture the directional shifts in income. As a substantial majority of the surveyed households experienced drops in income in an impact year, few 'outlier' households that showed an increase in income during an impact year were segregated out.

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<sup>64</sup>  $\mu = (\text{Normal income} + \text{Impact income})/2$ , and  $\sigma^2 = [(\text{Normal income} - \text{Mean income})^2 + (\text{Impact income} - \text{mean income})^2]/2$ .

## **Appendix C: International Conference on Adaptation to Climate Variability and Change—Towards a Strategic Approach**

The International Conference on *Adaptation to Climate Variability and Climate Change: Towards a Strategic Approach* was held in New Delhi, India on December 7 - 8, 2006. It was organized by the World Bank, in collaboration with the Government of India's Ministry of Environment and Forests (MoEF), and the European Union (EU). The Department for International Development (DFID), the Swiss Agency for Development and Cooperation (SDC), and the German Technical Cooperation Agency (GTZ) co-sponsored and participated in the event. The logistics of the event were organized by The Energy and Resources Institute (TERI).

The main objective of the conference was to take stock of the latest progress in adaptation knowledge and practices, including policy and financing aspects in India and globally. This was made possible through a consultative process involving all stakeholders, from the donor community to the policy makers. The conference provided a forum for the exchange of information on recent developments, programs, and challenges in India. The aim was to strengthen the commitment to future strategies and programs and to stimulate discussions on a possible action framework for integrating efforts towards strengthening adaptation in India. The outcomes include:

- an increased awareness of government officials in India of the adaptation challenge and its implications for the development and implementation of climate-related policies and programs;
- the enhanced ability of participating state governments to develop climate-related adaptation policies and programs;
- the improvement of the stakeholders' knowledge base in climate-related areas; and
- an enhanced coordination of adaptation-related work programs among development partners.

The event was well attended and received coverage in the international and local media. The conference's agenda and the presentations made by participants at the conference can be found at: [http://www.teriin.org/events\\_inside.php?id=17797](http://www.teriin.org/events_inside.php?id=17797). Below is a summary of the key points raised at the conference on a session-by-session basis.

### **Session 1. Inaugural Session**

The session highlighted that climate change evokes the need to consolidate and share information on contemporary initiatives aimed at reducing vulnerability and strengthening adaptation. The vulnerabilities of developing countries to climate change underscore the urgency for taking proactive measures on the mitigation and the adaptation fronts.

### **Session 2. Adaptation and Sustainable Development**

The challenges posed by climate variability and change require prompt action. Useful information can be drawn from local communities' historical and current coping measures in dealing with climate variability and extreme events. The key challenge, however, is to



incorporate principles of equity and conflict resolution, beneficiary selection and benefit sharing, transparency in project implementation, information sharing, and adequate representation of minority communities in the decision making processes.

Key points:

- Targeted research and development is required to enhance adaptive capacities of communities – some initiatives in this context include revitalizing cooperatives and credit institutions, enriching the technological base, and strengthening the insurance system through the promotion of innovative measures such as index-based, weather-risk insurance.
- National development policies and government programs need to integrate adaptation initiatives - increase resilience of livelihood and infrastructure, improve governance, empower communities, and mainstream climate risk management.
- Watershed development and management should be pushed, especially in rain fed areas - priority intervention areas include provision of potable water for consumption and of protective irrigation for crops, while integrating livestock management and considering equity concerns.

### **Session 3A. Climate Risk Assessment: Emerging Approaches and Tools**

Screening tools provide a broad overview to project managers and development planners about the key climatic risks that could affect the implementation of development projects and related investments by the government, donor agencies, and other institutes.

Key points:

- Screening tools are required to mainstream climate risks into development planning and to provide guidance to project managers and development planners.
- A framework is required in order to integrate disaster risk management efforts with climate risk and development concerns. By strengthening adaptive capacities at the macro level, it is possible to create win-win situations that result in improvement in overall well-being of the community/ecosystem.

### **Session 3B. Sector Impacts: Policy and Economic Implications**

The implications of climate change on the agricultural sector demands urgent attention. Stakeholders, such as scientists and policymakers, will be required to work together to integrate research into policy successfully.

Key points:

- There is need for effective policy support to bolster the adaptive capacity of farmers.
- Autonomous adaptation in the agricultural sector faces constraints such as the time lag in responses, the unpredictability of extreme events, and the lack of extension services and technical guidance.

- The cost of adaptation should include support for building infrastructure to promote research, development of models for integrated assessments, and provision of information on policy research.
- There is a need for structural and non-structural investments in win-win strategies for better preparedness to climatic stress. This includes strengthening the methods for impact prediction of climatic trends and strengthening public services such as health care, sanitation, disease surveillance, access to vector and disease control services, integration of health concerns in policies, efficient urban planning, housing regulations, water treatment etc.

#### **Session 4. Adaptation Strategies: Emerging Approaches**

Planned and autonomous approaches to adaptation are not unrelated; while some risks, and necessary adaptation, can be identified and planned for, responses to other risks depend on the inherent flexibility of systems.

Key points:

- Resilient systems are better equipped to meet basic environmental, economic, and social needs when faced by sudden climatic extremes.
- Adaptation to droughts and floods at the local level depends on certain key factors such as:
  - the extent to which people are able to diversify into livelihood based on less climate-sensitive sectors;
  - the extent to which people have the ability to access information relaying early warnings and transport channels for goods and services;
  - the presence of assets and security such as insurance and the resilience of key infrastructure;
  - the condition of key environmental resources, such as groundwater in a drought-prone area, and the presence of institutional arrangements, self-help groups (SHGs), and credit groups;
  - the presence of institutional or self financial mechanisms (credit systems or remittances).
- Synergies need to be developed between planned and autonomous adaptation by focusing on disaster management strategies, scientific information, and the use of financing and insurance mechanisms.
- Targeted sector-wide interventions can be used to reduce the risks associated with climatic variability and extreme conditions. These include:
  - water-based intervention - the adoption of better irrigation practices, the recharging of groundwater through strengthening water harvesting structures, the revival and restoration of community-based water conservation measures, and the revitalization of water user groups;
  - land-use-based interventions - control of soil erosion losses, crop advisory, development of agro-forestry, and kitchen gardens which can promote nutritional security;
  - energy-based interventions - provision of improved cook-stoves, promotion of bio-energy crops, and promotion of briquette making; and

- livestock-based interventions - livestock management, pasture land development, and development of fodder banks.
- The perceived barriers to adaptation are the lack of timely weather-forecasting information, of credit and savings, and of appropriate technology.
- Experiences from various fields need to be pooled - including institutional, financial, and technical systems and participatory planning and implementation - to contribute towards livelihood diversification, provision of a low-cost and input-internalized production system, natural resource management, resolution of property-rights issues related to land and water, and enhancement of community-based local institutions' roles.
- Communities employ various measures to deal effectively with the consequences of climate change. These include looking at temporary, i.e. reactive, and permanent, i.e. proactive, models of response. There is a need to identify and incorporate these measures into the enhancement of communities' adaptive capacities.
- Linkages should be drawn between the local level of delivery and implementation of adaptation measures and the efforts to include adaptation in international agreements.

## **Session 5. Mainstreaming Adaptation: Policy Issues and Options**

Key vulnerabilities to climate change need to be identified. There is also a need to strike a balance between adaptation and mitigation.

Key points:

- Partnerships with other countries (both developing and developed) are required to address the challenges of sustainable development and climate change in accordance with the goals of the UNFCCC. There is also need to look at partnerships or linkages between governmental and non-governmental sectors.
- At the community level, sustainable livelihoods need to be promoted in order to avoid future risks. In the case of climate-sensitive occupations, income diversification is the key to resilience. Agro-based industries are critical in providing the support structure. Social capital forms an extremely important factor to enhance community resilience. Also, a balance needs to be struck between finance mechanisms of credit, savings, increased engagement of SHGs, development of insurance structures, asset-building at household and community level, incentive-driven watershed management, and disaster preparedness and mitigation.

## **Session 6. Strengthening Global Cooperation on Adaptation**

Key points:

- To strengthen global cooperation on adaptation, there is a need to promote knowledge sharing and communication platforms among global actors, establish institutional frameworks for adaptation that are in line with development priorities, and assist in integrating adaptation in the planning process.
- Some examples where global collaboration could be forged include the initiation of small pilot projects planned to be integrated into ongoing larger scale development programs such as the watershed development programs and early warning systems. This would include risk

assessments, risk management including the development of a national adaptation strategy, integration into investment programming, and application of adaptation tools and methods.

- There needs to be adequate research on the economics of adaptation, on methods to mainstream adaptation in development, and on the involvement of other stakeholders.
- Current sustainable development practices related to rural livelihoods, disaster risk management and urban development need to be strengthened.

## **Session 7A. EU-India Cooperation on Climate Change and Adaptation Policies: Research and Policy Activities on Adaptation**

Key points:

- Several EU-India collaborative efforts are already in place and a number of new funding instruments have also been introduced in addition to individual member state programs. An integrated framework for the assessment of climatic hazards, vulnerability, and risks, along with spatial planning, mapping, and modeling would be required for development of robust adaptation and mitigation strategies.
- For development and implementation of strong adaptation projects stakeholder engagement is critical.
- Uncertainty related to the resolution of results can often lead to faulty predictions and recommendations; these should be adequately researched before packaging the climate agenda.
- Time and effort needs to be invested to promote researcher exchanges between India and the EU to build human resource capacity and develop technical expertise.
- It is essential to recognize the obstacles to adaptation including institutional barriers.

## **Session 7B. State-Level Dialogue on Adaptation Issues and Options: The Way Forward**

The state-level discussions were aimed at attaining a regional/state-level understanding of the diverse aspects of adaptation, including the key components of a state-level adaptation plan and institutional structures and delivery mechanisms.

Key points:

- Ecosystem management should be promoted as part of a multi-pronged adaptation strategy.
- Before incorporation of climate change concerns into ongoing programs and plans, an assessment of ground situations and requirements should be made.
- The various innovative adaptation strategies being employed by communities to cope with current climatic stress need to be documented and further supported.
- Prior planning is essential for efficient adaptation and this can be reflected in terms of changes in infrastructure and resource use pattern.
- Models of development need to be revisited to reduce unsustainable patterns of development.
- Identification of 'vulnerability' hotspots is needed for better preparedness.

- More research is required in the agricultural sector to promote growth of tolerant crop varieties and address food security concerns.
- Weather data management needs to be strengthened at all levels, as well as the requirement for instituting better warning systems.
- There is a need to build inter- and intra-departmental cooperation to address the challenges of climate change in an integrated manner.

