Annals of Arid Zone 47(3&4): 1-11, 2008

Coping and Adapting to a Changing Climate: Concepts, Issues and Challenges

Brian H. Hurd

Department of Agricultural Economics and Agricultural Business, New Mexico State University, Las Cruces, New Mexico 88003, (505) 646-2674

Abstract: The prospect of climatic changes introduces significant challenges to many vulnerable communities. How these communities choose to prepare depends much on their specific sensitivities, economies, and adaptive capacities. This paper presents an overview of key concepts that underlie the consideration and design of effective climate change adaptation strategies, including issues of the scope of adaptation activities, reactive versus anticipatory adaptation, vulnerability assessment, and adaptation timing. Examples include those related to water resources with a focus on issues relating to the uncertainties involved in designing appropriate climate-wise strategies.

Key words: Climate change, adaptation, coping strategies, vulnerability.

Intelligence is the ability to adapt to change.

Stephen Hawking, Physicist

If intelligence is the ability to adapt to change, then-wisdom is to know how and why to adapt for more than personal or economic gain.

Ivan Urlaub,
Executive Director, North Carolina
Sustainable Energy Association

Intelligence and wisdom form the foundation of individual and collective capacity to adapt and cope with adversity and change. Add to these, foresight and the capability to anticipate and forecast social and environmental changes, and the result is the remarkable ability of humans to plan and prepare for the future. Perhaps with somewhat varying levels, humans also possess an ability to reflect upon past experiences and shortcomings, from which to learn, imagine, and anticipate complex system behavior and the consequences stemming from alternative actions, conditions, and changes.

The dynamic and evolving nature of global and regional climate and its interactions with both natural and human systems is difficult to fully understand and characterize, and challenges the intellect, wisdom, and decision making capacity of both communities and individuals. That should not, however, dissuade efforts to identify and take well reasoned and appropriate actions, for example, those that further develop information and knowledge about climate systems and their interactions (research), reduce greenhouse gas emissions and raise rates of sequestration (mitigation), and promote individual and community abilities to cope with adversity and to leverage opportunities (adaptation). The primary focus of this paper is on this latter category, and on presenting a structured overview of key concepts that underlie the design and development of highly credible adaptation strategies.

In addition, general starting points for efforts to build adaptive capacity are identified. These strategies are attractive starting points because they offer benefits beyond those stemming from climate change preparedness and can be characterized as "no regrets" or "win-win" tactics. For example, additional research into the management and technology associated with water use could potentially raise water-use efficiencies, and thus provide benefits for regions experiencing long-run drought and increased water demands, independent of climate change. These additional benefits, thus, effectively lower the action threshold for project implementation.

Vulnerability, Adaptation, and Credible Strategies

Adaptation is understood primarily as efforts and actions taken by individuals, families, communities, and other organizations as they consider changes in conditions or circumstances so as to hopefully realize some tangible benefit that they would otherwise forego. Climate is certainly a condition fundamental to many activities in both the natural world and human societies, and long-run changes are likely to lead to pronounced effects on resulting circumstances and opportunities. Concern for these effects, whether realized or anticipated, leads inherently to a consideration of possible courses of action or adaptations and to their efficacy and timing.

The earliest climate change studies that attempted to measure potential impacts on agricultural systems, for example, made strong assumptions about the adaptive behavior of farmers. These studies, driven largely by the biophysical crop data that was available, assumed that farmers would act naively by failing to adjust their practices even in the face of observed changing conditions (Waggoner, 1983). Such myopic or naive farmer type assumptions provided for "worst-case-scenario" estimates that did not require researchers to guess about farmer behavior. However, in spite of these limitations, the studies did, yield some insights about the range and the upper-bound magnitude of economic impacts and about the regional distribution of potential impacts (e.g., Adams *et al*., 1998, 1999, and 2001; Reilly and Schimmelpfennig, 1999; Smit *et al*., 1996). Recognizing the importance of adaptation, researchers began to consider how, when, and where adaptations might occur and their effect on the eventual outcomes that would be realized.

