

# Global Change and Extreme Hydrology

## TESTING CONVENTIONAL WISDOM



**UNDERSTANDING HOW CLIMATE CHANGE WILL IMPACT HYDROLOGY**—the movement, distribution, and quality of water—is one of the grand challenges facing the climate and water science communities. The basic laws of physics demonstrate that as climate warms, Earth's atmosphere will hold more moisture. This threatens to increase the occurrence of severe storms, potentially leading to more extreme floods and droughts.

**AS CLIMATE CHANGE WARMS THE ATMOSPHERE,**

Earth’s hydrology is shifting—with the potential to make floods and droughts more extreme. There is now a pressing need for decision-makers to better understand the ongoing changes in hydrologic extremes in order to make preparations for the possibility of changing conditions. This report assesses potential changes in the frequency and severity of floods and droughts, abilities of communities to understand and forecast these changes, and strategies for better communicating the science to water resources practitioners.

Understanding how climate change will impact hydrology—the movement, distribution, and quality of water on earth is one of the grand challenges facing the climate and water science communities. The basic laws of physics demonstrate that as climate warms, Earth’s atmosphere will hold more moisture. This threatens to increase the occurrence of severe storms, potentially leading to more extreme floods and droughts.

These predicted changes in the atmospheric branch of the hydrologic cycle are well-supported in global climate models, and records show that precipitation has increased over the 20th century. Now water resource managers need more detailed information about if, where, and how hydrologic extremes will change in order to build infrastructure to withstand future conditions.



However, patterns of floods and droughts have proven difficult to pin down, in part because of the complex dynamics of Earth’s atmosphere, but also because their incidence is influenced by more than climate-driven phenomena alone. Other human-caused changes, such as deforestation, urban expansion, and the construction of water engineering projects—such as impoundments, irrigation systems, and water diversions—also impact Earth’s hydrology and can influence the occurrence of flood and drought. As a result, a coherent picture of how hydrologic extremes will shift as climate changes has yet to emerge.

In order to better prepare for the possibility of changing conditions, this report reviews current knowledge about how climate warming translates into hydrologic extremes and assesses the effectiveness of current efforts to translate scientific knowledge into water policy and management actions.



***What happens to the atmosphere as climate warms?***

*According to a basic physical law, known as the Clausius-Clayperon relation, air holds more water vapor at higher temperatures. In fact, the water holding capacity of Earth’s atmosphere increases by about 7 percent per degree Celsius increase in temperature (or about 4 percent per degree Fahrenheit).*

## What Scientists Know About Changing Hydrology

Recent analyses of a broad spectrum of water cycle variables, including precipitation, snow cover, and droughts, show that climate change is already affecting hydrology—and some of these changes have been unexpected.

Conventional wisdom, in the form of global climate models and the basic laws of physics, predicts that the hydrologic cycle will accelerate as climate warms. Changing patterns of precipitation could potentially lead to more extreme floods and droughts.

However, observations show few statistically significant trends in major floods in the United States, although low and medium range flows in many streams increased over the second half of the 20th century as the country became generally wetter. Evidence of changes in U.S. drought characteristics is mixed. Droughts have become longer, more frequent, and more severe in parts of the eastern and western United States (see Table 1), but other evidence shows droughts have become

less severe in other parts of the eastern and central United States.

This disconnect between climate model simulations and observations is due in part to the complexity of interactions between the atmosphere and land-surface systems. Often, the global climate models that predict increased precipitation have too large a scale and too coarse a spatial resolution to tell scientists how hydrology will change at local and regional scales. Smaller-scale regional climate models are not yet sophisticated enough to add significant information, in part because smaller regions have greater variability from daily to multiple year time-scales making it even more difficult to distinguish real changes from background noise.

Moreover, these models don't comprehensively address non-climate issues, such as the construction of dams and changes in land cover that can also affect water cycles. More information on all these factors, and how they interact, is needed to gain a better understanding of how climate change will translate to floods and droughts on a regional and local scale.

