CLIMATE AND WATER RESOURCES: A PRIORITY ISSUE OR MINOR ISSUE FOR WATER RESOURCE MANAGERS?

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INTRODUCTION

This paper is an invited personal perspective on the importance of climate information in the management of water. Recently, this issue has received attention both internationally and nationally with the World Water Forum III and the various initiatives launched by different countries in advance of this event. In addition, water has been recognized as a critical issue for the Intergovernmental Panel on Climate Change (IPCC) assessments and national climate programs. This article outlines some of the issues confronting water managers and the possible consequences of climate variability and change for these managers.

WATER ISSUES

Climate is one of several important factors influencing water availability. Furthermore, climate has a pervasive influence that affects many management issues. As a result it is important to have a strategy for studying and responding to climate variability and change where these changes can be predicted with some confidence.

By virtue of the finite limits to freshwater on this planet and the increasing demands for freshwater in many parts of the world, it will become an increasingly precious resource over the next few decades. Many physical issues affecting water are related to this constraint. Furthermore, the connection between the wealth creating processes and water could interest corporations and financial institutions in promoting water as a commodity. However, water issues go beyond economics – they are connected to life itself.

The current and emerging issues related to water can briefly be described as follows:

1) *Insufficient water for basic human needs*: It has been estimated that for a healthy lifestyle at subsistence levels, every human needs 50 liters of water per day (Gleick, 2000). Unfortunately, in many countries there are large numbers of people who do not have access to even this amount of water. This deficiency generally leads to poor health and poor hygiene. Furthermore, where adequate sanitation is lacking, pathogens, viruses and bacteria can flourish, raising mortality levels among the young and causing outbreaks of diarrheal and other diseases. It appears from other evaluations that even Severe Accelerated Respriatory Syndrome (SARS) may be transmitted in buildings and areas where the water distribution systems have leaks. Climate exacerbates these problems because people in these developing countries often rely on rain for their limited supplies, so when droughts occur, they bring very detrimental impacts.

2) *Over allocation of water supplies*: Globally, demands for water are increasing in many countries as a result of general population growth and increasing per capita water usage. Water is needed to fuel industrial growth, to support expanded food production and is even used to provide services such as irrigated golf courses and lawns. However, in some regions the allocation of water to these varied needs has now exceeded the average annual renewable supply. This situation leads to water shortages, especially during drought periods. In general these water shortages affect users in different ways depending on their susceptibility to water shortages and the institutional policies of the state or nation.

3) *Inadequate protection of water*: Water is a universal solvent and a very convenient way to transport waste. It is frequently used as a means of removing untreated sewage and even toxic wastes. In other cases it may transport the diffuse emissions of chemicals applied to farming areas. The consequences of these practices have been recognized in the developed world and actions are being taken to reduce the extent of the problems they create and to reclaim the polluted waters. However, reducing water pollution has required a commitment by governments to regulate industry emissions. In many developing countries, the infrastructure is not in place to control pollution or to treat wastes and the pressures of poverty may cause governments to accept industrial

pollution so that citizens can have a livelihood. Climate again is a factor because variations in water quantity affect the water available to dilute pollutants and determine their rate of transmission. During droughts, river flows are frequently insufficient to adequately dilute pollutants. On the other hand, heavy rainfalls sometimes are responsible for erosion and release large quantities of pollutants from sediments, urban pavement and rural landfills into the receiving waters.

4) Deteriorating or inadequate water infrastructure: Much of the infrastructure in large urban centers put in place 50 to 100 years ago for water distribution are deteriorating. The result is that water distribution systems become leaky and inefficient leading to water losses and the leakage of contamination into water supplies. Imposed on the problem of aging infrastructure are the rising costs and environmental concerns associated with large water developments. Maintaining the robustness of urban water infrastructure is becoming more urgent as more people move to cities. It is estimated that by 2015 50% of the population of the world's less developed regions will live in urban areas. (United Nations, 2003). In many cities floods exacerbate these problems because the infrastructure does not adequately deal with storm water. Storm waters can wash pollutants from urban surfaces and transport them directly into the ponds and streams that supply a city's water. In the USA where many small agricultural earthen reservoirs were completed before 1970, there are concerns about decreases in their storage capacity and in the accumulation of toxics in the sediments behind their dams.

5) *Water for the environment*: Water plays a critical role in the global climate and natural ecosystems: it regulates climate and supports and provides the basis for plant and animal life in ecosystems. Changes in precipitation patterns could lead to profound changes in ecosystem distribution and plant composition. Changes in the amounts of water reaching the earth's surface result in changes in the amount evaporated into the atmosphere, primarily from the oceans. Not only does the runoff to the ocean influence the quantity of nutrients supporting biological life in the ocean, but it also influences the salinity of the oceans, a factor that could influence the thermohaline circulation and many climate and oceanic effects associated with it.