A concept central to this paper is that of a *credible* adaptation strategy. By this is meant, a strategy with the highest potential for success against the most likely range of changes in environmental and societal conditions and behaviors, and importantly, which also considers and weighs the feasibility, costs, and consequences of implementation. In other words, though a specific adaptation might enhance system resiliency and robustness and, therefore, in concept produce measurable benefits by limiting physical and economic damages, its implementation may, in fact, not be feasible or desirable under present circumstances. For example, current estimated discounted project costs and benefits are not presently commensurable, or perhaps, the project is not consistent with existing laws and institutions (e.g., laws regarding private property). Or, stated another way: the failure to undertake a credible adaptation strategy risks loss of life, opportunities, income or wealth, or economic competitiveness.

The development of a credible adaptation strategy begins with the concept of vulnerability and its assessment. What characteristics or features give rise to or affect a system's vulnerability of susceptibility to changing conditions or adverse events? Following Easterling *et al*. (2004) and Hurd (2007), it is helpful to first decompose the concept of vulnerability into three interacting components: sensitivity, exposure, and adaptability, which are defined and described as follows:

Sensitivity

Conceptually similar to the economist's notion of elasticity, sensitivity describes the extent to which a system and its functionality are potentially affected by changes or events. Without some degree of sensitivity, vulnerability would not exist. In agriculture for example, some crops have a smaller tolerance for conditions hotter and drier conditions, and as such when such conditions occur crop performance is significantly diminished. One important example is corn, which is much more physiologically sensitive to hot and dry conditions than wheat.

Exposure

Though a system may be highly sensitive to certain changes or events, if it is not likely to experience or be exposed to such changes or events, then vulnerability again does not pose a concern. Exposure is a critical element affecting vulnerability, and is a factor that institutions and policy can often affect. The vulnerability of coastal communities to sea-level rise and storm surges, for example, is highly determined by the extent of population and development that is exposed, as people are drawn to aesthetic and recreational opportunities. In these cases, updating zoning and building codes maybe possible mechanisms whereby development occurs in a less vulnerable fashion.

Adaptability

With systems that are both sensitive and exposed to adversity, the next consideration concerns the extent of adaptability when confronted with adverse events and changes. Adaptability is the notion that changes can be made to the design, function, or behavior of a system that can strengthen its ability to withstand and/or recover from adversity, for example, through limiting sensitivity or exposure, or by enhancing robustness and resilience.

There are many examples of climate change vulnerability assessments. Fig. 1, for example, is taken from Hurd *et al*. (1999) and builds on the work of Lane *et al*. (1999) where they used expert judgment and watershed-level data to construct indicators of relative regional vulnerability to climate changes. The figure shows the results from aggregating across 18 individual indicators of water resource vulnerability to climate change. The analysis highlights the particular vulnerability to high water using, arid regions such as the American Southwest. This approach can also be applied at much smaller scales by tailoring aspects of vulnerability to particularly sensitive regional systems and the available data as shown in Hurd *et al*. (2006) where they assessed water resource vulnerability at a much higher resolution using bi-national data in the borderlands of

