

# IMPACT OF GLOBAL CHANGE ON WATER RESOURCES

Ernest T. Smerdon\*

*All that lies between the cradle and the grave is uncertain.*

—Seneca

## I. INTRODUCTION

Some things in life are certain; others are not. Perhaps the only certainty upon which we could reach agreement without any dissent are death and taxes. It is virtually certain that you will not reach total agreement on the impact of global change on water resources. In fact, you won't reach total agreement on whether global change is occurring—or will occur—as a result of the buildup of the greenhouse gases in the atmosphere.

Because the climate is subject to natural variability, we cannot prove without a doubt that change is occurring. When studying the climate, a record of years or decades is not enough. It takes much longer to “prove” that the variations which we see are not simply a part of the natural variability of the climate.

During the extraordinarily hot summers of 1989 and 1990 with the widespread droughts of the time, some newspaper articles suggested that the greenhouse gas induced warming had begun. In those two years, Tucson did have 165 and 178 days, respectively, with temperatures over 90°F, compared to the normal 141 days.<sup>1</sup> The maximum temperature in 1990 reached a scorching 117°F, an all time record.<sup>2</sup>

Perhaps greenhouse warming has begun. However, no professional climatologist would make such an unqualified statement based on limited observations. Although the temperature extremes we were observing in the late 1980s “fit in” with the global change scenario, good science is not the result of “feelings.” Good science requires careful and patient analysis of vast amounts of data. Then, hopefully, the truth will emerge. Although the data supporting most aspects of climate change are mounting, there is still much uncertainty regarding climate change and its potential effects on water resources.

This paper provides a brief overview of some issues related to the buildup of carbon dioxide and other greenhouse gases. While global warming is the most apparent global change that will occur, there will be many others. Very

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\*Dean, College of Engineering and Mines, University of Arizona.

1. Personal communication with the Nat'l Weather Serv., Tucson, Ariz., Mar. 1992.

2. *Id.*

important among these are changes in the hydrologic cycle, the pathway of water circulation in the world. The cycle takes the form of clouds and other atmospheric moisture, rain or snow, streams and rivers, freshwater ponds and lakes, oceans, soil moisture, ground water, or ice caps and glaciers. This article will focus on the water supply of the southwestern United States since water is the lifeblood of this region. The hydrology of the region is complex, and greenhouse gas buildup and global warming could significantly alter it. This desert Southwest is probably more at risk in terms of its critical water supply than any other area of the United States.

## II. HISTORY OF GLOBAL CHANGE AND BACKGROUND

Alan Hecht has reported on which historic climate variability shows interesting swings in temperatures over the last million years.<sup>3</sup> For example, in the last 100 years in the northern hemisphere, temperatures increased from the 1890s until the 1940s, decreased until the mid-1960s, and have leveled off since then. Variations in the last 1000 years suggest a range of temperatures of nearly 1.5°C during that time. The warm period from 900 to 1200 A.D. is referred to as the Medieval Warm Period. By contrast, the period from 1450 to 1850 was significantly cooler and is known as the Little Ice Age. Thus many climatic events which we believe to be extreme, in the short-term climatology sense, have occurred many times in the past.

The last million years show that there have been many ice ages. Scientists know that the Earth's orbit, which tilts the poles toward and away from the sun with frequencies of about 21,000, 41,000, and 90,000 years, affects the solar radiation the Earth receives. In 1941, Yugoslav astronomer M. Milankovitch proposed this widely accepted theory which explains glacial periods.<sup>4</sup> Since the last major ice age occurred about 18,000 years ago, one could speculate that we might experience another glacial period in about 3000 years. However, the rate of temperature change due to variations in the earth's orbit, according to Milankovitch's Theory, is extremely slow compared to the rate of temperature change resulting from the build up of the greenhouse gases, which has been rapid since the beginning of the industrial revolution. These past climate changes have been on a geologic time scale. Instead of thinking in a geologic time scale, however, we are interested in what will happen in our lifetime—or perhaps the lifetimes of our children and grandchildren—and their children and grandchildren.

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3. Alan D. Hecht, *The Challenge of Climate to Man*, 62 EOS 1192 (1981).

