California's Water Resources History
and
The Central Valley Project's First 75 Years

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Abstract

Over the last 150-plus years, California has been a leader in the development of water resources and infrastructure, which have more recently involved transferring scarce water from available sources to needy destinations. The 1930s Central Valley Project involved large dams, lengthy canals, pumping stations, and other important features. It helped turn the Central Valley into one of the most productive agricultural areas in the world. This paper traces the important history of California's water resources and infrastructure development; highlights the CVP's origin, planning, design, construction, operation, and recent developments; and focuses on some of the people who made major contributions.

Introduction

California probably has the most complex water system in the United States. This paper summarizes the pre-1900 and the 1900 to 1930s history of California's water resources and infrastructure development and discusses the state's evolution into a world leader on many of the fields associated with water resources engineering. The paper then summarizes the 75-year history of California's Central Valley Project.

Spanish Missions Period

Franciscan Father Junípero Serra founded Mission San Diego de Alcalá on July 16, 1769, on Presidio Hill. For various reasons, the mission was moved to its present location just north of the San Diego River five years later. Development of agriculture around the mission was slow. After a drought of several years, construction was begun around 1803 on a diversion dam across the San Diego River. The dam consisted of cemented granite stones and was located at the upper end of Mission Gorge about

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10 km (6 mi) upstream of the mission. Old Mission (or Padre) Dam was completed around 1813 and the 8 km (5 mi) long tile-lined flume/aqueduct was completed around 1816 along the north side of the river to convey water to the mission's fields. Old Mission Dam was 67 m (220 ft) long, 3.7 m (12 ft) high, and 4.6 m (15 ft) thick at the base. The aqueduct was about 0.6 m (2 ft) wide and 0.3 m (1 ft) deep. The dam, which still exists and can be seen in Mission Trails Regional Park, appears to have included a water wheel at the north end to power a gristmill.

Other missions were able to develop their water resources more rapidly. Mission Santa Barbara was founded on December 4, 1786. In 1806, a stone reservoir was constructed about 152 m (500 ft) from the mission to collect water for the mission's orchards and gardens; this reservoir is still used by Santa Barbara's Water Department. In 1807, a dam was constructed of native sandstone blocks on Pedregoso (Mission) Creek in Mission Canyon; it can still be seen in the Santa Barbara Botanic Garden. The dam is located about 2.4 m (1.5 mi) from the mission and an aqueduct of baked tile and redwood pipes, which runs through the Blakesley Botanic Gardens, was also constructed to convey the water to a dome-roofed filter house, which still stands on the edge of Mountain Drive near the intersection of Mission Canyon Road. The water trickled through a bed of charcoal and gravel, into the stone-walled reservoir discussed above. Mission San Miguel Arcangel was founded on July 25, 1797, near the Salinas River. Many dams and canals were built to convey water from the river to irrigate the orchards and crops in the vicinity of the mission (Hoover, Rensch, and Rensch, 1932).

Agriculture, Gristmills, and Sawmills

California civilization expanded rather slowly during the early to mid-1800s and did not extend very far beyond the coastal areas. Under the Spanish and Mexican control of California, agriculture expanded into areas like the Sonoma and Napa Valleys and the Central Valley. Settlers like John A. Sutter and Dr. Edward T. Bale immigrated to California. Dr. Bale, originally from England, arrived in Monterey in 1837, married Maria Ignacia Soberanes (the niece of General Mariano Vallejo), and in June 1841 was given a land grant of four square leagues or 7,275 ha (17,962 ac) in the upper Napa Valley near St. Helena. In the early 1840s, Bale built a sawmill and then a gristmill on his property, the latter being completed around 1846. The gristmill used water from Mill Creek for power, initially using a 6 m (20 ft) water wheel that was replaced in the early 1850s with a wooden 11 m (36 ft) diameter overshot water wheel. Several mill pond dams were constructed upstream of the gristmill to capture the flow from several springs, and a ditch and elevated flume carried the water from the lower pond to the water wheel. After Dr. Bale's death in 1849, the gristmill changed ownership several times and continued to operate until about 1905. Along with the rehabilitated gristmill, the breached lower pond dam, ditch, elevated flume, and an old redwood-log flume section can be seen at the Bale Grist Mill State Historic Park.

Mining

James W. Marshall's January 24, 1848, discovery of shining gold flakes in the tailrace of the sawmill he was building at Coloma for John Sutter on the South Fork of the American River in the Sierra Nevada, precipitated the famous California Gold Rush. As a side note, the fact that California became part of the United States on February 2, 1848, via the Treaty of Guadalupe Hidalgo couldn't have been better timed. People from all over the world flocked to the California and the Sierra Nevada Mother Lode, which initially extended from the Feather River in the north to the San Joaquin River in the south. The California State Mining Bureau in a 1912 report estimated the following gold production (Cleland, 1922): 1848 - $245,301, 1849 - $10,151,360, 1850 - $41,273,106, 1851 - $75,938,272, and 1852 - $81,294,700 (which was 60 percent of the world's production that year).

Water was involved in all phases of this gold mining, from the initial working of placer deposits to the subsequent drift, hydraulic, and hard rock mining. The first miners used equipment like gold pans, shovels, picks, rockers, small sluice boxes, Long Toms, and large sluices to remove the gold from the sand bars and banks of the streams and rivers. As these efforts quickly depleted the easy placer gold deposits, the miners progressed to larger-scale operations and diversions of entire streams and rivers, which included dams, ditches, flumes, and tunnels to expose the gold-bearing alluvium. In the 1850s, the entire Yuba River between Downieville and Goodyear's Bar was flumed out of its channel, which is one example of how massive some of these water systems and operations were. Unfortunately, spring runoff in the Sierra Nevada frequently destroyed these systems and they had to be rebuilt or abandoned.

In 1852, the miners discovered a new source of gold - the famous "Blue Lead" of the Tertiary Gravel deposits formed by prehistoric stream and river channels now known as the Ancestral Yuba and Jura Rivers. (The bluish gravels occurred below the water table.) These gold deposits were mined using various processes, primarily drift mining and hydraulic mining. Drift mining tunneled into or beneath the Blue Lead gravels and removed the material, which was then processed with water to wash or sluice the gravel to remove the gold. Hydraulic mining began at American Hill in Nevada County in 1852 and used massive amounts of water piped to monitors/giants to wash away the overburden deposits and extract the Blue Lead gravels, which were similarly washed or sluiced to remove the gold. Between 1855 and the Sawyer Decision and Anti-Debris Act in 1884, an estimated 190 million m^3 (250 million yd^3) of material from the ancestral Yuba deposits was washed into nearby river drainages, clogging them and leading to the court case Woodruff vs. North Bloomfield Gravel Mining Co. Much of the silty mud produced by this mining method eventually settled in San Francisco Bay and is referred to as "Bay Mud." At the Malakoff (hydraulic) Mine pit near North Bloomfield (now the Malakoff Diggings State Historic Park), nearly 4 km^3 (1 mi^3) of material was removed during the mine's operation. The tremendous water volumes used by hydraulic mining resulted in the construction of diversion dams, lengthy ditches, canals, flumes, and trestles, quickly followed by the construction of relatively large earthfill and timber-crib rockfill dams to provide adequate water storage. Some of these mining dams were as high as 38 m (125 ft) (Jansen, 1983). These water supply systems generally created the earliest water rights in California, which are owned and still used by the state's municipalities and irrigators today.

In June 1850 a Grass Valley miner named George McKnight stumbled on some rock, which broke off and allowed him to discover an extensive gold-bearing quartz deposit. Hard-rock mines were quickly developed there and elsewhere throughout the Mother Lode. The North Star and Empire Mines in Grass Valley are two of the most famous in California. Before closing in 1956, the now-flooded subsurface workings of the Empire Mine extended to a maximum incline-depth of over 3,350 m (11,000 ft). The surface plant included eighty 793 kg (1,750 lb) stamps to crush the ore; they were initially powered by wood-steam engines and then by water and electric power. The initial hard rock mining used adits, tunnels, shafts, and inclines to reach the underground rock. Once the gold ore had been brought to the surface, it had to be reduced to separate the gold from the rock. The Mexican *arrastre* was replaced by crushers and stamp mills. Power for the early stamp mills was supplied by wood-powered steam engines and low-efficiency water wheels. In 1878 at Camptonville, Lester Allen Pelton invented his world-famous Pelton Water Wheel (an ASCE National Historic Civil Engineering Landmark, NHCEL). Pelton patented his water wheel in 1880 and in 1888 formed the Pelton Water Wheel Company, which moved operations from Nevada City to San Francisco. The ninety percent efficiency of the Pelton Water Wheel became known world-wide and its use rapidly expanded, especially for mining applications. Besides those at the Empire Mine State Historic Park, the nearby North Star Mine Powerhouse and Pelton Wheel Museum contains an excellent collection of Pelton water wheels, including one of the largest ever manufactured with a 9 m (30 ft) diameter. The Kentucky Mine Museum at Sierra City (east of Downieville) contains an excellent working example of an old stamp mill and shaking table, both powered by Pelton water wheels.

