Title
Ice, Snow and Water: impacts of climate change on California and Himalayan Asia

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Ice, Snow and Water: impacts of climate change on California and Himalayan Asia

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This Briefing Note describes the issues discussed at an international Workshop held in San Diego in May 2009 which focussed on the impact on water resources of declining mountain snows and glacier retreat in Himalayan Asia and the Western United States. The Workshop concluded that as adaptation strategies are locally conditioned, new *regional* climate assessments are required that link global climate models to local decision making.

1. Introduction

The new Sustainability Solutions Institute at the University of California San Diego has created a partnership with the University of Cambridge in the UK. The aim is to explore how collaborations like this can work with governments and intergovernmental organisations by reviewing current and predicted impacts; identifying key scientific questions, technological opportunities, and monitoring needs; and comparing best practices in science-based decision support, so as to identify good ways to shape broader alliances that do support regional decision-making.

With the support of the Gordon and Betty Moore Foundation the partnership has begun with a pair of workshops to develop a Global Water Initiative. The first, held in May 2009 at the Scripps Institution of Oceanography compared the climatic causes and impacts of declining mountain snows on water availability in California (and the American West) and in Himalayan Asia. Workshop experts represented the United Nations World Climate Research Program, the Chinese Academy of Sciences, the Indian Space Research Organisation, the British Antarctic Survey, the California Department of Water Resources as well as several American universities. The second workshop, in Cambridge in September 2009 will examine the impacts of climate change in Africa and frame ideas for new institutions for science-based decision support. The results of both workshops will be presented to a special session at the Science and Technology Forum in Kyoto on October 3rd.

The key themes and outcomes of the first Workshop are summarised below:

2. Problem

There have been a number of extreme weather events worldwide over the last 20 years.
The monsoon, which provides water to over 1 billion people in Asia, has been weakening and becoming more erratic in recent years. In 2006 Assam, East India, one of the wettest places on Earth, experienced a drought whilst heavy rain fell in desert areas of northwest India for the first

time in 50 years. In 2008, there were heavy snowstorms in sub-tropical southern China, never seen before. California is facing a serious drought. The Sierra Nevada snowpack, a vital summer water source already in decline, will be reduced by up to 90% by the end of this century [1] The flow in many of the major rivers in China is decreasing; the Yellow River sometimes fails to reach the sea as does the Colorado River. Melting glaciers in Asia are forming larger mountain lakes and are likely to cause potential catastrophic floods.

Deglaciation in the Hindu Kush-Himalayan-Tibetan region has led to a 21% decrease in the area of 465 glaciers studied in the Indian Himalaya [2]. At the current rate of retreat the region's glaciers and snow packs are expected to shrink by as much as 75% before 2050, with projections already showing that East and South Asia will suffer from water stress over the same period (not yet accounting for the impacts of glacier retreat). The contribution of snow and glacial melt to the major rivers in the region ranges from 5-45 %of average flows, and about 70% of summer flows in the main Ganges, Indus,Tarim and Kabul rivers, and is even greater to inner Asian rivers. In western China about 12 % of total discharge is glacial melt runoff, providing water for 25% of the Chinese population in the dry season [3] .

Particulate air pollution in the form of black carbon (i.e. soot) is already contributing to the disruption of water supplies by raising air temperatures and by increasing the light absorption of snow and ice as pollutants darken the frozen surfaces. Temperatures in the Hindu Kush – Himalayan - high Tibetan plateau have increased by 1 ^{o}C in the last 30 years with climate scientists predicting a further rise of 2.0 to 2.6 ^{o}C by 2050, partly caused by atmospheric soot,[2]. Black carbon absorbs heat from the sun and collects at mountain latitudes and furthermore the soot coats the snow reducing it's albedo and therefore accelerating melting [4]. Atmospheric brown clouds (resulting from indoor combustion of biofuels for cooking, biomass burning outdoors and use of fossil fuels), have been measured to be 1-3 km thick surrounding the high Asian glaciers. Between 1950 and 2002 soot emissions increased three fold in India and five fold in China,

Population dynamics create pressure on freshwater resources through increased water demands and pollution, and affect water resources indirectly through changes in land use and water use patterns. Population growth and rapid economic development are leading to accelerated freshwater withdrawals. While population growth has slowed since the 1970s and is expected to continue this downward trend, emerging market economies and steady economic development have put additional pressures on water resources [5]. These regional problems with strong local features are predicted to be exacerbated by climate change, adding to uncertainty about water resources and exacerbating water scarcity trends. They have particular resonance in the

Himalayan/Asian region of snow, ice, water, and mountains, with huge implications for food security, flood and drought hazards and disruptions to water supply to over 2 billion people in Asia.

