

Climate change, exponential curves, water resources, and unprecedented threats to humanity

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Received: 16 February 2010 / Accepted: 9 March 2010 / Published online: 19 May 2010
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It is hard to look back over 30 years of climate change research and not lament the lack of movement among policymakers as our knowledge has improved, the science has strengthened, and the evidence that we live in a world that is being fundamentally altered by human activities has accumulated. The failure of scientists to convince policy makers to act, or the failure of policy makers to take action on the information the scientific community is providing, means that unavoidable climate change will alter our planet in increasingly serious ways. The world will not end. But it now seems unavoidable that human misery, caused by our own actions, will be more extensive than it otherwise would have been and worse than it should be. This is especially true for our natural and built water systems.

The vagaries of human nature cannot be denied; indeed, they lead to proverbs with staying power because they reflect true insights into how individuals and society evolve. In the world of climate change and water resources, several proverbs come to mind, such as the famous French proverb, “the more things change, the more things stay the same.” Or “you can’t teach an old dog new tricks.” I am sure we all have our favorites. But the underlying truth behind these proverbs is that society is slow to react to fundamental changes or unusual or unanticipated risks. Under normal circumstances, that natural conservatism is good. It means that over time we develop ways of doing things, institutions, laws, and policies that work through incremental, careful, and linear steps.

Circumstances are no longer normal. Humans have reached the stage where we are capable of planetary-scale disruptions of the very ecosystems that sustain us. And we have reached this stage through various simultaneous exponential increases: increases in populations, energy use, emissions of climate-altering gases, economic activity, and more. And as every college science student knows, exponential increases are no big deal until, all of a sudden, they are a very big deal. The old trick science question about algae that doubles in size every day asking how much of a pond is

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covered on the day before the pond is completely overwhelmed still amazes many people. Sometimes things sneak up on us fast if we are not paying attention.

That is the way it is now with climate change; that is why the exponential curves of greenhouse gas concentrations, and temperature rise, and sea-level increase, and the rate of glacial melt, together with global population growth, are all coming together to impose unprecedented stresses on our ecosystems, political systems, and economies that typically only react in linear ways.

Water offers a good example of the challenges we face. Water and climate are fundamentally linked: the hydrologic cycle is the climate cycle. Even 30 years ago, when climate models were far less robust and comprehensive and regional hydrologic impact assessments were rudimentary and limited, it was apparent that water resources were likely to be especially vulnerable to changes in temperature and precipitation patterns, storm frequency and intensity, and rising sea levels. Looking back over summaries of the expected consequences of climatic changes for water in the 1991 book *Climate Change and US Water Resources* (Waggoner 1990), produced by the American Association for the Advancement of Science, or the reports done for the UN's Comprehensive Assessment of the Freshwater Resources of the World in the mid-1990s (Raskin et al. 1997), or the report "Water: The Potential Consequences of Climate Variability and Change" written for the US National Assessment released in 2000 (Gleick et al. 2000), or the latest IPCC findings from Working Group II (Parry et al. 2007), reveals only incremental improvements in our understanding of regional impacts and risks for water resources from climate change.

What are these findings? As climatic changes accelerate, evaporative demands for water will grow with temperature. Precipitation patterns will change but in ways that we understand only imperfectly, with a likely intensification toward higher latitudes and in regions that are already relatively well-watered. Dramatic changes in snowfall and snowmelt in mountain regions with distinct changes in the seasonality of runoff are more certain, as are increases in sea level, which will threaten coastal groundwater aquifers, the water supplies of islands, and the health of marshes, tidelands, and wetlands. Water quality will worsen where it is sensitive to temperatures and flow changes. Extreme events are likely to increase in some regions, including both floods and droughts.

This list of consequences (and more), could have been presented as a summary of climate and water effects 20 years ago. Indeed, all of these impacts are discussed in the reports mentioned above. So what, if anything, has changed? Over the past three decades, we have begun to observe actual impacts on water systems around the world. Far more information on specific regional risks is available. And there have been more and more efforts to understand the implications of these changes for different kinds of water systems and how water managers should begin to respond.

Impacts will be felt differently in different places. Water systems around the world vary enormously in their structure, management, and design. In regions like rural sub-Saharan Africa or even rural parts of the USA, very little infrastructure has been built and very few water-management institutions are in place. In these kinds of regions, water availability and quality are far more dependent on, and vulnerable to, climatic conditions. Changes in climate that significantly alter local hydrology in such areas will be felt immediately, and resilience to such changes is likely to be low. Other parts of the world have far more extensive water systems that have been put

in place to help local populations manage variability of supply and quality. Even in these regions, however, special vulnerabilities remain, particularly where demands for water approach the limits of renewable supplies, such as the western USA. More and more evidence from these regions indicate that the ability of developed water systems with extensive infrastructure to respond to climate-induced changes in water supply are ultimately limited, if changes are not also made in the legal and regulatory rules that guide them.

