California water: the present and looking to the future

By David Zilberman[1] and Ben Gordon[2]

Introduction

During a span of two centuries, California transformed itself into the leading agricultural and economic state in the United States. Much of this transformation has been the result of water resource management. The northern and eastern parts of the state are relatively water-rich. The southern region of California, to a substantial extent, is a desert but has climatic and biophysical conditions that are appropriate for agricultural production. Not to mention, the coastal area is very hospitable to humans. The state's transformation relied heavily on diverting water to areas where the lack thereof was the limiting condition to growth. This article overviews the historical development of the California Water System, beginning with the policies that initially drove its expansion, followed by an overview of the environmental consequences that drove the more recent policies of conservation and environmental protection. The drivers that have allowed for increased productivity during limited expansion, as well as some perspective for the future will also be discussed.

Expansion of Water Resources Era

The history of water use and management in California (Table 1) can be divided into four phases. The first stage, 1820-1890, is early settlement. The Gold Rush provided the impetus for a large migration to California and to the diversion of water for hydraulic mining, and then to growing urban areas associated with it. At the same time, farming started in order to supply settlers with basic foods, and then expanded during the latter half of the 19th century. Early water rights systems (e.g. riparian rights) constrained the movement of water among regions. However, the introduction of the prior appropriations water rights system in the American West provided the

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legal foundation for water diversion. The basic principles behind it are: (i) first-in-time, first-in-right and (ii) use it or lose it. This system, as well as homesteading policies, were instruments that enhanced settlements (Zilberman et al 2017).

The second stage, 1890-1930, is local water projects. Early investment in water diversion for agriculture was accomplished through collective action of farmers organized in water districts (Mercer and Morgan 1991). Many of these districts were near the Sierras. Agricultural settlements in the Northern Central Valley were rainfed, while early agricultural settlements in the southern part of the Valley relied on groundwater. The settlements in Southern California received a major boost in 1913 with the completion of the Los Angeles Aqueduct that brought in water from the Owens Valley. The water supply for the San Francisco Bay Area was enhanced by the large Hetch Hetchy Project completed in 1934.

The third stage, 1930-1970, is federal water projects. While in the initial stages, government provided support for water projects through enabling legislation. During this third stage, the government actually constructed water projects. Three of the major water projects in California are the Colorado Aqueduct, Central Valley Project (CVP), and California State Water Project. The major California water projects are depicted in Figure 1.

Year	Legislation	Notes
1855	Prior appropriation rights established	See *Irwin v. Phillips*
1868	Reclamation districts authorized	
1870	CA Fish Act (and subsequent Fish and Game code section 5937)	Principle of minimum flow requirement (amended in 1880 and 1915 Flow Acts)
1902	Federal Reclamation Act	Federal funding for water projects & dams
1913	Raker Act	Authorizes Hetch Hetchy Dam
1928	Boulder Canyon Project Act	Allocated Colorado River flow among states
1930	First State Water Plan created	5-year updates to state of water resources and management
1933	Central Valley Project (CVP) Act	Updated in 1992
1945	State Water Resources Act	Creates Water Resources Board to coordinate development & inventory of water resources
1956	Department of Water Resources launched	Brings together 52 previously independent agencies
1969	Federal Environmental Protection Act	Establishment of EPA
1969	Clean Water Act (Porter-Cologne)	Establishes water quality standards
1970	Endangered Species Act	
1983	Economic & Environmental Principles & Guidelines	Implementation studies for water and related land resources
1992	CVP Improvement Act	Changes in CVP for protection, restoration and enhancement of fish & wildlife
1994	Bay-Delta Accord (CALFED)	Funding and mechanism to develop multi-stakeholder water quality and management plans
2014	Sustainable Groundwater Management Act	Establishes districts to attain sustainable groundwater aquifers by 2030

Table 1: Timeline of major events affecting California water history.

