



April 17, 2009

America's Climate Choices  
The National Academies  
500 5th St. NW, W603  
Washington, DC 20001

**RE: Summary of Submission to the Panel on Advancing the Science of Climate Change**

Dear Committee Members:

The American Water Works Association (AWWA), the Association of Metropolitan Water Agencies (AMWA) and the Water Research Foundation (Foundation) are submitting these joint comments to the America's Climate Choices Panel on Advancing the Science of Climate Change. AMWA and AWWA together represent drinking water utilities of all sizes that serve more than 90% of the U.S. population. The Foundation sponsors research to enable water utilities to provide safe and affordable drinking water to consumers. In 2008 the Foundation established the Climate Change Strategic Initiative – a research program focused on impacts of climate change on water supplies.

AWWA, AMWA and the Foundation are very concerned with the effects of climate change on water resources as many of the most critical impacts of global climate change will manifest themselves through the hydrologic system. Because the exact effects of climate change on water resources are uncertain and will vary by region, the drinking water, wastewater, flood management, and stormwater utilities responsible for managing water resources for local communities face daunting challenges. These water utilities are already preparing to mitigate, adapt and plan for climate change in the midst of the uncertainties about the potential ranges of climate change impacts.

This joint letter summarizes the three documents we are submitting for consideration during the study process. The documents include:

- **Comments on the Sub-Questions:** We have reviewed the sample sub-questions that illustrate the range of issues the Panel may address and provided responses to each. The responses include a description of some of the predicted impacts on water quantity and quality as well as recommendations for actions to increase the reliability and utility of predictions of future climate changes. We submit these suggestions for the Committee to consider as future actions.

- **Article Entitled *Stationarity is Dead*:** In early 2008, an article was published in *Science* that clearly articulates the water sector's concerns regarding the impacts of the increased rate of climate change on the design and management of drinking water systems. As these impacts are potentially significant, the water sector looks to the science community to provide more detailed information on the rate of change.
- ***Potential Climate Change Impacts of Precipitation (Draft)*:** This document was developed recently by the California Department of Health and discusses the potential impacts of changes in precipitation patterns due to climate change on water suppliers in California. The document provides details on some of the abrupt changes that could occur, resulting in significant challenges for the drinking water sector.

AWWA, AMWA and the Foundation are also submitting detailed joint comments to each of the other three panels within the America's Climate Choices Study and to the Committee on America's Climate Choices.

Sincerely,



Diane VanDe Hei  
Executive Director, AMWA



Tom Curtis  
Deputy Executive Director, AWWA



Robert C. Renner  
Executive Director, Water Research Foundation

Attachments:

Comments to the Panel on Advancing the Science of Climate Change  
*Stationarity is Dead*  
*Potential Climate Change Impacts of Precipitation (Draft)*

## ADVANCING THE SCIENCE OF CLIMATE CHANGE

### **What are the primary causes and mechanisms of climate change, what and where have the most notable climate changes and climate change impacts been, and how significant are these changes in the context of natural climate variability and historical climate impacts?**

There is general agreement among experts that increases in greenhouse gases, especially carbon dioxide, are a primary cause of climate change and that indications of these changes are already being seen at moderate elevations (3,300 to 6,500 feet) and at higher latitudes (Arctic and Antarctic regions). For the water sector, the potential effects on hydroclimate (weather and hydrology) appear to be greater than would be due to historical natural climate variability.

The rate of climate change has increased over the past few decades and scientists generally agree that past observations should be considered differently in developing projections of the future, especially with respect to air temperature increases and precipitation patterns. For example, there is agreement among experts that the amount of snowpack stored in mountains (e.g., Sierra Nevada and Cascades) of the western United States is expected to decrease at a much greater rate than previously. This raises serious concerns for water managers depending on snow-fed streams who must try to respond to changes in the timing of runoff and determine how to replace the lost natural reservoir capacity.