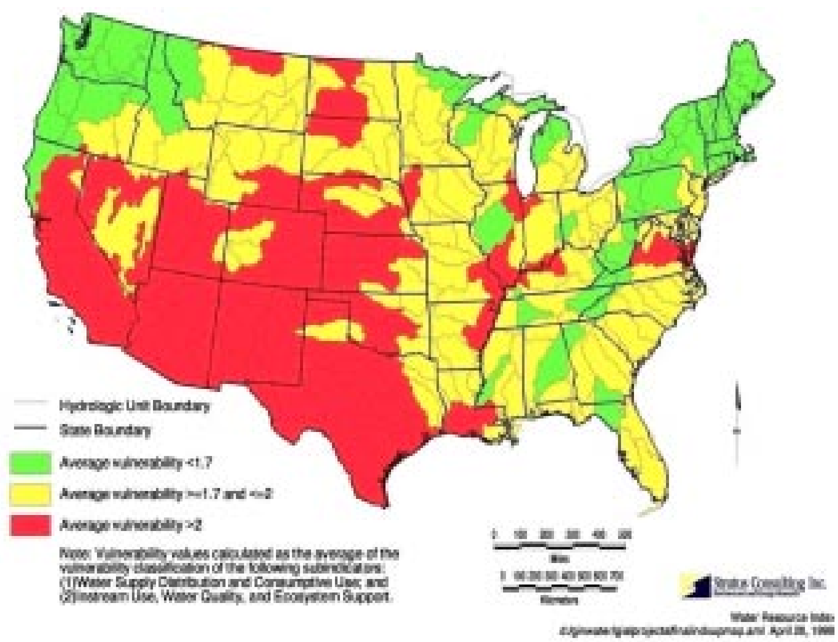

Fig. 1. Index of overall relative regional vulnerability of water resources to climate change from Hurd et al. (1999).

the Southwest. Efforts to develop conceptual frameworks (Fusell and Klein, 2006) as well as applications are increasingly widespread, for example Brenkert and Malone (2005) examine vulnerability and resilience for India, and Finan *et al*. (2002) apply methods to the U.S. Southwest.

When to Adapt? Reactive and Anticipatory Adaptation Strategies

The well-worn expression that "hindsight is 20/20" hints at the problem of time and timing when decisions must be made under uncertainty, i.e., decisions made (or left unmade) ex ante are never as clear as they are ex post. Just as there are uncountable examples of adverse events and situations that could have been avoided - or at least damages lessened - if only events had been anticipated and appropriate actions taken earlier. To what extent was the horrendous aftermath of Hurricane Katrina or the Great 2004 Tsunami, for example, avoidable? Which outcomes could have been anticipated and which were complete surprises? In dissecting such events, Gopalakrishnan and Okada (2008) have compiled several excellent papers describing the intersection of water and disasters, and highlight preparedness and response, adaptation, and planning.

With most adverse events and changes there are certain aspects which can be anticipated and others that cannot. And with most of these events there are usually examples of both failures to anticipate adequately and to respond or react effectively. Reactive adaptation can result from two situations. First, no consideration is given at all to changing conditions or

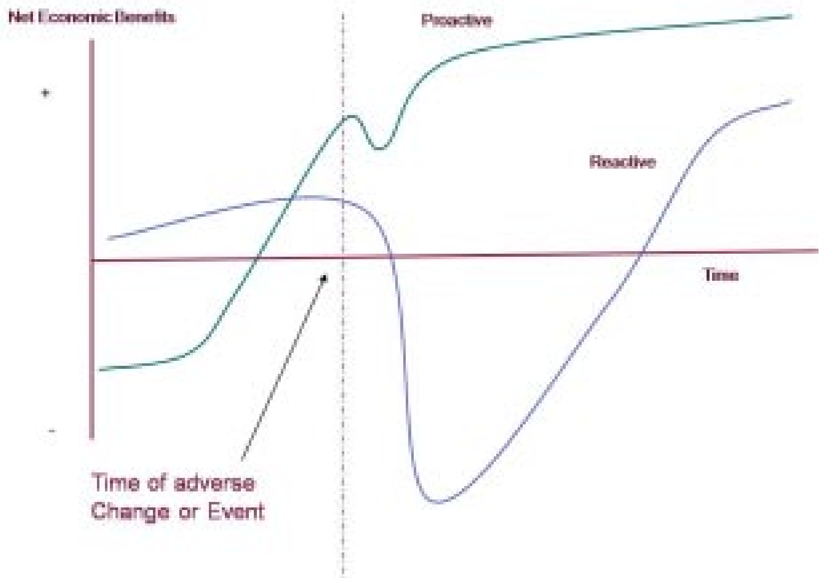

Fig. 2. Comparing the temporal patterns of net economic benefits for anticipatory and reactive adaptation strategies in response to a disaster event.

events, and adaptation occurs as conditions warrant it. Second, a deliberate decision to delay or postpone investment is taken, perhaps because of inherent uncertainty or political reluctance. This results in adaptative actions that may have been anticipated, but acted upon too late for their full benefits to be realized. Third, proactive adaptation tries to anticipate changing conditions and prepare for them well in advance.