## Appendix D: Programs that Address Droughts and Floods in the Case Study Areas

<i>Water Resources Programs</i>	
<b><i>State-sponsored schemes initiatives implemented by the Water Resources Department, GoM except where noted</i></b>	<ul style="list-style-type: none"> <li>• Major, medium and minor irrigation projects: <i>Investments in irrigation were done through five irrigation corporations created between 1996 and 1998. Around 40% of irrigation potential is yet to be tapped, but the cost of such investments is very high.</i></li> <li>• Minor irrigation projects: <i>Schemes with a command area of less than 2,000 hectares such as irrigation and percolation tanks, diversion bandharas, kolhapur and konkan type weirs, lift irrigation schemes, tube wells, renovation of malgajari tanks, and land drainage schemes.</i></li> <li>• Cooperative lift irrigation schemes (implemented by the Agriculture Department): <i>Schemes which make irrigation water available to cultivators who cannot access rivers, canals, dams, etc.; they include isolated patches of land which cannot be served by major or medium projects.</i></li> <li>• Water auditing: <i>Pioneered for irrigation projects in 2003-04, the objective is to see whether water-use efficiency is as per design and to assess the efficiency of irrigation projects' operations.</i></li> <li>• Benchmarking of irrigation projects: <i>Since 2001 all major and medium irrigation projects have been evaluated against a set of 12 indicators covering system performance, agricultural productivity, financial aspects, assessment recovery ratios, and environmental and social aspects.</i></li> </ul>
<b><i>Centrally-sponsored schemes</i></b>	<ul style="list-style-type: none"> <li>• Command Area Development (CAD) Projects: <i>Projects that prepare land to receive irrigation water, taking an integrated area development approach with an emphasis on balanced and comprehensive development of irrigated areas, water user associations, and farmer participation.</i></li> <li>• Accelerated Irrigation Benefit Programme (AIBP): <i>It largely funds major and medium irrigation projects to create additional irrigation potential.</i></li> <li>• Rural Infrastructure Development Fund (RIDF): <i>This scheme by the National Bank of Agriculture and Rural Development (NABARD) is meant to create rural infrastructure including major and medium irrigation schemes.</i></li> <li>• National Finance Commission Grant: <i>A Rs. 10 crore grant from this source has been allocated in the Tenth Five Year Plan for Orissa to augment traditional water resources.</i></li> </ul>
<i>Watershed Programs</i>	
<b><i>State-sponsored schemes implemented by the Department of Water Conservation, the Employment Guarantee Scheme (EGS), and the</i></b>	<ul style="list-style-type: none"> <li>• Employment Guarantee Scheme (EGS): <i>It guarantees unskilled labor employment in rural areas, and uses this labor to create community assets, such as soil and water conservation structures. Since the early 1990s, the EGS has been extended to cover individual assets such as wells and horticultural plantations; it does not have a coordinated or integrated approach to watershed development.</i></li> </ul>

<p><b>Department of Agriculture, GoM</b></p>	<ul style="list-style-type: none"> <li>• Integrated Watershed Development Program: <i>It is intended to arrest soil erosion, recharge groundwater and control runoff by treating the watershed from ridge to valley, strengthen and protect drinking water sources, develop waste land, degraded land and highly eroded lands, bring sustainability to agricultural production and generate employment in rural areas.</i></li> <li>• Adarsh Gaon Yojana (Ideal Village Development Program): <i>The program aims to develop self-reliant and self-sufficient villages in Maharashtra, with an emphasis on the development and regeneration of land and water resources; core activities include afforestation of watersheds, soil and water conservation (on both arable and non-arable land), drainage line treatment, and construction of water storage structures.</i></li> <li>• Marathwada and Vidarbha Watershed Development Missions: <i>Created by government resolutions to develop fallow and undeveloped land and groundwater tables in large rain-fed areas with poor vegetation and water scarcity.</i></li> </ul>
<p><b>Centrally-sponsored schemes implemented by the Department of Water Conservation, the Employment Guarantee Scheme (EGS), and the Department of Agriculture, GoM</b></p>	<ul style="list-style-type: none"> <li>• River Valley Project: <i>Its main objectives are: (a) to prevent land degradation by adopting a multi-disciplinary integrated approach to soil conservation and watershed management in catchment areas; (b) to improve land capability and moisture regimes in watersheds; (c) to promote land use to match land capability; and (d) to prevent soil loss from catchments in order to reduce siltation of multi-purpose reservoirs and (e) to enhance in-site moisture conservation and surface rainwater storage in the catchments to reduce flood peaks and volume of runoff.</i></li> <li>• Desert-Prone Areas Program (DPAP): <i>The earliest area development program (1973-74) tackles the special problems faced by areas constantly affected by severe drought conditions; these projects take up land and water resource development, afforestation, and pasture development using a watershed approach in watersheds measuring 500 hectares. Funding of Rs. 6,000 per hectare is shared by central and state governments in the ratio of 75:25.</i></li> <li>• Integrated Wastelands Development Program (IWDP): <i>It implements five-year projects with community participation for sustainable rural development following a ridge-to-valley 'watershed approach' for in-situ soil and water conservation, afforestation, and water resources development in areas not covered by the DPAP or the Desert Development Program (DDP).</i></li> <li>• National Watershed Development Program for Rain-fed Areas (NWDPR): <i>It takes a demand-driven participatory approach to develop local watershed plans and converge ongoing (agricultural) production programs; it is implemented with community contributions with the assistance of Project Implementing Agencies (PIAs).</i></li> <li>• Watershed Development Fund: <i>A Rs 200 crores-fund set up at the National Bank for Agriculture and Rural Development (NABARD) to promote integrated watershed development in 100 priority districts in 18 states (including Maharashtra) through a participatory approach.</i></li> <li>• Additional Central Assistance (ACA): <i>Under the Revised Long Term Action Plan (RLTAP) for KBK districts in Orissa, this Planning Commission program aims at drought proofing and improving the moisture regime in these micro-watersheds to improve agricultural</i></li> </ul>

	productivity.
<b>NGO schemes</b>	<ul style="list-style-type: none"> <li>• Watersheds Organizations Trust (WOTR): <i>Established in 1993, WOTR is the capacity building organization of the Indo-German Watershed Development Program (IGWDP); it is financially supported by the Government of Germany and NABARD. WOTR currently supports several NGOs in implementing a multi-sectoral, multidisciplinary approach to watershed development which involves continual interaction and exchange between various sectors and disciplines.</i></li> <li>• Bharat Agro-Industries Foundation (BAIF): <i>Set up in 1967 as a non-profit public charitable trust, BAIF has developed an array of watershed interventions to promote sustainable rural development, food security, and clean environment. These include water and land-resource development, livestock development, tribal rehabilitation, empowerment of women, community health, renewable energy and environment, and training in sustainable development.</i></li> <li>• Agragame: <i>This NGO works on natural resource management, watershed management in particular, in the tribal dominated uplands of Orissa. Agragamee spearheaded Sanjojana (meaning co-ordination), a network of 45 NGOs and individuals implementing projects in watershed development, NRM, poverty alleviation, and community empowerment. Currently the Sanjojana network has seven projects in operation, six of which are located in southern tribal belt and one in the northern plateau.</i></li> </ul>
<b>International donors</b>	<ul style="list-style-type: none"> <li>• The Western Orissa Rural Livelihood Project: <i>Implemented by the Orissa Watershed Development Mission (GoO) with support from the DFID the project covers 274 watersheds in Western Orissa. The project's Watershed-Plus approach targets additional resources for the poor and marginalized; it has adopted innovative institutional arrangements to address the issues confronting the poorest and aims at organizing and enabling them to plan and implement participatory livelihood-focused development effectively.</i></li> <li>• Orissa Tribal Empowerment &amp; Livelihoods Programme (OTELP): <i>Funded by DFID, the World Food Programme (WFP), and the International Fund for Agricultural Development (IFAD), the program facilitates the transfer of land rights to tribes before taking up any land- and water-based development measures. It is being implemented in seven predominantly tribal districts of Orissa by the Scheduled Tribe and Scheduled Caste Development and Minorities and the Backward Class Welfare Department.</i></li> </ul>
<b>Agricultural Programs</b>	
<b>State-sponsored schemes implemented by the Department of Agriculture, GoM</b>	<ul style="list-style-type: none"> <li>• Developing Drought Resistant Varieties: <i>Although several varieties have reportedly been developed in agricultural universities and state research institutions, the extension staff of the Department of Agriculture has found it difficult to transfer these findings to the field.</i></li> <li>• Dry Land Horticulture Development Program: <i>Its objective is to accelerate the coverage of new areas with fruit crops.</i></li> <li>• Drip and Sprinklers: <i>There is a state-funded sprinkler and drip irrigation scheme for sugarcane and a centrally-sponsored program for sprinkler and drip irrigation for horticulture and other crops. Sprinkler sets are also distributed under the National Oilseeds Production Program and the Horticulture Program.</i></li> </ul>



*Rural Livelihoods Programs/Schemes*

<p><i>State-sponsored schemes implemented by the Department of Rural Development, GoM</i></p>	<ul style="list-style-type: none"> <li>• <i>Swarnajayanti Gram Swarozgar Yojana (SGSY): The SGSY focuses on the organization of the poor at the grassroots level through a process of social mobilization. Its aim is to establish a large number of micro-enterprises in order to bring poor families above the poverty line by providing them with income-generating assets through a mix of bank credit and governmental subsidy. It is a holistic program of self-employment which covers activities such as organizing the poor into self-help groups, building capacity through training, selection of key activities, planning activity clusters, building up infrastructure, and providing technology and marketing support.</i></li> <li>• <i>Sampoorna Grameen Rozgar Yojana (SGRY): The main objectives of the program are (a) to provide additional wage employment and food security and (b) to create durable community, social, and economic infrastructure in rural areas suffering from endemic labor migration or distress and in backward or calamity-prone rural areas.</i></li> <li>• <i>National Food for Work Programme (NFFWP): The objective is to provide additional resources to the most backward districts of the country to further intensify the generation of supplementary wage employment and provision of food-security through creation of need-based economic, social, and community assets.</i></li> <li>• <i>National Rural Employment Guarantee Scheme (NREGS): The GoI enacted the National Rural Employment Guarantee Act to guarantee 100 days/year of rural employment to every BPL household from which an adult member volunteers to do unskilled manual work. The GoI meets the entire cost of wage payments, 75% of material cost, and a certain percentage of the administrative cost. The state Government meets the cost of unemployment allowance, 25% of material cost, and the administrative cost of the state council.</i></li> </ul>
<p><i>State-sponsored livelihood support schemes implemented by the Horticulture, Animal Husbandry and Dairy Development Departments, GoM</i></p>	<ul style="list-style-type: none"> <li>• <i>Animal Husbandry: This Department's goal is to create self-employment opportunities for the educated unemployed youths and rural poor by supplying milch animals and goat units to the poorer sections of society.</i></li> <li>• <i>Dairy Development: The dairy development sector aims to ensure guaranteed remunerative price to milk producers for their milk. Ongoing work under the state plan include establishment of milk chilling plants in several districts in the Marathwada and Vidarbha regions.</i></li> <li>• <i>Horticultural Development: In Orissa, the National Horticulture Mission promotes plantation development and post-harvest activities such as production of planting materials, establishment of new fruit gardens, cultivation of flowers, rejuvenation of old plantations, protected plantations and organic farming.</i></li> </ul>

## **Appendix E: A Conceptual Framework for a Maharashtra Drought Adaptation Pilot in Rain-Fed Areas**

This appendix presents a framework for a drought adaptation pilot, using the state of Maharashtra as an example.

### **Background**

In the drought-prone regions of Maharashtra, current coping strategies appear to be increasingly inadequate in reducing people's vulnerability to the effects and impacts of climate variability and climate change. This suggests an urgent need for more effective integration of focused interventions to enhance the resilience of communities to current and potentially more disruptive future climate conditions. An ongoing World Bank-supported study entitled *Addressing Vulnerability to Climate Variability and Climate Change through an Assessment of Adaptation Issues and Options* (hereafter "the Study") has analyzed issues and options for a more comprehensive integration of climate-related matters into the Government of Maharashtra's operations. This Study also supports the development of a policy framework that integrates climate risk management into the development process.

Preliminary findings of emerging issues and options from this study were discussed in high-level meetings with Government of Maharashtra (GoM) officials in May and August 2006. These meetings concluded with the recognition that the effects of climate variability (to be further compounded by climate change) were costing the government significant time and resources, and that current crisis management was both expensive and sub-optimal. GoM officials supported the idea of looking at opportunities to better address climate-related considerations in Maharashtra's development programs. To this end, GoM officials requested that the Bank team develop a framework for a state-level pilot project on drought adaptation, as part of the ongoing Bank Study. It was agreed that the Department of Water Conservation would be the designated nodal agency for this exercise, and it would work in collaboration with other departments, including the rural development, agriculture, and horticulture departments.

A draft conceptual framework was prepared in response to this request and is used as a basis to facilitate further discussions with GoM officials. The note was presented to a group of senior GoM officials at a meeting chaired by the Secretary of Water Conservation and EGS in October 2006. Following a detailed discussion, it was decided that two designated officials, the Director of Soil Conservation and the Director of Social Forestry, would prepare responses to the draft document, which would then be integrated into a concept note. Responses were received by February 2007 and have been incorporated into this document.

### **Development Context and Rationale**

About a quarter of India's drought-prone districts are in Maharashtra, with 73% of its geographical area classified as hot and semi-arid regions. Maharashtra's 13 drought-prone districts account for 60% of its net sown area. Even districts in the moderately assured rainfall zone are increasingly affected by vagaries in monsoon rainfall. As a result, a large part of the state's predominantly rain-fed cultivable land suffers from crop failures and associated

hardships. The state faced consecutive years of drought from 2001 to 2004, and the agrarian crisis has become so acute that farmers in the rain-fed regions of the state have resorted to extreme measures, indicating a complete break-down of coping mechanisms.