Included in the February 2008 issue of *Science* was an article addressing the concept that stationarity no longer applies when planning for the future of the nation's water resources. This article, which is provided as attachment SC-2, has been widely discussed in the water sector. It is generally thought to clearly articulate the sector's concerns regarding the potential impacts of the increased rate of climate change on the design and management of drinking water systems. The California Department of Public Health has drafted a document discussing the potential impacts from changes in precipitation patterns due to climate change. This document is provided as attachment SC-3.

In addition, the Water Research Foundation (formerly AwwaRF) has developed a primer that outlines the state of scientific understanding regarding the potential impacts of global climate change on water utilities. The document addresses impacts on water supply, demand, and relevant water quality characteristics and can be found at the following link:

<http://www.waterresearchfoundation.org/research/TopicsAndProjects/projectProfile.aspx?pn=2973>

### **What climate changes and impacts are expected to occur under different scenarios of future greenhouse gas emissions, climate sensitivity, and vulnerability of human and natural systems? What irreversible impacts, abrupt changes, or other "surprises" could be in store?**

Abrupt changes in snowpack lead to a reduction in the amount of natural fresh water storage and an increase the duration and frequency of flood flows during the winter months. Existing drinking water infrastructure that is already considered vulnerable due to lack of maintenance could be unable to manage these flooding events. The lack of snowpack can also lead to drought conditions once the winter and spring flooding events have passed. As the amount of surface water from both rivers and reservoirs is reduced during these anticipated drought periods, the

resulting impacts on water quality can be significant. The amount of total dissolved solids in the surface water supplies can increase as can the salinity in surface waters that are tidal influenced. Also, as the water levels in reservoirs decrease due to prolonged drought periods, the likelihood for increased algae growths and also warmer water temperatures will occur. The warmer water will support a different set of bacteria and other microorganisms than is found in colder waters. The possibility that pathogens that thrive in warmer waters that historically have not been present may be detected in the drought impacted supplies.

Little attention has been paid to the relationship of climate change impacts to heavily populated geographic areas of the United States and other countries. It is important to consider how vital infrastructure can adapt to these changes to enable people to continue to live in these areas and to meet the needs of increasing population. If one considers the climate impacts on water supplies in large areas of the United States – such as the Southwest, Southern California, Texas, the South (including Florida) and some parts of the East Coast that may become subject to sea level rise issues and storm surges/damages – the potential for migration shifts may be considerable in the future. Some parts of the United States may remain at some advantage for livability and ability to meet water needs for growing communities under climate change scenarios. However, possible changes in international and international migration patterns over time have not been adequately researched.

**What can be done to increase the reliability, accuracy, and utility of predictions and projections of future climate and climate-related changes?**

The high degree of uncertainty associated with precipitation and sea level rise on long time horizons makes today's decision-making process more difficult. The drinking water community has identified two critical needs in its efforts to adapt to the impacts of climate change. In the short term, there is a need for a paradigm shift toward planning with uncertainty using multiple models and scenarios to describe future possibilities with no regret planning timelines. In the long term, the need is for the science community to reduce the uncertainty of the global climate models (GCMs) and the sea level rise models.

When refining the models, it is important to remember that water resource planning is done at a regional and local scale. Currently, GCM scales and downscaling methods are too large for most regional and local planning. Statistical downscaling is typically based on 100- to 1,000-year historical patterns but global climate change may result in new patterns that are unlike the past 1,000 years. Dynamic downscaling methods can be better at predicting these new patterns but are expensive and slow to develop. Methods need to be developed that allow for inexpensive and rapid downscaling of precipitation forecasts to specific watersheds. It will be important that these modeling efforts address specific regional patterns (i.e, monsoons in the Southwest).

