California Future Water Demand Projections (WEAP Model): Implications on Energy Demand

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Abstract

As part of recent California Water Plan Update (2009) process, a physically-based water resources model called Water Evaluation And Planning (WEAP) was used to project the impacts of population growth and climate changes on Ag, Urban and Environmental demand through the mid-century (2050) for the 10 hydrologic regions of the State. WEAP is a fully integrated water resources system analysis tool. It integrates water demands from all sectors directly with the elements of water supply such as rivers, reservoirs, canals, groundwater, desalination and hydropower projects. In the Update 2009 planning process, impacts of 3 population growths and 12 climate change scenarios on future water demands were considered at the regional scale of the 10 hydrologic regions. The results showed that the future Statewide urban water demands increased with rapid pace under the three growth scenarios and were heavily influenced by the assumptions of future population growth and to a lesser extent by future climate. Future agricultural water demands, however, declined mainly because of decline in agricultural lands due to urbanization but were heavily influenced by future climate conditions across the 12 climate scenario examined. Environmental water demands were more influenced by the year type (wet or dry) so there was less variation across the three growth scenarios.

As demand for water increases in the future due to population growth, climate change and other socioeconomic factors, so will the water-related energy consumption. A recent study by California Energy Commission (CEC) concluded that water sector is the largest energy user in California. It consumes about 19% of all electricity used in the State as well as 30% of all non-power plant-related natural gas consumption. Increases in water and energy demands will stress the existing water-energy infrastructure which may require system expansion at the cost of additional financial burden and environmental impacts. Water management strategies like water conservation and demand reduction (e.g. State Conservation Plan 20% reduction by 2020) will greatly reduce the demand for water and energy without drastic adverse impacts on financial obligations and environment.

Model Overview

WEAP (Water Evaluation and Planning) model is a fully integrated water resources system analysis tool. It is a physically-based simulation model that integrates water demands from all sectors directly with the elements of water supply such as rivers, reservoirs, canals, groundwater, desalination and hydropower projects (Yates et al. 2005). It uses a rainfall-runoff "catchment" module which simulates hydrologic processes including surface runoff, subsurface interflow and baseflow, deep percolation, surface-ground water interaction, root zone soil moisture, and irrigation demand based on crop ET. This integration of watershed hydrology with water planning process makes WEAP particularly suitable to evaluate the potential impacts of climate change both on water demand and supply of a region's water management project in a single tool.

WEAP has been applied in many countries for long term water demand evaluation and supply planning for future policy and water management decisions (Raskin et al. 1992, Yates et al. 2009). Recently, it has been applied in California Water Plan Update 2009 to quantify future statewide water demand under different urban growth and climate change scenarios (Juricich, et al. 2011). The demand was modeled at the 10 hydrologic regions scale and then aggregated up to give statewide total. The model was calibrated using 8–year historical data 1998-2005. The base year for future projection was year 2005 with planning horizon through year 2050 and a monthly time step. This gives a monthly dynamic projection of demand as it evolves through time, rather than a static snap shot of the future conditions. Below is a narrative description of future scenarios (Source: California Water Plan, Update 2009)

FUTURE SCENARIO NARRATIVES

Urban Growth

- **Current Trends**. Recent trends are assumed to continue into the future. In 2050, nearly 60 million people live in California. The search for affordable housing has drawn families to the interior valleys. Commuters take longer trips in distance and time. In some areas where urban development and natural resources restoration has increased, irrigated cropland has decreased. The state faces lawsuits on a regular basis: from flood damages to water quality and endangered species protections. Regulations are not comprehensive or coordinated, creating uncertainty for local planners and water managers.

- **Slow & Strategic Growth**. Private, public, and governmental institutions form alliances to provide for more efficient planning and development that is less resource intensive than conditions in the early 21st century. Population growth is slower than projected—about 45 million people live here in 2050. Compact urban development has eased commuter travel. Californians embrace water and energy conservation. Conversion of agricultural land to urban development has slowed and occurs mostly for environmental restoration and flood protection. State government implements comprehensive and coordinated regulatory programs to improve water quality, protect fish and wildlife, and protect communities from flooding.