While all of these issues are important, the broad water community with its diverse interests and concerns has not mounted an authoritative and comprehensive assessment activity to address the state of world's water resources. However, water is gaining recognition as a critical issue. The World Water Council and its World Water Vision study was an attempt to deal with this need for water assessments and brought a great deal of useful information together for use by planners. Water was identified as a major issue for the World Summit on Sustainable Development in August 2002. The more recent World Water Forum held in March 2003 brought together a number of interests in water. Although it facilitated interesting discussions and led to the formation of a few new committees, it did not appear, however, to be a mechanism that could implement bold new actions related to water.

There are several reasons why we should not be surprised that water is a more difficult issue than climate for forging international cooperation. Although climate has its complexities, the atmosphere is clearly a "global commons" and it is necessary for diffusive gases such as carbon dioxide, or pervasive emissions such as atmospheric aerosols and sulphur dioxide, to be studied globally. The climate community has established an effective mechanism for collaboration through the Intergovernmental Panel on Climate Change (IPCC) and the various scientific programs that contribute to it. Water resource issues are regional because the precipitation that falls in a watershed will either be used in that watershed or will flow into the ocean or a larger river basin. Accordingly, surface water often is perceived as a more regional issue and individual nations exert control over this resource in different ways, including restrictions on the sharing of information and data between countries. Furthermore, the local politics of water can be even more contentious than those of climate because political boundaries often divide watersheds forming trans-boundary basins and requiring agreements to ensure equitable treatment of all partners using the resource. In spite of good intentions, the ability to live up to such agreements depends on changing development and demand patterns and on the vagaries of the climate.

THE ROLE OF WATER IN CLIMATE ISSUES

Climate has an important role to play in the availability of water through the cycling of water from the ocean to the atmosphere, then to the land and back to the ocean. However the water cycle is also an integral part of the climate system. Clouds control the radiation budget, runoff influences ocean salinities and soil moisture determines the partitioning of incoming solar radiation between latent and sensible heat fluxes, to name just a few couplings. Through these mechanisms the water cycle exerts a control on the climate either by enhancing variability and change through positive feedbacks or by bringing the climate back to some equilibrium value through negative feedbacks.

For more than two decades, there has been concern that the increasing levels of atmospheric CO_2 arising from the burning of fossil fuels is leading to significant changes in climate. Given the current US position regarding the Kyoto carbon dioxide protocol and the debate among scientists on the rate at which carbon policies should be developed and implemented, there has been a new focus on reducing the uncertainties associated with climate change projections. According to IPCC assessments (IPCC, 2001), some climate change effects are known well enough to make them the basis of policy actions. For example, based on model projections average global temperatures are expected to increase by 1.4 to 5.8 ^{o}C by 2100. The climate models show much less consensus on water cycle variables such as precipitation and soil moisture, however. While the models used to produce these estimates do include some cloud and water vapor effects, the IPCC reports acknowledge that water cycle processes are a significant source of uncertainty for these estimates. In particular, the wide range of scales associated with cloud processes make them difficult to represent in climate models. There is a need to obtain fundamental data to enable the better understanding and model representation of basic cloud processes.

Other complexities arising from water cycle processes include the need to better represent the land-atmosphere interactions and to determine how changing land use has affected and will affect the climate. Research and model improvements are needed to increase the confidence in projections of water cycle variables such as precipitation, soil moisture and runoff. In addition, complex changes arising from reservoirs and diversions may have produced feedbacks to the atmosphere that have had a long-term effect on the climate. As noted by Hornberger et al. (2001), the prediction of water cycle extremes is also important. To some extent, the rate and timing of the acceleration of the global water cycle is related to changes in the intensity and frequency of extreme events such as droughts and floods. An integrated effort looking at remote and local factors in triggering and maintaining a drought or flood is needed.

In all of these discussions and speculations it is important to have access to good baseline data sets to determine recent trends. Global temperature data indicate a warming trend over the past three decades that appears quite robust. While there are a few alternate explanations, such as land use change, the most widely accepted explanation is the greenhouse warming effect arising from increasing concentrations of atmospheric CO_2. Some climate trends have been reported for precipitation although they are less convincing. For example, according to the IPCC assessments, rain amounts over northern land areas have been increasing over the same time period. Other data sets, such as the GEWEX Precipitation Climatology Project multi-decadal data set, show increases of precipitation on a regional basis, but not on a global basis. However, other water cycle variables do exhibit global trends. Global atmospheric water vapor, the most significant greenhouse gas, appears to have been increasing while, based on data from the International Satellite Cloud Climatology Project (ISCCP), clouds appear to have been decreasing. A strategy for water cycle observations is needed to ensure that a broad range of water cycle variables is monitored in a consistent way to determine how the water cycle may be contributing to or affected by climate change.

