SUGGESTED RESEARCH ON THE EFFECT OF CLIMATE CHANGE ON CALIFORNIA WATER RESOURCES

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ABSTRACT

Quite significant changes in climate are being predicted for the latter part of this century due to global warming. The changes would be the result of increases in greenhouse gases from human activities, such as carbon dioxide, methane, and other trace gases. These potential changes are expected to affect many of our water resources systems. Some of the more important changes would be temperature increases which would raise temperate zone snow levels and change the pattern of runoff from mountain watersheds, thereby affecting reservoir operation. Other consequences would be sea level rise which could adversely affect the Sacramento San Joaquin River Delta, source of major water exports for the State; possibly larger floods and more extreme precipitation events; and changes in the water requirements of crops.

By and large, reservoirs and water delivery systems and operating rules have been developed from historical hydrology on the assumption that the past is a good guide to the future. With global warming, that assumption may not be valid. This paper will briefly look at the major factors affecting water resources systems and go on to suggest eleven priority items of research. The emphasis will be on items important in California and other western states.

In view of these forecasts of a significant change in future climate, with the author's knowledge of the existing water resources system in California, an analysis of potential effects and a list of higher priority research items has been developed. In summary, the list is as follows, and will be explained in more detail subsequently in the paper:

- --Monitoring of hydrologically important variables
- --Test operation of the Central Valley Project and State Water Project system with modified runoff
- --Modeling of future precipitation
- --Update depth-duration-frequency rainfall data
- --Evaluate Golden Gate Tide Gage datum
- --Catalog sea level trends along the coast, in San Francisco Bay and the Delta
- --Check for recent changes in evapotranspiration
- --Estimate future changes in evapotranspiration and crop water use.

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--Evaluate effect on major multipurpose flood control reservoirs
--Water temperature modeling in major reservoir/river systems
--Effect of climate change on regions adjoining California, such as the Colorado River and the Pacific Northwest

POSSIBLE CHANGES AFFECTING WATER RESOURCES SYSTEMS

Most of the forecasted climate changes by year 2100, the end of the century, due to the increase in greenhouse gases have been developed by the Intergovernmental Panel on Climate Change (IPCC). The IPCC was jointly established in 1988 by the World Meteorological Organization and the United Nations Environment Programme to study climate change. The IPCC has issued several reports since 1990 outlining possible global warming and the effects as a result of increased amounts of carbon dioxide, methane, and other trace gases originating from human activities.

A good assessment of the state of research on the potential consequences of climate change on water resources in the United States, including what is known and what is not known, is the report of the National Water Assessment Group for the U. S. Global Change Research Program (Gleick and Adams, 2000).

The most recent IPCC Working Group I Summary Report, in its third assessment (IPCC, 2001), projects a 1990 to 2100 average surface temperature increase of around 3 degrees C, with a range of 1.4 to 5.8 degrees. The different scenarios cover a wide range of assumptions about the rate of future increases in greenhouse gases and the amount of temperature forcing in the climate system. The increase in global temperature during the 20th century was estimated to be about 0.6 degrees C. much of which occurred by 1940, and a recent significant increase after 1980 which is believed to be primarily of human origin. Because of warmer temperatures, some increase in global evaporation and therefore precipitation is projected for the 21st century, more likely at higher latitudes. For hydrology and water resources, precipitation is the most important variable; rainfall changes in specific California regions cannot be well defined by the current general circulation climate models of the atmosphere.

Sea level (IPCC,2001) is projected to rise around 0.5 meter (1.6 feet) by 2100, with a range of 0.1 to 0.9 meters (0.3 to 2.9 feet). The rate during the 20th century appears to have been around 0.2 meters (0.7 feet) with a range of 0.1 to 0.25 meters (0.3 to 0.8 feet). The 0.2 meter figure is consistent the historical trend at the Golden Gate tide station, although it is possible that tectonic movement, or settlement, has influenced the stages there.

There is a general expectation that a warmer climate would lead to more intense precipitation events, thereby causing somewhat bigger floods and more intense convective storms, thereby affecting the rainfall statistics used for storm drainage design. The IPCC report rates prediction confidence in more intense precipitation events as "very likely, over many areas".