- **Expansive Growth**. Development is more resource intensive than conditions in the early 21st century. Population growth is greater than projected with 70 million people living in California in 2050. Families prefer low-density housing, and many seek rural residential properties, expanding urban area boundaries. Where urban development and natural restoration have increased, irrigated crop land has decreased. Some water and energy conservation programs are offered but at a slower rate than trends in the early century. Protection of water quality and endangered species is driven mostly by lawsuits, creating uncertainty for local planners and water managers.

Climate Change

To incorporate the impacts of global warming and climate change on the future water demand, each of the three growth scenarios mentioned above was evaluated under 12 climate scenarios. These climate scenarios were identified by the Governor's Climate Action Team (CAT) to be used for planning studies in California. The 12 climate scenarios were based on the results of 6 General Circulation Models (GCM) and 2 Greenhouse Gas Emission (GHG) scenarios. These scenarios have distinct estimates of future precipitation and temperature that were used with other factors to estimate future water demands. The 6 climate models were:

- France: CNRM CM3
- Japan: MIROC3.2 (med)
- Germany: MPI ECHAM5
- USA: NCAR CCSM3
- USA: NCAR PCM1

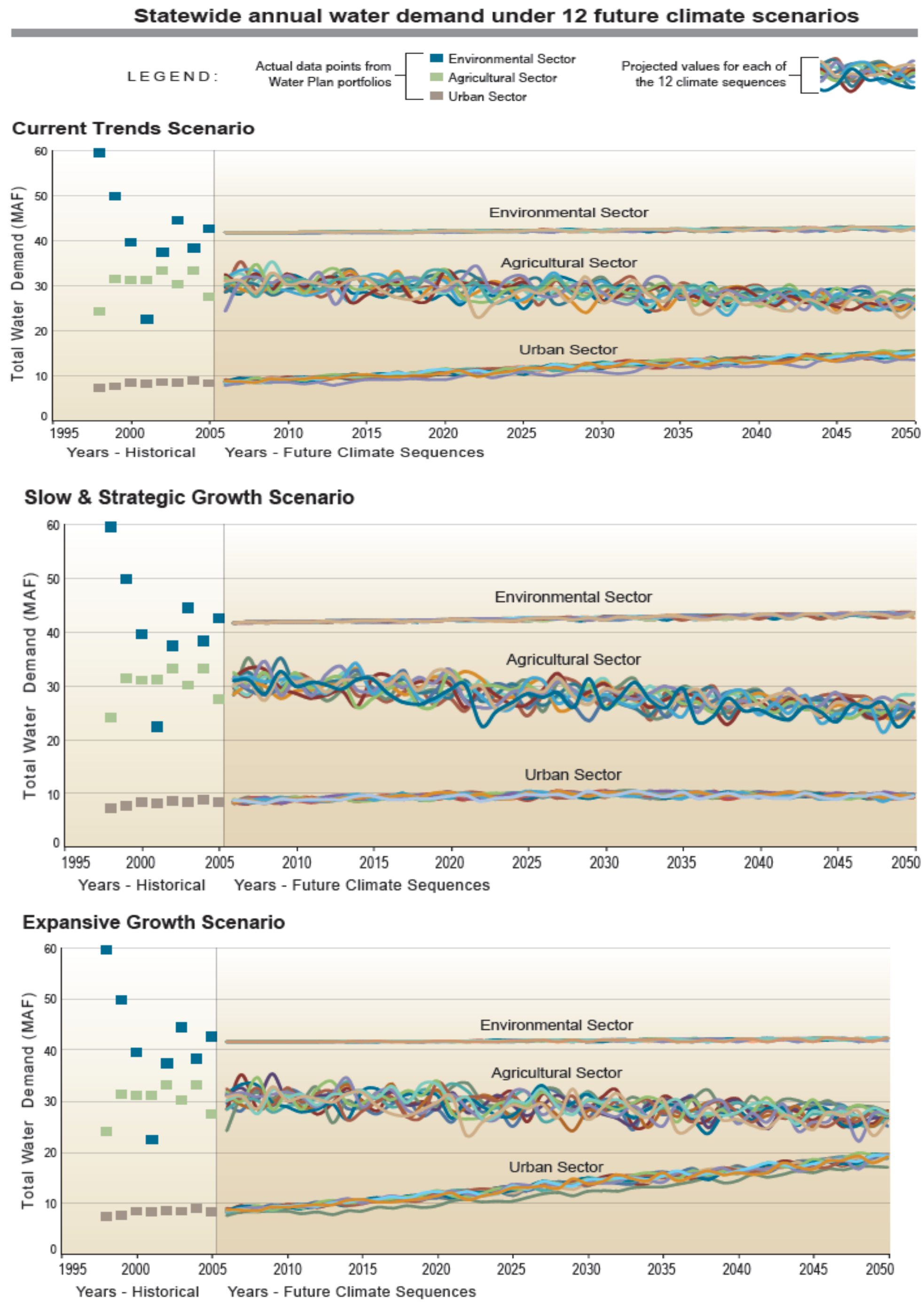
• USA: GFDL CM2.1

These models were chosen on the basis of the availability of detailed outputs for use in various parts of the assessment process and upon consideration of certain aspects of their performance. The results from the 12 future climates were downscaled to the hydrologic regions of California to give time series of future climate (temperature, precipitation) for each of the three urban growth scenarios.

FUTURE WATER DEMAND

Future water demand is affected by a number of demographic, socioeconomic and land use factors like population growth, single family and multi-family housing types, family income, water price, urban outdoor landscapes and cropping patterns of agricultural areas. Values of these factors were varied in the model according to scenario themes to test their effects upon the system being analyzed. In this way, scenario analysis is similar to sensitivity