4. Norman J. Rosenberg, *Climate Change: A Primer*, 86 Resources for the Future 2, 3-4 (1987).

### III. SOME INTERESTING HISTORICAL DATA

The world's population grew from 3.0 billion in 1960 to 5.2 billion in 1989, and according to United Nations estimates, it is likely to grow to 8.2 billion by 2025. The dominant contributors to this growth are projected to be China and other developing nations that have historically had low rates of energy consumption. The current high levels of per capita energy consumption in the United States and Europe could decrease if optimistic projections regarding energy conservation are realized. However, considering the projected increase in the per capita energy use rate for China and the third world, and their expected population growth, the prospect for dramatically reducing greenhouse gas emissions worldwide is not bright. These developing countries assert they should not be deprived of the opportunity to develop their economies and benefit as the highly developed world had. As a result, the developing nations are projected to be the dominant source of carbon emissions by 2010 and beyond, although their collective contribution presently is relatively small, given the large populations involved.<sup>5</sup>

Greenhouse gases were not regularly measured until continuous observations were started in 1958 as part of the International Geophysical Year. The increase in atmospheric carbon dioxide from 280 ppm in 1870 at the beginning of the industrial revolution to 316 parts per million in 1958 and about 345 ppm now is striking.<sup>6</sup> Methane is another important greenhouse gas, and it has grown from 1.51 ppm in 1977 to over 1.65 ppm now. Other greenhouse gases accumulating in the atmosphere include the chlorofluorocarbons ("CFCs") and nitrous oxide. The combined effect of these trace gases in the atmosphere is to trap the sun's energy and alter the heat balance of the Earth. The gases are relatively transparent to the short wave radiation of the sun, but they are relatively opaque to the longer wave outward radiation from the Earth. This causes warming.

The argument that the greenhouse effect will cause temperature rises at unprecedented rates has its critics. Some contend that compensating effects will essentially negate the predicted warming.<sup>7</sup> These compensating effects include increased cloudiness, an altered albedo of the Earth reflecting more of the sun's energy, and greater carbon fixing through enhanced photosynthesis of plants in a CO<sub>2</sub> enriched atmosphere. Although some argue that we do not have "proof" of change, I hope we don't put our heads in the sand and say it's not happening. The evidence that convinces me that the global change problem is real.

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5. Christopher Flavin, *Slowing Global Warming*, St. of the World 17, 36 (1990).

6. Norman J. Rosenberg, *Climate Change: A Primer Part 2*, 87 Resources for the Future 8, 9 (1988).

7. Richard Kerr, *Greenhouse Skeptic Out in the Cold*, 246 Science 1118 (1989).

#### IV. SOME IMPACTS OF GLOBAL CHANGE BESIDES WATER

What is the relative impact of some of the local changes that might occur as a result of climate change from greenhouse warming? Some of the effects will be positive. For example, a CO<sub>2</sub> enriched atmosphere will lead to a more productive agriculture, all things being equal, because the photosynthesis process will be more efficient. This result is due to less carbon rich air diffusing through the leaf stomates for the same biomass production. At the same time, the water use efficiency of the plants should increase slightly.

Many areas of the world will benefit from the direct impact of warming, too. Canada will potentially experience improvements in its agricultural production, as will the Russian republic, with large, marginally acceptable areas perhaps becoming another grain belt because of the lengthened growing season. The United States corn belt could move northward and up into Canada. The southern pine forests could shift northward into the Northeast. If the water supplies are not adversely affected, the agricultural productivity of the world could be significantly enhanced.

A rise in sea level will be one of the negative impacts of global change. The many coastal cities of the world will be more subject to flooding and coastal erosion. If the sea were to rise by one meter—to say nothing of the two or three meters which some speculate could be possible—then sea levels would seriously encroach on many areas of the world.<sup>8</sup> Current flooding problems of Venice, Italy resulting from subsidence would become nearly impossible to resolve, and other areas might suffer even more. Salt water encroachment into coastal region ground water would foul many water supply aquifers. Low lying rice production areas of Southeast Asia could be flooded with seawater and become worthless for production.

Perhaps one of the most serious things about the buildup of greenhouse gases, and the CFCs in particular, is the potential effect on the ozone layer. The recently observed hole in the ozone layer in the southern hemisphere, and even more recent thinning of the layer in the northern hemisphere, should be adequate cause for concern. Arizonans are particularly sensitive to the potentially cancerous effect of poorly filtered solar radiation. It is too early to accurately predict the long term effects of greenhouse gases on the ozone layer, but there still must be concern.