At a macro-economic level, state-wide growth in the agricultural sector has been slower than in either the industrial or service sectors, and agricultural productivity is much lower than the national average. Notwithstanding unfavorable agro-climatic conditions, agriculture appears to be increasingly unproductive or only marginally productive due to a number of reasons including (a) high and unsustainable input costs (with heavy mono-cropping in some areas), (b) inadequate extension and knowledge services (resulting in suboptimal cropping practices), (c) little value added to support agri-businesses, (d) inadequate availability of groundwater and poor soil-moisture conservation, and (e) market policies that do not support the majority of farmers with small and marginal holdings (less than 5 hectares of land). Furthermore, irrigation, which covers only 16% of the total agricultural area, is mainly accessible to the large farmers due to the inequitable distribution of water resources governed largely by power subsidies<sup>65</sup>. Nonetheless, agriculture continues to be the main source of livelihood for about 58% of the state's population. All this suggests that much greater attention to rain-fed ecosystems and agriculture is needed in terms of improved productivity, income, employment, and marketing. More importantly, providing support to nonfarm livelihood approaches and income-generating activities is also needed in rural Maharashtra.

The Government of Maharashtra supports a number of development programs aimed at helping poor rural communities during drought episodes. In response to the severe drought of 1970-73 which affected 15 to 30 million people, Maharashtra led the way by introducing (for the first time in the country) the Employment Guarantee Scheme (EGS) to provide gainful employment through relief works. Over the past thirty-odd years, the EGS has provided a substantial amount of demand-led manual employment through labor-intensive public works (roads, percolation tanks, contour and 'nala' bunding, horticulture-linked works), especially during off-season periods of low employment opportunities. While the EGS is today considered a successful drought-relief program, it has not made a significant impact on reducing the drought-proneness of the state. Nor has it reduced poverty through the creation of productive assets and their maintenance or through building long-term capacity and awareness on drought resilience.

Apart from EGS, there are a number of state and centrally-sponsored programs that seek to improve community resistance to drought, such as the Drought Area Development Program (DPAP), the Integrated Wasteland Development Programme (IWDP), the National Watershed Development Programme for Rainfed Areas (NWDPA), the Jalswarajaya Water Supply and Sanitation Programme, the National Food for Work Program (NFFWP), the Swaranajayanti Gram Swarazgar Yojana (SGSY), the Sampoorna Gram Rozgar Yojana (SGRY), the Jawahar Gram Samridhi Yojana (JGSY), and the recently introduced National Rural Employment Guarantee Scheme (NREGS). There is also a rich heritage of donor and NGO supported watershed development and rural livelihood enhancement programs. Despite these programs, the rural poor appear to be increasingly vulnerable to drought conditions in the state as a whole. This

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<sup>65</sup> 2% of the farmers in the state have access to 70% of the irrigation; 80% of the state's rural population does not benefit from any irrigation schemes.

is evidenced by significant rural stress, groundwater mining, distress migration, and large and persistent inequalities in incomes and development outcomes.

Overall, lessons learned from ongoing development programs show that there has been a limited degree of success with the different approaches being implemented by different agencies under various framework and guidelines (e.g. seven different watershed conservation and development programs are currently ongoing in the state). Achievement of desired adaptation outcomes at the household and community levels has consequently been sub-optimal, even problematic. Therefore, coordinating between the multiplicity of sectors and agencies involved is a central challenge for developing a successful adaptation program in Maharashtra. This requires planning of development programs on the basis of local priorities and the lessons learned from implementing a variety of rural development projects. There is a need for a more strategic and effective integrated programming approach, with proper institutional arrangements, to help communities (a) save and recharge water, (b) adjust farming practices and cropping patterns in view of water scarcity and market conditions, and (c) provide options other than agriculture for sustaining broader livelihoods.

## **Links to Ongoing Activities and Added Value**

The focus on long-term adaptation strategies in the context of global climate change and integration of climate-risk management into developmental planning is a key area of cooperation between the World Bank and the Government of India. The Adaptation Pilot Program outlined in this concept note is in line with the programs of the Government of India and Maharashtra which give high priority to measures which would reduce the vulnerability of rural communities in rain-fed areas to climate-related risks, especially with a view of reducing and then eliminating rural poverty and regional disparities. The GoM has been allocating significant resources to programs which provide drought relief in affected areas. The pilot will build upon, and facilitate synergy with, a number of ongoing and relevant programs chiefly run by the departments of water conservation, rural development, agriculture, water resources, and forests among others. In choosing areas for a pilot activity, coordination and complementarities would be established with the ongoing activities in groundwater management and projects in the water supply, irrigation, agriculture, and forestry sectors (figure E.1). The focus of the pilot will be on long-term adaptation approaches and outcomes that go much beyond the usual programs for rural development, agriculture, forests, and water resources.

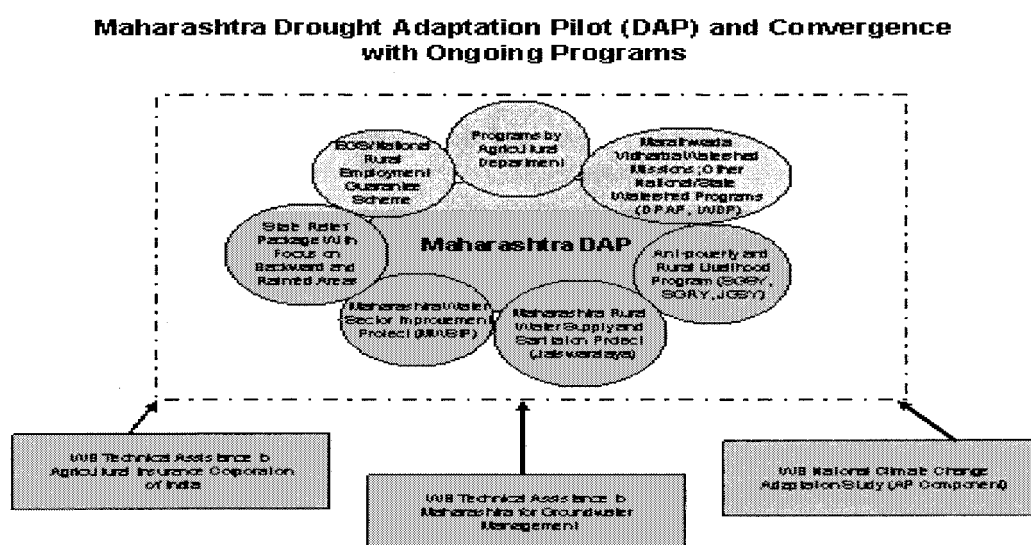
## **Objectives**

The proposed Drought Adaptation Pilot will take an integrated approach to designing and implementing adaptation strategies to droughts in rain-fed areas. The proposed primary objectives of the Drought Adaptation Pilot concept are the following:

- identify, analyze, and then recommend measures for state-level policy framework that is supportive of drought adaptation in rain-fed regions;
- improve institutional and service delivery coordination between government and programs to focus their actions and outcomes on increasing resilience to droughts;

- improve the capacity and awareness of small and marginal farmers living primarily in rain-fed areas, as well as options available to them for adapting to the impacts of climate change;
- test and evaluate measures that help (a) diversify livelihood options, (b) enhance productivity and management of dryland ecosystems through sustainable management practices, (c) improve production systems through adoption of innovative, cost-saving, and risk-minimizing technologies, and (d) safeguard vulnerable flora and fauna in their natural habitats.

**Figure E.1 Maharashtra Drought Adaptation Pilot (DAP) and Convergence with Ongoing Programs**



## Components of the Adaptation Pilot

The pilot will involve the following main components/stages:

### Component 1: Support for Development of a State-Level Policy Framework on Adaptation Including Monitoring and Knowledge Management

There is a need to develop a policy framework that supports adaptation in the state and that can take the lessons and best practices from this pilot into a larger program. The expected outcomes of the pilot would be improved awareness of and capacities for drought adaptation options and approaches, a demonstration of programmatic convergence, and a more effective packaging of focused interventions. The pilot would carry out participatory and real-time monitoring and evaluation to assess its performance in order to identify problems early on and suggest mid-term course corrections. A well-formulated monitoring strategy will therefore have to be an integral part of the pilot program. Another key area of work that could contribute to a basis for future policy work is knowledge management and sharing on drought adaptation options and experiences. The pilot will support activities on forming learning alliances for information exchange, education and communication, awareness-raising campaigns, training workshops, and creating a network of knowledge centers including websites that provide information on

adaptation. Effective monitoring and evaluation and knowledge management systems will support drought adaptation activities beyond the period of the regional pilot programs.

### **Component 2: Strengthened Convergence with Ongoing Programs**

The pilot will strengthen convergence with ongoing programs to focus the impact of these programs on drought adaptation. For instance, the convergence with EGS/National Rural Employment Guarantee Scheme (NREGS) would be established to support a range of allied activities, including public works, land development, soil and water conservation, crop planning, horticulture, and agro-forestry through people's participation. Further, convergence through EGS could include renovation and restoration of communally-owned malgajari tanks, which if repaired could give significant support to farmers. Apart from the EGS/NREGS Program, the pilot can learn lessons and build upon a plethora of relevant activities in Maharashtra. These include (a) the existing watershed development programs - the Maratwada and Vidharbha Watershed Missions and the Bank-supported Jalswarajya community-based water supply initiative, (b) the aquifer mapping and management pilots and Maharashtra Water Sector Improvement Project, (c) the Department of Agriculture's programs for drought-prone area, and (d) the work being done by the Forest Department, which owns a major portion of the degraded areas of drought-prone districts in Maharashtra.

### **Component 3: Institutional Support and Capacity Building**

The pilot's design and implementation would require specialized professional inputs and the participation of NGOs, line departments, local governments, and community-based organizations (e.g. rural cooperatives and self-help groups which could be formed by government department programs for agriculture, rural development, and forestry). In addition, the pilot can aim to develop farmer groups and user groups to take collective action. Further, these institutional groups could be linked with tied grants and micro-finance programs. The capacities and awareness levels of all of these institutional players will be developed through a well-coordinated capacity-building program at the grassroots level. Players in such a sensitization and capacity-building exercise could also include the Social Forestry Directorate, which has on-going outreach work in drought-prone areas.

### **Component 4: Community-Level Planning and Implementation of Drought Adaptation Plans**

The findings of the Bank-supported study on climate change and adaptation indicate a strong need for adaptation solutions in Maharashtra. These solutions should be based on multi-sector interventions and take into account the full range of local conditions. Therefore, it is proposed that the planning of adaptation interventions and packages be done by the communities themselves. This will require the development of micro-plans on drought adaptation, possibly linked with tied grants, taking into account ongoing programs and missing links and gaps in the village-level activities. Detailed studies on integrated planning methodologies for micro-planning in drought-prone areas would help identify ways to institutionalize such micro-planning activities in future government activities in the field. An initial assessment of the rain-fed regions in Maharashtra points to the following categories of interventions, which have the potential to make a difference in building resilience in communities.

### ***Management of Common Natural Resources (Water and Land)***

In a majority of the drought affected areas in Maharashtra, the degradation of the soil in rain-fed cultivate areas due to denudation of tree and grass cover and the ineffectiveness of programs to check soil erosion have been major problems. There is a need, therefore, for more efficient use of local rainfall to improve soil moisture and recharge groundwater. Further expansion of surface and groundwater irrigation through major or medium irrigation projects and tubewell projects is not feasible and many of the irrigation facilities in rain-fed areas require repair and maintenance. Given these circumstances, the central focus of the pilot will be on activities at the micro-watershed level, building on the Marathwada and Vidharbha Watershed Missions as a strategic entry point. Specific activities would take into account both surface and groundwater catchments<sup>66</sup> in the early stages of planning. The focus will be on (a) reducing demand, (b) developing collective protocols and mechanisms for the proper maintenance of watershed works, and (c) regulating entitlements for equitable access and use of water and biomass. This will be done through technical and participatory management techniques and systems involving Village Self Help Groups (VSHGs), grassroots NGOs, and Panchayati Raj Institutions (PRIs) which endorse the Hariyali Guidelines towards empowerment of the PRIs. These watershed investment activities will also build upon available best-practice models and the promising work of several NGOs in the state, which chiefly include the work of the Watershed Organization Trust (WOTR) under the Indo-German Watershed Development Program, BAIF, AFARM, and MSSM. It will also examine feasible mechanisms for introducing community-led management of water demand to ensure that additional water, captured through soil and water conservation, is not used up completely for expansion of irrigated areas or to support water-intensive agriculture.