To illustrate these different perspectives and to highlight the role of adaptation, Fig. 1 or 2 presents a simple model that isolates the potential effect and value associated with anticipatory actions in contrast to taking a purely reactive stance toward disaster. This figure depicts a community's net economic welfare before, during, and after a significant adverse change or event for both reactive and anticipatory adaptation modes.

Considering first the mode of reactive adaptation, initial net economic benefits are positive and growing until the time of disaster. As with Hurricane Katrina, disaster costs are significant and recovery time long, possibly resulting from inadequate infrastructure, delayed emergency response, and slow or insufficient institutional capability.

In contrast, anticipatory adaptation is illustrated by the second line, showing a time path in which the potential for disaster is anticipated and where prudent, but costly actions are taken a priori, thus reducing net economic benefits by the adaptation costs. In the periods that follow, net economic benefits continue to grow until the onset of disaster. In this case, however, successful adaptation can be seen to mitigate both intensity and duration of economic harm, which in the long-run result in faster and farther increases in economic welfare relative to reactive adaptation alone. To illustrate, consider how the outcomes surrounding Hurricane Katrina might have been altered if, for example prior to the disaster, levees had been strengthened and evacuation plans practiced. Losses surely would have occurred, however, the total impact might not have been as substantial or as nearly long-lasting as what did occur.

The distinctions between anticipatory and reactive adaptation are further highlighted by two additional examples. First, the implications of climate change and the potential roles for adaptation are more severe for ecosystems than they are for managed systems like agriculture. For example, fractured migration pathways limit mobility - the most immediate adaptive strategy available to wildlife. Largely, lacking foresight and the capacity to anticipate changing climates, reactive adaptation is the only form available to large-scale, unmanaged ecosystems. In these cases, climate change adaptation - at least in the short-run ~ is likely to follow from opportunities for species migration, including the response and fecundity of invasive species, to the dynamics of ecosystem succession. Less likely, owing to the rapidity of climate change, are the genetic and evolutionary responses that often characterize adaptive response over the very long-run. While many biological systems might accommodate minor (or slowly occurring) perturbations in a smooth continuous fashion, even minor changes in climate may be disruptive for many ecosystems and individual species. Prevailing environmental conditions such as urban development and pollution, as well as the introduction of invasive species and the isolation of habitats can place great stress on indigenous organisms. Furthermore, the relatively rapid rate of anticipated climate change could pose insurmountable challenges for many species, given their lack of resiliency and difficulty adapting to the changing environment.

A second and arguably more complex example concerns how climate affects water resources. Nohara *et al*. (2006) illustrates modeled changes to the hydrographs of many of the worlds' rivers. Atmospheric warming, fluctuations in rates and patterns of precipitation, and changes in snow pack accumulation as well as the timing of its release can profoundly affect rivers and water delivery systems throughout the world. Ultimately, these impacts affect the ecosystems, farmers, and cities that rely on the rivers, particularly those in the arid regions. For example, a significant and persistent decline in late season streamflows is reasonably expected to accompany earlier peak runoffs from the high-altitude snowfields of the Rocky Mountains, as forecast by climate and hydrologic scientists and illustrated in Fig. 3 for the Rio Grande flowing south into New Mexico from the mountains of Colorado. This shows current and projected average seasonal streamflow for two future time periods, 2050 and 2100, under the influence of climate change. The streamflow at this gauge represents roughly 65% of the renewable, recurring water supply serving the farmers, cities, and ecosystems of Southern Colorado, Central New Mexico, and West Texas. Such profound changes in the underlying hydrology affect the functioning of many