#### V. THE HYDROLOGIC CYCLE— THE PATHWAYS OF THE EARTH'S WATER

Laws of nature can describe every single process that occurs in the atmosphere. These processes include global circulation patterns, formation

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8. Jodi L. Jacobson, *Holding Back the Sea*, St. of the World 79 (1990).

and movement of weather fronts which transfer large air masses across continents, large hurricanes, small but devastating tornados, isolated showers drifting across the city of Tucson, and even the tiny (in a relative sense) dust devils in the Sonoran Desert.

The hydrologic cycle is complicated. Like the global circulation models, which are even more complex, the hydrologic processes can be mathematically modeled to provide useful estimates of future conditions. However, hydrologic processes are very sensitive to local conditions. This is particularly true in desert areas interlaced with mountains as in Arizona and in the southwestern United States.

Any increase in precipitation will impact the projected change in soil moisture<sup>9</sup> and changes in runoff. The five major global circulation models<sup>10</sup> all predict an increase in average worldwide precipitation. More evaporation from the earth's water surfaces due to higher temperatures makes this prediction reasonable. However, the precipitation increase is not projected to be uniform across the world.<sup>11</sup> In fact, some regions are projected to have decreases in precipitation and lowered soil moisture at least in some seasons.<sup>12</sup>

The models tend to agree that the interior of the United States is likely to be drier in the summer. This could be very serious for the wheat belt of the Great Plains and corn belt of the north central states. There is far too much uncertainty to speculate on whether Arizona will be drier or wetter. However, any drying in the desert Southwest will have extremely adverse effects since even a slight decrease in the rainfall seriously affects the water supply in this desert region.

The five global climate models assume a doubling of the atmospheric carbon dioxide levels. While such an increase could not occur until well into the next century, we can benefit by looking at what changes might occur. Temperature increases range from 2°C to 5°C.<sup>13</sup> These averages mean little since the temperature increases will be greatest at the poles and quite small at the equator. Projected precipitation increases range from 7.1% to 15.8% with the average being 10.1%. The precipitation patterns are not so orderly and the confidence of these predictions is much less than for temperature.

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9. Soil Moisture is crucial for agricultural production.

10. The five global models are (1) Geophysical Fluid Dynamics Laboratory at Princeton, (2) Goddard Institute for Space Studies, (3) National Center for Atmospheric Research, (4) Oregon State University Model, and (5) United Kingdom Meteorological Office.

11. See, e.g., Robert M. White, *The Great Climate Debate*, 263 Sci. Am. 36, 41 (1990).

12. Many inconsistencies are apparent in the results of the five recognized global circulation models. The ability of the models to predict changes in soil moisture is not perfect by any means.

13. Philip H. Abelson, *Climate and Water*, 243 Science 461 (1989).

## VI. RAINFALL-RUNOFF RELATIONSHIPS AND WATER SUPPLY

The potential effects of global change on water supplies may be more serious than the temperature changes. This is particularly true in regions where surface water supplies come from snowpack-stored water in the mountains. That is the case for the southwestern United States where the Colorado River is a major source of water for densely populated cities in the deserts of southern California and Arizona. In these regions even if the total precipitation stays the same, we will face a decreasing water supply in a warmer world.

Much of the desert Southwest (Arizona, Nevada and southern California) has an average annual precipitation of less than 10 inches. For this region, the future supply significantly comes from the Colorado mountains via the Colorado River and associated distribution projects. There is little dependable runoff in most of the West except for the mountainous regions. However, in the Colorado Rocky Mountains, for example, there is over 20 inches of runoff in some areas. That dependable runoff is the water supply that ultimately will be used in Arizona, southern Nevada and southern California since this area is projected to experience trouble with water supply.<sup>14</sup> Ground water overdraft already is serious in these areas. The extended California drought of the late 1980s and early 1990s has brought the seriousness of the water supply problem into focus.

It is worth noting that we have an insatiable thirst for water. In the United States, the population grew from about 150 million in 1950 to nearly 250 million in 1980, an increase of 53%. Yet, the total offstream water withdrawal increased from about 180 billion gallons per day ("bgd") in 1950 to 450 bgd in 1980—a 150% increase. Much of that increase was due to irrigation expansion.<sup>15</sup>

The Colorado River is the key water supply for the desert southwestern United States just as throughout history the Nile has quenched the thirst of its region. The Colorado Basin covers southwestern Wyoming, western Colorado, eastern Utah, all of Arizona, and portions of southern Nevada, northwestern New Mexico and southeastern California. The Colorado water supply comes largely from the mountains in the upper mountainous basin. Much of the water falls as snow and accumulates as snowpack on the mountain slopes. The water waits there without the need for reservoirs for the spring and summer thaw to release it in an orderly fashion at the time when crops need the water, and people in the searing heat of the lower basin thirst for it.