Also, biodiversity conservation in these drought-prone areas needs to be addressed in a more holistic manner. Given the tough competition for limited resources, appropriate water and food management is necessary to reduce the conflicts between human beings and wildlife, such as attacks on human beings and cattle over utilization of habitat and crop raiding of agricultural and horticultural fields.

### ***Diversification of Production Systems and Technology Innovation***

In certain parts of the rain-fed regions in Maharashtra, there is a significant practice of monocropping and utilization of farming practices (e.g., purchase of commercial seeds) that are conducive only to irrigated conditions and therefore detrimental in terms of overall productivity. In addition, the use of pesticides is excessive in some rain-fed areas. These practices result in sub-optimal production levels and low price realization. The pilot would liaise with ongoing programs to strengthen the advisory and extension support services to farmers in order to suggest ways to improve existing support services for dryland agriculture. The focus of the extension services could range from recommendations on the timing and quantum of application of water and fertilizers, to recommendations on the diversification of cropping systems to include short-duration, drought-resistant seed varieties and practices that significantly increase the yield

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<sup>66</sup> There are significant variations in the state's hydrogeology that will have to be considered in order to determine the feasibility of, and potential for, groundwater recharge activities.

potential of coarse cereals, pulses, oilseeds, and fibers that are the backbone of a rain-fed agriculture.

As part of this process, the pilot will organize learning platforms that bring scientists and farmers together in order to extend lessons learned from dryland agriculture research to the farmers' fields and agricultural projects. The focus of the entire exercise will be on optimizing the available gene pool, minimizing the input costs of agriculture, and increasing the revenue per unit of land and per unit of water in rain-fed areas and irrigated tracts, hence increasing profits from sustainable agriculture overall. In addition to the focus on agricultural development, the pilot would look at issues such as apiculture, vermi-composting, and the prevention of forest fires. The pilot would also develop systems to familiarize rural communities with 'watershed plus' activities that attend to end-uses of harvested rainwater and promote livelihoods, including the development of fodder banks in order to meet the increased demand for stall feeding and the promotion of leasing arrangements of common lands to the landless for the cultivation of fodder crops and the promotion of fisheries.

### ***Nonfarm Livelihood Diversification***

In some drought-prone areas where agriculture is becoming increasingly unviable, it would be necessary to promote nonfarm livelihoods. This strategy of income diversification through alternate livelihoods can play an important role in building farmers' long-term coping abilities during drought conditions. For instance, women SHGs and other collective action groups can be mobilized to plan and implement a variety of income-generating activities with the assistance of grassroots NGOs, market-based institutions, and micro-finance institutions. A wide variety of approaches have been tried throughout different parts of the country, from which lessons will be distilled for locally-appropriate piloting. The emphasis, however, would be on developing institutional and community-based mechanisms to generate and share economically-viable options for livelihood diversification, so as to improve resilience to drought and to reduce stress migration and its attendant strain on urban areas.

### ***Economic Support Tools and Marketing***

Poor credit availability and poor marketing systems are crucial impediments in drought-affected areas, as a result of which the poor farmers suffer on various accounts. The farmers in these regions, among the poorest in the state, usually take out large loans from the informal system, the bulk of which comprise unlicensed money lenders. In practical terms, credit is required for the input cost of seeds, fertilizers, and pesticides. To strengthen the lines of credit from cooperative banks to farmers, the pilot will look at ways to troubleshoot the existing initiatives of public and private micro-finance institutions to ensure effective access to credit. For example, the National Bank of Agriculture and Rural Development (NABARD) has the capacity to create systems for providing credit lines and training in credit assessment, disbursal, and recovery to smaller nodal agencies which, in turn, can distribute these lines of credit to individual entities. There are, however, several bottlenecks that impede effective access, as demonstrated in the low adoption of farmers' insurance, and more recently, in the disbursal problems of the drought-relief credit package announced for farmers in Vidharbha. The pilot will also endeavor to develop and test innovative economic instruments for weather-related insurance and other social safety-net funds



established as contributory funds at the community level to tide the farmers over during periods of immediate distress.

### **Institutional Aspects/Partners**

The pilot program will help to further clarify the roles and responsibilities of different institutions/stakeholders, including state and local governments, NGOs, communities, sector support service agencies/line departments, local banks, and other financial institutions, in implementing such programs on a larger scale. Adaptation success stories often correlate with the presence of good NGOs, suggesting that grassroots civil society organizations can be made an important part of an adaptation strategy. To the extent possible, the pilot will try to make use of existing rural development, agricultural programs, and micro-financing schemes running successfully in the state. Institutional mechanisms for channeling tied grants to community-based groups and PRIs will need to be explored.

### **Geographical Coverage**

A pilot assessment will be performed in two or three districts, representing four to five different agro-climatic zones and geographical and socio-economic conditions, with coordinated inputs from different departments and agencies (e.g., Agriculture, Horticulture, Soil Conservation, Forest, Minor Irrigation, IMD, GSDA), research institutions, and NGOs (e.g. BAIF, AFARM, MSSM, WOTR). The final selection of districts will be made upon assessing a range of factors, including:

- the interest of the district/block level authorities;
- the availability/skill potential of NGOs and other institutions to participate in the implementation;
- the availability of a range of geo-hydrological and agro-climatic conditions in the area, so as to be able to test and evaluate a mix of interventions;
- the existence of relatively successful key programs such as EGS/NREGS and watershed activities in the area; and
- the potential to maximize learning value and usefulness of the pilot exercise, including the formulation of a larger program.

### **Implementation Arrangements**

A source of financing will have to be identified to support this pilot. Some financial and/or in-kind contribution will be expected from the state government. The overall exercise will take place in collaboration with and under the guidance of the Department of Water Conservation and EGS. A nodal agency/contact point at the state government level will be identified and will coordinate/facilitate/oversee the work in the state. Implementation arrangements at the district and block levels will be discussed and identified in consultation with the state nodal agency. Pilot programs will involve a range of stakeholders including state and local governments, NGOs, SHGs, WUAs, consulting firms (for training), local banks, etc. A steering committee chaired by the Secretary of the Department of Water Conservation and EGS could be

established, that includes representatives from other departments (such as the rural development, agriculture, revenue and planning departments), NABARD, and key NGOs.

**Table E.1 Potential Impacts and Responses for Addressing Vulnerability to Climate Variability and Climate Change in Maharashtra**

Sectors	Economic Impacts	Ecosystem Impacts	Impacts on Poor	Potential Intervention Options
<b>Irrigation, Tank Management</b>	Drought, floods, water supply, and power	Impact on biodiversity	Irrigation potential, vulnerability to drought	<ul style="list-style-type: none"> <li>• Restoration and more efficient management of tank system</li> <li>• Adoption of more efficient methods of irrigation</li> <li>• Desiltation of canals and feeder channels and restoration of lakes</li> <li>• Demand-side response strategies, such as water pricing, water rights, social regulation of private borewells, reform in water laws, etc.</li> </ul>
<b>Agriculture and Livestock</b>	Loss of production	Pests and diseases	Food poverty and malnutrition	<ul style="list-style-type: none"> <li>• Crop diversification and livestock production and management strategies</li> <li>• Development of new technologies and improved extension services</li> <li>• Changes in land use practices, including changes in timing, cropping sequence, and intensity of production; land rights policies</li> <li>• Minimizing external and high cost inputs (pest and soil productivity management)</li> <li>• Seed management for normal and contingent years</li> <li>• Community management of livestock and fisheries</li> <li>• Changes in marketing systems and risk financing options (e.g. credit and insurance)</li> </ul>
<b>Natural Resource Management, Livelihoods</b>	Loss of assets and livelihoods; migration	Depletion in groundwater, soil cover, and moisture content	Food and income poverty for human and livestock systems	<ul style="list-style-type: none"> <li>• Management of common land and private fallow land as buffer for drought vulnerability</li> <li>• Changes in graze-land management practices (time, location, duration)</li> <li>• Natural regeneration of biomass through social fencing</li> <li>• Promotion of non-farm income generation and livelihood opportunities</li> </ul>
<b>Economic Instruments</b>	Loss of production and livestock	Low productivity	Food and income poverty, large debts, acute economic stress during calamity conditions	<ul style="list-style-type: none"> <li>• Changes in risk financing options (crop insurance, weather-based insurance)</li> <li>• Social safety nets</li> </ul>

## Appendix F: Program for Stakeholder Consultations

<b>Date &amp; Place</b>	<b>Event</b>	<b>Objective</b>	<b>Participants</b>	<b>Responsibility</b>
June 3-4, 2004 New Delhi	Roundtable Discussion	To examine issues and options surrounding the emerging issue of adaptation to climate change and implications for India and the rest of South Asia	MoEF, DEA, IIM, TIFAC, Development Alternatives, TERI	World Bank
August 16, 2004 New Delhi	Roundtable Discussion	To discuss and seek feedback on the Working Draft Concept Note of the study	MoEF, DEA, IIM, TIFAC, Development Alternatives, TERI	World Bank
February 1, 2005 New Delhi	Review Meeting	To discuss and finalize the study concept note and terms of reference	Government of India, (MoEF, MoA, MoRD, MoWR, MoST, DEA, PC), Institutions and Experts (IIM, IARI, IIT, IPCC), Bilaterals (DFID)	World Bank
May 9, 2005 New Delhi	Launch Workshop	To launch the study and to discuss the study methodology with a wide range of stakeholders	Government of India ministries and agencies, RMSI, TERI, NGOs, and TAG experts	Government of India and World Bank
October 26, 2005 New Delhi	Meeting with Technical Advisory Group (TAG) and policy experts	To discuss and seek feedback on the study methodology	Members of TAG, MoEF, and other central government officials	World Bank
April 25, 2006 New Delhi	Meeting with Secretary and other senior officials of MoEF	To discuss the status and next steps of the study	MoEF, World Bank, TERI	MoEF
April 26, 2006 New Delhi	Technical Advisory Group (TAG) Meeting	To discuss and seek feedback on preliminary results of climate modeling and household surveys	Members of the TAG (select Indian experts)	TERI and World Bank
April 29, 2006 Bhubaneswar	Roundtable Discussions	To share the objectives of the study and methodology in order to set the stage for a more in-depth discussion once the preliminary analysis of data was complete	Senior officials from various state departments and NGOs	Department of Relief and Rehabilitation and Department of Water Resources, OSDMA, Government of Orissa

May 8, 2006 Mumbai	Roundtable Discussions	To share the objectives of the study and methodology in order to set the stage for a more in-depth discussion once the preliminary analysis of data was complete; to initiate a rapid assessment of the existing line-department programs for coping with floods and droughts in Maharashtra	Senior officials from various state departments	Department of Rural Development and Water Conservation, Government of Maharashtra
August 28-29, 2006 Bhubaneswar	Bilateral Meetings with state departments	To discuss preliminary study findings from the case study	Chief Secretary and Secretaries from the Departments of Planning, Revenue, Water Resources (WRD), Rural Development (RD), Relief and Rehabilitation, and Agriculture (DOA)	World Bank
August 31-September 1, 2006 Mumbai	Bilateral Meetings with state departments and Roundtable	To discuss preliminary findings from the case study and the follow-up, in-depth analysis undertaken in cooperation with state government agencies	Secretaries from the DOA, Environment, RD, and Water Conservation; officials from GSDA, Irrigation, and other line departments	Department of Rural Development and Water Conservation, Government of Maharashtra
November 3-4, 2006 Mumbai	Roundtable	To discuss preliminary findings from the case study and the follow-up, in-depth analysis undertaken in cooperation with state government agencies	Department of Rural Development and Water Conservation, Government of Maharashtra	Department of Rural Development and Water Conservation, Government of Maharashtra
December 7-8, 2006 New Delhi	International Conference on Adaptation to Climate Variability and Change	To disseminate emerging adaptation programs and strategies; to present emerging international models of adaptation actions and programs; to discuss emerging findings of the study	State governments, Government of India ministries and agencies and experts	Department of Rural Development and Water Conservation, Government of Maharashtra
December 18-22, 2006 Bhubaneswar	Roundtable and Bilateral Meetings with state departments	To initiate a rapid assessment of the existing line-department programs for coping with floods and droughts in Orissa	US Geological Survey, WRD, Watershed Development Mission, Department of Revenue, DOA, OSDMA, ORSC, Department of Planning & Coordination, Government of Orissa	Department of Water Resources, Government of Orissa

## Appendix G: A Description of the Economic Model

The structure of the economic model has been determined by the outputs, sequence and constraints imposed by the agronomic model EPIC. The approach in this report extends and draws upon previous work where EPIC has been linked to economic models to determine the impacts of agricultural policy in the EU.<sup>67</sup>

Following the steps in EPIC it is assumed that once land area has been allocated to different crops, farmers make farm management decisions in response to the observed weather pattern, by altering fertilization, watering etc to optimize payoffs. This suggests a two stage modeling process: in the first stage, the crop mix is determined based on the anticipated weather outcomes and expected profits from each crop. Once crop choices and land allocation decisions are made, planting, fertilizing and irrigation occurs and is adjusted in response to the actual weather.