San Francisco's Water Supply

In 1776, Juan Batista de Anza founded Presidio Pueblo and Padre Francisco Palou established Mission San Francisco near a small stream called Arroyo de los Dolores. People at the Presidio and Mission San Francisco obtained water from local sources, including Laguna del Presidio (Mountain Lake) Arroyo del Puerto (Lobos Creek), and several springs including El Polin near the encampment. In July 1846, the Pueblo of Yerba Buena, containing about 450 residents was renamed San Francisco by its new American Alcalde or Mayor, Lt. Washington Bartlett. Another result of the Gold Rush was the swift increase in the importance of the existing communities like San Francisco and Sacramento. In January 1848, the number of "white residents" of California numbered not more than 12,000 people, and only four years later, the population exceeded 250,000 (Lewis, 1949). By 1849, San Francisco's existing water supplies were no longer adequate, with households resorting to buying water by the barrel sold by vendors who transported the water from various sources. In 1851, the Sausalito Water and Steam Tug Company was barging water across San Francisco Bay by tank steamer from springs on the Marin shore, using 65 water carts to supply

San Francisco households. That same year, Mountain Lake Water Company was formed to bring water from Mountain Lake to the Presidio. By 1859, San Francisco's population numbered nearly 100,000 residents. In 1856, the San Francisco City Water Works (popularly known as the Bensley Company) was franchised by the city, and Alexei Waldemar von Schmidt became its chief engineer in 1857. He dammed the mouth of Lobos Creek and brought 7.6 million liters (2 million gal) per day by flume and tunnel around Fort Point through the Presidio and under Fort Mason to the Black Point Pumping Station at the foot of Van Ness Avenue. The water was pumped through two sets of heavy double-force pipes to the Francisco and Lombard Reservoirs on the north slope of Russian Hill, which reservoirs are still in use today.

The Spring Valley Water Works had been organized in 1858, and San Francisco's population in 1860 had grown to 78,000. In 1860, Schmidt had a dispute and left the Bensley Company to become chief engineer and a leading stockholder of the Spring Valley Water Works. To obtain additional water, San Francisco's sources of water had to be extended south into San Mateo County. As early as 1870, San Francisco formed a committee and began to investigate Lake Tahoe and other potential sources. Schmidt built additional water works and constructed Pilarcitos Dam, several tunnels to convey water from areas south of San Francisco to reservoirs in the city. Hermann Schussler arrived in San Francisco in 1864 and quickly found employment as an engineer with Spring Valley; Schmidt left Spring Valley that same year, and it bought out the Bensley Company in 1865. Schussler was named Chief Engineer of the Spring Valley Water Works in 1866 at the age of 23. He raised Pilarcitos Dam to a height of 21 m (70 ft) in 1867. It was a dry rolled earthfill dam with a piddled clay core and was then one of the world's highest earth dams. Pilarcitos Dam was raised eight years later to a height of 29 m (95 ft) with a crest length of 159 m (520 ft), impounding 3.79 Hm^3 (3,070 ac-ft) of water. San Andreas Dam and Reservoir were completed in 1870; the dam was raised five years later to a height of 32 m (105 ft) and a crest length of 276 m (905 ft), which impounds 23 Hm^3 (19,000 ac-ft) of water. This was followed by Upper Crystal Springs Dam and Reservoir in 1876 and Lower Crystal Springs Dam and Reservoir in 1888, with subsequent raises in 1890 and 1911 to its present height of 47 m (154 ft), crest length of 183 m (600 ft), and reservoir of 862 Hm^3 (69,380 ac-ft). Lower Crystal Springs Dam was designated a California Historic Civil Engineering Landmark by ASCE in 1976 (San Francisco Water and Power, 2005). In 1898, Schussler decided to begin tapping the Livermore Valley basin's groundwater found in deep gravel beds, drilling wells up to 229 m (750 ft) deep for subsequent delivery to San Francisco. Besides storage dams and reservoirs, San Francisco's early water system included diversion dams, aqueducts, tunnels, pipelines, and related equipment.

The East Bay's Water Supply

During the early 1800s, ranchos such as Rancho San Antonio owned by Don Luis Peralta were established along the eastern shore of San Francisco Bay. After the 1846 revolt, and the discovery of gold and California becoming part of the United States in 1848, the village of Contra Costa began near the estuary, becoming Oakland and then an incorporated city in 1854. The East Bay contained 21 creeks that provided an adequate water supply for a while. Privately owned water development was common, and the first organized in Alameda County in 1860 was the Alvarado Artesian Well Company. In 1866, a former miner named Anthony Chabot arrived and was granted a franchise by Oakland to establish his Contra Costa Water Company, which was the East Bay's dominant water development institution for the next 41 years. Chabot acquired water rights to Temescal Creek, but his initial water supply was a well from which the water was steam-pumped to an elevated tank from which water flowed down into his system of pipes and household water taps. The first water from Temescal Creek arrived in June 1867 and Chabot began construction of an earthfill dam on the creek in early 1868 (the same year the University of California was established nearby in Berkeley). By 1870, Oakland had a population of 15,000 people. Construction of the earthfill San Leandro Dam (renamed Chabot Dam) on San Leandro Creek began in 1874 and was completed in 1875 to a structural height of 35 m (115 ft) above the original creek bed. The earthfill was transported to the embankment by horse-drawn wagons, placed in lifts, and compacted by a "herd of wild mustangs" obtained from Oregon. The dam's downstream slope was buttressed by a hydraulic fill placed between 1875 and 1888, and the dam was raised using wagon fill and hydraulic fill in 1890-92. Subsequent modifications raised the dam to its final height of 41 m (135 ft), crest length of 152 m (500 ft), and reservoir capacity of 25 Hm^3 (20,000 ac-ft). The Contra Costa Water Company installed filtration systems at its San Leandro and Temescal plants in 1890, but the water quality was still not very good. Anthony Cabot also built early water systems for San Jose and Vallejo. Contra Costa Water Company merged with its competitor, the Oakland Water Company, in 1898 (Noble, 1999).

Irrigation

Several Spanish expeditions entered the great interior valley in search of sites for new missions, and Gabriel Moraga explored the Central Valley in 1808 and gave one river the name Sacramento. John Sutter settled in the Central Valley in July 1839 where he'd been granted 11 leagues or 20,000 ha (49,000 ac) of land. Sutter planted large fields of wheat, diverted water from the American River for irrigation, built a water-powered sawmill and a flour mill (1849), and grazed large herds of cattle and horses. Other settlers soon followed and developed their own large ranches in the Central Valley. With the Gold Rush, the miners' demand for flour increased dramatically and new grain fields were planted and flour mills were constructed. By the mid-1860s, enough wheat was being produced that the Central Valley's surplus could be exported overseas (Lewis, 1949). The joining of the Central Pacific and Union Pacific Railroads in 1869 connected California to eastern markets. Large-scale wheat ranches of up to 20,000 ha (50,000 ac) were developed in the Central Valley during the 1870s and 1880s. The vast holdings acquired by "Cattle King" Henry Miller and Charles W. Lux included construction of the first long-distance canals in the San Joaquin Valley, some of which are still in use.

With the completion of Atchison, Topeka, and Santa Fe Railway linking Kansas City with Los Angeles in 1885, Southern California experienced the beginning of its population boom and further development of the area's water resources for irrigation and municipal purposes. Early masonry dams like Frank E. Brown's landmark Bear Valley Dam, completed near Redlands in 1884, and Sweetwater Dam (NHCEL), designed and constructed by James D. Schuyler (M. ASCE) east of San Diego in 1888, were completed along with canals and distribution systems. Sweetwater Dam was subsequently raised and modified several times by Hiram N. Savage (M. ASCE) to its current size: height 39 m (127 ft), crest length 213 m (700 ft), and capacity 35 Hm^3 (28,000 ac-ft).