## CLIMATE CHANGE

# Stationarity Is Dead: Whither Water Management?

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Systems for management of water throughout the developed world have been designed and operated under the assumption of stationarity. Stationarity—the idea that natural systems fluctuate within an unchanging envelope of variability—is a foundational concept that permeates training and practice in water-resource engineering. It implies that any variable (e.g., annual streamflow or annual flood peak) has a time-invariant (or 1-year-periodic) probability density function (pdf), whose properties can be estimated from the instrument record. Under stationarity, pdf estimation errors are acknowledged, but have been assumed to be reducible by additional observations, more efficient estimators, or regional or paleohydrologic data. The pdfs, in turn, are used to evaluate and manage risks to water supplies, waterworks, and floodplains; annual global investment in water infrastructure exceeds U.S.\$500 billion (1).

The stationarity assumption has long been compromised by human disturbances in river basins. Flood risk, water supply, and water quality are affected by water infrastructure, channel modifications, drainage works, and land-cover and land-use change. Two other (sometimes indistinguishable) challenges to stationarity have been externally forced, natural climate changes and low-frequency, internal variability (e.g., the Atlantic multidecadal oscillation) enhanced by the slow dynamics of the oceans and ice sheets (2, 3). Planners have tools to adjust their analyses for known human disturbances within river basins, and justifiably or not, they generally have considered natural change and variability to be sufficiently small to allow stationarity-based design.

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An uncertain future challenges water planners.

In view of the magnitude and ubiquity of the hydroclimatic change apparently now under way, however, we assert that stationarity is dead and should no longer serve as a central, default assumption in water-resource risk assessment and planning. Finding a suitable successor is crucial for human adaptation to changing climate.

*How did stationarity die?* Stationarity is dead because substantial anthropogenic change of Earth's climate is altering the means and extremes of precipitation, evapotranspiration, and rates of discharge of rivers (4, 5) (see figure, above). Warming augments atmospheric humidity and water transport. This increases precipitation, and possibly flood risk, where prevailing atmospheric water-vapor fluxes converge (6). Rising sea level induces gradually heightened risk of contamination of coastal freshwater supplies. Glacial meltwater temporarily enhances water availability, but glacier and snow-pack losses diminish natural seasonal and interannual storage (7).

Anthropogenic climate warming appears to be driving a poleward expansion of the subtropical dry zone (8), thereby reducing runoff in some regions. Together, circulatory and thermodynamic responses largely explain the picture of regional gainers and losers of sustainable freshwater availability

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

that has emerged from climate models (see figure, p. 574).

*Why now?* That anthropogenic climate change affects the water cycle (9) and water supply (10) is not a new finding. Nevertheless, sensible objections to discarding stationarity have been raised. For a time, hydroclimate had not demonstrably exited the envelope of natural variability and/or the effective range of optimally operated infrastructure (11, 12). Accounting for the substantial uncertainties of climatic parameters estimated from short records (13) effectively hedged against small climate changes. Additionally, climate projections were not considered credible (12, 14).

Recent developments have led us to the opinion that the time has come to move beyond the wait-and-see approach. Projections of runoff changes are bolstered by the recently demonstrated retrodictive skill of climate models. The global pattern of observed annual streamflow trends is unlikely to have arisen from unforced variability and is consistent with modeled response to climate forcing (15). Paleohydrologic studies suggest that small changes in mean climate might produce large changes in extremes (16), although attempts to detect a recent change in global flood frequency have been equivocal (17, 18). Projected changes in runoff during the multidecade lifetime of major water infrastructure projects begun now are large enough to push hydroclimate beyond the range of historical behaviors (19). Some regions have little infrastructure to buffer the impacts of change.

Stationarity cannot be revived. Even with aggressive mitigation, continued warming is very likely, given the residence time of atmospheric CO<sub>2</sub> and the thermal inertia of the Earth system (4, 20).

*A successor.* We need to find ways to identify nonstationary probabilistic models of relevant environmental variables and to use those models to optimize water systems. The challenge is daunting. Patterns of change are complex; uncertainties are large; and the knowledge base changes rapidly.