Accordingly, by backward induction, the second stage of the model, where farm techniques are determined, is solved first. Specifically, for any given crop  $i \in (1, n)$ , the farmer varies farm management techniques to maximize the per hectare payoffs from the crop:

$$1. \quad \pi_i = p_i y_i(Z_i, \Gamma) - c_i(Z_i)$$

where  $\pi_i$  is per hectare profits from crop  $i$ ,  $p_i$  is price of crop  $i$ ,  $y_i(Z_i, \Gamma)$  is yields from EPIC based on farm management strategy  $Z_i$  and a vector representing climate event  $\Gamma$ . The properties of  $y_i(Z_i, \Gamma)$  are determined by EPIC and typically appear to exhibit single peaked behavior. Specifically: for some  $z_k \in Z_i \exists$  a  $\bar{z}$  such that for  $z < \bar{z}$ ,  $\partial y_i / \partial z_k > 0$  and for  $z > \bar{z}$ ,  $\partial y_i / \partial z_k < 0$ .  $c_i(Z_i)$  are the corresponding costs of farm strategy  $Z_i$ . Costs are linear in inputs and

are expressed as:  $c_i(Z_i) = \sum_{k=1}^h c^k V^k$ , where  $c^k$  is the cost coefficient of input  $V^k$ ,  $k \in (1, h)$ .  $\Gamma$

represents the many dimensions of climate incorporated in EPIC and includes among other factors the *daily* level and distribution of temperature, rainfall, soil moisture and carbon dioxide.

Thus for an element  $\Gamma^j \in \Gamma$ ,  $\partial y_i / \partial \Gamma^j \geq 0$  and  $\partial y_i^2 / \partial \Gamma^{j^2} \leq 0$ . Since the focus is on the farm household at the district level it is natural to assume that all prices are exogenous.

For purposes of the simulations a range of discrete farm management strategies are used covering variations and different combinations of (a) seeding, (b) fertilization, (c) irrigation and (d) tillage techniques. Let \* denote the optimum value of inputs from the maximization of equation (1), then in stage two farmers determine land allocation based on the expected profits from each crop:

$$2. \quad \max_{L_i} \Psi = \sum_{i=1}^n \{\Pi_i L_i - \sigma D(\Pi_i)\}$$

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<sup>67</sup> See, e.g. FIPM 2005.

where  $\Pi_i = E(\pi_i^*)$ ,  $E$  is the expectations operator with expectations defined over climate events that determine yields for any given farm management strategy,  $L_i$  is land devoted to crop  $i$ , and  $D(\Pi_i)$  is the sum of negative deviation of payoffs from crop  $i$  and  $\sigma$  is a risk aversion parameter. Together these terms capture risk taking behavior in a simple way using the familiar mean-variance approach. Other more complex methods are left for future extensions of the framework. Equation (2) is maximized subject to a series of technical constraints. The key among these are a land availability constraint:

$$3. \quad \sum_{i=1}^n L_i \leq \bar{L} \quad \text{land availability constraint}$$

where  $\bar{L}$  is the given endowment of land.  
And a water supply constraint:

$$4. \quad \sum_{i=1}^n w_i L_i \leq \bar{W} \quad \text{water supply constraint}$$

where  $w_i$  is water consumption coefficient for crop  $i$ , and  $\bar{W}$  is total water supply. For completeness a number of additional constraints are incorporated into the spreadsheet for seeds, fertilizer and labor but are not allowed to bind since there is little evidence of quantity constraints of these inputs on farms.

In Andhra Pradesh, an additional constraint is imposed requiring a minimum of 0.5 hectares is devoted to rice. This captures survey evidence showing that rice is grown on these farms to meet subsistence needs for fodder and consumption.

$$5. \quad L_r \geq \tilde{L}_r \quad \text{subsistence rice consumption constraint}$$

where  $\tilde{L}_r = 0.5$  ha, and subscript  $r$  denotes rice crop.

Since not all farmers are identical, the analysis distinguishes between three types of cultivators, depending on the availability of land. *Subsistence* farmers are classified as those with landholdings up to 2 hectares. They are driven by subsistence needs and the imperative to survive takes precedence over commercial considerations. This is modeled as a safety-first constraint where the primary objective is to earn a threshold amount of Rs. 12,000, which is the subsistence threshold in the National Sample Survey (NSS). *Medium* farmers have holdings between 2 and 3.5 hectares and *large* farmers have holdings in excess of 4.5 hectares. The farmers attempt to maximize the commercial payoffs from farming, as defined in equations (2) – (5). To capture subsistence behavior an additional simple constraint is imposed for small land holders:

$$6. \quad \sum_{i=1}^n \{\Pi_i L_i\} \geq \bar{\Psi} \quad \text{small farm subsistence constraint}$$

where  $\bar{\Psi} = \text{Rs. } 12,000$ . The simulations allow for rational expectations where expectations are based on the known distribution of events and adaptive expectation where there is learning and expectations are based on past series of events.

**Sensitivity Analysis of the Farm Economic Model**

The results of quantitative assessments are dependent on key modeling decisions and assumptions. It is therefore important to assess the robustness of the results to various plausible changes. This section describes sensitivity assessments of the results presented in the main report. The focus is on (a) crop and input prices (b) levels of farmer’s attitude towards risk (c) assumptions on farmer’s knowledge of climate events and (d) levels of water availability/shortage.

The farm economic model finds that in Andhra Pradesh, irrespective of farm size, the bulk of the cropped area is devoted to groundnut. Under climate change scenarios, groundnut still remains the most profitable crop, and consequently there is no change in the planting mix. Table A.1 assesses the extent to which changes in input parameters (including price of crops, total labor cost, and fertilizer cost) would be required to alter the current findings. Table A.1 reports critical percentage changes that make rice and jowar competitive to groundnut.

**Table G.1 Critical Percentage Changes for Diversification out of Groundnut in Andhra Pradesh**

	Rice			Jowar		
	Price	Total Labor Cost	Fertilizer Cost	Price	Total Labor Cost	Fertilizer Cost
Baseline	27	-57	-107	44	-229	-188
A2	23	-23	-60	29	-151	-108
B2	25	-50	-103	47	-246	-186

Table G.1 suggests, for example, that under the baseline scenario the price of rice has to increase by 27% (from 5.7 to 7.3 Rs/kg) to induce farmers to start growing rice, while this is 44% (from 5.3 to 7.6 Rs/kg) for jowar. Fertilizer cost for rice needs to be reduced by as much as 107% to make rice competitive – an unrealistic situation even if subsidized.

Turning next to variations in the risk aversion parameter, the degree of risk aversion is likely to be negatively associated with farm size – asset holdings and wealth, so results are presented for medium farmers as an illustration of the insensitivity of the cropping mix results.<sup>68</sup>

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<sup>68</sup> Binswanger (1980) conducted an experimental study with 330 individuals from arid areas in Andhra Pradesh and Maharashtra and found that more than 80% were “moderately” risk-averse. Only 2% of individuals were found to be “extremely” risk-averse.

**Table G.2 Risk Aversion and Cropping Mix in Andhra Pradesh**

risk aversion coefficient	Baseline			A2			B2		
	Rice	GN	Jowar	Rice	GN	Jowar	Rice	GN	Jowar
0	0.5	3	0	0.5	3	0	0.5	3	0
1	0.5	3	0	0.5	3	0	0.5	3	0
2	0.5	3	0	0.5	3	0	0.5	3	0

Table G.2 gives an example of medium farmers cropping patterns with varying levels of attitude towards risk. Higher risk coefficient implies a higher degree of risk aversion. Under all climate scenarios, the crop mix is not sensitive to whether farmers are risk-neutral or risk-averse<sup>69</sup>.

Turning next to Maharashtra. The economic assessment finds that, on farms where there is adequate water, sugarcane is the dominant crop due to its significantly higher profits. Table G.3 shows the levels of crop prices, fertilizer costs, and user charge of water necessary to make bajra and jowar competitive to sugarcane. For this, bajra and jowar prices have to be increased more than three fold. The level of user charge of water for sugarcane farmer is assumed to be minimal (1.2 Rs/mm) to reflect simply costs of irrigation without water charges. If water charges were increased to the levels shown in Table G.4, the area of land allocated to sugarcane would shrink and farmers would start growing less water-intensive crops. The analysis with variations in risk aversion shows that sugarcane remains dominant regardless of whether farmers are risk-neutral or risk-averse (Table G.4).

**Table G.3 Competitive Crop Prices, Fertilization Cost, and User Charge of Water in Maharashtra (Rs/kilogram and Rs/mm)**

	Price of Bajra	Bajra Fertilizer Cost	Price of Jowar	Jowar Fertilizer Cost	User Charge of Water
<b>Baseline</b>	24	-82	28.5	-123	59.3
<b>A2</b>	17.8	-50	20.2	-80	43.8
<b>B2</b>	19.5	-55	21.3	-85	41.8

Note: current price of bajra and jowar is 5.25 Rs/kg, while their fertilization cost is 12 Rs/kg

**Table G.4 Risk Aversion and Cropping Mix in Maharashtra**

risk aversion coefficient	Baseline			A2			B2		
	Bajra	Jowar	Sugarcane	Bajra	Jowar	Sugarcane	Bajra	Jowar	Sugarcane
0	0	0	3.5	0	0	3.5	0	0	3.5
1	0	0	3.5	0	0	3.5	0	0	3.5
2	0	0	3.5	0	0	3.5	0	0	3.5

<sup>69</sup> A substantial majority of individuals in these areas are moderately risk-averse, and this is recognized in the literature (e.g. Anderson and Dillon, 1992) as equivalent to the risk-aversion factor of 1. The exercise allows risk-aversion coefficient up to the factor of 2, the level beyond which is very unlikely to be found among households in these areas.



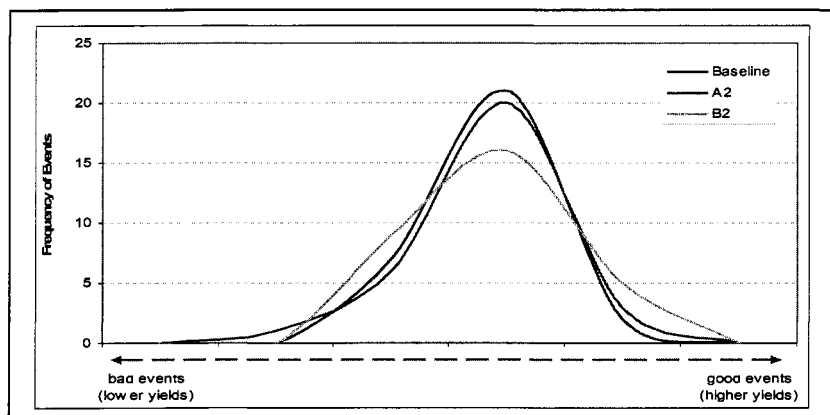
**The Role of Expectations:** Expectations on climate events also play a significant role in determining how farmers respond to climate change. The main analysis presented is with the case where farmers hold rational expectations - based on the actual distribution of climate events. Further analysis shows that, even when farmers are not as well-informed, the relative profitability among the crops under consideration remains unchanged – groundnut being the most profitable in Andhra Pradesh and sugarcane in Maharashtra. Thus, the findings are not contingent on whether the farmers have full knowledge of climate change or make planting decision based on year-by-year past experience of weather events (table G.5). This reflects the extreme conditions in these areas.