One debate surrounding the climate change issue concerns response options and, particularly, the relative merits of mitigation versus adaptation. Clearly, mitigation has been given a great deal of attention through the Kyoto agreements and, within the USA, through research priorities such as the Climate Change Science Plan and its Carbon Cycle element. However, even if mitigation were to commence today, the effects of the carbon dioxide already in the atmosphere would continue for a number of years. Consequently, adaptation is an essential element for any response to the climate change issue. To address this issue effectively it is important to clarify the present and future roles of climate in water issues.

One issue that is receiving attention internationally, particularly in the context of the Global Water System Project (GWSP), arises from research results that identify the important influence of the land surface and land use change on the atmosphere, particularly during the summer months. These findings suggest that changes in the distribution of water on the land surface due to the construction of reservoirs, the drainage of wetlands and swamps, inter-basin water transfers, changing vegetation patterns, etc are likely to have a significant influence on the climate. This is an important source of uncertainty for climate change that has not received much attention in the past. However, if historical water management practices are shown to be a factor in climate trends it could have significant implications for water policy. The GWSP will draw upon the expertise in the World Climate Research Program (WCRP), the International Geosphere-Biosphere Programme, the International Human Dimensions Programme and Diversitas to look at this issue.

THE ROLE OF CLIMATE IN WATER ISSUES

Climate variability plays an important role in water management. Flood events, one of the most dramatic manifestations of climate variability, create physical hazards in basins that must be planned for and responded to on an emergency basis. Seasonal variability in precipitation leads to a need to retain water from the seasons when it is readily available for those seasons when it is scarce. The large variability in flow from year to year has led to the development of different strategies for retaining flow excesses and providing water during droughts. Drought prone areas such as the southwestern USA often have large reservoirs to retain water for use during these periods. In many states the use of reservoirs in water management has led to maximum water allocation based on the average flows and has removed most of the flexibility for dealing with variability.

Society is moving away from the heavy reliance on developing new reservoirs for water management, in part because this capacity is fully developed in many areas and, in part, because concerns about both the immediate and long term environmental consequences of dams and reservoirs have made the approval process for new developments very complex. However, with emerging capabilities to predict water cycle variability, it is possible to use existing infrastructure more effectively in water resources management. For example, reservoirs can be emptied in advance to reduce flood potential when heavy rains are predicted or water can be rationed if a period of drought is expected. Consequently, more efficient use of existing reservoir facilities can provide opportunities for meeting some of the needs for more water.

Given the interest in non-structural approaches to water management, the future management of water is likely to rely more directly on climate forecasts. This means the development of better forecast systems capable of producing reliable monthly to seasonal predictions and decision support systems that allow for the use of information that contains different levels of uncertainty. For example, in the western part of the United States, during years with predictions of strong equatorial Sea Surface Temperatures (the ENSO phenomena), it is possible to say with some confidence that precipitation will be above or below normal during a season with 3 to 6 months lead time. As shown by Georgakakos et al. (1998) the use of probabilistic forecasts together with flexible decision support systems can result in significant savings.

The issue of projecting the consequences of climate trends and change on water resources based on the temperature and precipitation scenarios from climate models merits some discussion. In addition to evidence that temperatures are warming over many regions of the Earth, there is also evidence in some regions that precipitation amounts are changing on a regional basis, and that runoff peaks are occurring earlier in the year for basins in the western USA and Canada (Stewart et al., in review). Other areas, such as the large north-flowing rivers in Siberia, are showing trends of larger late winter and early spring discharge. While these trends have been observed there is a need to evaluate the extent to which these trends indicate climate change.

As noted earlier, climate models often produce widely varying trends for their projections of precipitation and soil moisture patterns. As a result, many water resource agencies have been reluctant to invest much effort in addressing the projected consequences of climate change. They feel that the information provided by the climatological community is wanting. Viewed from some perspectives, this caution is advisable. However, there are some trends such as changes in the seasonality of runoff, mountain glacier melt, shrinking continuous permafrost areas and increasing river flows in the North that support inferences made from climate scenarios and do merit attention. In some cases knowledge of these trends could provide opportunities for welcome changes in the approaches to water resource management, while in other cases this knowledge may be a challenge for water resource management philosophies and practices. However, in either case, it represents intelligence that should be part of contingency planning even if it is not considered in mainstream planning.