Hydroelectric Power

Alternating current (AC) electricity was quickly proven to be superior to direct current (DC) due to its long distance transmission capability. Single-phase AC hydroelectric power was first installed at the Willamette Falls station at Oregon City, about 21 km (13 mi) south of Portland in 1890. This was followed by the Ames plant near the mining district at Telluride, Colorado in 1891. Lucian Nunn's Ames plant was powered by a 2 m (6 ft) diameter Pelton water wheel under 98 m (320 ft) of head and transmitted the electricity 4.2 km (2.6 mi) to his Gold King Mine. The use of hydroelectric power for western mining increased dramatically during the 1890s (Hay, 1991).

California saw one of the earliest applications of hydroelectric power for municipal purposes when Horatio G. Livermore began development of his water plans on the American River at Folsom. His initial water-powered mill plan evolved in the early to mid-1890s to AC hydroelectric power instead, built by son Horatio P. Livermore. The original Folsom Dam was constructed along with an outlet canal to the forebay reservoir and Folsom Powerhouse (NHCEL) that began operation under a head of 17 m (55 ft) in 1895 (a visit to the Folsom Powerhouse State Historic Park just east of Sacramento is well worth your time). The three-phase, 60-cycle, 11,000 volt AC power was transmitted 35 km (22 mi) to Sacramento to power the electric street car system owned by Livermore and other municipal uses.

On the Yuba River near Nevada City, Eugene de Sabla, Jr., John Martin, and Romulus Riggs Colgate began their development of hydroelectric power with a diversion dam, flume, penstock, and the Nevada Powerhouse on the South Fork of the Yuba River that operated under a head of 58 m (190 ft) to drive the Pelton water wheels and generators. In 1896, the Nevada Powerhouse's electricity was transmitted 6.8 km (4.2 mi) and 12.2 km (7.6 mi) to the nearby Nevada City and Grass Valley mines, respectively. De Sabla and Martin next obtained the rights to the Brown's Valley irrigation district's water rights and ditch on the North Fork of the Yuba River, built the Yuba Powerhouse system that operated under a head of 90 m (295 ft) in 1898. Their hydroelectric power system expanded and included transmission lines to several nearby communities, including Marysville 29 km (18 mi) away. In 1899, a diversion dam, a 12.2 km (7.6 mi) long flume, penstock, and the Colgate Powerhouse operating under a head of 214 m (702 ft) to drive the Pelton water wheels were completed, and the transmission lines were extended 98 km (61 mi) to Sacramento and 48 km (30 mi) to Oroville (Coleman, 1952). This was the start of California's hydroelectric power system that was consolidated into the well known Pacific Gas and Electric Company (PG&E).

1900 to 1930s - San Francisco's Water Supply

In 1900, San Francisco Mayor James D. Phelan directed City Engineer Carl E. Grunsky (ASCE President, 1924) to study 14 possible water sources, including the Sacramento, Eel, Feather, Yuba, American, Mokelumne, Tuolumne, and San Joaquin Rivers and Lake Tahoe. The Hetch Hetchy Valley had been identified as a potential water source and dam site as early as 1870. Grunsky recommended the Tuolumne River and the Hetch Hetchy Valley as the best choices for a dependable, high quality water supply. The mayor and city engineers quietly and quickly sent engineer Joseph B. Lippincott (Hon. M. ASCE) to perform the necessary surveys. Mayor Phelan (as a private citizen) applied for the water rights and reservoir rights at Hetch Hetchy and Lake Eleanor on October 15, 1901, and he assigned his interests to the city in 1903 This water right application was denied by Secretary of the Interior E.A. Hitchcock on June 20, 1903, claiming he had no authority to make the grant. In 1906, it was learned that an earlier Attorney General's opinion was that the Interior Secretary did have such authority (San Francisco Water and Power, 2005). The Great San Francisco Earthquake and Fire of April 18, 1906, quickly gave San Francisco more reasons for obtaining a better and more dependable supply of water. After more water right applications and much debate on the use of Hetch Hetchy Valley, which included people like John Muir who vigorously campaigned against the project, a new examination and report by engineer John R. Freeman (Hon. M. and ASCE President 1922) was completed in 1912. The "Freeman Report" is 401 pages long and is one of the most complete water resource evaluations ever published (Freeman, 1912). It should be noted that the East Bay's communities planned to collaborate with San Francisco in developing this water supply, and their citizens and engineers assisted Mr. Freeman on his report. Other reports concerning San Francisco's water supply were produced at this time by engineers such as Brig. Gen. Hiram M. Chittenden (M. ASCE) and A.O. Powell (M. ASCE) (Chittenden and Powell, 1912). President Wilson signed the Raker Act into law on December 19, 1913, and granted San Francisco its long-sought "rights of way and use of public lands in the area concerned for the purpose of constructing, operating and maintaining reservoirs, dams, conduits and other structures necessary or incidental to development and use of water and power" (Wurm, 2000).

In early 1914, City Engineer Michael M. O'Shaughnessy (M. ASCE) quickly began the real work to design and construct the Hetch Hetchy Project. Note that the early development of the project's hydroelectric power was an important component and helped to pay its high cost. The project included several hydropower plants, such as the Moccasin Powerhouse with 401 m (1,316 ft) of head to drive the eight large Pelton water wheels that began operation in 1925. Due to cost considerations, it was decided to build the cyclopean concrete gravity arch dam across the gorge at the end of the Hetch Hetchy Valley in two phases. The contract for the initial dam was awarded to

Utah Construction Company on August 1, 1919, and the 69 m (226.5 ft) high dam was dedicated on July 7, 1923, at which time it was named O'Shaughnessy Dam. O'Shaughnessy retired in 1932 and it's interesting to note that it took until October 24, 1934, for the first Hetch Hetchy water to arrive in San Francisco. Tragically, "Chief" O'Shaughnessy had passed away on October 12th. The far-sighted O'Shaughnessy had designed the dam to be raised an additional 26.1 m (85.5 ft) to increase the reservoir's storage by 75 percent. The second contract was awarded to Transbay Construction Co. in April 1935 and the dedication ceremony was held in October 1938, at which time it was the second highest dam in the world. O'Shaughnessy Dam rises 131 m (430 ft) above the deepest foundation, has a crest length of 227 m (910 ft), and impounds 445 Hm^3 (360,360 ac-ft) of water (Wurm, 2000).

While the work to obtain water from the Hetch Hetchy Valley was going on, San Francisco expanded its supply to the East Bay, constructing a 762 mm (30 in) pipeline to convey the water from the Pleasanton in the Livermore Valley to Sunol in 1909. Construction of Spring Valley Water Company's Calaveras Dam in the East Bay began in 1913. It was designed as a hydraulic fill dam, but a large portion of its upstream slope failed during construction on March 24, 1918. San Francisco's Chief O'Shaughnessy unofficially kept "a watchful eye" on the dam's subsequent construction and it was completed in 1925 to a height of 70 m (230 ft), crest length of (1,200 ft), and capacity of 119 Hm^3 (96,860 ac-ft). It was the world's highest earthfill dam in 1925. Due to seismic safety concerns about the hydraulic fill left beneath the upstream shell, Calaveras Dam is currently being replaced with a new dam located downstream. San Francisco and its San Mateo County partners have continued to improve its municipal water system. The recent funding approval by the served Bay Area communities indicated their overwhelming support for the proposed multi-billion dollar rehabilitation improvement program to rebuild the aging system and continue its complex operation well into the 21st Century.