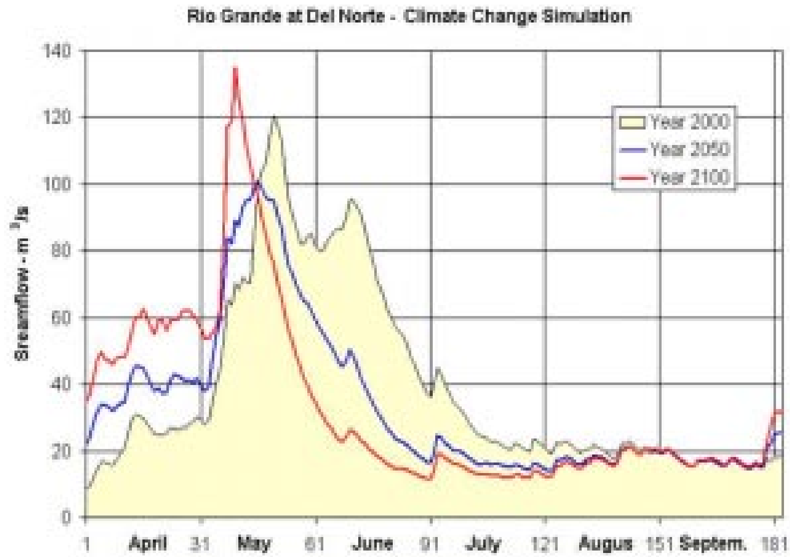

Fig. 3. Current and projected changes of the rio grande hydrograph under climate change.

communities and ecosystems that are dependent on existing patterns of water resources, including: water storage and distribution systems, urban and rural water users, water quality, hydropower, recreational and cultural functions, and riparian ecosystems and avian migratory patterns.

Uncertainty over magnitudes, rates, and timing of climate changes adds complexity to the challenge of identifying, evaluating, timing, and sequencing possible adaptations, and even deciding which, if any, should be taken prior to resolving the uncertainty. The decision rules for assessing the efficacy, desirability, and appropriateness of adaptation strategies, though not fundamentally different than for other investment and planning decisions, can be severely limited by the diminished relevance of historical data observed under an earlier climatic conditions. Climate change, by definition, breaks the statistical relevance of historical ranges and patterns, in what statisticians identify as non-stationarity. In a non-stationary world, particularly when the nature of the change is not well understood, statistical distributions and probabilities lose credibility and give way to greater subjectivity and judgment in decision.

How to Adapt? Building Adaptive Capacity and Preparedness for Changes

No less important than knowing when to adapt and whether to wait and react or anticipate and risk the uncertainties of change, are the questions of how and what to adapt. Adaptive capacity is essential in either case for the greatest success in protecting, mitigating, and restoring affected systems, where adaptive capacity is the ability of systems, organizations, and individuals to (1) adjust to adverse conditions, (2) leverage opportunities, (3) mitigate damages, and (4) recover from significant collapse or failure. Adaptive capacity is an indication of how well a system is expected to cope with the consequences of adverse events and changes. For example, possible strategies that a community can undertake to enhance adaptive capacity include raising its capability to protect and secure vital physical and social infrastructure, access financial resources, harness information and 'know how' (human capital), and deploy appropriate technology in the face of or anticipation of adverse events or changes. Success in adaptation would be observed if following a change or disturbance, the level of system services and functionality is approximately maintained or relatively quickly restored.

Perhaps the most prudent efforts and actions to consider first, particularly in the earliest periods of investment when uncertainties are greatest, are those where the outcomes are desirable whether or not the climate changes are realized, so-called "win-win" or "no-regrets" strategies. Strategies with substantial investment costs and which only produce benefits if and when climate changes occur may best be delayed or postponed, perhaps awaiting better information or technology.

Building and strengthening adaptive capacity is generally an accumulative process, which is not nearly as instantaneous as building a bridge - though building a bridge might be one particular and effective means to enhance adaptive capacity in certain situations. That is, adaptive capacity tends to develop over time, usually with sustained investment, and careful planning, and is also highly correlated with rising income, technological capabilities, and socio-political stability.

There are a variety of potential strategies that governments, institutions, and organizations can adopt that could contribute to adaptive capacity and which may yield additional benefits. Examples of these strategies are given below:

Improve scientific capabilities and research

In addition to the research needed to gain a more complete understanding of the processes that relate climate and human activities, significant gaps remain in understanding the nature and consequences of impacts and adaptation. The need for improved environmental monitoring, data, and information is important for climate change as well as the management of other environmental stresses. For example, adapting to a shift in a river's hydrograph requires better integration of experts across the scientific fields of climatology, hydrology, and resource management. This might be accomplished by strengthening institutional scientific capacity, cooperation, and collaboration by increasing the use of strategic partnerships such as those between state and local governments, universities, national laboratories, and selected stakeholders.