**Table G.5 Farmers’ Knowledge of Climate Events and Cropping Mix**

Knowledge Base of Climate Events	Andhra Pradesh			Maharashtra		
	Rice	Groundnut	Jowar	Bajra	Jowar	Sugarcane
Rational Expectations	0.5	3	0	0	0	3.5
Past 20 years	0.5	3	0	0	0	3.5
Past 10 years	0.5	3	0	0	0	3.5
Past 1 year	0.5	3	0	0	0	3.5

According to EPIC model, farmers are expected to deal with weather events that are more extreme more frequently compared to the past. Although higher returns are possible, the farmers will encounter undesirable outcomes in A2 that lie outside their experience (figure G1). It is important to note that the assessment so far is based on the optimistic notion that water and irrigation supplies are unaffected by climate change. With warmer conditions and higher rates of evapotranspiration, water demand is likely to increase and water tables, which are already in decline, may deplete even further. So, it is important to assess how growing water shortages, combined with climate change, affect farm incomes.

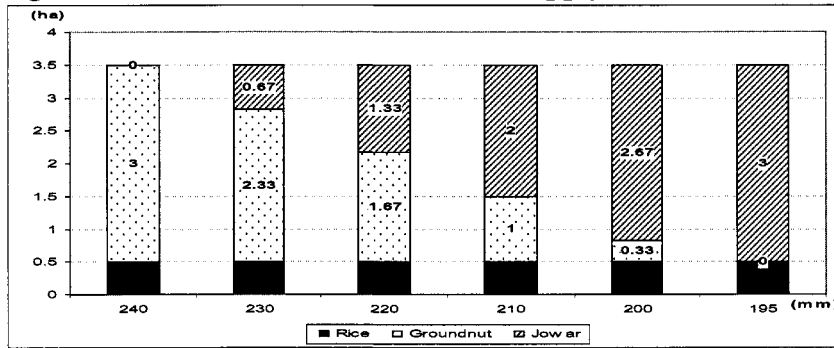
**Figure G.1 Distribution of Groundnut Yields in Andhra Pradesh**



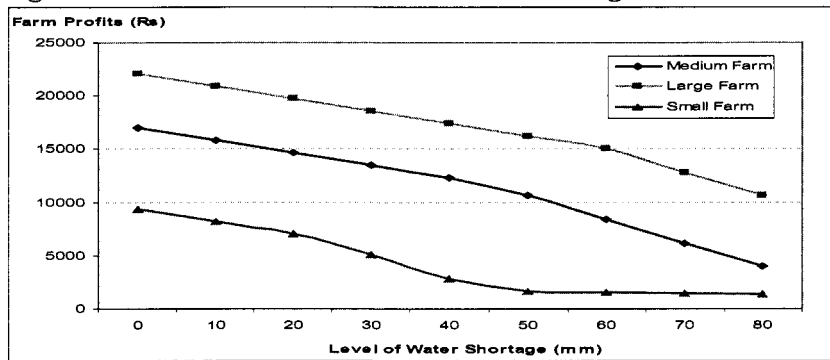
Significant water shortages lead to shifts in cropping patterns, a decline in cropped area and lower incomes. With shrinking water availability the balance shifts towards jowar, (figure G.2).

Figure G.3 shows the consequences of water shortages on farm incomes. Even medium-sized farms fall below the “survival threshold” of Rs 12,000 in the A2 scenario, when the constraint binds sufficiently. Though these results are illustrative rather than predictive, the implied magnitudes highlight the importance of strengthening water conservation initiatives across the state.

**Figure G.2 Area Allocation and Water Supply, Medium Farm, Andhra Pradesh**

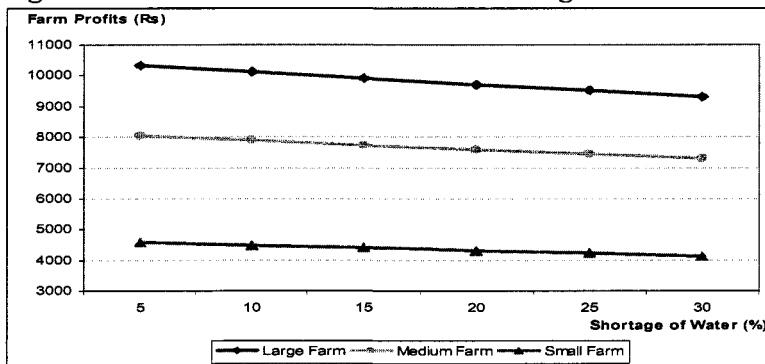


**Figure G.3 Profits and Levels of Water Shortage in A2 Scenario in Andhra Pradesh**



Farmers in these arid areas are typically water constrained, and a similar pattern emerges for both millets and sugarcane farmers in Maharashtra. Corresponding to the declining water availability is a decline in farm income. Figure G.4 shows that a 30% water shortage results in an 11% decline in income.

**Figure G.4 Millet Farm Profits and Shortage of Water in Maharashtra**



Overall, the sensitivity assessment finds that the predicted cropping patterns are relatively robust to the various assumptions that potentially affect farm practices. However, the level of water availability/shortages has a significant implication on farmers' planting decisions and associated levels of their incomes.

## Econometric Analysis and Results

This section reports detailed findings of the analysis of determinants of household vulnerability to drought in Andhra Pradesh and Maharashtra. It is aimed to supplement the discussion in chapters 3 and 4. The organization is as follows. First, key statistics for Andhra Pradesh are summarized in table G.6, then table G.7 presents those for Maharashtra. A summary of statistics and pair-wise correlation coefficients are given from table G.8-11, with the description of variables provided in table G.12.

**Table G.6 Andhra Pradesh – OLS Regressions**

Variable	(1)	(2)	(3)
	Income in Normal Year	Income Volatility	Diversified income in drought year
District dummy	386.04*** (145.14)	0.074*** (0.02)	-89.26** (53.42)
Landholding size	528.47*** (82.47)	0.064*** (0.009)	
Infrastructure development	493.14*** (148.39)	-0.02 (0.02)	127.28** (54.69)
Water needs	0.11*** (0.02)	4.10e-06*** (1.30e-06)	-0.008** (0.003)
Education	48.68*** (16.39)	-0.001 (0.001)	6.47** (3.49)
Tubewell irrigation access	1190.68** (560.84)	-0.004 (0.04)	64.04 (87.07)
Canal irrigation access	344.28* (234.73)	0.015 (0.03)	146.99** (83.08)
Diversified income in drought year		-1.9e-04*** (1.8e-05)	
Indebtedness		4.9e-04** (2.8e-04)	
Non-agricultural occupation	367.05** (187.82)		
Observations	505	505	505
R <sup>2</sup>	0.37	0.35	0.03

*Notes:* Constants are not reported. Standard errors in parenthesis and are corrected for heteroskedasticity. \*\*\*, \*\*, and \* indicate statistical significance at the 1, 5, and 10% level, respectively.

The econometric exercise utilizes cross-sectional, household-level survey data from the two states, and uses the Ordinary Least Square (OLS) technique with linear specifications. Standard errors are corrected for heteroskedasticity. Multicollinearity is a possible concern; however, it is unlikely to present in the analysis – correlation coefficients among the explanatory variables are low (see tables G.10 and G.12) and there is no evidence of substituting impacts.

Estimated coefficients should be interpreted with care. The low explanatory power of some regressions suggests the potential of omitted variable bias. Keeping in mind the cautions,

messages and implications for the study are drawn from key determinants that are highly significant and that the direction and magnitude of impacts are stable across various specifications. Table G.8-12 provide a summary of data and variable used in the analysis.

**Table G.7 Maharashtra – OLS Regressions**

Variable	(4)	(5)	(6)
	Income in Drought Year	Income Volatility	Diversified income in drought year
District dummy	-1022.90** (509.07)	0.36*** (0.05)	-980.99*** (179.67)
Landholding size	261.15*** (98.07)	-0.05*** (0.01)	
Infrastructure development	540.60** (236.36)		393.63** (181.05)
Tubewell irrigation access	659.55** (373.97)	0.09*** (0.03)	
Canal irrigation access	-187.58 (332.88)	0.05 (0.07)	
Diversified income in drought year		-3.0e-05** (1.6e-05)	
Education			26.95** (11.97)
Indebtedness			-102.44*** (39.47)
Observations	409	409	409
R <sup>2</sup>	0.06	0.29	0.09

*Notes:* Tubewell and canal access used for (4) are in drought year, while those for (5) are in normal year. Constants are not reported. Standard errors in parenthesis and are corrected for heteroskedasticity. \*\*\*, \*\*, and \* indicate statistical significance at the 1, 5, and 10% level, respectively.

**Table G.8 Descriptive Statistics for Andhra Pradesh**

Variable	Obs	Mean	Std.	Min	Max
			Dev.		
Landholding size	509	2.51	1.06	1	4
Infrastructure development	509	0.6	0.49	0	1
Water needs	509	2870	5980	0	58750
Education	509	6.71	8	1	54.6
Tubewell irrigation access	505	0.08	0.26	0	1
Canal irrigation access	505	0.1	0.3	0	1
Diversified income in drought year	509	303.8	493.2	0	1200
Indebtedness	509	7.48	24.36	0	500
Non-agricultural occupation	509	0.83	0.37	0	1

**Table G.9 Correlation Matrix for Andhra Pradesh**

Landholding size	1								
Infrastructure development	-0.08	1							
Water needs	0.49	-0.08	1						
Education	0.18	0.18	0.21	1					
Tubewell irrigation access	0.23	-0.01	0.26	0.14	1				
Canal irrigation access	0.18	-0.28	0.12	-0.03	-0.09	1			
Diversified income in drought year	-0.04	0.08	-0.05	0.09	0.01	0.06	1		
Indebtedness	-0.09	-0.02	-0.03	0.01	-0.02	-0.01	-0.01	1	
Non-agricultural occupation	-0.16	0.13	-0.11	0.06	-0.09	-0.1	0.25	-0.05	1

**Table G.10 Descriptive Statistics for Maharashtra**

Variable	Obs	Mean	Std. Dev.	Min	Max
Landholding size	409	2.09	1.01	1	4
Infrastructure development	409	0.57	0.50	0	1
Tubewell irrigation access in normal year	409	0.41	0.49	0	1
Canal irrigation access in normal year	409	0.03	0.18	0	1
Tubewell irrigation access in drought year	409	0.17	0.37	0	1
Canal irrigation access in drought year	409	0.02	0.15	0	1
Diversified income in drought year	409	680.14	1601.18	0	20000
Education	409	14.64	10.67	1	54.598
Indebtedness	409	0.41	1.38	0	21.505