East Bay's Water Supply

The Contra Costa Water Company continued to struggle to provide adequate water supplies and decent water quality. The company announced plans for a new dam and reservoir in the Pinole area. One proposal submitted to Oakland in 1904 suggested the use of the Mokelumne River 100 miles away in the Sierra Nevada as a water source. By August 1906 (after the earthquake), Oakland's population had swelled to almost 150,000 people. People's Water Company was incorporated on August 30, 1906, and it took in the old Contra Costa Water Company along with the six year old Richmond Water Company and then the Syndicate Water Company. Peoples Water Company served people from San Leandro to Richmond and its combined facilities were completely inadequate for such a large population. The East Bay Water Company was incorporated on November 13, 1916, partly to take over the poorly funded Peoples Water Company. The new company provided water to eight cities in Alameda and Contra Costa Counties: Oakland, Berkeley, Alameda, Richmond, Piedmont, Emeryville, Albany, and San Leandro, which collectively occupied an area 56 km

(35 mi) long by 3 to 8 km (2 to 5 mi) wide. The East Bay suffered a drought and water crisis in 1917 and 1918 that created more problems. San Pablo Dam was completed in 1919; the hydraulic earthfill dam was 52 m (170 ft) high above the streambed, had a crest length of 381 m (1,250 ft), and added 47.6 Hm^3 (38,600 ac-ft) of water storage. However, the area's water problems continued.

In May 1921, California passed the Municipal Utility District Act, and on May 8, 1923, the proposed East Bay Municipal Utility District (EBMUD) was approved by voters in seven of the nine cities (El Cerrito had incorporated in 1917 and was now included among the seven; Piedmont and Richmond joined later). EBMUD quickly began efforts to take over the East Bay Water Company's assets, but the company wouldn't agree to a deal. In August 1923, EBMUD obtained the services of Arthur Powell Davis (ASCE President, 1920), the former head of the U.S. Reclamation Service (which became the Bureau of Reclamation in 1923) to be its general manager and chief engineer. The district quickly obtained the services of Major General George W. Goethals (M. ASCE) of Panama Canal fame and William Mulholland (M. ASCE), engineer for the Los Angeles Department of Water and Power who had directed the design and construction of the Owens River - Los Angeles Aqueduct Project to work as a board of engineers with Chief Engineer Davis to evaluate alternative water sources. They began by reviewing the Freeman Report's information and started detailed engineering studies on twelve potential sources, including the Trinity, Eel, McCloud, Sacramento, American, Mokelumne, and Tuolumne Rivers.

By July 1924, they had narrowed the list to the Eel, upper Sacramento, Tuolumne, and Mokelumne Rivers, and in September the three engineers selected the Mokelumne. PG&E already had a hydropower dam at Electra and was planning another at Salt Springs on the Mokelumne River. The Mokelumne River's water could be stored behind a new dam below the hydropower dams at a good damsite at Lancha Plana and then conveyed across the Central Valley to the East Bay's reservoirs. Former California Governor George C. Pardee was elected to EBMUD's Board of Directors in 1924, was promptly elected its president in November, and remained in that capacity until retirement in 1941. EBMUD's Upper San Leandro Dam was completed in 1926. Contracts for Pardee Dam and Tunnel, the East Bay Aqueduct, the Walnut Creek and Lafayette Tunnels and Pipeline were awarded on September 29, 1925. The project construction proceeded rapidly and in the midst of another drought, the first Mokelumne water reached the East Bay and San Pablo Reservoir on June 23, 1929, which was just in time – the reservoir had only a 48-hour supply of water remaining. The concrete gravity Pardee Dam was dedicated on October 19, 1929; it is 109 m (358 ft) high above the river bed, crest length 408 m (1,337 ft), and stores 259 Hm^3 (209,950 ac-ft) of water. The completed system included several tunnels, two aqueducts, several pumping plants, and several water treatment plants (Noble, 1999). EBMUD has always been very proud of the fact that it beat San Francisco's delivery of Hetch Hetchy Project water by five years. Upper San Leandro and San Pablo Dams have both been modified to address seismic stability concerns. EBMUD was able to struggle through the Great Depression, has added a number of additional dams, reservoirs, and other facilities, and is today one of the world's premier municipal utility districts.

Southern California's Water Supply and Early Irrigation

As Los Angeles rapidly expanded and grew to a population of 102,000 in 1900, its need for dependable water supplies increased dramatically. The public supply of water had begun in the early 1860s when the city gave a franchise to the privately owned Los Angeles City Water Company. William Mulholland had begun working for the Los Angeles City Water Company as a ditch cleaner and rose to become superintendent and chief engineer in 1882. After the company's franchise expired, Los Angeles obtained control of the company's assets and initiated municipal ownership in February 1902. In the early 1900s, a number of well known engineers became involved in Los Angeles' search for water; they included Joseph B. Lippincott, J.C. Clausen, John R. Freeman, Frederick P. Stearns (ASCE President, 1906), and James D. Schuyler (M. ASCE). The resulting proposal was the well known Owens River – Los Angeles Aqueduct Project (NHCEL). The project was designed by Freeman, Stearns, and Schuyler and their final estimate was $24,485,600 (Schodek, 1987).

The project would take five years to construct, would convey water by gravity flow a total of 378 km (235 mi) through the Haiwee Reservoir to the Fairmont Reservoir, and would include 39 km (24 mi) of unlined canal, 85 km (53 mi) of tunnels, 60 km (37 mi) of lined canal, 158 km (98 mi) of covered conduit, 19 km (12 mi) of inverted siphons, and 16 km (10 mi) power waterways. Construction began on the 8,165 m (26,780 ft) long Elizabeth Tunnel through the San Fernando Mountains in October 1907 and holed through on February 28, 1911. Owens Valley water first reached Los Angeles on November 5, 1913, and Mulholland made his famous comment: "There it is; take it!" Relative calm continued until 1921-22 when a severe drought affected Owens Valley's farms and trouble continued for several years until a 1929 court case made Los Angeles buy all the Owens Valley ranches whose owners wanted to sell (Schodek, 1987; Mulholland, 2000).

One component of the water project developed by Los Angeles Water and Power was the 1924-26 construction of St. Francis Dam, which failed near midnight on March 12, 1928, killing between 430 and 500 people and destroying several million dollars worth of property. As a direct result, California enacted two pieces of legislation in 1929 that: (1) required that all non-Federal dams in the state be reviewed, employing consultants as necessary, examine all of the state's dams within three years and issue recommendations, and supervise the maintenance and operation of all non-federal dams; and (2) created the Board of Registration for Civil Engineers and required the registration of civil engineers in order to practice as such in California.

The development of the irrigation water supply for the Imperial and Coachella Valleys should be noted as well. People had settled in the Imperial and Coachella Valleys located south and north of the Salton Sink (Ancient Lake Cahuilla), respectively, in the 1890s, and they quickly sought to obtain irrigation water from Colorado River.

Irrigation headworks were constructed below Yuma in Mexico, and the Imperial Canal was constructed through Mexico to the Imperial Valley to convey irrigation water to the dry farmland. After several years of operation, the Colorado River's spring floods in 1905 overwhelmed and failed the irrigation headworks, causing the river to change course and flow uncontrolled northward toward the Salton Sink. When finally controlled and diverted back into the previous river channel in February 1907, the Salton Sea had been created. The Southern Pacific Railroad, its construction engineer, Colonel Epes Randolph, and its engineer in charge of the work, H.T. Cory (M. ASCE), were greatly credited for the massive and lengthy construction effort with rock and earthfill to turn the river and close the breach then discharging about 570 m^3/s (20,000 ft^3/s), which saved the Imperial Valley (Grunsky, 1907). The Boulder Canyon Project Act, which authorized the construction of Hoover Dam and the All-American Canal, was signed by President Coolidge on December 21, 1928. Construction of the All-American Canal was started in 1934 and was completed in 1942, and the Coachella Canal's construction began in 1938 and first delivered water to the valley's lands in 1948. The Salton Sea continues to exist, supplied primarily by irrigation drainage from the Imperial and Coachella Valleys. However, those inflow sources are being reduced by various water conservation measures and other operational changes, such as the sale of water to coastal communities like San Diego.

Hydroelectric Power

In 1900-01, de Sabla and Martin extended their system 228 km (142 mi) to Oakland with a transmission line constructed by civil engineer John D. Galloway (Hon. M. ASCE) across the Sacramento River through Woodland and across the Carquinez Strait at Dillon's Point, which is located on the north shore between Vallejo and Benicia. The world-record cable span across the Carquinez Strait was 1,350 m (4,427 ft) long between the steel towers and used Roebling designed and supplied wire cables to support the power lines that were at least 85 m (280 ft) above high tide to avoid the topmasts of sailing ships. The transmission lines were then extended another 68 km (42 mi) to San Jose (Coleman, 1952).