Develop appropriate risk management institutions and policies

As recent disasters such as Hurricane Katrina illustrate, systems of emergency management, government relief, insurance, long-term recovery, and land use planning can be complex and not always consistent or rational. Major insurers, such as Swiss

RE, are looking at the risks of climate change regarding property damage in addition to human health and liability (Hoffman, 2006). Greater understanding of the interactions of commercial and government insurance programs and their incentive effects on damage exposure and liability harmonization is likely needed. Shifts in river hydrographs can directly impact flood protection systems, exposing system operators to liability, insurers to property damage risks, and citizens to health and property loss.

Increased use of market-based programs for resource management

Decision makers at all levels respond according to the incentives, opportunities, and constraints that they face. When risks and rewards are misaligned, the result is frequently poor planning and decision making, inefficient resource use, and higher costs. Programs and policies that use market-based incentives and prices (like marketable permits for air pollutants) flexibly achieve desired outcomes and behavioral changes with lower costs than alternative regulatory and coerced enforcement approaches (Baumol and Gates, 1988).

Add flexibility and safety to long-lived infrastructure design and improvements

Long-lived or durable infrastructure that is exposed to potential climate change risks, such as dams, bridges, sea walls and levees, ports, and coastal developments, may be at risk of under-performing or potentially failing if specifications do not account for the stress of climate changes impacts. Sea level rise and shifting river hydrographs can subject infrastructure to acute stress if these conditions are not at least considered during planning and design. Often it is less costly to achieve greater infrastructure flexibility, durability, and safety at the design stage than to attempt retrofit solutions at later stages.

Consider climatic factors in land use planning and building codes

State and local governments are typically responsible for land use, zoning, and building codes. As such, they have a critical role in strengthening adaptive capacities. As temperatures rise and hydrographs shift, risks to health and property can change. Appropriate land use and zoning can lessen potential flood risks. Also, building codes can be adjusted to better account for future risks and the stresses of people living with higher temperatures.

Unfortunately, there are many potential road blocks and limitations that can confound strengthening adaptive capacity. Among them are the potential for political gridlock and institutional paralysis, a dearth of leadership with long-term perspectives, shortness in political cycles, tax fatigue among the voting populace, and competition for scarce public resources. In combination, these factors highlight the importance of looking for additional ways that adaptive capacity benefits society. Recently, political interest has turned to infrastructure needs, as a result of the bridge collapse in Minneapolis and levee failures in New Orleans. Perhaps this is an opportune time to enhance renovations and future planning by considering climatic changes.

Moving Forward

In general, there is considerable uncertainty in understanding the possible trajectories that climate change can take. Possibilities range from gradual and smooth paths to rapid and discontinuous trajectories. To the extent that climate change is rapid or discontinuous, adaptation will be more difficult. Faster rates of climate change necessitate more rapid and costly adjustments associated with any adaptive response and increase the likelihood that necessary adaptive responses will lag behind changes in climate. Also, when the time path of expected adaptation benefits is uncertain, then postponing action may be desirable because more time allows for the accumulation of knowledge and information and the potential resolution of some uncertainty. Moreover, postponing action may also enable more accurate project scopes and timing as well as the emergence of better technologies and potentially lower project costs. On the other hand, there are several risks to delaying action. For example, delay might result in less successful adaptation as the time frame to deploy projects is shortened. Delay could also raise the likelihood of irreversible losses.

In spite of the challenges this decision environment presents, affirmative steps can be taken by communities, governments, and institutions that inform the decision making process and which take into account the nature and types of changes that are more likely than not with a change in climate. Consideration of such changes within planning processes can be expected to result in greater flexibility in institutional and infrastructure design and greater alignment of the resulting structure or system with the likely trends and changes that are expected with climate change.

Acknowledgements

This paper reflects many ideas and thought accumulated throughout past collaborations with many colleagues all of whom have stimulated my research and thoughts including, William Easterling, Joel Smith, Richard Adams, Bruce McCarl, Mac Callaway, and Robert Mendelsohn. Finally, my appreciation extends to the Agricultural Experiment Station of New Mexico State University for their ongoing support of my research program.