**Table G.11 Correlation Matrix for Maharashtra**

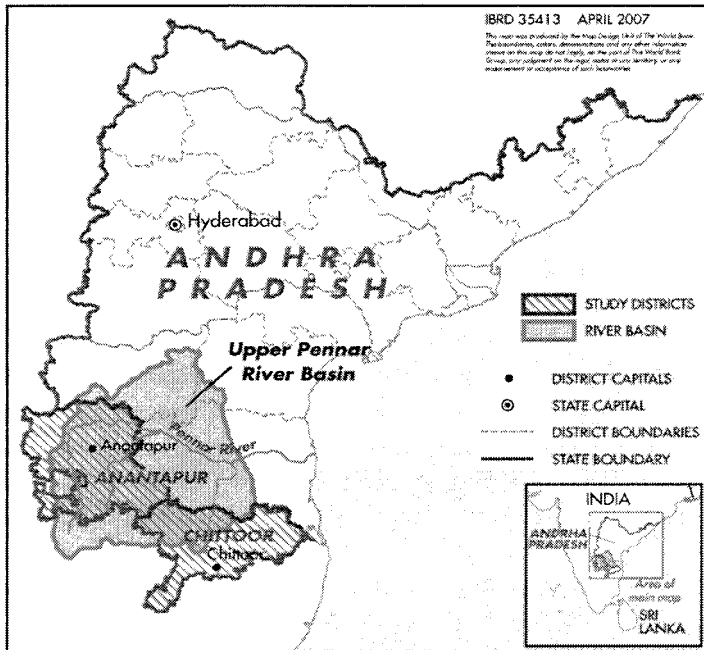
Landholding size	1								
Infrastructure development	0.06	1							
Tubewell irrigation access in normal year	0.38	0.36	1						
Canal irrigation access in normal year	0.08	0.16	-0.05	1					
Tubewell irrigation access in drought year	0.20	0.15	0.53	-0.05	1				
Canal irrigation access in drought year	0.05	0.13	-0.09	0.80	-0.02	1			
Diversified income in drought year	0.10	0.05	0.07	-0.04	0.09	-0.02	1		
Education	0.20	0.10	0.18	-0.01	0.09	0.00	0.17	1	
Indebtedness	0.05	-0.04	0.05	0.05	-0.08	-0.02	-0.08	0.16	1

**Table G.12 Description of Variables**

Variable	Description
Landholding size	An index measuring the size of land ownership: landless (1), marginal (2), medium (3), and large (4)
Infrastructure development	A village-level index capturing the availability of health and education facilities, electricity, drinking water, banks, agricultural cooperatives, and communication linkages, classified into low (0), moderate (1), and high (2)
Water needs	Total water needs of the households in normal years (in millimeters), calculated by multiplying water requirement of crops grown by the area cultivated for each crop
Education	The level of education based on the number of schooling years with the assumption of increasing return to education, captured through an exponential function
Tubewell irrigation access	A dummy variable capturing whether a household has access to tubewell irrigation, with 1 and 0 value indicating access and no access, respectively
Canal irrigation access	A dummy variable capturing whether a household has access to canal irrigation, with 1 and 0 value indicating access and no access, respectively
Diversified income in drought year	The total level of non-agricultural incomes (Rs) including non-agricultural labor, petty and diary businesses, and remittances that a household derives in drought year
Indebtedness	The ratio of credit/loan amount taken by a household to total yearly income
Non-agricultural occupation	A dummy variable reflecting whether a household is engaged in cultivation, with 0 indicating cultivation and 1 otherwise

# APPENDIX H: MAPS OF LOCATION AND CLIMATE CHANGE IMPACTS IN STUDY AREAS

**Figure H.1 Andhra Pradesh Study Area**



**Figure H.2 Maharashtra Study Area**

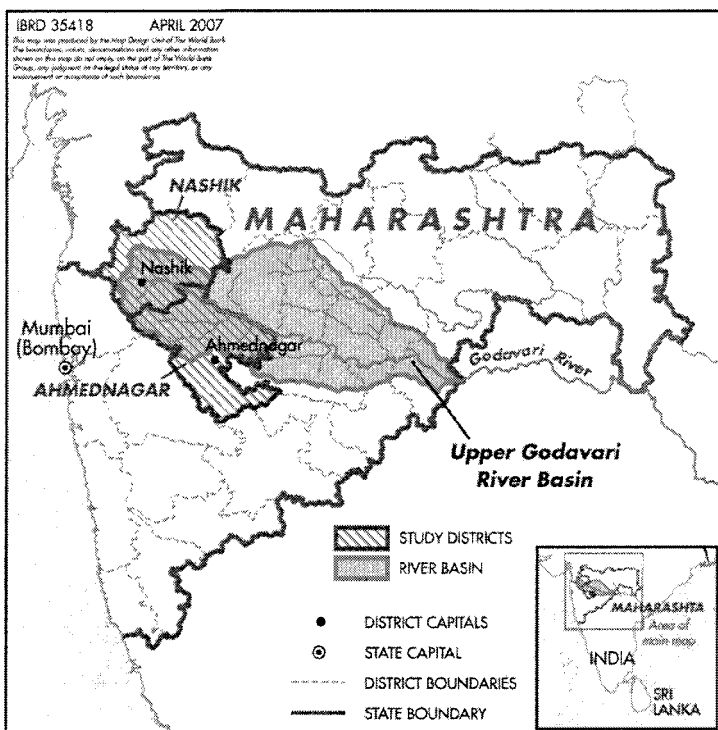
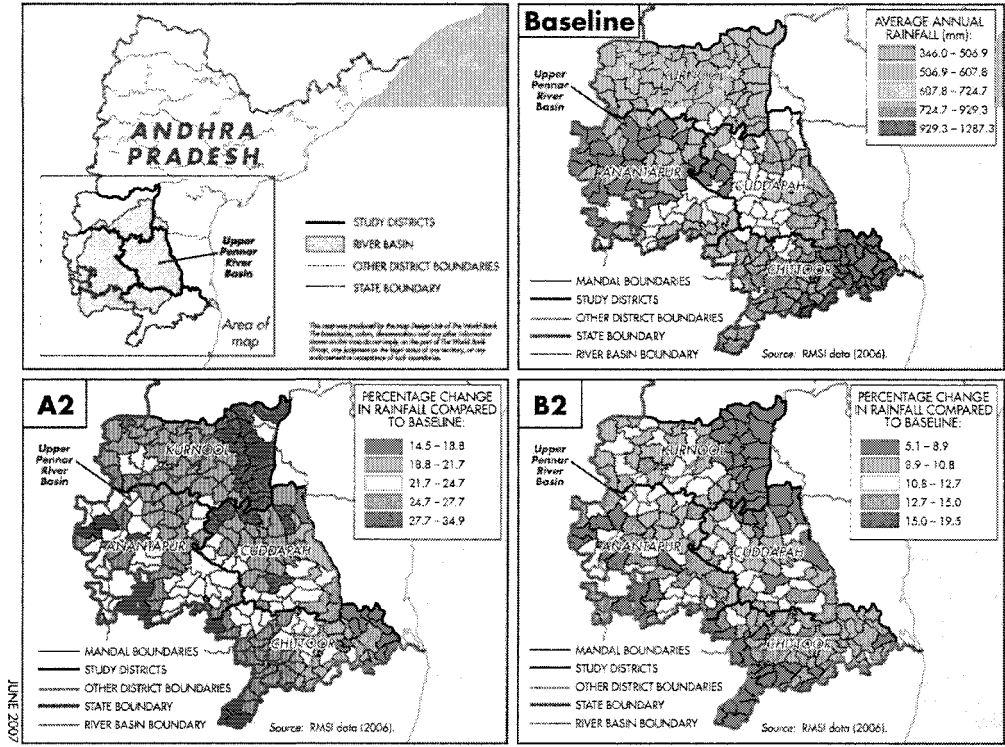