The increase in carbon dioxide, from the current 370 ppm to perhaps 600 or 700 ppm, is expected to be beneficial to plant growth on many food crops, provided the water supply is adequate. To some extent, higher carbon dioxide concentrations in the air could partly offset the higher water use (evapotranspiration) resulting from warmer temperatures.

All of these projected changes, as well as some not yet identified, are likely to affect the hydrologic cycle and the water resources of California.

WATER SUPPLY RELATED RESEARCH

Probably the most significant change, which is judged fairly certain in the next 100 years, is a change in temperate zone mountain runoff patterns. Even if precipitation remains the same, the rise in temperatures means less snow, less snow covered area, and winter rain to higher elevations. The higher snow levels during storms, about 450 meters (1500 feet) under the 3 degree median projection, would produce more winter runoff. Less spring snowmelt would make it more difficult to refill winter reservoir flood control space during late spring and early summer of many years, thus reducing the amount of water deliverable during the dry season. Lower early summer reservoir levels also would adversely affect lake recreation and hydroelectric power production, with possible late season temperature problems for downstream fisheries.

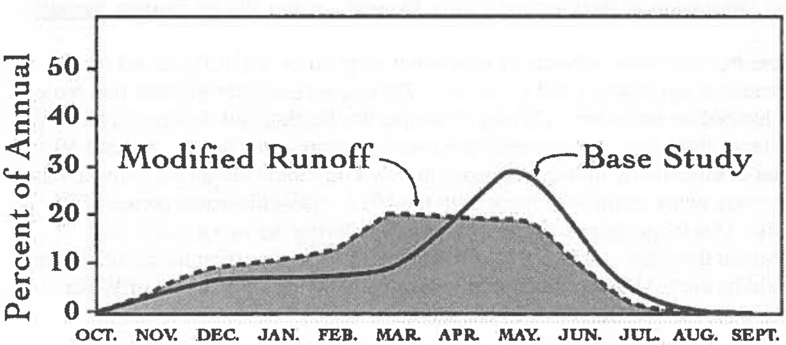

Figure 1. Comparison of historical and modified runoff from a mid-Sierra snow runoff watershed, assuming 3 degrees C warming

It is possible, if precipitation increases and the mountains are high enough, for the volume of April through July snowmelt to increase. In California, this could happen in the higher elevation southern Sierra, where about 70 percent of the historical April 1 snow zone area would remain with a 450 meter (1500 feet) rise. In the northern Sierra, however, the same rise in snow levels would reduce estimated snow covered area by over 70 percent, so a reduction in spring snowmelt is virtually certain. In fact, there has been such a trend during the last 50 years.

Monitoring of Hydrologically Important Variables

The first research need is good hydrometeorologic monitoring. Regular, consistent and sustained measurements of hydrologically important variables are essential to track what is happening and to verify model predictions. This means continuing measurements of variables such as precipitation and other climate data, snowpack, streamflow, and ocean and Delta tide levels. Emphasis should be in the locations where significant change is expected, for example the mountain snow zone. The National Weather Service, in its reorganized Climate Services Division, is developing a climate reference network of 250 high grade weather stations to be a national benchmark for long term climate monitoring. That would be a good start, but only 5 of these are likely to be located in California. Scripps Institution of Oceanography, in cooperation with the Yosemite National Park and others, has recently installed a number of new snow measurement and meteorological instruments in the Park, with high hopes that these will be operating for the long term. But more thought should be given to several networks along gradients from east to west and north to south, and across climate zones.

Test Operation of the Central Valley Project – State Water Project System

These two big water projects furnish about 30 percent of California net water demand for agricultural and urban use. The major reservoirs of these two projects are located on watersheds (Trinity, Sacramento, Feather and American) likely to see large shifts in runoff patterns as a result of rising snow levels. At least 50 years of monthly hydrology are suggested as a minimum length for comparisons. Currently many studies are made with the 1922 – 1994 historical period of 72 years. This longer period includes simulation during the two major 6-year historical droughts , 1928-1934 and 1987-1992. The operation model of choice would be the CALSIM model jointly developed by the Department of Water Resources and the Bureau of Reclamation.

