INFORMATIONAL HEARING

CLIMATE CHANGE AND WATER RESOURCES

9:00 a.m.
February 20, 2007

A Bibliography:
Scientific Reports Regarding
Climate Change and California Water

Significant State Agency Reports

California Department of Water Resources, *Progress on Incorporating Climate Change into Management of California's Water Resources* (2006)

Report Overview: This report contains eight chapters that present progress and future directions on incorporating climate change science into management of California's water resources. It focuses on assessment methodologies and preliminary study results. The technical chapters of this report were peer-reviewed by experts from water resources-related agencies and research institutions. Policy implications and recommendations are beyond the scope of this report.

California Energy Commission, *California's Water-Energy Relationship*

Abstract: In 2005, the California Energy Commission published a report, *California's Water-Energy Relationship* (CEC 700-2005-011-SF), that estimates the magnitude and intensity of water-related energy consumption by segment of the water-use cycle. Because water-energy is a new area of study, and data were not readily available, this report relied on a number of different data sources and methods to develop the magnitude and intensity estimates.

The current study reviewed and updated these estimates for the magnitude and intensity of water-related energy consumption by segment of the water-use cycle. This review indicates that while the data and methods used to prepare the Energy Commission's 2005 report were not perfect, they offered a reasonable starting place for prioritizing water-energy research and development, as outlined in the Energy Commission's *Integrated Energy Policy Report*. Further, this study provided adjusted water-energy proxies that are sufficient for informing policy and prioritization of research and development investments. The study also describes important data gaps and includes the collection of primary data from water utilities and the disaggregation of data geographically and within water-use cycle segments. A greater understanding of the sub-segments of the water-use cycle offers an opportunity to more effectively target research and development decisions at the technology level, and a phased approach is recommended to continually refine water-related energy intensity estimates on an ongoing basis.

Abstracts of Significant Reports

American Water Works Association Research Foundation, *Primer for Municipal Water Providers: Climate Change and Water Resources* (2005)

Abstract: A primer for municipal water providers developed in 2005 to 1) introduce water utility managers to the science surrounding climate change; 2) suggest the types of impacts it can have on water resources; and (3) provide guidance on planning and adaptation strategies.

Cayan, D., A. Luers, M. Hanemann, G. Franco and B. Croes; *Scenarios Of Climate Change In California: An Overview;* California Climate Change Center, Scripps Institution of Oceanography (San Diego, CA): 53 (2006)

Abstract: In 2003, the California Energy Commission's Public Interest Energy Research (PIER) program established the California Climate Change Center to conduct climate change research relevant to the state. This Center is a virtual organization with core research activities at Scripps Institution of Oceanography and the University of California, Berkeley, complemented by efforts at other research institutions. Priority research areas defined in PIER's five-year Climate Change Research Plan are: monitoring, analysis, and modeling of climate; analysis of options to reduce greenhouse gas emissions; assessment of physical impacts and of adap- tation strategies; and analysis of the economic consequences of both climate change impacts as well as the efforts designed to reduce emissions. Executive Order #S-3-05, signed by Governor Arnold Schwarzenegger on June 1, 2005, called for the California Environmental Protection Agency (CalEPA) to prepare biennial science reports on the potential impact of continued global warming on certain sectors of the California economy. CalEPA entrusted PIER and its California Climate Change Center to lead this effort. The "Climate Scenarios" analysis summarized here is the first of these biennial science reports, and is the product of a multi-institution col- laboration among the California Air Resources Board, California Department of Water Resources, California Energy Commission, CalEPA, and the Union of Concerned Scientists. FINAL report from California Energy Commission, Public Interest Energy Research (PIER) Program, California Climate Change Center.