3. Progress

Climate science and technology has enabled the monitoring and assessment of these trends to demonstrate how these are part of global climate change caused by increased emissions of greenhouse gases. Over the past 10 years, there has been significant progress in diagnosing and predicting the regional climate change and variability and their impacts on water availability in the American West. For example the declining mountain snowpack in western North America will have profound consequences for water use in a region already contending with the clash between rising demands and increasing allocations of water for endangered fish and wildlife [6] (see Figure 1). By the end of the century if temperatures rise to the medium warming range and precipitation decreases, late spring stream flow could decline by up to 30%, with California farmers losing as much as 25% of their water supply. Rising sea levels could also degrade California's aquifers, especially in the San Joaquin/Sacramento River Delta. As more winter precipitation falls as rain instead of snow, water managers will have to balance the need to fill constructed reservoirs for water supply and the need to maintain reservoir space for winter flood control. Set against the likely increase in electricity demand, diminished snow melt will decrease the potential for hydropower production, which could be reduced by up to 30% [7].

There have also been significant advances in understanding of the changes in Himalayan Asia. California, China, and India have developed policies linking climate change to water resources and the lessons from the implementation of these policies need to be shared around the world. For example the new California Water Plan (2009) outlines new analytical methods and tools to help plan for future effects of climate change, population growth and development patterns, economic change, and other factors outside the water community's control. Climate change data is being used in planning models for water resources assessments to identify key vulnerabilities and to develop adaptation strategies that consider the impact assessment from a risk-based point of view [1]. These approaches are essential as demand for water increases worldwide. Dettinger and Culberson [8] have identified a range of challenges which show that changes will be multi-variate, geographically pervasive and rapid, whilst projections will remain uncertain so that surprises will be likely and effects will interact. Recommended strategies include emphasis on long-term eco- and resource system adaptability, commitment to long term monitoring of restoration targets and impacts, even more integration across scientific disciplines, observations and models, increased use of manipulative experiments, and a recognition "that the climate of the foreseeable future will be a constantly changing framework upon which all other ecosystem and resources problems will be draped" [9].

In the Himalaya quantitative projections of downstream effects of changing water flow regimes in Greater Himalayan rivers is rare [10]. No model yet exists that captures the interaction of the following critical variables: melting Himalayan glaciers, degraded permafrost and wetlands, shifting alpine ecosystems, and changes in monsoon climates [3]. There is considerable uncertainty in this region but there will be significant shifts in volumes and timing of river flows and freshwater sources, but precise responses are unknown.

The Workshop addressed these data gaps called for more long term tracking of ice glacial ice volumes, monitoring of alpine flora and fauna, landscape and transboundary approaches to biodiversity conservation, open data exchange, and cooperation between all countries in the Greater Himalaya. Xu [3] has identified three critical scales of adaptation: local community, urban and rural, and regional and transboundary. For local adaptations rural people in the Greater Himalaya remain divorced from natural resource decision making [11]. At the urban–rural scale there are inherent differences between city and village dwellers over specific climate change adaptations. Policies addressing centralised downstream populations, urban infrastructure, and large scale agricultural systems must be integrated with those for local peoples living montane livelihoods. Designing integrated land and water resource management at river basin levels would help bridge this urban-rural divide [12]. It has been argued that in both urban and rural areas, attention should focus on reducing overall water demand and modernising irrigated agriculture [3]. Urban demands should not trump the creation of low cost community scale adaptations.

Regional risk assessment and mapping across the Greater Himalayas would help decision makers select appropriate strategies . At present no regional or transboundary authority is addressing the complexities of climate change. China and India have critical roles to play here because they contain most of the greater Himalayas within their borders. Although a Greater Himalayan climate change authority may provide a way forward, there has been a decidedly mixed track record of top-down policy making in the region [13].

4. Discussion

A key focus of the workshop was on how to implement regional climate assessment. This generated wide debate which raised an interesting tension between the push of climate scientists and modellers who focussed on seeking more data to provide an understanding of the physical processes at work and the pull from the downstream users who need to develop adaptation strategies. A balance needs to be struck between the increasing sophistication of climate models and their ability to provide useful information on the processes that dictate water availability. A two way dialogue is needed in which feedback from the local level can inform the scientific community.

This view is shared by Michael Anderson, State Climatologist at the California Department of Water Resources, who has noted that water resources managers looking for information and resources to guide their adaptation and mitigation efforts can easily become overwhelmed by the breadth and depth of scientific information available. Feedback to science is required on the data needs and the scale and format in which it is needed [1].