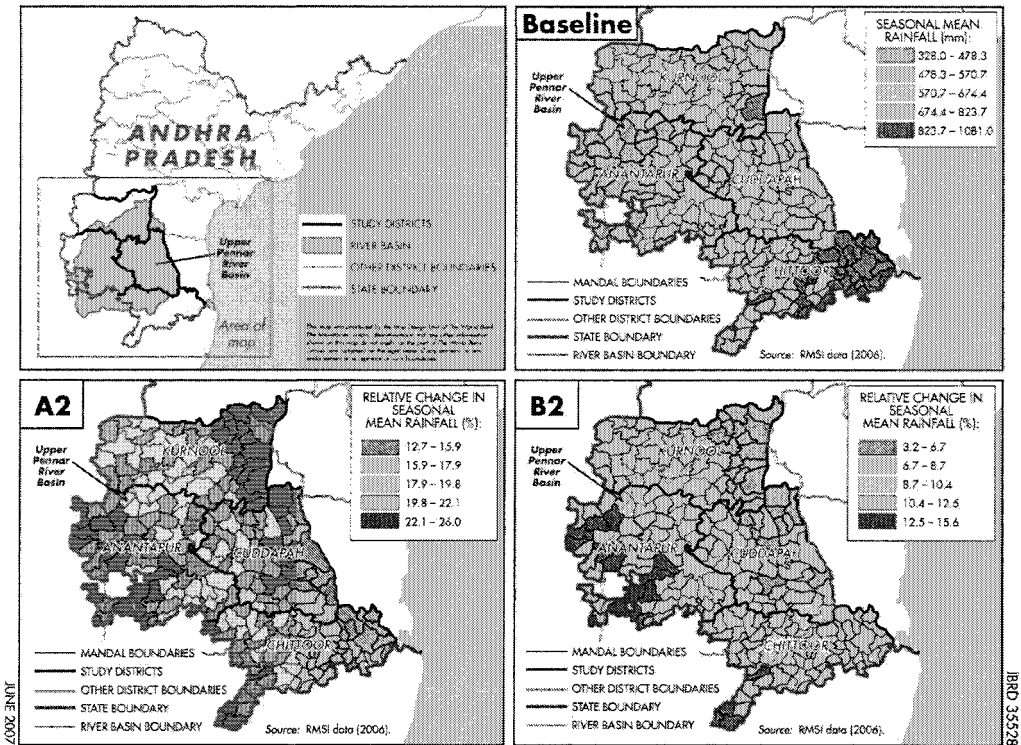
Figure H.3 Orissa Study Area



**Figure H.4 Average Annual Rainfall in Four Districts in Andhra Pradesh**

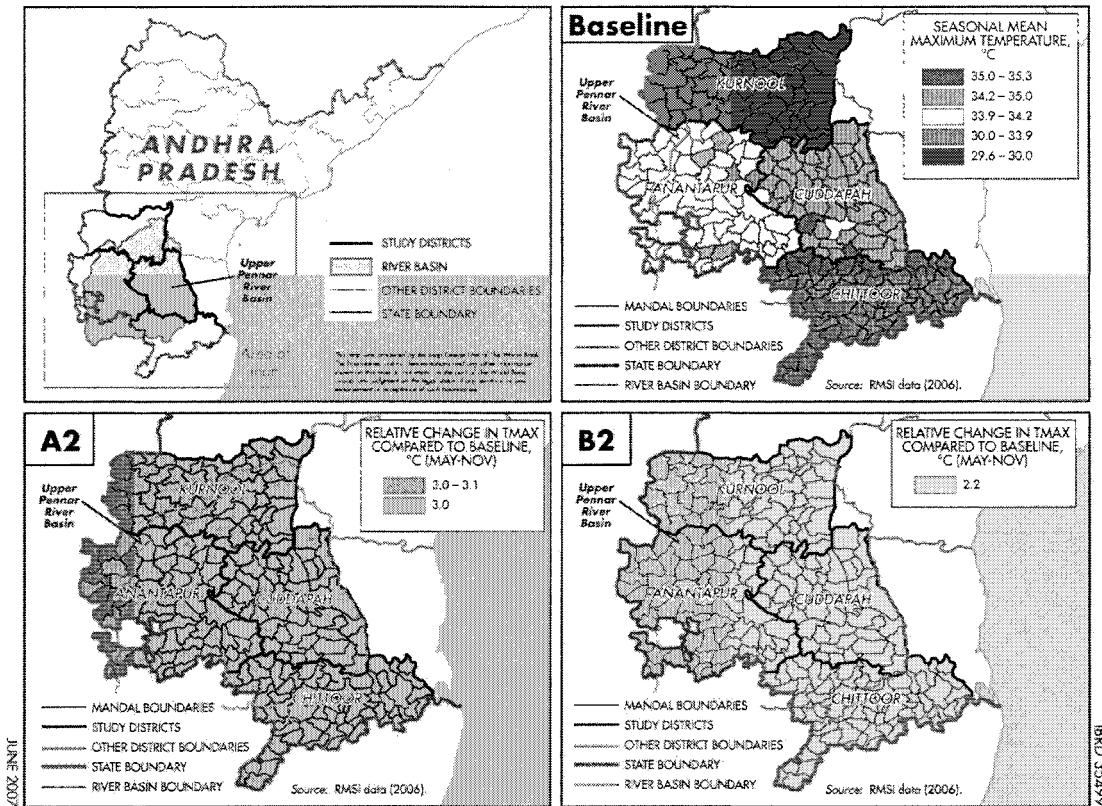


**Figure H.5 Average Rainfall in Kharif Season in Four Districts in Andhra Pradesh**





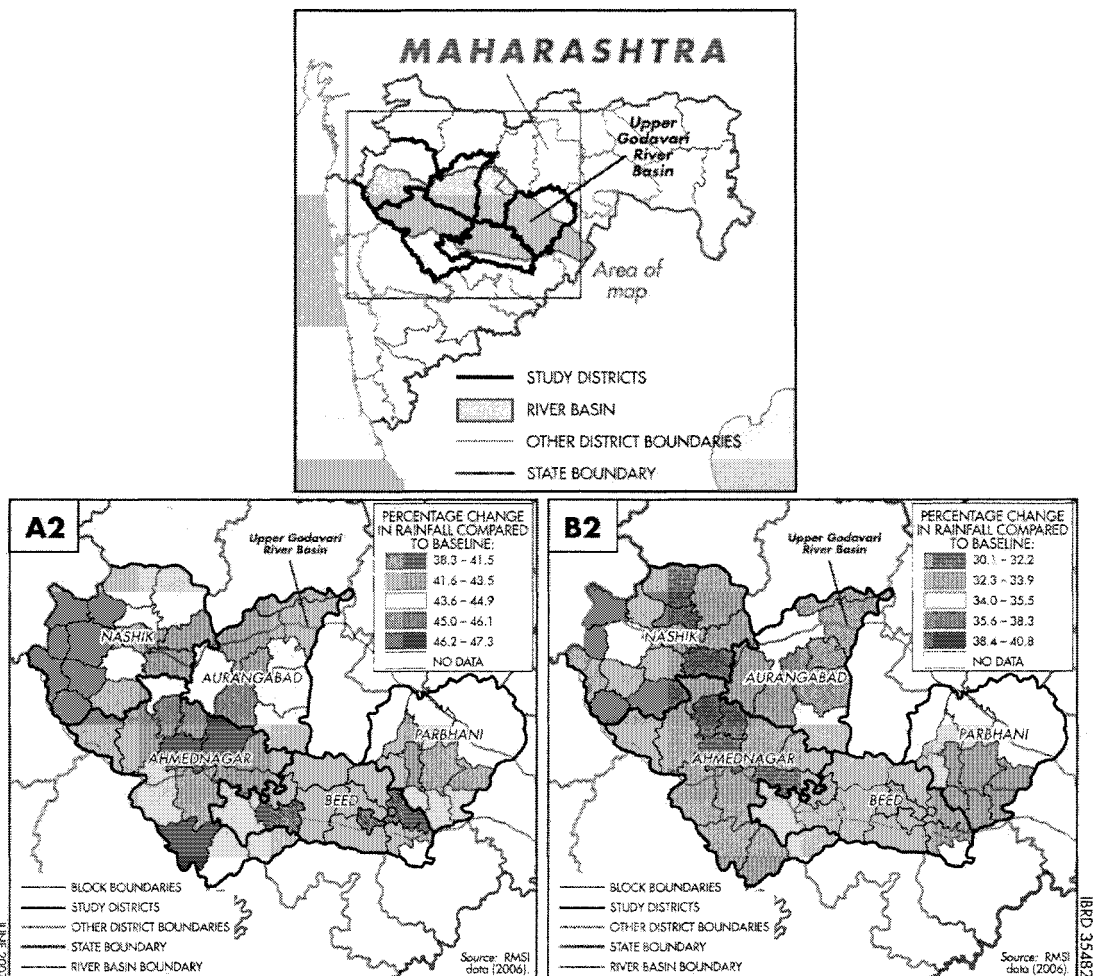
**Figure H.6 Average Maximum Temperature in Kharif Season in Four Districts in Andhra Pradesh**



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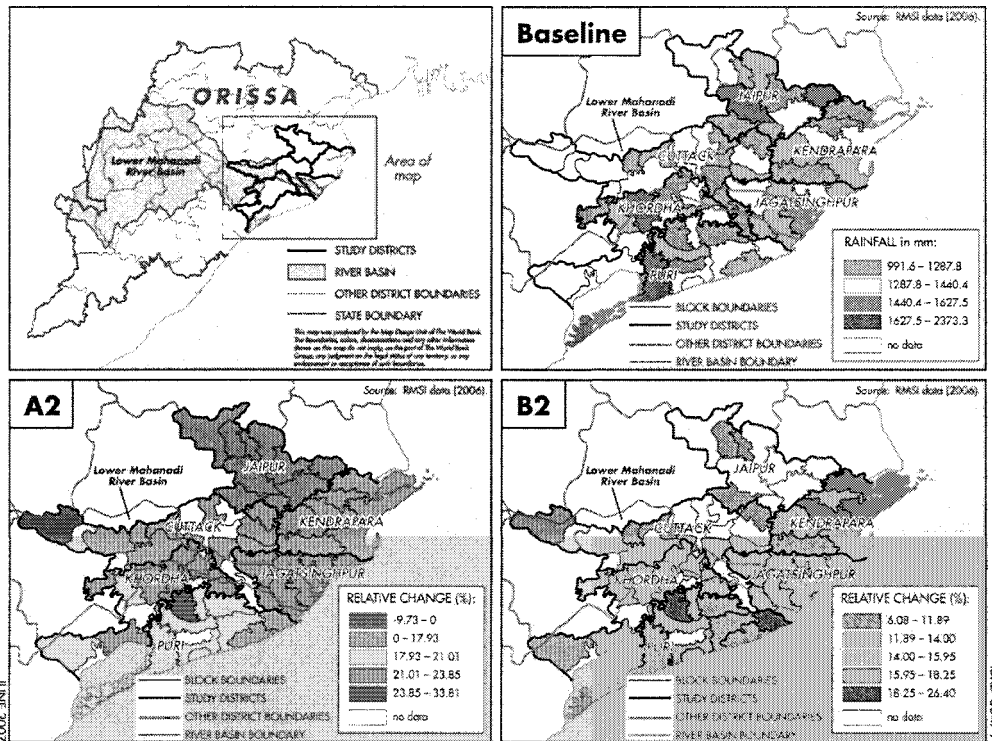
Figure H.7 Average Kharif Season Rainfall in Five Districts in Maharashtra<sup>70</sup>



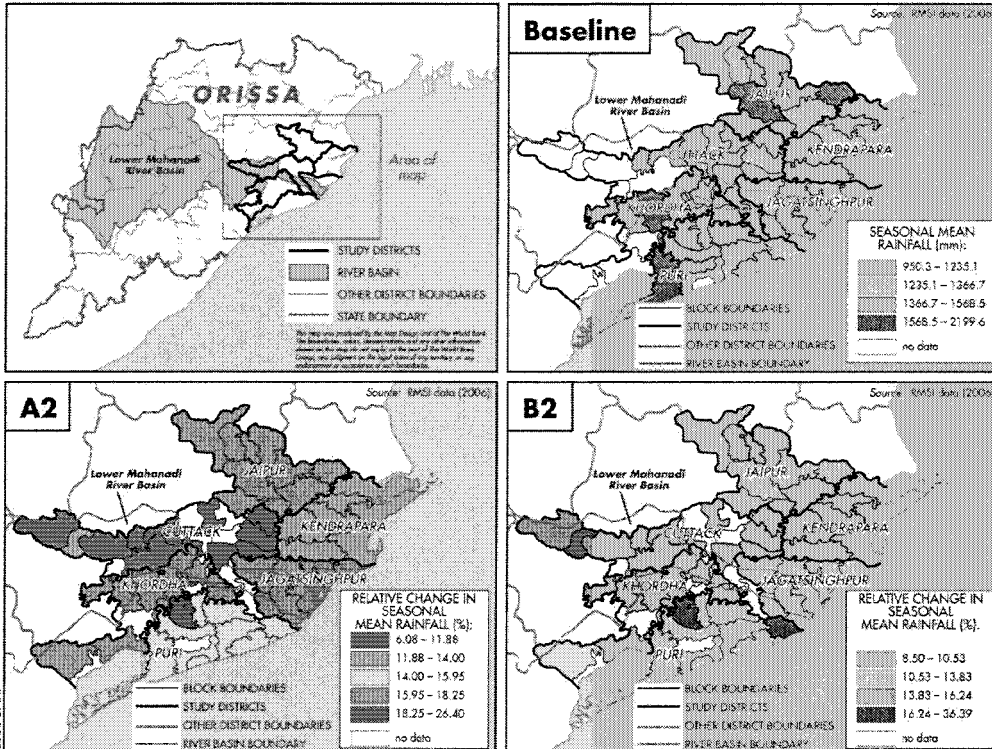
**Average Maximum and Minimum Temperature:** Kharif season temperature for the A2 scenario will be in the order of 3.3 °C throughout the 5 districts. In the B2 scenario the increase in maximum temperature will vary in the narrow range of 2.3 °C to 2.4 °C. Similarly, the kharif season minimum temperature increases would be in the order of 3.4 °C to 3.5 °C in A2 and of 2.5 °C to 2.6 °C in B2. Due to this uniformity in changes, no map was produced.

<sup>70</sup> Block-level rainfall observations were available for kharif season only. Hence, no annual projections were possible.

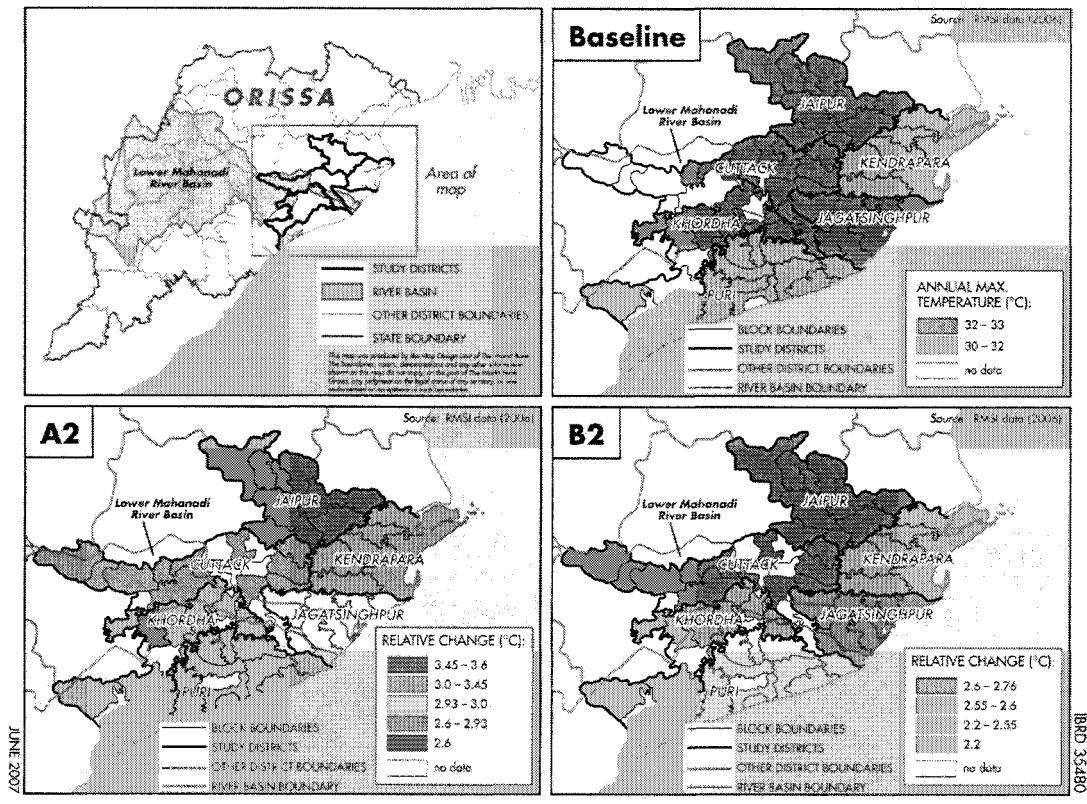
**Figure H.8 Average Annual Rainfall in Six Coastal Districts in Orissa**



**Figure H.9 Average Rainfall in Kharif Season in Six Coastal Districts in Orissa**



**Figure H.10 Average Maximum Temperature in Kharif Season in Six Coastal Districts in Orissa**



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