Observed Water-Related Changes During the Last Century		
Observed Change	Direction of Change	Region Affected
One to four week earlier peak streamflow due to earlier warming-driven snowmelt	Earlier	West and Northeast
Proportion of precipitation falling as snow	Decreasing	West and Northeast
Duration and extent of snow cover	Decreasing	Most of the United States
Mountain snow water equivalent	Decreasing	West
Annual precipitation	Increasing	Most of the United States
Annual precipitation	Decreasing	Southwest
Frequency of heavy precipitation events	Increasing	Most of the United States
Runoff and streamflow	Decreasing	Colorado and Columbia River Basins
Streamflow	Increasing	Most of East
Amount of ice in mountain glaciers	Decreasing	U.S. western mountains, Alaska
Water temperature of lakes and streams	Increasing	Most of the United States
Ice cover on lakes and rivers	Decreasing	Great Lakes and Northeast
Periods of drought	Increasing	Parts of West and East
Salinization of surface waters	Increasing	Florida, Louisiana
Widespread thawing of permafrost	Increasing	Alaska

Table 1. Century-scale changes in a broad array of water cycle variables contribute to the scientific evidence for detectable climate warming in the United States. Taken together, these variables indicate that the hydrologic cycle is accelerating.

Source: The U.S. Global Change Research Program's national assessment of climate impacts. Reprinted, with permission of Karl et al (2009). Copyright 2009, Cambridge University Press.

## Translating the Science of Hydrologic Extremes to the Policy and Management Sectors

Scientists face the challenge of identifying trends in floods and droughts and predicting future shifts in hydrology as climate continues to change, but also need to communicate about hydrologic extremes to the water resource managers who will prepare for shifting conditions, for example by changing water regulation at dams or by designing flood protection infrastructures that will withstand extreme floods.

In the past, water resource managers typically built infrastructure such as dams, bridges, and reservoirs based on the assumption of *stationarity*: the statistically-based idea that hydrologic systems may fluctuate, but always remain within a defined set of boundaries. Engineers assumed that an event outside of these boundaries would be extremely rare, occurring perhaps once a century, giving rise to the idea of the “100-year flood”.

Yet observational evidence increasingly shows flaws in the assumption of stationarity. An example comes from the American River in California, where over the past 100 years, the five largest flood volumes all occurred within the last 50 years; as did 10 of the 13 largest floods.

Despite these changing conditions, water managers in the United States currently determine flood potential using a data-based set of methods

presented in *Bulletin 17B of the InterAgency Advisory Committee on Water Data*, a document that has not been updated since the early 1980s—and does not sufficiently address the growing concern of non-stationarity. As a result, there’s now a pressing need for new flood-frequency guidelines that draw on advances in hydrologic and climate science over the past 25 years.

Many different groups, from climate scientists to atmospheric modelers to water resource managers, can help build a better understanding of changing hydrology—but currently, communication between such disciplines is limited. The lack of interaction is illustrated by differences in the terminology; for example, to hydrologists, “extreme” events are those that occur very rarely, for example a 100-year flood. In contrast, the climate science community describes much more frequent event as “extreme,” such as an increase in the number of days per year that precipitation exceeds a threshold 50 millimeters. These varied metrics can lead to miscommunication, and limit the transfer of information between the various disciplines.

A common vocabulary or understanding of the meaning behind various terms would facilitate collaboration between the scientists and practitioner communities. In the absence of common language, different uses of important terms should be clearly defined and accepted, and communities should be flexible and adaptable with respect to how others use the terms.

### ***What is a 100-year flood?***

*Terms such as 50-year flood and 100-year flood are used to estimate the probability of a flood occurring. For example, a 100-year flood refers to a level of flood water that has a 1 percent chance of being equaled or exceeded in any given year.*





### CONVENTIONAL WISDOM AND THE CEDAR RAPIDS FLOOD OF 2008

*The summer of 2008 brought the worst floods the city of Cedar Rapids, Iowa has ever known. On June 13, 2008, the Cedar River surged to 31.2 feet—far exceeding the previous record of 20 feet—and flooded more than 10 square miles of the city. More than 5,390 houses were inundated and more than 18,000 residents displaced.*

*In the wake of the flood, the water resource managers of Cedar Rapids had many questions as they set about rebuilding the city's flood related infrastructure. Was the flood a truly rare event, or evidence of shifting hydrologic extremes?*

*Because the flood of 2008 was one of the largest in the city's history, many residents believed that the chances of another large flood occurring were slim, and that there would be little economic benefit in implementing significant flood risk reduction projects. However, researchers at Iowa State University used global climate models to predict that precipitation will increase by 21 percent in Iowa over the next 50 years; with the net result of increasing river flows by 50 percent. This work suggests that in the future, large floods could be more common in the Midwest than they were in previous years—and that climate change is an important consideration in planning for future floods and droughts.*