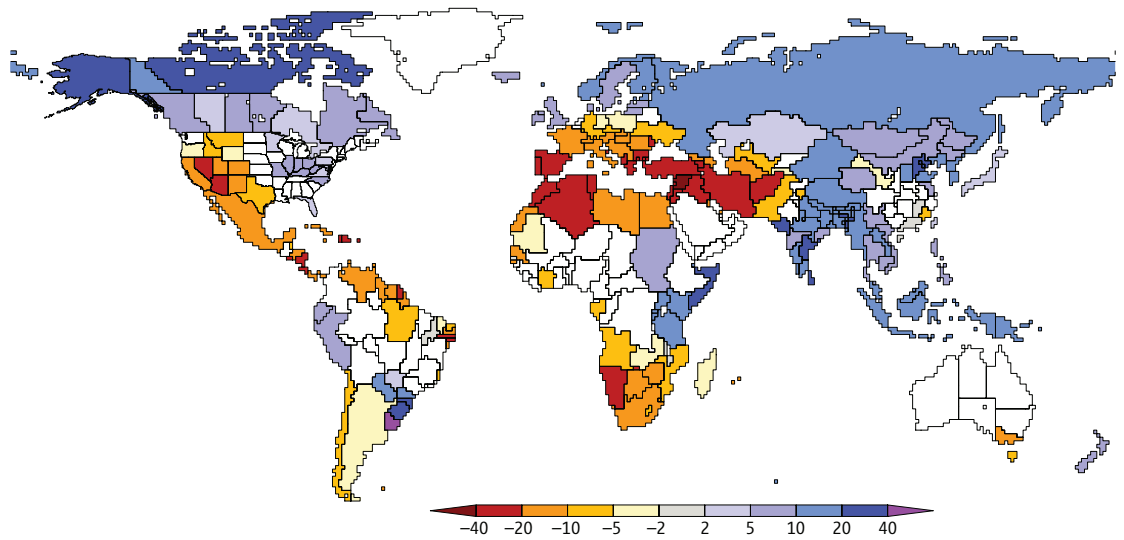
Under the rational planning framework advanced by the Harvard Water Program (21, 22), the assumption of stationarity was

combined with operations research, statistics, and welfare economics to formulate design problems as trade-offs of costs, risks, and benefits dependent on variables such as reservoir volume. These trade-offs were evaluated by optimizations or simulations using either long historical streamflow time series or stochastic simulations of streamflow based on properties of the historical time series.

This framework can be adapted to changing climate. Nonstationary hydrologic variables can be modeled stochastically to describe the temporal evolution of their pdfs, with estimates of uncertainty. Methods for estimating model parameters can be developed to combine historical and paleo-hydrologic measurements with projections of multiple climate models, driven by multiple climate-forcing scenarios.

Rapid flow of such climate-change information from the scientific realm to water managers will be critical for planning, because the information base is likely to change rapidly as climate science advances during the coming decades. Optimal use of available climate information will require extensive training of (both current and future) hydrologists, engineers, and managers in nonstationarity and uncertainty. Reinvigorated development of methodology may require focused, interdisciplinary efforts in the spirit of the Harvard Water Program.

A stable institutional platform for climate predictions and climate-information delivery may help (23). Higher-resolution simulations of the physics of the global land-atmosphere system that focus on the next 25 to 50 years are crucial. Water managers who are developing plans for their local communities to adapt to climate change will not be best served by a model whose horizontal grid has divisions measured in hundreds of kilometers. To facilitate information transfer in both directions between climate science and water management, the climate models need to include more explicit and faithful representation of surface- and ground-water processes, water infrastructure, and water users, including the agricultural and energy sectors.