During California's early hydroelectric power development and evolution, this river diversion dam, flume, penstock, and powerplant approach to generating electricity, and the lack of a year-long sustained supply of water for generating power, were quickly recognized as being a significant problem. The gold miners had built reservoirs to provide better long-term water storage capacity, and the hydroelectric power operators quickly moved toward that approach too. This resulted in the design and construction of ever larger dams and reservoirs throughout the Sierra Nevada. By 1900, California's civil engineers had already built several dams that exceeded 30 m (100 ft) in height (including San Andreas in 1870 and Chabot in 1875). Most of these new, higher embankments were rockfill dams constructed in California for hydroelectric power water storage. PG&E and other hydroelectric power companies, such as Great Western Power and the San Joaquin Light and Power Corp., learned to cooperate with the Central Valley's farmers and irrigators who wanted to use the Sierra Nevada's water too. Both groups continued to want more and more water, and combining their mutual systems and operations to the extent possible made for good business. These collective water operations continued to expand to rivers located further away (i.e., the Pit River in Shasta County) from the initial turn-of-the-century areas.

The rockfill dams had to be lined (or faced) on their upstream side to prevent the loss of water. Steep upstream facings of sawn timber and then formed concrete were designed and constructed as the critical component of these rockfill dams. Between 1900 and 1910, timber facings were used and the steep-sloped rockfill embankments were placed by dumping and sluicing the rockfill. A relatively smooth layer of masonry rock was placed on the upstream slope beneath the timber facing, using derricks and/or hand work in order to support and attach the timber facing. On Bishop Creek, Sabrina and South Lake (Hillside) Dams are examples of such dams, which were constructed in 1908 to 1910 with lodgepole pine timber facings that were replaced with redwood timber facings in 1929 (Galloway, 1939). After 1910, reinforced concrete became the preferred material for these upstream rockfill dam faces. From 1900 to 1925, about 15 of these rockfill dams were constructed, primarily in California for hydropower water storage.

A notable example is Strawberry Dam on the South Fork of the Stanislaus River that was completed in 1916 as a concrete-faced granite rockfill, rising to a height of 44 m (143 ft), crest length 220 m (720 ft), and storing 23 Hm^3 (18,312 ac-ft) of water. This dam was significantly exceeded by the completion of Salt Springs Dam on the North Fork of the Mokelumne River in 1931, also as a concrete-faced granite rockfill. It rose to a height of 100 m (328 ft), crest length 383 m (1,257 ft), and impounded 175 Hm^3 (141,857 ac-ft) of water. An unfortunate problem with these dumped and sluiced rockfill dams was the settlement of the rockfill over time. This settlement caused their concrete facings to crack and the reservoir water to leak out, and the seepage was expensive for the hydroelectric power operator. At Strawberry Dam, the seepage reached a maximum flow of about 0.3 m^3/s (10 ft^3/s), and at Salt Springs Dam, reached an outflow of about 0.9 m^3/s (30 ft^3/s) in 1932 (Kollgaard and Chadwick, 1988). Several of these timber- and concrete-faced rockfill dams have recently been modified with CARPI geomembranes installed on their upstream face.

A second, important aspect of this hydroelectric power development in California involved the fact that it has a lot of elevation drop from the Sierra Nevada's upper reaches down to the valley floor. This factor gave rise to the quick and extensive use of Pelton (impulse) water wheels, which are the only type of turbine that could handle the very-high water heads possible in California's Sierra Nevada. There are many notable early high-head hydroelectric powerplant examples in Northern and Southern California, which are now owned by PG&E and Southern California Edison, respectively. Among the early powerplants in Northern California, notable examples were: the Kilarc Powerplant on Old Crow Creek near Whitmore in Shasta County, which began operation in 1903 under a head of (351 m (1,150 ft), and the Drum No. 1 Powerplant on the South Yuba River near Alta in Placer County, which began operation in 1913 under a head of 418 m (1,372 ft). The highest-head early Northern

California powerplant was Bucks Creek on the North Fork of the Feather River near Storrie in Plumas County, which began operation in 1928 under a head of 780 m (2,558 ft) – it remained the world's highest head powerplant for about 35 years. Among the early powerplants in Southern California, notable examples were: the Azusa Powerplant on the San Gabriel River in Los Angeles County, which began operation in 1898 under a head of 427 m (1,401 ft); the Kaweah No. 1 Powerplant on the Kaweah River near Three Rivers in Tulare County, which began operation in 1899 under a head of 579 m (1,899 ft); and the Bishop Creek No. 3 Powerplant on Bishop Creek near Bishop in Inyo County, which began operation in 1905 under a head of 339 m (1,112 ft). The highest-head early Southern California powerplant was Big Creek No. 2A on Stevenson Creek near Big Creek in Fresno County, which began operation in 1928 under a head of 737 m (2,418 ft). The Big Creek hydroelectric system should be noted because it eventually included a total of eight powerhouses, a total elevation drop of 2,110 m (6,200 ft), and a total rating of 685,000 kW (Hay, 1991).

The third important related aspect of California's hydroelectric power development was mentioned above on the Bishop Creek system: its steep river topography that allowed a series of reservoirs and powerplants to be operated in series to completely maximize the river's flow downstream. PG&E's hydropower system on the North Fork of the Feather River is another good example of this factor.

Relocating Water — The Central Valley Project

The 75-year-old Central Valley Project (CVP) has had a dramatic effect on California's economy and its production of valuable agricultural products for consumption in both the United States and the world. At the time of its origin and early development, it was a landmark example of moving surplus water, a critical resource, a considerable distance from its area of origin to where it could be used to great value, while also providing other important public benefits.

The Central Valley of California lies between the Sierra Nevada and Coast mountain ranges, being about 800 km (500 mi) long and averaging about 70-80 km (45-50 mi) wide. The northern one-third, the Sacramento Valley, is the drainage area of the Sacramento River, which with its tributary streams receives some two-thirds of the yearly precipitation. The southern two-thirds, the San Joaquin Valley, receives only about one-third of the rainfall, an obvious imbalance. The northerly portion of the San Joaquin Valley is the drainage area of the river of the same name, while the more southerly portion is the closed Tulare basin; each portion has many important tributary streams. The Sacramento and San Joaquin Rivers join near Stockton in what is known as the Delta, where the flows pass out through Suisun Bay to San Francisco Bay and eventually the Pacific Ocean. This fresh water is a major factor in controlling salinity in the Delta area, and thus has been a continuing issue in use of Central Valley water supplies.

The Coast Range and the Valley floor generally receive lighter precipitation than does the Sierra Nevada, at elevations up to 4,600 m (14,000 ft), where the melt of the annual snow pack provides the bulk of the runoff. The precipitation does not occur evenly through the year, but is concentrated from November to about March, and the major runoff takes place from April through July in a “normal” year. Historically, valley groundwater has been a major source for human use, but levels have steadily declined for over 100 years as the area developed.

Various parts of the Central Valley ranged from marshes to semi-desert, depending on their relationship to the streams. The first uses—before and just after California became a state—were primarily cattle-raising and then dry-farming. However, the soils of the valley floor proved to be well-suited to intensive agriculture, given adequate water supplies: a (or the) primary basis for creation of the CVP (Kahrl, 1978).

Early Studies and Actions

The first studies of the Central Valley’s hydrology, in the 1870s, were conducted by the United States Army Corps of Engineers (USACE), but these were relatively limited. The United States Reclamation Service (USRS) was formed in 1902, and one of its earliest projects was near Orland in the upper Sacramento Valley in 1906, incorporating the East Park and Stony Gorge Dams.

A critical factor in beneficial Central Valley water use is the need to store annual runoff so that its distribution and use can be extended beyond the normal runoff period, and unusually large flows in one year can be preserved for later use in drier years. In 1912-1914, the USRS studied possibilities of major storage at Iron Canyon on the Sacramento River between Red Bluff and Redding, but that site had problems, including insufficient storage space. The State of California was also active in evaluating needs and possibilities.

In 1919, a Chief Geologist for the United States Geological Survey (USGS), Col. Robert B. Marshall, developed a comprehensive water plan for the Central Valley, which became known as the “Marshall Plan.” The proposed features included improving flow and new storage on the Sacramento River, irrigation in the Sacramento Valley, supplies for the San Francisco Bay Area, and even diversion to the Stanislaus River area, supposedly to replace San Joaquin Valley supplies sent to the Los Angeles area. The Marshall Plan was the subject of three different proposed amendments to the state Constitution, all of which were defeated by the voters during the 1920s (Kahrl, 1978; Bureau of Reclamation).