K. Hayhoe, D. Cayan, C.B. Field, P.C. Frumhoff, E.P. Maurer, N.L. Miller, S.C. Moser, S.H. Schneider, K.N. Cahill, E.E. Cleland, L. Dale, R. Drapek, R.M. Hanemann, L.S. Kalkstein, J. Lenihan, C.K. Lunch, R.P. Neilson, S.C. Sheridan, J.H. Verville, *Emissions Pathways, Climate Change, And Impacts In California*, Proceedings of the National Academy of Sciences

Abstract: The magnitude of future climate change depends substantially on the greenhouse gas emission pathways we choose. Here we explore the implications of the highest and lowest Intergovernmental Panel on Climate Change emissions pathways for climate change and associated impacts in California. Based on climate projections from two state-of-the-art climate models with low and medium sensitivity (Parallel Climate Model and Hadley Centre Climate Model, version 3, respectively), we find that annual temperature increases nearly double from the lower B1 to the higher A1fi emissions scenario before 2100. Three of four simulations also show greater increases in summer temperatures as compared with winter. Extreme heat and the associated impacts on a range of temperature-sensitive sectors are substantially greater under the higher emissions scenario, with some interscenario differences apparent before midcentury. By the end of the century under the B1 scenario, heatwaves and extreme heat in Los Angeles quadruple in frequency while heat-related mortality increases two to three times; alpine/subalpine forests are reduced by 50–75%; and Sierra snowpack is reduced 30–70%. Under A1fi, heatwaves in Los Angeles are six to eight times more frequent, with heat-related excess mortality increasing five to seven times; alpine/subalpine forests are reduced by 75–90%; and snowpack declines 73–90%, with cascading impacts on runoff and streamflow that, combined with projected modest declines in winter precipitation, could fundamentally disrupt California's water rights system. Although interscenario differences in climate impacts and costs of adaptation emerge mainly in the second half of the century, they are strongly dependent on emissions from preceding decades.

Luers, A. , D.R. Cayan, G. Franco, M. Hanemann, B. Croes and (2006). *Our Changing Climate: Assessing The Risks To California*; California Climate Change Center, Scripps Institution of Oceanography (San Diego, CA): 16 (2006)

Abstract: This document summarizes the recent findings of the California Climate Change Center's "Climate Scenarios" project, which analyzed a range of impacts that projected rising temperatures would likely have on California. The growing severity of the consequences as temperature rises underscores the importance of reducing emissions to minimize further warming. At the same time, it is essential to identify those consequences that may be unavoidable, for which we will need to develop coping and adaptation strategies.

Medellin, J. , J. Harou, M. Olivares, J. Lund, R. Howitt, S. Tanaka, M. Jenkins, K. Madani and T. Zhu; *Climate warming and water supply management in California*; California Climate Change Center, Scripps Institution of Oceanography, San Diego, CA (2006)

Abstract: This paper examines economic water management adaptations, effects, and other implications of a GFDL-A2 year 2085 dry climate warming scenario for California's water supply system with estimated year 2050 water demands and land use. The GFDL-A2 year 2085 scenario was chosen because it is the driest of the four scenarios in the overall study. Economically adaptive water management activities for this climate scenario are compared with a similar modeling scenario with a continuation of the historical climate. The effects of population growth and land development alone to 2050 are developed and compared with those where dry climate warming also occurs. Overall, such a dry climate warming scenario would impose large costs and challenges on the state. While this scenario would severely affect the economies of some rural and agricultural regions of California, the state's overall predominantly urban economy would survive and remain largely unhindered by water supply limitations. The dry climate scenario reduces average annual water availability by 27%, which results in an average annual water scarcity of 17%. Statewide, average agricultural areas see water deliveries 24% lower than demand targets, and urban areas see an average of 1% less deliveries than their demand targets. However, there are great regional disparities. Southern California experiences almost all of the urban water scarcity. Economic water scarcity costs increase by $118 million/year from 2020 to 2050, with population and land use change. Adding dry climate warming to 2050 water demands raises water scarcity costs by an additional $121 million/year. Of the $360 million/year in average water scarcity costs for 2050 with dry climate warming, $302 million/year results from lost agricultural production and $59 million/year is from urban water shortages. Of the $302 million/year seen by agricultural water users, over two-thirds occur in the Tulare Basin and Southern California. Almost all urban water scarcity costs occur in urban Southern California, which has limited ability to increase water imports to accommodate growth without expanding the Colorado River or California Aqueducts. Dry climate warming imposes an additional increase of $384 million/year in system operating costs. Statewide costs increase over $100 million/year if interregional water transfers are limited to 2020 conditions, without climate warming. With the climate warming, the costs of policies limiting interregional water transfers increases to $250 million/year. Although these costs are sizable, they remain a small proportion of California's economy (which is today $1.5 trillion/year). However, the greater part of this cost is borne by rural parts of the state.