analysis, but the scenario analysis tests groups of factors in an organized way. Together, these factors are used to quantify future water demand for urban, agricultural, and environmental sectors. Each factor is varied between the three scenarios to describe some of the uncertainty that water managers face. For example, the three scenarios use three different, but plausible values of future population when determining future urban water demands.

Results of future demand are shown in figures below to depict temporal projection of statewide demand by WEAP model as it steps through time. They are shown for all 3 demand sectors and for 3 growth scenarios under the 12 climate scenarios. The 8 years of actual historical demand data (1998-2005) are also shown for comparison. As shown in the three figures below, environmental demand tops agricultural demand followed by urban sector in all 3 growth scenarios. Although, urban sector demand increases over time due to population growth and urbanization in all 3 growth scenarios, but Expansive Growth showed a faster rate of increase as expected. Because climate factors impacted only the outdoor portion of the urban demand, variability across the 12 climate change scenarios on total urban sector is less visible. Also shown in these figures, agricultural demand shows decline over time due to decline in irrigated lands as a result of urbanization and urban encroachment into agricultural lands. This decline in irrigated lands was such that it overshadowed the rise in evapotranspiration and crop water use rates due to warming trend in climate over time, resulting in agricultural water demand “volume” to decline following the declining pattern of irrigated lands over time. Variability across the 12 climate change scenarios, however, was more apparent in agricultural sector than in Urban sector as shown in the figures below. This was because climate factors were key factors in determining demand in agricultural sector. Environmental demand on the other hand increased little over time when compared with urban and agricultural sector for all three growth scenarios. This was because instream flow was the major component of environmental sector demand and was more influenced by the year type (wet or dry) so there was less variations across the three growth scenarios.