In 1924, the Federal Power Commission investigated power possibilities in the Trinity River basin to the west of the upper Sacramento Valley (later added to the CVP).

Early State Planning

In 1916, a California conference on water use identified a variety of flood control, hydroelectric power, navigation, irrigation, and land reclamation needs requiring consideration, but developed no specific proposals. Starting in 1921, the California Legislature directed the State Division of Engineering to study the Central Valley. These studies covered the valley’s hydrology and evaluated over 1,000 possible dam sites. Included was construction of a physical barrier below the Delta for salinity control, an idea also studied by the USACE, which subsequently proposed such a project. (Installing a barrier there has always been a highly controversial matter and thus has never received any major support.) The state studies looked at dams on the major rivers, “swapping” water with the San Joaquin Valley, and the effects on riparian rights (always a highly complex and sensitive issue).

In 1927, the state arrived at a plan generally similar in concept to the eventual CVP, with a large dam 26 km (16 mi) north of Redding and the pumping of water from the Delta for use to the south, but no Bay barrier to control salinity. This was formalized in a State Water Plan submitted in 1931 and conceptually approved by a commission formed by President Herbert Hoover and Governor Clement Young. The State Engineers involved were Wilbur F. McClure, Paul Bailey (M.ASCE), and, most prominently, Edward Hyatt (M.ASCE).

In 1933, the Legislature adopted the California Central Valley Project Act, authorizing the sale of revenue bonds. $170 million in bonds were approved by the voters in 1933 but could not be sold due to the national depression. The state then turned to the Federal Government, requesting that the project be undertaken.

Throughout both the state and federal efforts, power was a controversial issue. In particular, the PG&E opposed public ownership of transmission facilities, especially for deliveries to local customers. This opposition even included a ballot initiative against the state plan, which was rejected by the voters (Kahrl, 1978; Bureau of Reclamation).

Enter the Federal Government

Through the Rivers and Harbors Act of 1935, the Federal Government took control of the CVP, authorizing the USACE to construct the initial facilities. The first appropriations were provided in the Emergency Relief Appropriation Act of 1935 based on a finding of feasibility by Secretary of the Interior Harold Ickes; that Act also transferred project implementation to the U.S. Bureau of Reclamation (USBR). (The USRS became the USBR in 1923, and its acronym has recently been changed to BOR.) The project was reauthorized in 1937, and made subject to Reclamation law. Three purposes were stated: improved flood control and navigation, water for irrigation and domestic use, and hydroelectric power generation.

These decisions by President Franklin Roosevelt did not end struggles between the USACE and USBR over control of CVP and other projects in California. It was President Harry Truman who made the final decisions in the late 1940s, allocating construction, power, and water use responsibilities between the two agencies.

The 1935 appropriations totaled $32 million, with full construction funding being added later. Included was $5 million to relocate the Southern Pacific Railroad main line around the Shasta Dam and Lake (Bureau of Reclamation).

The Initial Facilities

The principal initial facilities were: Shasta (formerly Kennett, after a near-by old copper mining town) Dam, Keswick Dam, Friant Dam, the Delta pumping plant, and the Contra Costa, Madera, and Friant-Kern Canals. (A number of additional features were added through subsequent legislation extending into the 1970s, many of which were actually implemented but some were not.)

Shasta Dam was one of three major dams commenced by USBR in the 1930s, the other two being Hoover Dam and Grand Coulee Dam. Of these, Shasta was second to Hoover in height and second to Grand Coulee in volume/mass. As of Shasta's completion in 1945, the five largest U.S. concrete dams in volume were: Hoover, Grand Coulee, Shasta, Friant, and

Fontana (on the Tennessee River).

The original concept for Shasta Dam was earthfill, but State authorities had decided that concrete was most suited to the site. USBR essentially accepted that conclusion in the interest of commencing construction as soon as possible. Otherwise, Shasta's final location and design were generally similar to the state plan, but with some dimensional and capacity increases. Shasta is a curved concrete gravity dam, 184 m (602 ft) in height with a 1,150 m (3,460 ft) crest length, and a volume of 4.79 million m^3 (6.27 million yd^3). The impounded Shasta Lake is 17,260 km^2 (6,665 mi^2) in area with 5.61 Hm^3 (4.55 million ac-ft) capacity. Shasta's spillway is, at 157 m (480 ft), the highest man-made artificial waterfall in the U.S. The author recalls in the winter of 1950-51 passing through a tunnel under the spillway when maximum discharge was taking place from the tubes in the dam face and the upper spillway; the tunnel walls were vibrating about 2 cm (0.8 in), a testimonial to the force of that heavy flow (Bureau of Reclamation).

Shasta Dam bids were opened on June 1, 1938, with the low bid from Pacific Constructors, Inc. (PCI) being $35,939,450, "leaving on the table" only $262,907 based on the only other bid received. PCI, a joint venture of 13 construction companies, retained as its construction superintendent Francis T. (Frank) Crowe (Hon. M. ASCE), who had recently filled the same role on Hoover and Parker Dams. Mr. Crowe brought with him a team of experienced personnel. The government provided certain materials, especially aggregate and cement for the concrete, the contracts for which were awarded to companies controlled by Henry J. Kaiser (Bureau of Reclamation; Pacific Constructors, 1945; Allen, 1989).

Construction commenced in September 1938, and was essentially completed in 1945, a real achievement considering the concurrent demands of World War II and a major flood in which more than 5,230 m^3/s (185,000 ft^3/s) passed through the site. The concrete and related materials were handled by a system of seven cableways, three of which were over 0.8 km (0.5 mi) long. The aggregate source was the Kutras Tract in the City of Redding and the then-longest beltway was employed to move the material to the dam site. The largest day's concrete pour was 9,000 m^3 (11,800 yd^3), greater than the maximum day pour at Hoover Dam. The Shasta Power Plant has five generating units, which initially produced 75,000 Kva each at 13,800 volts. Part of the head tower was left in place because of the wartime need to fill the reservoir early for power generation, and has "reappeared" at times during periods of low water. The USBR's principal dam design engineer was John L. (Jack) Savage (Hon. M. ASCE) and its Shasta construction engineer was Ralph Lowry (Pacific Constructors, 1945; Billington, Jackson, and Melosi, 2005).

Keswick Dam, a straight concrete gravity dam 19 km (12 mi) below Shasta, re-regulates flows and also has a power plant. Keswick Reservoir is also the destination of flows from the Trinity River Diversion.

Friant Dam is on the San Joaquin River northeast of Fresno in Fresno County. It is a straight concrete gravity dam, 105 m (319 ft) high with a crest 1,150 m (3,500 ft) long. It was built in 1939-1943 by Griffith Construction Company using trestle and crane methods. The impounded Millerton Lake is 1,983 ha (4,900 ac) in area, with a capacity of 640 Hm^3 (520,000 ac-ft).

Sacramento River water goes to San Joaquin Valley via the Tracy Pumping Plant, which was completed in 1951. The Delta Cross Channel was created to allow a more direct route through the Delta. The Tracy plant has a 65 m (197 ft) lift to the Delta-Mendota Canal, which extends 285 km (177 mi) to a pool in Fresno County. This water serves to replace the riparian rights below that point which were acquired by USBR in 1939, and thus permitting San Joaquin River diversion from Millerton to the valley's east side.

The Madera and Friant-Kern Canals commence at Friant Dam. The Madera Canal is 58 km (36 mi) long, serving the county of the same name. Friant-Kern is a much larger canal extending from Fresno County through Tulare County to Kern County near Bakersfield, a distance of 245 km (152 mi). These two canals provide irrigation water to 339,000 ha (837,000 ac), which produced $1.9 billion in product value in 1990. Fresno County typically has the highest annual agricultural production value of any county in the nation, with Tulare and Kern Counties right behind.

The third initial canal is the Contra Costa, serving the county with that name. It is 77 km (48 mi) long, and in 1944 was the first CVP feature to commence service. This water is separately pumped from the Delta below the Tracy Pumping Plant.

Hydroelectric power generated at Shasta and Keswick Dams goes through USBR lines to the Tracy Pumping Plant. Ultimately, there was agreement that Federal power lines would only be used between Federal facilities, and that PG&E would wheel hydroelectric power to districts, municipalities, and other such customers (Bureau of Reclamation).