<http://www.cedar-rapids.org/government/departments/public-works/engineering/Flood%20Protection%20Information/Pages/2008FloodFacts.aspx>

## The Way Forward

Building strong links between the climate science and water resource communities is essential, if researchers are to understand how climate variability and change can affect hydrologic processes. Hydrologists occupy a useful niche between climate change scientists and water practitioners, promoting the translation of critical research findings into better informed planning and applications

In the meantime, the construction of water engineering projects will continue. From a planning standpoint, uncertain flood or drought frequencies cause major problems with projects that have long life-spans, such as dams, levees, and sewers. One solution to this problem is to construct infrastructure in smaller units that have shorter expected longevities or design re-visit times (on the order of 10-20 years). In addition, engineers can use reconstructions of conditions during past periods of climate change, based on historical or paleohydrologic records—evidence of hydrologic systems as they existed during previous periods of Earth history—to design projects that could adapt to predicted future conditions. Such strategies have been used to avoid future flood damage to urban areas

in the Mississippi River floodplain, by establishing a margin-of-error in the design of infrastructure, or moving assets to higher ground.

Progress toward addressing basic questions on hydrology will require a continued commitment to monitoring and routine observations of climate, weather, and hydrologic conditions. The United States has an enviable record of hydrologic measurement, but in recent years hydrologic observing networks have become increasingly fragmented. Without firm commitments to retain observational networks by federal, state, and municipal agencies, efforts to understand the risk of hydrologic extremes will be compromised—as will abilities to prepare for, adapt to, and mitigate the impacts of these extremes as climate conditions change.

*Many pieces of water infrastructure are still in use 50 or even 100 years after they are constructed. For example, the New York City public water system was constructed in 1899 and much of the original infrastructure is still in use today.*



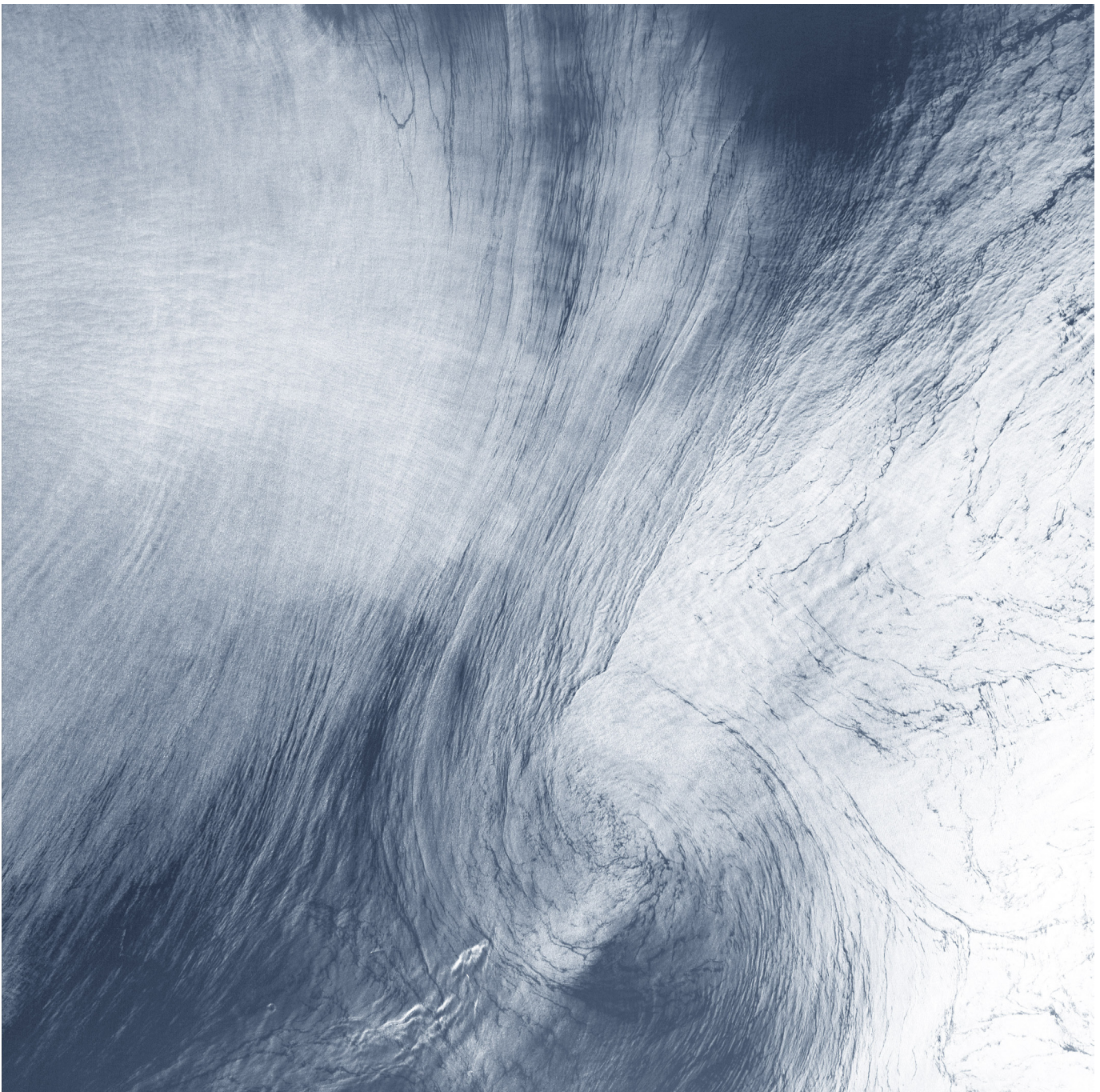
### ***Understanding Flood and Drought Risk***