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14. Sondra Postal, *Saving Water for Agriculture*, St. of the World 40 (1990).

15. Sondra Postal, *Water for Agriculture: Facing the Limits*, 93 Worldwatch Paper (Dec. 1989).

This thaw-driven flow into Lake Powell on the Colorado River nears its annual average from January to April, then rises slowly until June when it increases rapidly just as the water-use need of the lower-basin users starts to reach its peak. Keeping the water in the mountains until needed is a convenient by-product of nature that Bureau of Reclamation engineers have utilized. Still, to complement the natural snowpack storage, several reservoirs have been constructed on the Colorado River to provide storage lakes and flood control. Managing these reservoirs is complex since one cannot maximize storage to guard against a future drought and maximize flood protection at the same time. So a compromise must be reached—even though some group will surely criticize when an event occurs at either end of the drought or flood extremes.

## **VII. REEMPHASIZING THE UNCERTAINTY REGARDING FUTURE PRECIPITATION**

Let me restate that I do not know whether the southwestern United States will have more or less rainfall in the next century at the time when the amount of greenhouse gases in the atmosphere has doubled. What I can say is that either way we will almost certainly see some significant changes in our water supply because of the global warming.

Water experts have used various models to estimate what changes in runoff may occur with the temperature increasing and have done so for cases where the precipitation is projected to either increase or decrease.<sup>16</sup> Among the river basins that scientists have analyzed are the Colorado River and other rivers in the Great Basin (the region from Arizona northward), the Sacramento River Basin in California and the Pease River in Texas.

One point to remember is that when basins extend to mountain areas, and the winter temperatures are warmer, more of the precipitation is in the form of rain instead of snow. Rain soaks into the ground where it falls or runs off at the time. The massive storage potential of mountain snow packs lessens. That is not a trivial matter with regard to the water supply which could have been stored and used later for human purposes.

To illustrate, consider a basin reaching snowcapped mountains where the temperature rises due to global change. Even if the precipitation amount does not change, the total runoff and usable water supply will decrease. Naturally, for a basin where the precipitation decreases, the runoff and available supply will decrease even more.

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16. Notable among those researchers have been Charles Stockton and his colleagues of the University of Arizona's Tree Ring Laboratory.

### VIII. EFFECTS OF GLOBAL WARMING ON RUNOFF

The following models cannot possibly describe all of the complex hydrologic processes, however, they provide a good guide regarding what one might expect under various scenarios. For the moment accept the fact that temperature increases will occur as a result of the greenhouse gas buildup. Although the magnitude varies, the models consistently predict temperature rises, and scientists have the greatest confidence in this prediction.<sup>17</sup> They are also confident that global average precipitation will increase. But one cannot be sure whether there will be increases or decreases in any given location. So one must look at all possibilities. A greater portion of the precipitation will be rain instead of snow because of the warmer temperatures—a very important factor in basins which have snowpack accumulation.

Researchers have used two approaches. First, one compares the long term runoff averages in basins with periods of several years of abnormally high or low rainfall. Then one looks to the runoff response during these periods. The Illinois River Basin provides a recent example (see Table I).<sup>18</sup> In northern Illinois precipitation has been 9% to 14% higher in the last 20 years compared to the previous 60 years. The Illinois River flow during this period was 20% to 25% higher than normal. In this case, the runoff increase was about double the precipitation increase. In the spring flood season, during that 20-year wet period, the precipitation was 8% to 23% over normal, but the flood peaks increased much more, 46% to 56%. Similar studies show that during periods of low rainfall, the percentage runoff decreases exceeded the precipitation decreases. In both cases the streamflow change is greater than the precipitation change.

A second method for estimating the changes in runoff and water supply when precipitation changes is the use of a volume balance mathematical model. Such a model is useful in estimating the effects of global change on water supply and has provided projections of runoff changes for various reasonable climate change scenarios for several basins. The following are examples from four basins, all in the relatively arid West or Southwest.

The first example is for the Colorado River Basin. The study assumed a 2°C temperature rise and calculations were made for precipitation decreases of 10% and increases of 10%. Stockton and Boggess analyzed the runoff changes in the upper basin and the lower basin separately.<sup>19</sup> In a similar

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17. White, *supra* note 11.