Figure 1: California Water Projects (Source: Dennis Silverman, UC Irvine[1])

Conservation and Environmental Protection Era

The fourth stage, 1970-present, is intensification and environmental considerations. As the California economy and its agricultural sector has grown, the demand for expansion of water supply has increased. At the same time, some of the negative side effects of water extraction have prompted a significant shift in policy. First, the establishment of the Environmental Protection Agency in 1970 and a series of acts including the Clean Water Act of 1972 and the Endangered Species Act of 1973 created a legal environment for the protection of wildlife and reduction of pollution. In California, the State Water Resources Control Board oversaw monitoring water quality and enforcing water quality standards. Furthermore, it became clear that political economy considerations were leading to over investment in water projects (Reisner 1993). The government began requiring the use of cost-benefit analysis for Federal projects based on criteria established by the Water Resources Council (WRC 1983). These criteria explicitly recognized the environmental benefits of water use as well as the multiple costs of diversion and groundwater extraction. In the 1950s and 1960s, there were plans to divert water from the Eel and other northern rivers to the agricultural heartland of California. Following the new policies, the construction of big dams and reservoirs drastically slowed, with the last major dam (New Melones Dam) completed in 1979.

Public investments have since been diverted to projects that increase the safety of existing water conveyance facilities and protect the environment (including water to protect endangered species). The Kesterson Crisis of 1985 illustrates the importance of environmental considerations in California agriculture. The Bureau of Reclamation established wetlands to drain agricultural waterlogging to the Kesterson Reservoir in the heart of the San Joaquin Valley. However, the water had a high concentration of selenium and harmed migratory birds. The Bureau of Reclamation threatened to cut water supply to Central Valley contractors unless the issue was remedied. The threat led to changes in land use practices including buildup of evaporation ponds, adoption of drip irrigation to reduce runoff, and even diversion of land away from agriculture (Dinar and Zilberman 2012). Similarly, the multi-agency CALFED Bay-Delta Program was established to maintain reliability and quality of the Delta

1 http://sites.uci.edu/energyobserver/2015/04/28/california-water-projects-feeding-southern-california/

water, provide protection for the Delta ecosystem and protect against invasive species, and strengthen the levees on the Delta.

The constraints on availability of new sources of water in California for agriculture have led to a growing emphasis on increased water productivity (further discussed below). Since the 1970s, water use, especially in agriculture, has been revolutionized by adoption of innovative technologies and changes in land use. While California agriculture has grown substantially, its water use has stabilized.

Many of the reforms in California water use were in response to drought conditions. California agriculture responded to the drought between 1987-91 by fallowing land that had been used to grow low-value crop, increasing reliance on groundwater, and adopting modern technologies. However, in 1990, California introduced a water bank to allow owners of water rights north of the Delta to sell those rights to farmers in the south. This water trading reduced the production of rice, but allowed for sustained growth of high-value, perennial crops. The CVP Improvement Act recognized environmental use as a beneficial use of CVP water, diverted 10% of CVP water to environmental uses, and allowed CVP agricultural contract holders to sell their water rights on an annual basis to non-agricultural users (Zilberman et al 2002). Sunding et al (2002) compare adaptation mechanisms to reductions in water rights to CVP agricultural users. They find that water trading reduces the cost of adaptation by 50-75% compared to proportional reduction in water allocation to CVP water users. This is consistent with other findings of the literature that show transition from water rights to water trading increases economic efficiency and leads to adoption of improved practices (Schoengold and Zilberman 2007).

California responded to the recent severe drought of 2012-2016 by reducing agricultural acreage and increasing reliance on groundwater extraction. Howitt et al (2014) and Medellin-Azuara et al (2016) suggest that despite reductions in production, California agriculture was able to sustain, and even grow, its revenues during the drought mostly due to high commodity prices. However, during the drought, groundwater aquifers were significantly depleted, reducing water quality and availability to some regions. It became apparent that continued reliance on groundwater extraction was unsustainable, and the state passed its first Sustainable Groundwater Management Act in 2014 that requires monitoring and sets limits on groundwater pumping. This Act will require the establishment of groundwater management districts that will be responsible to establish mechanisms to attain sustainable groundwater aquifers by 2030. Bruno (2018) suggests that attaining sustainable targets will be much more cost effective using trading mechanisms rather than direct control.

Based on the California Water Plan, Mount and Hanak (2014) display applied water use in California between 1998 and 2010, as shown in Figure 2. Approximately 80 million acre-feet (MAF) of water are used annually in California, ranging from 61 to 104 MAF. Agriculture accounts for 40% of applied water and 10% of the urban sector, with environmental uses accounting for the remaining 50%. The figure suggests that while most of applied water in the north goes to the environment, the majority of applied water goes to agriculture in the Central Valley, and to urban uses on the coast.