As a first step in introducing these ideas into water management, the concept of change needs to be accepted in the planning process. The engineering community has a strong commitment to design criteria based on the statistics of historical data for a given period and on the assumption of a stationary climate mean. This approach is entrenched in engineering practices because it has been used for many decades. However, to prepare for the future, the engineering community needs to take up the challenge of finding ways to address the design process when the climate (and other environmental factors for that matter) is non-stationary – a condition that will always be with us. The debate about whether such trends have an anthropogenic cause or are part of a long-term cycle may continue to be debated by the scientific community, but for the engineering community the existence of trends, supported by climate model projections, should be a strong signal that a more flexible approach to design is needed now.

STEPS FOR THE FUTURE

It is clear that the interactions between climate and water resources are critical and will demand action now and for the foreseeable future. Clearly the hydrologic and climate communities must take steps to produce a better prediction capability both on short and longer time scales. The advent of major advances in our capability to measure the water cycle from space, along with rapid increases in computation capabilities means that we will be able to address monitoring, assimilation and prediction problems at much higher resolutions than has been the case in the past. Global observing systems that rely heavily on satellites is an opportunity area. The Tropical Rainfall Measurement Mission (TRMM) has shown the value of high resolution three dimensional maps of rain on a global basis. Through the cooperation of the international space agencies by their development and support of the Global Precipitation Measurement (GPM) Mission, we may soon have similar measurements for the entire globe taken every three hours. This will make it possible to derive global precipitation maps and will provide for a major advance in our ability to forecast runoff.

The ability to measure from space is also becoming important for mapping global soil moisture with European Space Agency's SMOS mission and, hopefully, the proposed NASA HYDRAS mission; for mapping ground water reserves with the GRACE mission, and for estimating river flow by altimetry measurements using data from the TOPEX/ POISDEN mission and possibly other similar data from a future water mission. It is important that the enthusiasm for these new technologies does not displace the commitment to existing measurement networks, however. Data sets from new satellite systems are unproven and it will be many years before we have the capability to fully interpret and exploit these data sets. Furthermore, the practice of treating most of these missions as research missions without a clear plan to transition them to operations means that surface networks will remain our primary hope for maintaining continuity in the measurement record for many years to come. As a result, there is a need to strengthen the current hydrometric and hydro-meteorological networks to ensure this needed continuity. Current activities by the Integrated Global Observing Strategy Partnership (IGOS-P) are attempting to address both aspects of this observing problem as part of its global water cycle observing strategy.

In some areas, such as the western US, seasonal predictions show skill but in other areas where continental influences are very strong, it is unlikely that we will find similar skill levels in the near future. Predictability studies are needed to identify the limitations of this skill. Furthermore, the models used to make projections of long-term changes of water cycle variables, such as precipitation and soil moisture, need to be improved. This can be achieved by putting more emphasis on the representation of water cycle processes in global climate models. These processes are difficult to represent because of the mismatch between the spatial scales of the processes and the coarse resolution of the computational elements in the model. For this reason, experimental field studies and research are needed to understand the processes and heterogeneity effects, and to develop methods for representing them at the much coarser scales of climate models. In particular, data sets are needed to advance the parameterization of the important processes and to challenge the existing parameterization schemes in the models.

One problem limiting the full exploitation of the information and capabilities that exist in the science community are that the communities that need the information seldom have access to it. Another is the mismatch between what water resource managers need and what the climate community can provide. In the USA, the National Weather Service produces forecasts that they deliver through the media but unless water managers have been introduced to these products they are unlikely to utilize them fully. Projects are needed to bring the research community together with the users of the information to develop, test and operationalize new products. This approach provides a dual benefit because the users can test in near real-time the new products that are being delivered and they can provide advice to the researchers on the needs for new development and research. One international project, Hydrology for Environment Life and Policy, being carried out under the auspices of the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the World Meteorological Organization (WMO), is an example of an initiative that promotes real-time interactions between scientists and users. It is anticipated that this project will develop some new ways for the science community and the water resource management community living in the affected basins to work together.

In summary, the water science community can view the climate change issue as a threat or as an opportunity. Many water managers, concerned about changing a system that now appears to work, have distanced themselves from the "climate change" issue, while many others do not fully understand the significance of the issue. A minority have embraced the concept of change and are assessing ways of including these ideas in decision-making without compromising the integrity of water systems. It is this author's opinion that the future sustainability of water resources rests with that minority of water managers working closely with the science community to look at strategies for managing water in a sustainable way within a context that integrates climate variability and change with other types of change and technologies for maintaining water supplies (e.g. desalinization, conservation).

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