18. Krishan P. Singh & Ganapathi S. Ramamurthy, *Climate Change and Resulting Hydrologic Response; Illinois River Basin*, Proc. ASCE Symposium, Watershed Planning and Analysis in Action 28, 33 (1990).

19. C.W. Stockton & W.R. Boggess, (U.S. Army Coastal Eng'g Res. Ctr., *Geohydrological Implications of Climate Change on Water Development*, (1979)



study, Revelle and Waggoner looked at the entire basin as a unit.<sup>20</sup> The results are in Table II.

An analysis of the upper basin in particular is important because that portion has higher annual precipitation, much of it snow. Note that even when precipitation increased, the annual runoff is projected to decrease. To understand the reasons, remember with higher temperatures the ground is not frozen (and impermeable) for so long. The winter rain can soak in at the spot, as opposed to being stored as snow for runoff after the spring thaw. These data suggest that any temperature rise, even if the annual precipitation increases, will adversely affect the water supply of the Colorado River. These studies both considered a 2°C temperature rise and changes in precipitation of both plus and minus 10%.

A second case comes from the work of Peter Gleick on the Sacramento River Basin in California.<sup>21</sup> The upper watershed where most of the runoff occurs is snow covered in the winter (see Table III). Gleick looks at winter (December, January and February) runoff separately from the summer (June, July and August). He also looks at the annual total to see the overall changes. Moreover, he analyzed +2°C and +4°C temperature change and precipitation changes of plus or minus 10 and 20% as well as no change.

Winter runoff is not reduced nearly as much as summer runoff in the model. This is very important because the winter runoff occurs when the water cannot be used for irrigation and other summer uses unless it is stored in reservoirs. To provide the same dependable supply for California users would require more costly reservoir facilities, including the southern Californians who receive the water through canals of the California Water Project. In general, the patterns of runoff change for the Sacramento River are similar to the Colorado River.

The last example, given in Table IV, is for several sub-basins in the Great Basin (most of Nevada and western Utah)<sup>22</sup> and for the Pease River in Texas.<sup>23</sup> Here the effects of precipitation changes magnify in terms of runoff changes. These basins do not have the dominant effects of snowpack on the watersheds, so winter versus summer seasonal considerations do not dominate. These results are quite similar to the case from the actual records from the Illinois River Basin. Note that in the case of the Pease River the

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20. Roger R. Revelle & Paul E. Waggoner, *Effects of a Carbon Dioxide-Induced Climatic Change on Water Supplies in the Western United States*, reprinted in *Changing Climate* 419 (tbls. 7.1, 7.2) (1983).

21. Peter H. Gleick, *Regional Hydrologic Consequences of Increases in Atmospheric CO<sub>2</sub> and other Trace Gases*, 10 *Climatic Change* 137, 148 (tbls. II and III) (1987).

22. Irmgard M. Flaschka, C.W. Stockton & W.R. Boggess, *Climatic Variation and Surface Water Resources in the Great Basin Region*, 23 *Water Resources bulletin* 47, 48-49 (1987).

23. J. Nemec & John Schaake, *Sensitivity of Water Resources Systems to Climate Variation*, 27 *Hydrological Sci. J.* 327, 334 (1982).

investigators assumed that a 1°C or 3°C temperature rise corresponded to a 4% and 12% increase in evapotranspiration on the watershed.<sup>24</sup>

## XI. WHAT DOES IT ALL MEAN IN TERMS OF WATER SUPPLY?

The most recent summary on climate change effects on the water resource systems of the United States comes from a recent report of the American Association for the Advancement of Science Panel on Climatic Variability, Climate Change and the Planning and Management of United States Water Resources.<sup>25</sup> The summary and conclusions of Chapter 8 in that report by John Schaake entitled "From Climate to Flow" clearly illustrate the importance of potential climate change to arid regions. That summary follows:

Stream flow is sensitive to climate change. Elasticities range from less than 1.0 to as high as 10 for different locations and climate and stream flow measures. Low flows will be more affected than high. Dry climates will be more affected than humid. Elasticity to precipitation change is greater than elasticity to potential evapotranspiration which means that warming of the atmosphere alone will decrease stream flow far less than warming plus a simultaneous decrease in precipitation. Reservoir yields will be affected, but the elasticity of reservoir yield is less than the elasticity of the mean flow. Because water quality problems tend to be coupled with low flow conditions, water quality effects of climate change may prove to be among the most significant, especially in arid areas.<sup>26</sup>

While not certain, the data strongly suggest that the temperature rises due to global change will reduce the water supplies of Arizona and southern California. These conclusions are not based on idle speculation. Granted, the science and models are not perfect, but it is good science, nonetheless.