Facilities Added by USBR

Increased service areas and water sources have been added since completion of the initial CVP facilities, based on further studies and actions by the Congress.

The Trinity Division was authorized in 1953-1955. The Trinity River lies west of Shasta County and is tributary to the Pacific Ocean via the Klamath River, not San Francisco Bay. The main feature is Trinity Dam completed in 1962, an earth fill structure 176 m (538 ft) high (the tallest earthfill dam built by the USBR), and costing $49 million. It impounds Clair Engle Lake with 3,080 Hm^3 (2.5 million ac-ft) capacity. Below Trinity Dam is the diversion and re-regulation Lewiston Dam. At this point Trinity River water is sent through a Coast Range tunnel to the Judge Francis Carr Power Plant and Clair A. Hill Whiskeytown Reservoir, where another tunnel leads to the Spring Creek Power Plant and thence into Keswick Reservoir. The combined hydroelectric power generation in these facilities is more than 400,000 kW. This division is included in the California Water Plan.

The Sacramento Canals Unit, authorized in 1950, irrigates over 40,000 ha (100,000 ac) via two canals: Corning, 34 km (21 mi) long, and Tehama-Colusa, 179 km (111 mi) long. Their source is the Sacramento River at the Red Bluff Diversion Dam, which was completed in the early 1960s.

The San Felipe Unit, serving portions of Santa Clara, San Benito, and Monterey Counties west of the Coast Range, was authorized in 1960. The water comes via a tunnel from the San Luis Reservoir near Los Banos. Construction started in 1964 and was completed in the 1980s. 15,700 ha (63,500 ac) are irrigated and 163 Hm^3 (132,000 ac-ft) of water is provided for municipal and industrial uses (Bureau of Reclamation).

Cooperative Features Added to CVP

The San Luis Division comprises a cooperative venture with the State of California, authorized in 1960; this was the first such agreement entered into by USBR. Costs are shared 55 percent state/local vs. 45 percent Federal for those parts of the facilities used by CVP. The shared facilities are San Luis Dam and Reservoir (one of the largest earthfill dams in the country and the largest ever built by USBR), O'Neill Forebay, and part of the California Aqueduct. San Luis Reservoir stores water from the Aqueduct for timely release. A plant at the base of the dam provides both pumping for storage and hydroelectric power generation during release. USBR's Coalinga and San Luis Canals in Fresno and Kings Counties are supplied from this source. USBR also started construction in 1968 on the San Luis Drain and Kesterson Reservoir, intended to dispose of saline tailwater from 3,200 ha (8,000 ac) in the San Luis area, but this was halted in 1975 due to environmental and other problems.

The American River Division involves Folsom Dam and the projected Auburn Dam, authorized in 1944-1949 for construction by the USACE. Folsom is a multi-purpose dam and reservoir near the town of that name east of Sacramento, with 1,233 Hm^3 (1 million ac-ft) capacity. Folsom Dam and Reservoir were transferred to USBR for operation as part of CVP. Auburn Dam, anticipated as early as 1928, has been the subject of a great deal of public controversy. Construction was started there in 1974 but was soon halted due to design and seismic stability concerns. Some related service canals were planned but have only been partially developed. This Division also includes a small Sly Park unit near Placerville.

The Eastside and New Melones Division, built by the USACE in cooperation with local districts, has also been transferred for CVP operation. The main purpose of New Melones Dam was flood control and those benefits have been realized; however, as an irrigation water supply source, it has not met quantity anticipations. As a result, USBR has sometimes had to purchase water from other sources to meet its contractual obligations.

Another issue arose in the planning of Pine Flat Dam on the Kings River in eastern Fresno County. Local irrigation interests preferred that USACE build the dam, having both flood control and water supply benefits, because of the reclamation acreage limitation situation. The USBR contended that it should be responsible because of the considerable added irrigation supply. The issue eventually reached the desk of President Truman, who split the responsibilities: USACE to handle the construction and USBR to administer the water (Bureau of Reclamation; Maass, 1951; Kahrl, 1978; Shallat, 1978).

Other Developments Affecting CVP

A long-standing issue in California concerns a proposed Peripheral Canal to move water around, not through, the Delta. While this was originally part of the California Water Project, CVP would also be a beneficiary. Multiple concerns caused this canal to be proposed, but also inspired major opposition. The Delta is a sensitive area, subject to some major problems such as levee failure and flooding. Bypassing the "pass-through" water would provide major relief, but would also generate questions on salinity invasion, related fish survival, and other environmental concerns. The first proposals were in 1963-1965, but control questions almost immediately surfaced and there was opposition by Contra Costa County (which feared losing water supplies). The state had construction authority but wanted USBR to build it, while USBR had no authority. California proposed to fund the Peripheral Canal through Proposition 9, which was rejected by the voters in 1982, perhaps largely because of its $3 billion cost. Recent major concerns regarding California's overall water situation have led to renewed interest in the Peripheral Canal, but it remains uncertain at this time (Kahrl, 1978).

Another aspect of resolving statewide water supply questions has involved a proposed major raising of Shasta Dam. USBR has determined that it is technically feasible to increase the impounded storage by as much as three times, but that would obviously involve many very difficult environmental, relocation, and financing questions (Bureau of Reclamation).

One aspect of damming the Sacramento, San Joaquin, and other California rivers has been survival of certain fish species, especially salmon and ocean trout. In some cases, hatcheries and/or fish ladders have been employed, but stream water temperatures and diverted flows continue as issues. USBR has added special facilities at Shasta Dam and other locations to permit more selective (colder) water releases while reducing impacts on water for power generation.

In 1992, the Congress passed and the President signed the "Central Valley Project Improvement Act" (CVPIA), which made major changes in the project's concept and ultimately its operation. The Act called for increasing the water-related benefits, contributing further to Delta improvements, and achieving a "reasonable" balance between the purposes related to fish/wildlife, agriculture, municipal & industrial, and hydroelectric power. In particular, it established environmental purposes as having equal, if not greater, stature with other purposes. The full impact of CVPIA remains to be seen.

Acreage limitations on eligibility to receive project water have been an issue from the first days of CVP. California's farm statistics illustrate: while $^2/_3$ of the farms are 40 ha (100 ac) or less, 80 percent of the farmlands are in parcels exceeding 400 ha (1,000 ac), and 75 percent of agricultural production is from 10 percent of the farms. The basic requirements of Reclamation law have called for a 65 ha (160 ac) eligibility per person—130 ha (320 ac) for a couple—and residency on the farm, at odds with the historic reality of farming in the Central Valley. Part of the problem is that the large Federal service areas include many farms having access to older, unlimited, water sources—such as pre-existing water rights and groundwater pumping. The 1950s California Water Project was structured to avoid major problems in this regard. California even considered buying CVP from the Federal Government, which was halted by Governor Goodwin Knight in 1954 largely due to the cost. Congress finally addressed this through the Reclamation Reform Act of 1982, which changed the farm limit to 388 ha (960 ac) and dropped the residency requirement (Shallat, 1978).

USBR has also participated in what is known as the CALFED Bay-Delta Program. Twenty-five state and Federal agencies are collaborating on a mission to improve the state's water supply while creating better ecological health for San Francisco Bay and the Sacramento-San Joaquin River Delta. A 30-year management and restoration plan has been drafted and an authority was created to oversee implementation. Funding is not yet fully in place, however.

Recent Federal court decisions have resulted in other questions affecting CVP. One requires water release from Millerton Reservoir and channel improvements to restore salmon runs on the San Joaquin River below Friant Dam. Agreement has been reached between the contending water users and fishing/environmental activists, but funding has not yet been provided through Congressional action. The other involves the condition of certain fish species in the Delta because of pumping for both CVP and the California Aqueduct. Both the state and USBR have been required to reduce pumping to reduce/avoid fish being destroyed at the pumping plants. The solution to this problem is still uncertain (perhaps the Peripheral Canal). San Joaquin Valley agricultural interests are concerned about whether they can depend on adequate supplies during growing seasons, and Southern California water agencies heavily dependent on the California Aqueduct to serve their 10+ million customers are equally if not more concerned.

Issues and questions such as these appear to be an inevitable aspect of developing and operating a complex, comprehensive, project such as the CVP.