**Human influences.** Dramatic changes in runoff volume from ice-free land are projected in many parts of the world by the middle of the 21st century (relative to historical conditions from the 1900 to 1970 period). Color denotes percentage change (median value from 12 climate models). Where a country or smaller political unit is colored, 8 or more of 12 models agreed on the direction (increase versus decrease) of runoff change under the Intergovernmental Panel on Climate Change's "SRES A1B" emissions scenario.

Treatments of land-cover change and land-use management should be routinely included in climate models. Virtual construction of dams, irrigation of crops, and harvesting of forests within the framework of climate models can be explored in a collaboration between climate scientists and resource scientists and managers.

Modeling should be used to synthesize observations; it can never replace them. Assuming climatic stationarity, hydrologists have periodically relocated stream gages (24) so that they could acquire more perspectives on what was thought to be a fairly constant picture. In a nonstationary world, continuity of observations is critical.

The world today faces the enormous, dual challenges of renewing its decaying water infrastructure (25) and building new water infrastructure (26). Now is an opportune moment to update the analytic strategies used for planning such grand investments under an uncertain and changing climate.

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## Potential Climate Change Impacts of Precipitation

Developed by: California Department of Health

### **Declining Snowpack Related Drinking Water Quality Issues**

Climate change has already had a significant impact on the frequency and magnitude of drought periods and the resulting snowpack in the Sierras in the State of California. There is agreement among the experts that the amount of snowpack in the Sierras is expected to significantly decrease which is likely to result in more frequent drought periods for many regions of the state. The snowpack in the Sierras serves as the States largest water reservoir that typically enters the stream and river systems in the late spring and summer as it melts.

Dealing with reduced snowpack availability for drinking water supplies will continue to challenge the water supply industry. There are a number of issues related to future drinking water supply needs that must be reliably addressed to deal with reduced snowpack and increased flood flows that are expected to occur because more precipitation is expected to occur as rain as opposed to snow in response to climate change.

As the amount of Sierra snowpack is reduced due to global climate change, the expectation is that the snowpack will be only maintained at higher elevations and the reduction in the amount of fresh water storage as snowpack will increase the duration and frequency of flood flows during the winter months. The ability of our existing reservoirs and conveyance structures to manage more water due to reduced amount of snowfall is expected to challenge the existing raw water infrastructure. The flood flows may overwhelm the Delta levees which already are considered vulnerable due to lack of maintenance.

During these flooding events, there may not be sufficient freeboard in the raw storage reservoirs to capture the flood flows which will then be discharged through the Delta into the Bay. The ability to capture this water for use during the summer and late fall is doubtful. Drinking water suppliers will be challenged to meet their summer demands without the capture of this water supply. Also, since flow in the Sacramento and San Joaquin Rivers will be lower than under current conditions, salinity in the water exported from the south Delta via the State Water Project will be higher in the summer and late fall. (See discussion in the previous Section.)

The flood waters can be expected to contain excessive turbidities, which will challenge many of the existing surface water treatment facilities that were designed to handle typical historical raw water quality. Improvements to chemical feed and solids handling facilities may be required to ensure that proper treatment is provided to meet drinking water standards during flood flow conditions. These flows will likely occur throughout the winter and spring precipitation periods.

There is also the likelihood that the storm flows may cause overflows of marginally treated wastewater or raw wastewater. This will increase the pathogen loadings in the source waters and require increased disinfection of the water delivered to drinking water systems which will increase the disinfection byproduct compliance problems faced by the water supply utilities.

Another concern with a reduced snowpack is the possibility for insufficient recharge of hardrock wells in the mountain communities. With more of the precipitation events occurring as rain, the ability to infiltrate and recharge the hardrock areas is unknown. Many communities may not be able to rely on their hardrock wells in the late summer and fall due to insufficient recharge. This potentially could affect the quality of the groundwater supplied by the hardrock wells and they may be more susceptible to influence from septic tanks and leach fields.

Increased use of groundwater is likely to make up for the shortfall in captured snowpack and flood flows which will result in lowered groundwater tables, increased pumping costs and possibly land subsidence problems. There is also the potential for significant changes in groundwater quality associated with these impacts.