5. Principal conclusions

There is a better understanding of the time-scale on which water resources are changing. Remote sensing and ground truth are revealing the relative proportions of the different sources of water; melting glaciers, snow and rainfall, coming from snow-covered mountains in Asia. Variations in precipitation and the melting of the ice and snow are caused by global temperature rise. Regionally, this is strongly affected by the influences of air pollution and dust on solar radiation, and changing weather patterns, such as the observed weakening and erratic timing of the monsoon.

These changes have created hazards which will adversely affect the populations of California and Asia – such as floods, increased intensity of wildfires and deterioration of ecosystems. Policy decisions will need to be made at the regional level to deal with these impacts. China has put into place a comprehensive plan to deal with its water pollution problems. California has ambitious targets to reduce its greenhouse gas emissions and policies to deal with the impacts; as well as a strategic water management plan.

Through conservation, technology, planning, and changed behaviour, more effective means of using water are being introduced. A great reduction in water demand would help re-establish healthy water environments.

Decision-making can be improved by better global and regional climate analysis and prediction. Much more detailed modelling using the world's largest computers and high resolution data are needed to make better predictions. In addition, many of the fundamental processes are still uncertain.

6. The future

Regional climate differs in complexity and character from global climate. The factors that combine to drive global climate may have a different balance regionally. A true regional assessment differs from a regionalised global assessment in its spatial specificity; topography and coastal proximity create local climatic and ecological zone's that cannot be resolved by contemporary global models, yet must be evaluated to make a regional impact assessment meaningful [4].

Human activities of deforestation, irrigation and agriculture influence local climate. More detailed global and regional observations, together with improved numerical simulations of climate and its impacts are needed. Existing data need to be accessed, integrated, and exchanged in order to guide regional policies. Progress has been made in international data sharing, but more needs to be done.

The internet, mobile communications technology, and social networking are opening up new possibilities for sharing knowledge within and between regions. Regional initiatives are needed to facilitate the organization of these data, to provide a structure for data analysis, access technology and social research and to interpret and present data to policy makers

Charles Kennel, one of the Workshop convenors, argues that the adaptation decisions will be locally conditioned. How should managed irrigation systems adjust to changes in the timing and volume of spring runoff? Which farmers and crops will be affected? Should farmers change their crop mix? How and when should investment be made in water delivery capacity, agricultural biotechnology, or monitoring systems? Rigorous and detailed regional climate change impact assessments are necessary to answer these questions. A new international framework that encourages and co-ordinates regional forecasts and links the global assessments is needed. The focus should be on developing a complex, hierarchical network of loosely connected regional assessments that connect global assessments to local decision making. A good place to start is water, as the path from assessment to decision support to adaptive management has been reasonably well charted [4]. In this respect water may prove to be the key driver in leading the adaptation to climate change.

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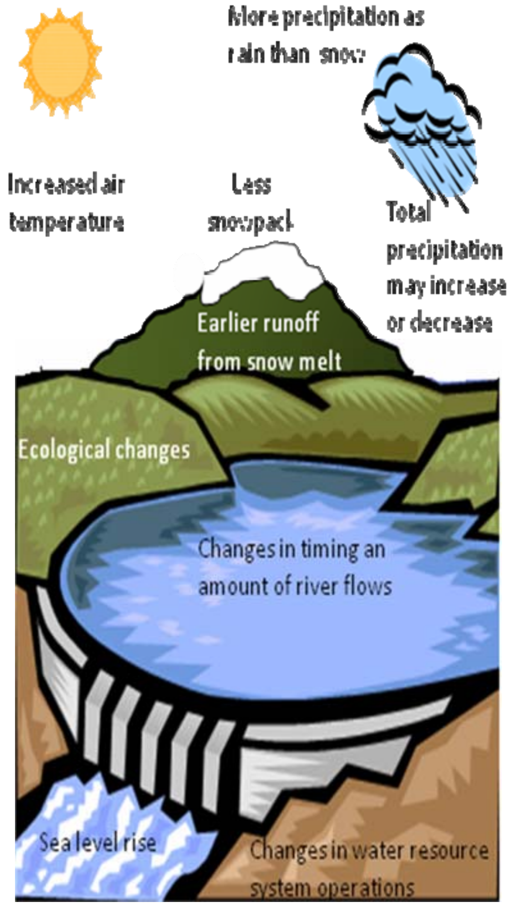

Figure 1: Potential climate change impacts on California water resources
(modified from Anderson M, 2009)

Possible image of glacier retreat:
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