1 MAF = 1233 Million cubic meters

Source: California Water Plan Update 2009

Figure 1. Statewide water demand under 12 climate change scenarios

IMPLICATIONS ON ENERGY DEMAND

Water - energy nexus in California is more profound due to its diverse geography and climate and its large population. This requires to transport large quantity of water over a long distances of hilly terrains from sources of supplies in the north to places of demands in the south. Although water generates energy, but energy is needed to convey, deliver, treat and distribute water to end-users. According to California Energy Commission (CEC) Report 2005, water sector is the largest energy user in California. On the average, it consumes about 19% of total electricity and 30% of natural gas. Out of 250 Bkwh (Billion kilo watt-hr) electric energy used in California in 2001, about 48 Bkwh was water-related. State Water Project (SWP) is the largest single consumer of energy in California, 9.1 Bkwh/yr; or about 20% of water-related energy use. But it also generates much of the electricity it needs for pumping lifts through its hydropower plants; about 6.6 Bkwh/yr on the average. This means it still needs to purchase an additional 2.5 Bkwh of electric energy each year (on the average). Edmonston pumping plant alone, uses about 5 Bkwh/year electricity to pump an average of 4480 CFS in a 2000 ft single lift over Tehachapi mountains to southern California.

It seems that, according to the CEC Report 2005, water conveyance and transport is not the largest component of water-related energy consumption (about 20%). It is the end-users that collectively accounted for larger share (about 73%) of total water-related energy use ((Rojas and Vrsalovich 2011).. According to the same Report, Urban and Agricultural end-users combined share was about 50% of total water-related energy use.

Future demand for water may increase by water sectors as suggested by WEAP model requiring additional energy sources to deliver, treat and distribute water to end-users. Energy consumption intensity (ECI), which is the embedded energy per unit volume of delivered water to end-users, “kwh/acre-ft”, is a critical factor in determining future energy demand. For SWP delivered water, it is about 3000 kwh/acre-ft. To put this in perspective, each household in California on average used about 7000 kwh in 2009 (Rojas and Vrsalovich 2011). As the future total demand volume increases by end-users due to population growth and climate, so will the total energy demand. For example, based on WEAP model results shown above, if the future urban water demand in California increases between 16% to 128% under the population and climate scenarios tested, the implications on total energy demand would be enormous on high end of the projections. So, it seems there is an urgent need to improve either energy use efficiency (e.g. efficient devices, renewable energy) to reduce embedded energy requirements for water delivery and distributions on the energy-side of the water-energy nexus, and/or improve water use efficiency by end-users to reduce total water demand volume on the water-side of the equation in order to achieve a grand total of energy savings. (Water-Energy Nexus: Total Energy Demand = Energy embedded per unit demand volume x Total water demand volume)

SUMMARY AND CONCLUSIONS

A water resources system evaluation model (WEAP) was used to project future urban, agricultural and environmental demand under 3 urban growth and 12 climate change scenarios as a part of analysis and quantifications required in California Water Plan Update 2009. Three demand sectors; urban, agricultural and environmental were evaluated. The model was applied at the 10 hydrologic regions of State and then the results were aggregated up to give statewide total. The results showed future urban water demands increased with rapid pace under the three growth scenarios and were heavily influenced by the assumptions of future population growth and to a lesser extent by future climate. Future agricultural water demands, however, declined mainly because of decline in agricultural lands due to urbanization but were heavily influenced by future climate conditions across the 12 climate scenario examined. This decline in irrigated lands was such that it overshadowed the rise in evapotranspiration and crop water use rates due to warming trend in climate over time. Environmental water demands were more influenced by the year type (wet or dry) so there is less variation across the three growth scenarios. Due to strong water-energy nexus in California, increase in future water demand, as shown by WEAP results, can have potential impacts on energy demand. But, since Urban and Ag end-users account for much of water-related energy use, relative to conveyance and transport component, significant savings can be achieved by efficient use of water by end-users.

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