References

Adams, R.M., Hurd, B.H., Lenhart, S. and Leary, N. 1998. Effects of global climate change on agriculture: An interpretive review. *Climate Research* 11: 19-30.

Adams, R.M., Hurd, B.H. and Reilly, J. 2001. Impacts on the US Agricultural Sector. In *Climate Change: Science, Strategies, and Solutions* (Eds. E. Claussen, V. Arroyo-Cochran and D. Davis), pp. 25-42. Pew Center on Global Climate Change, Arlington, VA.

Adams, R.M., McCarl, B.A., Segerson, K., Rosenzweig, C., Bryant, K.J., Dixon, B.L. 1999. The economic effects of climate change on US agriculture. In *The Impact of Climate Change on the United States Economy* (Eds. R. Mendelsohn and J.E. Neumann), pp. 18-54. Cambridge University Press, Cambridge, UK.

Brenkert, A.L. and Malone, E.L. 2005. Modeling vulnerability and resilience to climate change: A case study of India and Indian states. Climatic Change 72: 57-102.

Baumol, W.J. and Oates, W.E. 1988. *The Theory of Environmental Policy*, 2nd Ed. Cambridge University Press, Cambridge, UK.

Easterling, W.E., Hurd, B.H. and Smith, J.B. 2004. *Coping With Climatic Change: The Role of Adaptation in the United States.* Pew Center on Global Climate Change, Arlington, VA.

Finan, T.J., West, C.T., Austin, D. and McGuire, T. 2002. Processes of adaptation to climate variability: A case study from the US Southwest. *Climate Research* 21: 299-310.

Fussel, H.M. and Klein, R.J.T. 2006. Climate change vulnerability assessments: An evolution of conceptual thinking. *Climatic Change* 75: 301-329.

Gopalakrishnan, C. and Okada, N. 2008. *Water and Disasters.* Routledge Press, New York.

Hoffman, A.J. 2006. *Getting Ahead of the Curve: Corporate Strategies That Address Climate Change.* Pew Center on Global Climate Change, Arlington, VA.

Hurd, B.H. 2007. Challenges of adapting to a changing climate. *UCLA Journal of Environmental Law & Policy* 26: 77-92.

Hurd, B.H., Brown, C., Greenlee, J., Grandados, A. and Hendrie, M. 2006. Assessing water resource vulnerability for arid watersheds: GIS-based research in the paso del norte region. *New Mexico Journal of Science* 44: 39-61.

Hurd, B.H., Callaway, J.M., Smith, J.B. and Kirshen, P. 1999. Economic effects of climate change on US water resources. In *The Impact of Climate Change on the United States Economy* (Eds. R. Mendelsohn and J. Neumann), pp. 133-177. Cambridge University Press, Cambride, UK.

Hurd, B.H., Leary, N., Jones, R. and Smith, J. 1999. Relative regional vulnerability of water resources to climate change. *Journal of the American Water Resources Association 35:* 1399-1409.

Lane, M.E., Kirshen, P.H. and Vogel, R.M. 1999. Indicators of impacts of global climate change on US water resources. *Journal of Water Resources Planning and Management (ASCE)* 125: 194-204.

Nohara, D., Kitoh, A., Hosaka, M. and Oki, T. 2006. Impact of climate change on river discharge projected by multimodel ensemble. *Journal of Hydrometeorology* 7: 1076-1089.

Reilly, J.M. and Schimmelpfennig, D. 1999. Agriculture impact assessment, vulnerability, and the scope for adaptation. *Climatic Change* 43: 745-788.

Smit, B., McNabb, D. and Smithers, J. 1996. Agriculture adaptation to climatic variation. *Climatic Change* 33: 7-29.

Waggoner, P. 1983. Agriculture and a climate changed by more carbon dioxide. In *Changing Climate* pp. 383-418. National Academy Press, Washington, DC.

Author please see:

Red portion of the text.
Reprint order
Figure print in colour or black and white.