Tanaka, S. K. , T. Zhu, J. R. Lund, R. E. Howitt, M. W. Jenkins, M. A. Pulido, M. Tauber, R. S. Ritzema and I. C. Ferreira; *Climate warming and water management adaptation for California*." Climatic Change 76(3-4): 361-387 (2006)

Abstract: The ability of California's water supply system to adapt to long-term climatic and demographic changes is examined. Two climate warming and a historical climate scenario are examined with population and land use estimates for the year 2100 using a statewide economic-engineering optimization model of water supply management. Methodologically, the results of

this analysis indicate that for long-term climate change studies of complex systems, there is considerable value in including other major changes expected during a long-term time-frame (such as population changes), allowing the system to adapt to changes in conditions (a common feature of human societies), and representing the system in sufficient hydrologic and operational detail and breadth to allow significant adaptation.

While the policy results of this study are preliminary, they point to a considerable engineering and economic ability of complex, diverse, and inter-tied systems to adapt to significant changes in climate and population. More specifically, California's water supply system appears physically capable of adapting to significant changes in climate and population, albeit at a significant cost. Such adaptation would entail large changes in the operation of California's large groundwater storage capacity, significant transfers of water among water users, and some adoption of new technologies.

Weare, B. C.; *Global Climate Change Will Affect Air, Water In California*; California Agriculture 56(3): 89-96 (2002)

Abstract: As we enter the 21st century, it is possible to reach beyond the headlines to describe what is now known about climate change. The Intergovernmental Panel on Climate Change evaluated the scientific aspects of global climate change; the current consensus is described in a recent series of reports. Since the 19th century, concentrations of atmospheric carbon dioxide, methane, nitrous oxide and sulfate aerosol dust have increased significantly. While there is scientific agreement that warming is occurring, the controversy now concerns the extent of subsequent impacts in the future. In California, the impacts of global warming are likely to include reduced water availability and quality, poorer air quality, associated economic consequences, biodiversity shifts and health effects. The changes are expected to continue at an increasing pace well into the next century, perhaps outstripping our scientific, economic and social ability to cope with them.

Tingju Zhu, Jay R. Lund, Marion W. Jenkins, Guilherme F. Marques, and Randall S. Ritzema, *Climate Change, Urbanization, and Optimal Long-term Floodplain Protection*

Abstract: This paper examines levee-protected floodplains and economic aspects of adaptation to increasing long-term flood risk due to urbanization and climate change. The lower American River floodplain in the Sacramento, California metropolitan area is used as an illustration to explore the course of optimal floodplain protection decisions over long periods. A dynamic programming model is developed and suggests economically desirable adaptations for floodplain levee systems given simultaneous changes in flood climate and urban land values. Economic-engineering optimization analyses of several climate change and urbanization scenarios are made. Sensitivity analyses consider assumptions about future values of floodplain land and damageable property, along with the discount rate. Methodological insights and policy lessons are drawn from modeling results, reflecting the joint effects and relationships that climate, economic costs, and regional economic growth can have on floodplain levee planning decisions.

Other Peer-Reviewed Scientific Papers
(from Pacific Institute Website – www.pacinst.org)

Aguado, E., D. Cayan, L. Riddle and M. Roos (1992). "Climatic Fluctuations and the Timing of West Coast Streamflow." Journal of Climate 5(12): 1468-1483.