The main sources of applied water annually are (i) streamflow that varies significantly with average of 31 MAF, (ii) water projects averaging 26 MAF, (iii) groundwater extraction averaging 18 MAF, and (iv) other sources such as reuse, recycling, and seepage, averaging 15 MAF. These figures need to be adjusted for the recent drought, and for the gradual growth of desalination projects and the reuse of wastewater.

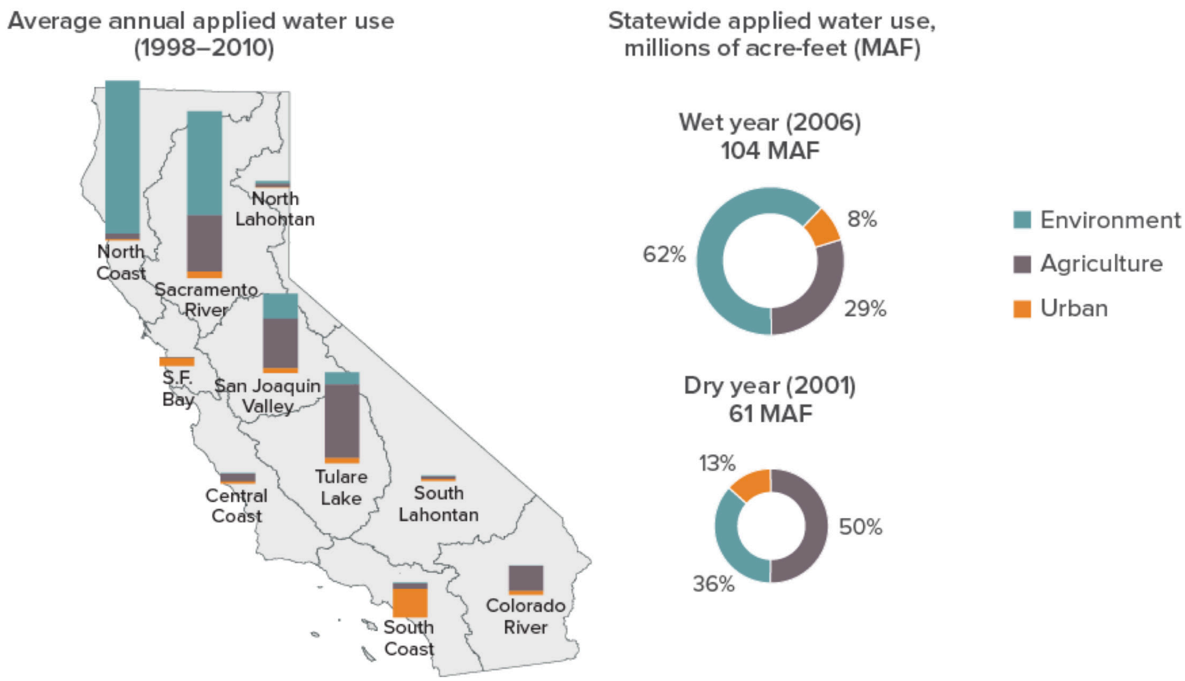

Figure 2: Applied water use in California: 1998-2010

Water Productivity in Agriculture

There were three drivers behind the changes in agricultural productivity during the era of limited expansion of supply and stricter environmental constraints: technological change, changes in consumer demand and environmental regulations. Caswell and Zilberman (1985) suggest a gap exists between applied water and effective water (utilized by crops). Water use efficiency, which is the ratio of effective to applied water, is dependent on land quality and technology. For instance, it is lower for sandy than heavy soils, and is lower for flood versus drip irrigation. Adoption of modern technologies tends to increase yields, may save water and reduce residue/runoff. However, modern technology is costlier. Furthermore, modern irrigation may increase efficiency by improving the timing of irrigation. As a result, farmers will adopt modern technologies for high-value crops, when water price is high or increasing and within regions of lower land quality.

Historically, California relied on furrow and flood irrigation. Sprinkler irrigation was introduced in the 1940s, and mostly adopted on fruit and vegetable fields. Drip irrigation was introduced in the late 1960s and primarily adopted by avocado growers with steeply-graded soil in Southern California. After a slow start, adoption of drip irrigation expanded significantly during the droughts of 1976-77 and 1987-91. It moved throughout the state from high-value fruits and vegetables to lower-value crops (on a per acre basis). The diffusion also benefited from implicit collaboration between manufacturers that improved the technology and University Extension services that modified production systems to accommodate the technology. This led to the large-scale adoption of drip irrigation for processing tomatoes. While in 1980, less than 5% of irrigated agriculture used drip and low-pressure irrigation. By 2010, the figure rose to 40%. Flood and furrow irrigation declined over time, and by 2010 was below 40% (Taylor and Zilberman 2017). The adoption of drip also allowed for the application of fertilizers and pesticides through irrigation systems. This was correlated with more sophisticated irrigation scheduling, frequently using the California Irrigation Management Information System (CIMIS). The estimated net annual benefit from the adoption of drip irrigation is approximately $700 million (Taylor, Parker and Zilberman 2014).