The test evaluations would logically proceed in two stages: (1) a simplified run involving approximate adjustments to major project reservoir inflows with the changes anticipated with global warming, and (2) more detailed studies involving all major facilities, including local and upstream power reservoirs. Initial studies should focus on the assumption of precipitation similar to the historical amounts, except warmer. Later studies could try some of the projected precipitation scenarios derived from a new generation of atmospheric general circulation models (GCMs).

Modeling Future Precipitation

Future precipitation is probably the most important variable influencing water resources and water supply. It is also the most difficult to predict at the regional and watershed levels. It should be no surprise that research should continue into modeling likely future precipitation in enough detail in time and space to feed into individual watershed runoff models. We need to support the University of California and National Laboratory experts in analyzing results of newer GCM modeling by the modeling centers of the world as they apply to California and other western states, especially in simulating historical precipitation and predicting future precipitation. And feedback from these expert researchers to the GCM modelers should be encouraged.

Depth-Duration-Frequency Rainfall Data

Support of the processing and dissemination of up-to-date rainfall depth-duration-frequency data is important to incorporate extreme events of recent years and as more of these extreme events are expected in future years. These data are some of the most valuable rainfall statistics, widely used by engineers and designers for storm drains, culverts, roofs and host of works. These are the curves, for example, which show that a 1 in 25 year storm can produce 2 inches (50 mm) in 2 hours at a particular place. Continual updating will gradually incorporate expected storm intensity increases as a result of climate change so that structures built with their guidance will not be out of date with less protection than intended.

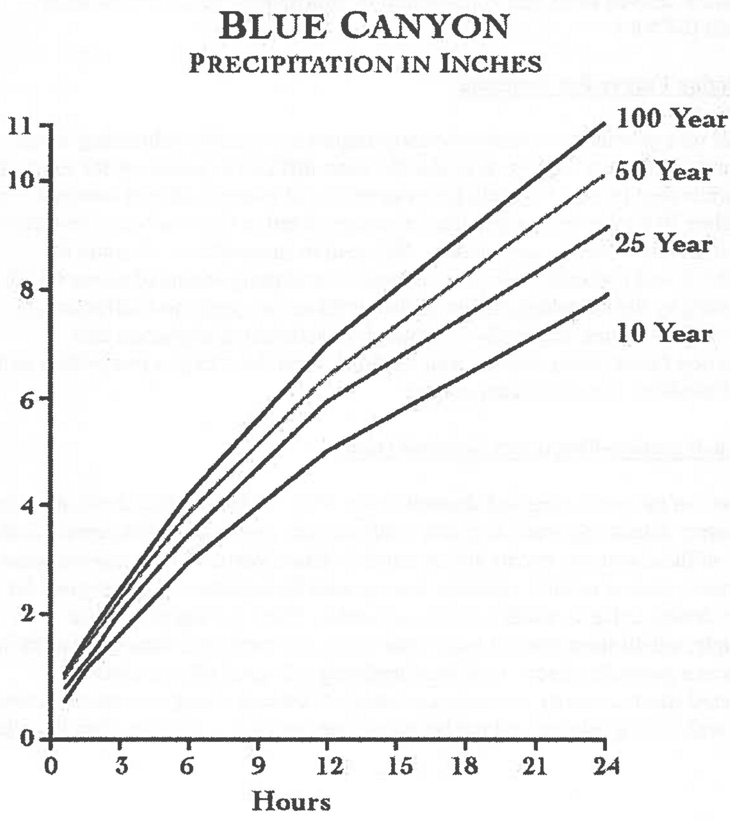

Figure 2. Chart of depth-duration-frequency statistics for Blue Canyon

SEA LEVEL RISE

California is not generally as vulnerable to sea level rise as some of the eastern and southern states, which have lower shorelines. Since California is tectonically active, it is the combined effect of geological change, rising or falling land, and global sea level rise that matters. But there are areas, such as San Francisco Bay and the Sacramento San Joaquin River Delta, which are vulnerable. Major water projects have been built to convey water from areas of plenty to the drier central and southern portions of the State. The tidewater region of the Delta is the hub of major water transfer; water quality there can be affected by salinity intrusion from the Pacific Ocean via San Francisco Bay.