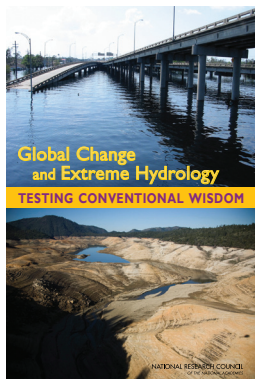
*Risk is a combination of the likelihood that a hazard will occur, and the exposure of assets to damage. In the past, researchers placed considerable emphasis on the probability component of risk, as illustrated by the idea of the “100-year flood.” There has been much less emphasis on developing well-defined measures of vulnerability to hazards, which in this context means susceptibility to and ability to cope with losses caused by extreme floods or droughts.*

*Vulnerability depends in part on social factors, and is constantly evolving. For example, the construction of dams and levees might decrease the probability of a flood, but could increase vulnerability by creating a false sense of security that results in the construction of buildings in flood-risk areas. Without research to better understand all the dimensions of risk, the design of effective climate change adaptation strategies will remain unrealized.*

## Closing Thoughts

There are still many challenges characterizing hydrologic extremes, translating scientific knowledge to the policy and management communities, and identifying a productive future role for hydrologic sciences. The committee agreed that the water cycle is indeed changing, but noted that many unknowns remain with respect to the drivers of change, system responses, and implications for society. Creating a better dialog between climate scientists and water resource managers is an essential first step toward understanding how climate change will impact hydrology.





**Committee on Hydrologic Science:** **Charles J. Vörösmarty** (*Chair*), City University of New York\*; **Victor R. Baker**, University of Arizona\*; **Dennis P. Lettenmaier**, University of Washington\*; **Daniel P. Loucks**, Cornell University\*; **David Pimentel**, Cornell University; **George F. Smith**, Riverside Technologies, Inc.\*; **Emily H. Stanley**, University of Wisconsin; **Chunmiao Zheng**, The University of Alabama\*; **Laura J. Helsabeck** (*Study Director*), **Anita Hall** (*Senior Program Associate*), National Research Council.

\*Workshop planning committee

The National Academies appointed the above committee of experts to address the specific task requested by the Nuclear Regulatory Commission and the National Oceanographic and Atmospheric Administration. The members volunteered their time for this activity; their report is peer-reviewed and the final product signed off by both the committee members and the

National Academies. This report brief was prepared by the National Research Council based on the committee's report.



For more information, contact the Water Science and Technology Board at (202) 334-3422 or visit <http://dels.nas.edu/wstb>. Copies of *Global Change and Extreme Hydrology: Testing Conventional Wisdom* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; [www.nap.edu](http://www.nap.edu).

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page 7, A giant whirlpool cloud, coaxed into shape by high-altitude winds. From Earth as Art II image series, provided by USGS Earth Resources Observation and Science Center. Image from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) aboard NASA's Terra satellite.