Atwater, B. F., D. P. Adam, J. P. Bradbury, R. M. Forester, R. K. Mark, W. R. Lettis, G. R. Fisher, K. W. Gobalet and S. W. Robinson (1986). "A Fan Dam for Tulare Lake, California, and Implications for the Wisconsin Glacial History of the Sierra-Nevada." Geological Society of America Bulletin 97(1): 97-109.

Botzan, T. M., A. I. Necula, M. A. Marino and H. Basagaoglu (1999). "Benefit-cost model for an artificial recharge scenario in the San Joaquin Valley, California." Water Resources Management 13(3): 189-203.

Bradbury, J. P. (1997). "A diatom record of climate and hydrology for the past 200 ka from Owens Lake, California with comparison to other great basin records." Quaternary Science Reviews 16(2): 203-219.

Brito-Castillo, L., A. Leyva-Contreras, A. V. Douglas and D. Lluch-Belda (2002). "Pacific Decadal Oscillation and the filled capacity of dams on the rivers of the Gulf of California continental watershed." Atmosfera 15(2): 121-137.

Burroughs, W.J. (1999). “The Climate Revealed.” Cambridge, UK, Cambridge University Press.

Dettinger, M. D. and D. R. Cayan (1995). "Large-Scale Atmospheric Forcing of Recent Trends toward Early Snowmelt Runoff in California." Journal of Climate 8(3): 606-623.

Dettiner, M. D., D. R. Cayan, M. K. Meyer and A. E. Jeton (2004). "Simulated hydrologic responses to climate variations and change in the Merced, Carson, and American River basins, Sierra Nevada, California, 1900-2099." Climatic Change 62(1-3): 283-317.

D'Agnese, F. A. (1999). Simulated effects of climate change on the Death Valley regional ground-water flow system, Nevada and California. Denver, CO, U.S. Geological Survey (Dep't. of the Interior): 40.

Goldstein, A. H., N. E. Hultman, J. M. Fracheboud, M. R. Bauer, J. A. Panek, M. Xu, Y. Qi, A. B. Guenther and W. Baugh (2000). "Effects of climate variability on the carbon dioxide, water, and sensible heat fluxes above a ponderosa pine plantation in the Sierra Nevada (CA)." Agricultural and Forest Meteorology 101(2-3): 113-129.

Haddad, B. M. , L. Sloan, M. Snyder and J. Bell (2003). "Regional climate change impacts and freshwater systems: focusing the adaptation research agenda." International Journal of Sustainable Development 6(3): 265.

Harvey, F. (2006). Melting glaciers 'mean less water for farming'. Financial Times. London: 3-3.

Hayhoe, K. , D. Cayan, C.B. Field, P.C. Frumhoff, E.P. Maurer, N.L. Miller, S.C. Moser, S.H. Schneider, K.N. Cahill, E.E. Cleland, L. Dale, R. Drapek, R.M. Hanemann, L.S. Kalkstein, J. Lenihan, C.K. Lunch, R.P. Neilson, S.C. Sheridan and J.H. Verville (2004). "Emissions pathways, climate change, and impacts in California." Proceedings of the National Academy of Sciences 101(34): 12422-12427.

Ingram, B. L., J. C. Ingle and M. E. Conrad (1996). "Stable isotope record of late Holocene salinity and river discharge in San Francisco Bay, California." Earth and Planetary Science Letters 141(1-4): 237-247.

Jackson, R. B., O. E. Sala, J. M. Paruelo and H. A. Mooney (1998). "Ecosystem water fluxes for two grasslands in elevated CO2: a modeling analysis." Oecologia 113(4): 537-546.

Jassby, A. D. (1998). "Interannual variability at three inland water sites: Implications for sentinel ecosystems." Ecological Applications 8(2): 277-287.

Kent, C. A. and M. L. Shelton (1994). "Climate-Change and Altered Runoff in the Semiarid Portion of Mono Basin, California." Physical Geography 15(1): 38-51.

Kim, J. (2005). "A projection of the effects of the climate change induced by increased CO2 on extreme hydrologic events in the Western U.S.." Climatic Change 68(1-2): 153-168.