Reservoirs in the north provide water storage and flood control. Water is then released downstream to meet Delta and fishery needs and to be exported by large pumps in the southwestern corner of the Delta. During low flow months additional water is released to repel ocean salinity incursion in the western Delta as a hydraulic barrier to preserve suitable fresh water quality within the estuary and for export. Much of the land within the Delta is below sea level protected by levees, many of which are on weak peat soil foundation.

Evaluate the Golden Gate Tide Gage Datum

Rising sea level is not only a concern along the coast but to the hub of California's water transfer system in the Sacramento San Joaquin Delta. Rising ocean levels could affect water transfer across the Delta from north to south by decreasing the stability of Delta levees. The second factor is more salinity intrusion, which would gradually degrade the quality of export supplies or require more precious fresh water releases from upstream reservoirs to repel ocean salinity.

Since the Golden Gate tide gage is the key reference for so many sea level determinations (i.e., the central California coast, the Bay, and the Delta), it is essential that an accurate determination of its vertical stability be made, checking for long term vertical movement of the datum. Tools may now be available by use of highly precise space geodetic techniques, which can measure very small changes in vertical elevation. The gage has shown an apparent rising sea level trend of about 0.2 meters (0.7 feet) per century over the past 80 years, but we can't be sure if this is real or due to settlement of the pier or tectonic movements in the underlying rock. The measurements should proceed in three stages: (1) compare previous precise leveling where the Golden Gate gage can be compared to nearby benchmarks on solid rock; (2) investigate whether the GPS system can be used for a precise determination of the Golden Gate tide gage datum and its changes, if any, over time and how long a record would be needed to give confidence of a measurement which could be less than 2 mm (.007 feet) per year; and (3) perform the measurements of actual tide gage datum over a period of time, probably years. The National Geodetic Survey does this kind of work.

Catalog Sea Level Trends Along the Coast

The objective of this proposed study would be to catalog all available tide station data along the California coast, in San Francisco Bay and in the Delta. Long term data is needed, at least 20 years and preferably 50 years, to look for apparent trends in annual sea level. Presumably an average of San Francisco at the Golden Gate and San Diego can be used to represent global sea level rise. Departures from that could be due to tectonic activity or possibly some other effect such as oil and gas extraction, or perhaps consolidation of deep sediments (as in the Delta, for example). The catalog would establish a useful base to guide government and developers in the coastal zone. The San Francisco Bay Conservation and Development Commission (1988) and the California Coastal Commission (2001) have both made some studies of this matter.

CHANGES IN WATER REQUIREMENTS

There are at least two factors which could change water use by vegetation. As a general rule, warmer temperatures mean more evapotranspiration. But higher carbon dioxide levels tend to reduce water consumption, at least in laboratory tests. Most observers expect the net change to be somewhat higher water requirements but not as high as would otherwise be expected from temperature change considerations.

Recent Changes in Evapotranspiration

Since carbon dioxide concentrations have increased about 17 percent over the past 40 years (Keeling and Whorf, 2001), one wonders whether there is any noticeably effect on evapotranspiration, especially the measured reference ET of grass. During the 1960s there were a number of well measured grass lysimeter plots in various locations in California, measuring directly, by weight changes, the water consumption of grass. The University of California, in cooperation with the Department of Water Resources, should reinstall or reoperate former lysimeters at Davis and Five Points (on the San Joaquin Valley west side). Since there is variation from year to year and day to day, depending on weather conditions, it will probably take 3 to 5 years, perhaps 10 years, to see if there is a noticeably change from the measurements 40 years ago. It is possible that higher carbon dioxide is a factor in the continuing improvement in crop yields.

Estimate Change in ET and Crop Water Requirements

Knowledgeable experts in plant water consumption at the University of California and the Agriculture Extension Service and land and water use analysts in State and federal government should estimate likely future ET rates for major crops. To do this, they will need to obtain reasonable median projections of weather in 2050 and 2100 from the GCM climate modelers. This would be primarily temperatures, both average and maximum and minimum, in our dry summer climate, but could include projections of monthly rainfall changes if significant, and should include projected carbon dioxide levels. One would expect that higher water consumption because of increased temperatures will only be partly offset by carbon dioxide based reductions. The result would be slightly higher water requirements, probably varying somewhat by crop type. A complicating factor is possible shifts in the growing season of annual crops. For example, because of less frost risk, tomatoes might be planted earlier when the sun angle is not as high.