Research that is focused on better understanding localized hydrology will improve our understanding of the climate and hydrologic systems of Earth. Some of that research will be here at the University of Arizona as a part of the large Earth Observing Satellite research program of NASA. I believe that one of the most serious problems of climate change will be changes in the water supply. Through our research we will learn how to more accurately predict those effects.

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24. *Id.*

25. Paul E. Waggoner, *Climate Change and U.S. Water Resources* (1990).

26. John C. Schaake, *From Climate to Flow*, reprinted in Waggoner, *Climate Change and U.S. Water Resources* (1990).

Table I

**CLIMATE CHANGE AND WATER SUPPLY  
PRECIPITATION - STREAMFLOW  
RELATIONSHIPS  
ILLINOIS RIVER BASIN**

**In northern Illinois precipitation has been 9 to 14% higher in the last 20 years compared to the previous 60 years.**

***How has this affected streamflow?***

Changes in the last 20 years compared to previous 60 years:

Annual precipitation	+ 9 to 14%
Average annual streamflow	+ 20 to 25%
March-June precipitation	+ 8 to 23%
Annual flood peaks	+ 46 to 56%

**Conclusion from this study: As a rough guide, the annual change in precipitation is doubly magnified in annual flow and further magnified in flood peaks.**

From: "Climate Change and Resulting Hydrologic Response: Illinois River Basin" by K. P. Singh and G. S. Ramamurthy -- 1990.

Table II

**EFFECT OF GLOBAL CHANGE  
(Temperature and Precipitation Changes)  
ON AVERAGE ANNUAL RUNOFF  
COLORADO RIVER BASIN**

Precipitation Change	-10%	+10%
<u>Upper Basin Runoff</u>		
Temperature $\Delta$ +2°C	-35%	-33%
<u>Lower Basin Runoff</u>		
+2°C	-56%	-2%
(from Stockton and Boggess 1979)		
<u>Entire Basin Runoff</u>		
Temperature $\Delta$ +2°C	-33 to -47%	-18%
(from Revelle and Waggoner 1983)		

NOTE: In all cases the higher temperatures caused annual runoff to decrease even when rainfall increased. Water supplies from the Colorado will be severely affected by the temperature increase.

**Table III**  
**EFFECT OF GLOBAL CHANGE**  
**(Temperature and Precipitation Changes)**  
**ON AVERAGE ANNUAL RUNOFF**  
**SACRAMENTO RIVER BASIN, CALIFORNIA**

(from Gleick 1987)

Precipitation Change	-20%	-10%	0	+10%	+20%
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<b>Summer (JJA) Runoff</b>					
Temperature $\Delta$					
+2°C	-35%	-26%	-18%	-9%	-1%
+4°C	-72%	-67%	-62%	-57%	-53%
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<b>Winter (DJF) Runoff</b>					
Temperature $\Delta$					
+2°C	-27%	-11%	+6%	+22%	+39%
+4°C	-21%	-4%	+14%	+32%	+50%
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<b>Annual Runoff</b>					
Temperature $\Delta$					
+2°C	-31%	-18%		+12%	+27%
+4°C	-34%	-21%		+7%	+23%

NOTE: Winter runoff increases relative to summer runoff because more of precipitation is rain instead of snow.

NOTE: Taken together for the year, the seasonal runoff pattern is altered and the river basin yield is severely reduced for the precipitation decrease scenario. If precipitation increases, average annual runoff increases somewhat proportionally.

Table IV

**EFFECT OF GLOBAL CHANGE  
(Temperature and Precipitation Changes)  
ON AVERAGE ANNUAL RUNOFF**

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Great Basin sub-basins

Precipitation Change	-25%	-10%
Temperature $\Delta$ +2°F	-38% to -51%	-17 to -28%

(from Flaschka et al. 1987)

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Pease River Basin, Texas

Precipitation Change	-10%	+10%
Temperature $\Delta$ +1°C (ET+4%)	-50%	+50%
+3°C (ET+12%)	-50%	+35%

(from Nemec and Schaake 1982)

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NOTE: The runoff change far exceeds the precipitation change. This means that dependable water supply is affected far worse than precipitation change would suggest.