Knowles, N. and D. R. Cayan (2004). "Elevational dependence of projected hydrologic changes in the San Francisco estuary and watershed." Climatic Change 62(1-3): 319-336.

Knox, J. B. and R. W. Buddemeier (1989). Impacts of Climate Change on California Water Resources. Second North American Conference on Preparing for Climate Change: A Cooperative Approach, Washington, DC, The Climate Institute.

Ku, T. L., S. D. Luo, T. K. Lowenstein, J. R. Li and R. J. Spencer (1998). "U-series chronology of lacustrine deposits in Death Valley, California." Quaternary Research 50(3): 261-275.

Joyce, B., S. Vicuna, L. Dale, J. Dracup, M. Hanemann, D. Purkey and D. Yates (2006). Climate change impacts on water for agriculture in California: a case study in the Sacramento Valley. San Diego, CA, California Climate Change Center, Scripps Institution of Oceanography: 85.

Landers, J. (2002). "Climate change to alter California's water supplies, study says." Civil Engineering 72(8): 16-17.

Lehman, P. W. (1992). "Environmental-Factors Associated with Long-Term Changes in Chlorophyll Concentration in the Sacramento-San-Joaquin Delta and Suisun Bay, California." Estuaries 15(3): 335-348.

Lehman, P. W. (2000). "The influence of climate on phytoplankton community biomass in San Francisco Bay Estuary." Limnology and Oceanography 45(3): 580-590.

Leung, L. R., A. F. Hamlet, D. P. Lettenmaier and A. Kumar (1999). "Simulations of the ENSO hydroclimate signals in the Pacific Northwest Columbia River basin." Bulletin of the American Meteorological Society 80(11): 2313-2329.

Leung, L. R. and M. S. Wigmosta (1999). "Potential Climate Change Impacts on Mountain Watersheds in the Pacific Northwest." Journal of the American Water Resources Association 35(6): 1463-1471.

Lewis, D., M. J. Singer, R. A. Dahlgren and K. W. Tate (2000). "Hydrology in a California oak woodland watershed: a 17-year study." Journal of Hydrology 240(1-2): 106-117.

Li, J. R., T. K. Lowenstein and I. R. Blackburn (1997). "Responses of evaporite mineralogy to inflow water sources and climate during the past 100 ky in Death Valley, California." Geological Society of America Bulletin 109(10): 1361-1371.

Loaiciga, H. A. and S. Renehan (1997). "Municipal water use and water rates driven by severe drought: A case study." Journal of the American Water Resources Association 33(6): 1313-1326.

Li, J. R., T. K. Lowenstein, C. B. Brown, T. L. Ku and S. D. Luo (1996). "A 100 ka record of water tables and paleoclimates from salt cores, Death Valley, California." Palaeogeography, Palaeoclimatology, Palaeoecology 123(1-4): 179-203.

McDonald, E. V., F. B. Pierson, G. N. Flerchinger and L. D. McFadden (1996). "Application of a soil-water balance model to evaluate the influence of holocene climate change on calcic soils, Mojave Desert, California, USA." Geoderma 74(3-4): 167-192.

Meko, D. M., M. D. Therrell, C. H. Baisan and M. K. Hughes (2001). "Sacramento River flow reconstructed to AD 869 from tree rings." Journal of the American Water Resources Association 37(4): 1029-1039.

Miller, C. and D. L. Urban (1999). "A model of surface fire, climate and forest pattern in the Sierra Nevada, California." Ecological Modeling 114(2-3): 113-135.

Miller, N. L. and J. Kim (2000). "Climate change sensitivity analysis for two California watersheds." Journal of the American Water Resources Association 36: 657-661. 2000

Miller, N. L. and J. Kim (2000). "Climate change sensitivity analysis for two California watersheds: Addendum to downscaled climate and streamflow study of the southwestern United States (vol 35, pg 1525, 1999)." Journal of the American Water Resources Association 36(3): 657-661.