The adoption of advanced irrigation technologies benefited from the expansion of the acreage of high-value fruits and vegetables. Increased consumer demand, both domestically and internationally (especially in Asia) occurred as a result. Kuminoff, Sumner and Goldman (2000) show that the acreage of high-value crops, including fruits, nuts and vegetables, increased from 2.1 million acres (27% of total acreage) to 4.1 million acres (48%) between 1964 and 2002.

The Future

California's water system is likely to face multiple changes in the future due to several drivers. First, the expected impacts of climate change may include migrating weather (e.g. Los Angeles weather may migrate to San Francisco, Napa Valley may face much warmer, drier weather), which may require either significant adaptation, or even migration of crops. For example, some of the wine grape industry may need to shift to northern regions. Already, farmers in California are using different technologies to reduce temperatures during critical parts of the year. For example, pistachio growers are using clay dust to reduce tree-level temperature to increase the likelihood of blooming that requires sufficient period of low temperature (Trilnick, Gordon and Zilberman 2018). Relocations in response to climate change will require investment in water infrastructure. Climate change may lead to increased likelihood of drought, which in turn may require improved water resource management over time. However, climate change may result in declining snowpack, which today serves as intra-seasonal water storage. The increased likelihood of drought, and declining snowpack, will require increased storage capacity and investment in conservation efforts. While it seems that conservation and storage are substitutes, they may be complements when the increase in water-use efficiency due to conservation increases the incremental value of storage. Xie and Zilberman (2018) illustrate the possibility of complementarity of conservation and storage in the context of California agriculture.

A second driver is economic growth and increased concern for environmental amenities. These factors are likely to increase the demand for water. A third driver can be met by this demand , which is improvement in technologies that can increase water supply. California is already reusing brackish water, but much below the level of reuse achieved in Spain and Israel (Dinar, Pochat and Albiac-Murillo 2015). California is also venturing into the use of desalinated water along the coast. Desalination remains expensive, but its cost is declining and is likely to be a competitive source of water in some coastal regions. Desalination is energy-intensive, so the use of fossil fuel-based energy production may make the technology less desirable in the long-run. Given the solar exposure of coastal regions in California paired with California's research and innovation capacity, one possible avenue to address this problem is long-term investment in research that will utilize solar energy for desalination of both seawater and brackish water. Development of a viable desalination capacity may lead to significant modification of California's water system. Urban regions may become less dependent on water conveyance from inland regions. Thus allowing this water to be used for environmental and other purposes, and possibly reducing the cost of water overall. For example, San Francisco is surrounded by water and can use desalinated water, allowing the restoration of the beautiful Hetch Hetchy Valley, and even capturing the value of the environmental amenities it generates.

While much of the discussion in this article focuses on water quantity, water quality regulations are playing a significant role in California agriculture. For instance, protection of fish and other wildlife led to restriction of water transfer through the Delta and are a major cause of the consideration of Delta Tunnels.[1] There is room for further economic research on the implications and merits of the tunnels compared to alternatives (e.g. increased desalination capacity). Enforcement of nutrient-load standards in water as well as the high cost of production have led to reallocation of dairy farms from Southern California to the Central Valley, and now from California to other states, including Idaho and New Mexico.[2] As we look to the future, we may see California's livestock industry decline as a result of both stricter quality standards and the introduction of animal-free meat and milk technologies, many of which are based in California. These changes may reduce overall demand for water and may shift water demand from crops like alfalfa to other feedstocks used for animal-free meat production or other water-consuming activities (e.g. aquaculture, marijuana, recreational activities). Research on water will need to continue to adapt to the changes in California's economy, environment and technologies.

1 Project description: https://s3.amazonaws.com/californiawater/pdfs/Draft_Final_DCE_Agreement_Combined.pdf

2 See table: https://hoards.com/article-13240-cows-continue-to-congregate.html

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