OTHER ITEMS OF RESEARCH

There are several other item of potential research which don't fit into the previous headings. These are discussed below.

Conduct a Systematic Review and Evaluation of the Effect of Global Warming on Major Multipurpose Flood Control Reservoirs

In a warmer world, some increase in the intensity of major precipitation events could be expected because saturated warmer air can hold more water vapor than cooler air. More intense precipitation would generate larger floods. Another factor on streams draining high mountain areas is that many storms now produce a mix of rain with snow on the higher parts of the watershed. A warmer climate means a greater proportion of storm precipitation is likely to be rain, producing more direct rain runoff.

Currently reserved flood control space in major multipurpose reservoirs during the winter may not be adequate for the larger storms. As a result, the degree of protection would gradually shrink. Additional flood control space or downstream channel capacity is likely to be expensive on our major rivers.

As GCM models are developed and improved, their precipitation results should be analyzed to see if there is a consistent trend for more intense storms and precipitation events in California. The model precipitation can then be entered into watershed runoff models to assess the higher risk. A careful analysis of historical trends during the last 30 years or so may be useful too.

Water Temperature Modeling in Rivers

Warmer air and less snowmelt will make it more difficult to maintain rivers cold enough for cold-water fish, including anadromous fish like salmon. This could create difficult problems for some salmon, such as the winter run, where fish spend the warm season in the streams. There may be similar problems for juvenile steelhead too. On most California rivers large foothill reservoirs provide some temperature control for downstream reaches.

There are some existing models of water temperature in reservoirs and downstream rivers. These models may need improvement as the job of maintaining suitable temperatures becomes more difficult. Analysis of selected foothill reservoirs and rivers is suggested to see what a different pattern of inflow and higher temperatures would do. Some new temperature modeling is anticipated as part of the Oroville power plant relicensing during the next several years. A logical extension would be to apply the new Lake Oroville and Feather River temperature models under a changed climate and runoff regime.

Effect of Climate Change in Other Regions

The Colorado River, which drains a huge area of the American Southwest, is a very important component of California water supply, especially in the south. Earlier studies (Nash and Gleick, 1993) have indicated a high probability of a change to less runoff. Since the Colorado River is already fully subscribed, if not oversubscribed, a reduction in average runoff could affect California's water supply as well as that of the other Colorado River Basin states. Hydroelectric power too could be affected, especially generation at Glen Canyon and Hoover dams due to change in reservoir levels.

California's long-term entitlements to Colorado River water are 4.4 million acre-feet (5.4 billion cubic meters) per year. In recent years, California's net diversions have been as much as 5.2 million acre-feet and the State is being forced to reduce its diversions as water demands in the other states build toward use of their entitlements. Climate change in the watershed could acerbate the water supply situation. It is also possible that a wetter scenario could improve Colorado River runoff, even to the point of generating more flood problems on the lower river.

California depends on the Pacific Northwest, including the Columbia River system, for about 10 percent of its electric energy supply. As we saw during 2001, when Columbia River runoff was down, there is an impact on California's electric power supply and reliability. In conclusion, the effects of climate change, especially precipitation, in the adjoining Pacific Northwest and Colorado River watershed would have an impact on California—on electricity for both regions and on water supply for the Colorado.

It is anticipated that new research and studies on runoff and water supply in both of these regions will be forthcoming by interested regional parties. It is recommended that the California Energy Commission and the Department of Water Resources monitor results of these studies as they are completed and try to assess what they might mean for California water supply and electric energy imports.

SUMMARY

The preceding are 11 areas of research on the effect of global warming on water resources systems in California that the author feels should have priority. There are many more items which could be added. In a report on potential water resources research ideas for a globally warmer world now being prepared by for the California Energy Commission Public Interest Energy Research (PIER) program, some 35 items were identified. However, completion of the work suggested herein would be an excellent start in adapting to a potentially different climate.

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