Munoz, J. R. and D. J. Sailor (1998). "A modeling methodology for assessing the impact of climate variability and climatic change on hydroelectric generation." Energy Conversion and Management 39(14): 1459-1469.

Nelson, S. T., H. R. Karlsson, J. B. Paces, D. G. Tingey, S. Ward and M. T. Peters (2001). "Paleohydrologic record of spring deposits in and around Pleistocene pluvial Lake Tecopa, southeastern California." Geological Society of America Bulletin 113(5): 659-670.

Nemani, R. R., M. A. White, D. R. Cayan, G. V. Jones, S. W. Running, J. C. Coughlan and D. L. Peterson (2001). "Asymmetric warming over coastal California and its impact on the premium wine industry." Climate Research 19(1): 25-34.

Quinn, N. W. T., N. L. Miller, J. A. Dracup, L. Brekke and L. F. Grober (2001). "An integrated modeling system for environmental impact analysis of climate variability and extreme weather events in the San Joaquin Basin, California." Advances in Environmental Research 5(4): 309-317.

Rademacher, L. K., J. F. Clark and G. B. Hudson (2002). "Temporal changes in stable isotope composition of spring waters: Implications for recent changes in climate and atmospheric circulation." Geology 30(2): 139-142.

Rayner, S., D. Lach and H. Ingram (2005). "Weather forecasts are for wimps: why water resource managers do not use climate forecasts." Climatic Change 69(2-3): 197-227.

Riebsame, W. E. and J. W. Jacobs (1988). Climate Change and Water Resources in the Sacramento-San Joaquin Region of California. Boulder, CO, Natural Hazards Research and Applications Information Center, University of Colorado: 66 pp.

Roos, M. (1989). Possible Climate Change and its Impact on Water Supply in California. The Oceans '89 Conference, Seattle, WA.

Royce, E. B. and M. G. Barbour (2001). "Mediterranean climate effects. I. Conifer water use across a Sierra Nevada ecotone." American Journal of Botany 88(5): 911-918.

Royce, E. B. and M. G. Barbour (2001). "Mediterranean climate effects. II. Conifer growth phenology across a Sierra Nevada ecotone." American Journal of Botany 88(5): 919-932.

Sheer, D. P. and D. Randall (1988). Methods for Evaluating the Potential Impacts of Global Climate Change on Water Related Activities: Case Studies from Atlanta, Georgia, and the State of California. Columbia, MD, Water Resources Management, Inc.

Shelton, M. L. (1998). "Seasonal hydroclimate change in the Sacramento River Basin, California." Physical Geography 19(3): 239-255.

Trenberth, K. E. (1998). "Atmospheric Moisture Residence Times and Cycling: Implications for Rainfall Rates and Climate Change." Climatic Change 39(4): 667-694.

U. S. Environmental Protection Agency (1997). Climate Change and California, Office of Policy, Planning and Evaluation: 4.

USGS (1978). Ground-Water Conditions in the Sacramento Valley, California 1912, 1961, and 1971. Menlo Park, CA, U.S. Geological Survey.

Vaux Jr., H. J. (1991). Global Climate Change and California's Water Resources. Global Climate Change and California: Potential Impacts and Responses. J. B. Knox and A. F. Scheuring. Berkeley, CA, University of California Press: 69-96.

Vaux Jr., H. J. (1991). Global climate change and California's water resources. Global climate change and California: potential impacts and responses. J. B. Knox and A. F. Scheuring. Berkeley, University of California Press: 184.

Wilkinson, R. and T. Rounds (1998). Climate Change and Variability in California: White Paper for the California Regional Assessment. Santa Barbara, CA, National Science Foundation: 45 pp.

Williams, A. E. and D. P. Rodoni (1997). "Regional isotope effects and application to hydrologic investigations in southwestern California." Water Resources Research 33(7): 1721-1729.

Zhu, C., D.W. Pierce, T.P. Barnett, A.W. Wood and D.P. Lettenmaier (2004). "Evaluation of hydrologically relevant PCM climate variables and large-scale variability over the continental U.S.." Climatic Change 62(1-3): 45-74.