### **Drought Related Drinking Water Quality Issues**

Climate change has already had a significant impact on the frequency and magnitude of drought periods in the State of California. There is agreement among the experts that the amount of snowpack in the Sierras is expected to significantly decrease which will result in more frequent drought periods for many regions of the state. Dealing with reduced availability of drinking water supplies will continue to challenge the water supply industry. There are a number of issues that will need to be addressed to assure that future drinking water supply needs are reliably met during anticipated drought periods.

As the amount of surface water from both rivers and reservoirs is reduced during these anticipated drought periods, the resulting impacts on water quality can be significant. The amount of total dissolved solids in the surface water supplies is expected to increase. During the current drought, the reduced flow in the rivers that feed the Delta into the supply has significantly increased the salinity of the water that is diverted to Southern California via the California Aqueduct. This is due to the reduction of low salinity snow melt entering the reservoirs/rivers that feed the Delta; the larger percentage of the flow that is comprised of treated wastewaters that are discharged into the Delta; and also the influence of some of the groundwater pump-in projects that have been operated in an attempt to secure additional resources for Southern California.

The groundwater supplies typically have higher total dissolved solids than the surface water. In addition, the wastewater treatment provided prior to discharge does not typically include reverse osmosis which is necessary to remove dissolved solids from the flow. The use of higher dissolved solids supplies will have a negative impact on consumer acceptance; will result in increased costs associated with mineral deposits in

water heaters and other plumbing fixtures; and eliminates blending as a solution for many public water systems that rely on the low salinity Delta water for use of high solids local supplies.

As the water levels in reservoirs decrease due to prolonged drought periods, the likelihood for increased algae growths and also warmer water temperatures will occur. The warmer water will support a different set of bacteria than is found in colder waters. The possibility that pathogens that thrive in warmer waters that historically have not been present may be detected in the drought impacted supplies.

Individual chemical constituents could also occur at higher concentrations during drought periods. Likely problem constituents are nitrates and arsenic, both of which are inorganic chemicals that can be present above drinking water standards in groundwater pumped into the Aqueduct. Systems that have balancing reservoirs above their intake structures may address this problem by blending the water in the reservoirs with water diverted from the Aqueduct to reduce overall concentrations of nitrate and arsenic to below their respective maximum contaminant levels. This may not occur for systems that have intake structures directly on the canal without any reservoirs for balancing.

In order to meet their water resource demands, many public water systems have developed integrated water resource management plans that outline the available resources and how they will be used to deal with global climate change. The portfolio of supplies that can be used include increased conservation; water recycling; use of local groundwater that may not meet drinking water standards without treatment; desalination of either brackish groundwater or seawater; and conjunctive use facilities. Each of these alternate strategies has many issues that must be properly addressed to ensure that the resulting water supply delivered to the system meets drinking water standards and does not pose a risk to public health.

Increased use of recycled water will elevate the potential for public health exposure if improper treatment occurs. Many uses of recycled water are being explored that have not previously been approved in California. Review and approval of these projects will be necessary along with an updated regulation package for recycled water that is sufficiently protective of public health.

Conservation efforts have already been undertaken by most of the larger systems that have resource issues associated with drought impacted supplies. This strategy is expected to be pursued by a broader group of systems as a result of the Governor's directive to reduce urban consumption by 20% by the year 2020. If the majority of water systems are already implementing Best Management Practices for water conservation during normal years, they will find it more difficult to achieve further reductions during droughts.

As the amount of surface water supplies are reduced as a result of drought conditions, the amount of groundwater pumping that occurs is expected to increase to make up for the shortfall. This has the potential to result in dropping water tables, land subsidence,

and poorer groundwater quality being used to meet drinking water demands. The increase use of ground water will also expand the disputes over water rights in areas of the state where the ground water basins are not adjudicated.