Summary

Beside its people, water is the most essential element in California's life and economy. The Central Valley Project has, by-and-large, achieved the goals and objectives under which it was conceived, authorized, and funded. It plays a critical role in California's economy, which has experienced tremendous growth in the 75 years since the CVP began to be implemented.

The CVP today includes 20 dams and reservoirs, 11 hydroelectric power plants, and 805 km (500 mi) of major canals, plus conduits, tunnels, and related facilities. It manages 11,100 Hm^3 (9 million ac-ft) of water, delivering 77 percent of that for agricultural, municipal, industrial, and wildlife uses. An annual total of 5.6 billion kilowatt hours of electricity are produced, serving over 2 million people. It is estimated that the economic values it has produced represent 100 times the $3 billion cost to date. CVP revenues in 1999 were $60 million for irrigation, $60 million from municipal, industrial, and other sources, and $34 million in hydroelectric power sales, for a total of $154 million. Other benefits are found in recreation and tourism, wetland protection, navigation, flood control, and other uses. Also, beyond the CVP and the Los Angeles Aqueduct, there have been other important long-distance water transfer facilities developed in California.

The Southern California region—Los Angeles, Ventura, Orange, Riverside, San Bernardino, and San Diego Counties—receives a major supply of water from Lake Havasu at Parker Dam through the Colorado River Aqueduct. The Metropolitan Water District of Southern California distributes much of this supply. Due to other Colorado River water rights, there have been recent reductions in the Southern California share. Starting in the 1960s, the California Water Project has provided considerable additional water for Southern California from the Feather River at Oroville Dam and Reservoir via the Delta and the California Aqueduct, including major pumping over the mountain ranges into Los Angeles. Thus, more than ever before, California is an international leader in moving water to meet today's needs.

While many citizens give little thought to the huge infrastructure that makes California's water available, as discussed in this paper, many who *are* aware have quite ambivalent feelings about it. Agricultural and other interests support the infrastructure and recognize the need to expand it to accommodate the continuing population increases. However, groups and individuals having more environmentally-oriented agendas not only oppose more large water infrastructure but want certain existing major facilities removed.

San Francisco's O'Shaughnessy Dam in the Hetch Hetchy Valley is a case in point. Its early 20th Century construction was opposed by John Muir and others, but today it is the principal storage serving not only San Francisco but many other Bay Area communities. The state has responded to demands that Hetch Hetchy Valley be returned to its previous "pristine" state by making a study which found that alternative storage was technically feasible. Despite the tremendous cost of dam removal, realigning or replacing related facilities, and loss of hydroelectric power capacity (estimated at up to $10 billion, using broad assumptions), this has encouraged the Sierra Club and other groups supporting removal. Funding the cost presents two main alternatives, neither of which may be politically achievable—force the served communities to pay, meaning that user rates would rise (to confiscatory levels for some customers); or obtain general Federal and/or state appropriations, which, even if available, would be unfair to general taxpayers who had no part in creating the facilities and enjoyed none of the benefits therefrom. Affecting this situation is the recent funding approval by the served Bay Area communities to rehabilitate the aging Hetch Hetchy system and its facilities.

In the Hetch Hetchy and other difficult California water issues, Californians are facing the need to reach a seemingly impossible political consensus about continuing growth versus either expanding or diminishing the ability to provide the water to support it. The story of the next century's California's water infrastructure may be of a decidedly different character than has been described in this paper.

References

Allen, Marion V. (1989). "Redding and the Three Shastas." Published by the author, Shingletown, CA.

Billington, David, Jackson, Donald, and Melosi, Martin (2005). “The History of Large Federal Dams: Planning, Design, and Construction.” U.S. Department of the Interior, Bureau of Reclamation, Denver, CO.

Bureau of Reclamation (1938). “Dams and Control Works, Second Edition.” By the Department, U.S. Department of the Interior, Washington, D.C.

Bureau of Reclamation: web site, www.usbr.gov.

Chittenden, H. M., and Powell, A.O. (1912). “Report on The Water Supply System of the Spring Valley Water Company.” San Francisco, CA.

Cleland, Robert Glass (1922). “A History of California – The American Period.” The McMillan Company, New York, NY.

Coleman, Charles M. (1952). “PG&E of California – The Centennial Story of Pacific Gas and Electric Company – 1852-1952.” McGraw-Hill Book Company, Inc., New York, NY.

Cooper, Erwin (1968). “Aqueduct Empire.” Arthur H. Clark Co., Glendale, CA.

De Roos, Robert (1948). “The Thirsty Land.” Stanford University Press, Stanford, CA.

Freeman, John R. (1912). “The Hetch Hetchy Water Supply for San Francisco.” The Rincon Publishing Company, San Francisco, CA.

Galloway, J. D. (1939). “The Design of Rock-Fill Dams." Paper No. 2015 with Discussions, Transactions Vol. 104, ASCE, 33 West 39th Street, New York, NY, 1-92.

Grunsky, Carl E. (1907). “The Lower Colorado River and the Salton Basin.” Paper No. 1051 with Discussions, Transactions Vol. 59, ASCE, Published by the Society, New York, NY, 1-62.

Hay, Duncan (1991). “Hydroelectric Development in the United States, 1880-1940, Volumes One and Two.” Prepared for the Task Force on Cultural Resource Management, Edison Electric Institute, Washington, D.C.

Hoover, Mildred Brooke, Rensch, H.E., and Rensch, E.G. (1932). “Historic Spots in California.” Stanford University Press, Stanford, CA.

Hundley, Norris (1992). “The Great Thirst.” University of California Press, Berkeley, CA.

Jansen, Robert B. (1983). “Dams and Public Safety.” U.S. Department of the Interior, Bureau of Reclamation, GPO, Denver, CO.

Kahrl, William L. (1978). “The California Water Atlas.” State of California, Sacramento, CA.

Kollgaard, Eric B., and Chadwick, Wallace L., Eds. (1988). “Development of Dam Engineering in the United States, Prepared in Commemoration of the Sixteenth Congress of the International Commission on Large Dams by the United States Committee on Large Dams.” Pergamon Press, Maxwell House, Fairview Park, Elmsford, NY.

Lewis, Oscar (1949). “California Heritage.” Thomas Y. Crowell Company, New York, NY.

Linenberger, Toni Rae (2002). “Dams, Dynamos, and Development: The Bureau of Reclamation’s Power Program and Electrification of the West.” U.S. Department of the Interior, Bureau of Reclamation, Denver, CO.

Maass, Arthur (1951). “Muddy Waters, The Army Engineers and the Nation’s Rivers.” Harvard University Press, Cambridge, MA.

McClurg, Sue (2000). “Water and the Shaping of California.” Water Education Foundation, Sacramento, CA.

Mulholland, Catherine (2000). “William Mulholland and the Rise of Los Angeles.” University of California Press, Berkeley, CA.

Noble, John Wesley (1999). “Its Name was M.U.D. – A Story of Water.” Books 1 (1970) and 2 (1999), East Bay Municipal Utility District, Oakland, CA.

Pacific Constructors, Inc. (1945). “Shasta Dam and Its Builders.” PCI, Los Angeles, CA.

Pisani, Donald J. (2002). “Water and American Government, The Reclamation Bureau, National Water Policy, and the West, 1902-1935.” University of California Press, Berkeley, CA.

Robinson, Michael C. (1979). “Water for the West, The Bureau of Reclamation 1902-1977.” Public Works Historical Society, Chicago, IL.

Rowley, William (2006). “The Bureau of Reclamation: Origins and Growth to 1945, Vol. 1.” U.S. Department of the Interior, Bureau of Reclamation, Denver, CO.

San Francisco Water and Power (2005). “A History of the Municipal Water Department & Hetch Hetchy System.” San Francisco Public Utilities Commission, San Francisco, CA.

Schodek, Daniel L. (1987). “Landmarks in American Civil Engineering.” The MIT Press, Cambridge MA.

Shallat, Todd A. (1978). “Water and the Rise of Public Ownership on the Fresno Plain, 1950 to 1978.” Public Works Department, City of Fresno, CA.

Spring Valley Water Company (1912). "The Future Water Supply of San Francisco." San Francisco, CA.

U.S. Bureau of Reclamation (1949). "Central Valley Basin." By the Bureau (Senate Document 113, 81st Congress), Washington, D.C.

Wurm, Ted (2000). "Yosemite's Hetch Hetchy Railroad – San Francisco's Water and Power Project." Stauffer Publishing, Fish Camp, CA.