Few rivers, for example, are more comprehensively developed than the Colorado River, shared by seven states in the USA and by Mexico. The Colorado is one of the most highly developed and managed systems in the world, with a total reservoir volume behind major dams that can store several years of total annual average runoff. On top of the physical infrastructure built in the river are complex layers of laws, international treaty agreements, and interstate compacts developed over many decades, managed by many different federal, state, and local agencies. Yet demands on the water resources of the Colorado River are so high that even minor long-term changes in flow have the potential to cause serious disruption in water allocations among different users, non-linear changes in reservoir levels, increases in river salinity, and reductions in hydropower generation (Nash and Gleick 1991; Barnett and Pierce 2009). In short, both highly developed and lightly developed water systems have vulnerabilities to climate change that are increasingly worrisome to water researchers and managers. These worries are especially relevant in watersheds that cross international boundaries, as do the vast majority of the world's major river systems. In these basins responding to climatic changes will be further complicated by politics, adding the risk of tensions and conflict to the list of the likely impacts of climate change on water resources (Cooley et al. 2009).

Some water managers respond to these concerns by arguing that the same kinds of policies and practices they have long used to address climatic variability will be sufficient for managing anthropogenic climate change. In part, this is true—these approaches have been developed over long periods of time and permit us to deal with a wide range of water challenges. But there are three reasons for concern over relying on traditional management responses.

First, climate change may cause the same kind of variations in hydrology that managers are used to addressing, but to a degree outside of historical experience. Thus, droughts and floods are no doubt likely to continue to occur, but some of these may be more severe than the current instrumental record would otherwise suggest. As a result, the traditional responses used for managing floods and droughts may be insufficient for managing the new conditions: reservoirs may be too small; the areas protected by levee systems or other flood management approaches may have to be expanded, or demands under higher temperatures may grow beyond the capacity of the existing system.

Second, climate change may cause the same kind of variability in hydrology that managers are used to addressing, but far faster. Sea-level rise far faster than historical experience will lead to faster changes in wetlands and ecosystem dynamics than natural ecosystems can handle. Changes in glacier melt rates already exceed those of the past several centuries, changing water management needs in many basins and beginning to force water managers to think about new and different operating rules.

Finally, climate change may have impacts on water systems completely different from those for which the systems are designed. These are the most difficult to predict,

precisely because they tend to be outside of the range of expectations or because models do not include the proper dynamics for forecasting such changes. Alterations in water quality that pose new threats to water systems, or changes in atmospheric dynamics that shift storm tracks, or radical changes in biota, or the complete loss of snowpack in mountainous regions are some examples.

In some basins and water systems, climate changes will not dramatically alter water quality, quantity, or management. But it is increasingly apparent that the inherently conservative nature of water managers, and the difficulty of making quick changes in systems that have developed over year, decades, and even centuries, means that in some regions there will be unavoidable impacts of climate change for which we will not be prepared.

What is necessary moving forward? I support the traditional call for new and better research by the climate community to improve our ability to both forecast coming changes and design appropriate regional responses. But we also know enough now for water managers to be more proactive in identifying and reducing the risks that climate changes will pose for water resources in both developed and developing countries. Uncertainty can no longer be used as an excuse for inaction, or the societal risks will be higher than they need to be.

In particular, for more than a decade now, the climate science community has called on water managers to begin to model different kinds of hydrology, to explore a wider range of operating rules and management tools in watersheds around the world, and to change their definitions of risks to include hydrology outside of the range of historical experience in order to evaluate both the sensitivity of existing systems and the potential for reducing those risks with existing or new approaches (see, for example, AWWA 1997). Very few such studies and assessments have been done. New technologies and tools for operating water systems are available that make better use of weather and climate forecasts, but few of these have been adopted by water managers, who are rarely rewarded for “out-of-the-box” thinking. And narrow-minded or ignorant politicians continue to block new assessments of regional and national vulnerabilities as though ignorance of future impacts and risks will prevent them from happening. This must stop. It is critical that we do better planning for the future, and that we act on those plans. As one version of an old Chinese proverb says, “Seeing the future is good; being prepared for it is better.”

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