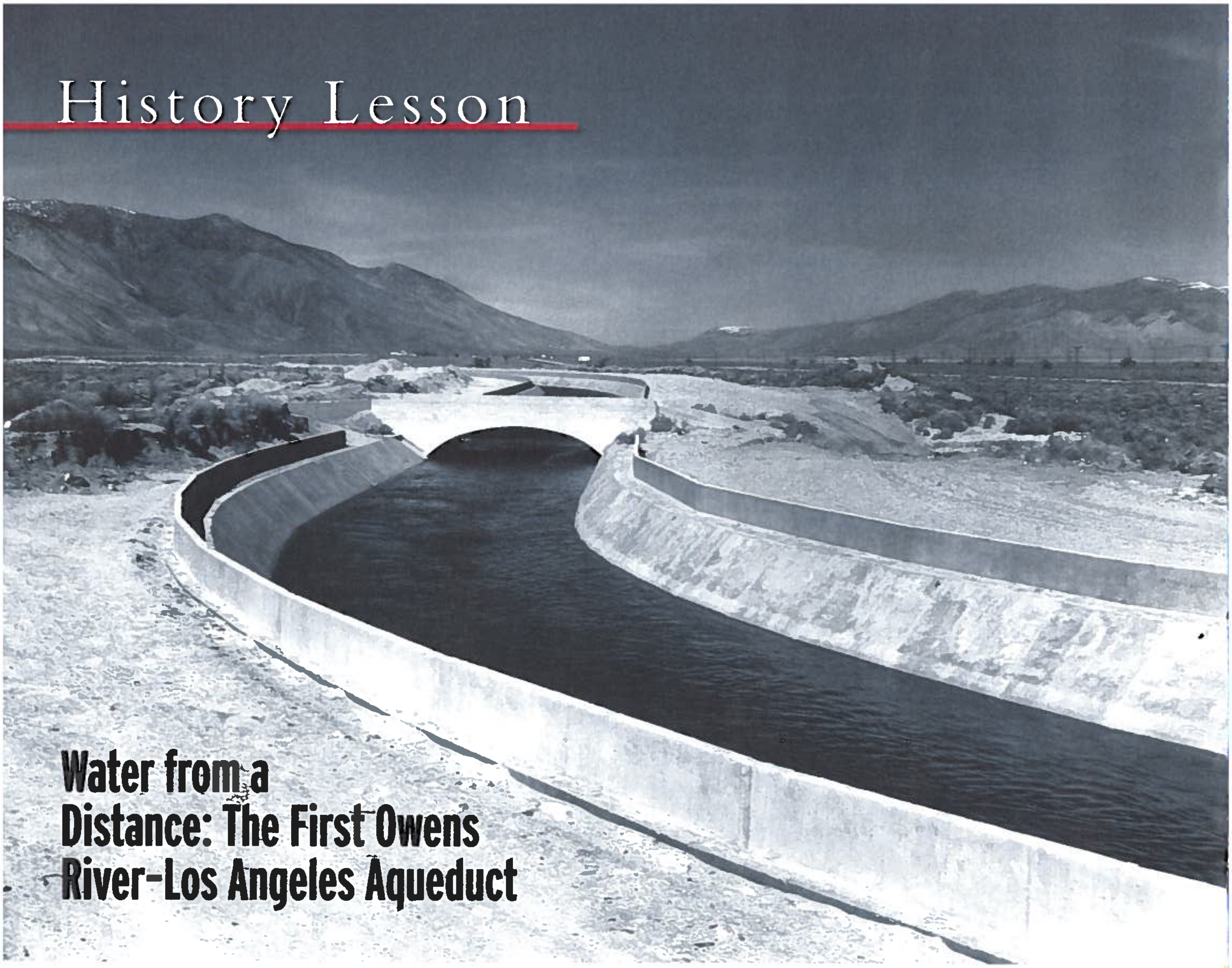
CE 3372 – Water Systems Design
Exercise 2

Purpose

- Demonstrate ability to summarize engineering literature, and communicating that summary in writing.

1. **Los Angeles Aqueduct History** Read the attached article from a 2013 issue of "Civil Engineering." Prepare a summary of the article. In the summary describe the Los Angeles Aqueduct. List the different types of conveyances and hydraulic machines that are employed (closed conduit, open conduit, lift stations, etc.) in its operation. Explain what design and/or construction features were employed that were novel for their time. Conclude with a comparison of the Los Angeles Aqueduct to a large-diameter gas pipeline. What are the similarities and differences (other than the working fluid!).[1]

[1]This exercise supports General Program Outcome (g) "an ability to communicate effectively" and (h) "the broad education necessary to understand the impact of engineering solutions in a global and societal context." This exercise is "Writing Intensive."



Water from a Distance: The First Owens River-Los Angeles Aqueduct

IN 1781, when Spanish settlers founded the village that would become the city of Los Angeles, it seemed to them that the Los Angeles River would provide all of the water they would ever need. That humble village, however, was destined for dramatic growth. In 1870 its population was 5,728, and by 1900 that number had swelled to 102,479.

Among those at the end of the 19th century who grasped the challenges that accompanied such growth were Fred Eaton, a former city engineer who had risen to the office of mayor in 1898, and William Mulholland, the superintendent of the privately owned Los Angeles City Water Company. To stretch the water supply, Mulholland introduced water metering in Los Angeles in 1889, successfully reducing per capita consumption by more than 100 gpd by 1903. But the population continued to grow, and he began to search for new sources.

It was Eaton who suggested the Owens River, located approximately 250 mi from Los Angeles. For a distance of some 150 mi, the river collected the snowmelt from the eastern Sierra Nevada and carried it south into a basin to form Owens Lake. Having no outlet, the water remained in the lake and became saline. Eaton believed this water could be captured while it was still fresh and redirected to Los Angeles. At his urging, Mulholland surveyed the area and determined that such a water delivery system not only was possible but also could be realized by using the force of gravity, making pumps unnecessary. Mulholland estimated that building the required infrastructure would cost less than $25 million.

Persuaded by Eaton and Mulholland that tapping the Owens River was the only viable option, the city's Board of Water Commissioners acted quickly. In a 1905 ballot initiative, the board sought and won the people's approval by a ratio of more than 10 to 1 to issue $1.5 million in bonds to purchase land in the valley of the Owens River. A year later, the city recruited three prominent engineers—John R. Freeman, Hon.M.ASCE, who would become ASCE's president in 1922; James D. Schuyler, M.ASCE; and Frederic P. Stearns, M.ASCE, who was then serving as ASCE's president—to study the feasibility of the project. The team enthusiastically endorsed the project, concluding it was not only feasible but also "admirable in conception and outline

More than 200 mi long, the aqueduct included an unlined canal; a concrete-lined channel, *above;* and a closed concrete conduit. Never before had so much water been moved so far to meet the needs of a city.

FROM THE ASCE LANDMARK FILE, ALL

and full of promise for the continued prosperity of Los Angeles." In a second referendum, in 1907, the people of Los Angeles approved an additional $23 million in bonds to construct the project. At that point oversight of the project passed from the Board of Water Commissioners to the Board of Public Works, Mulholland serving as chief engineer and J.B. Lippincott, Hon.M.ASCE, as his deputy.

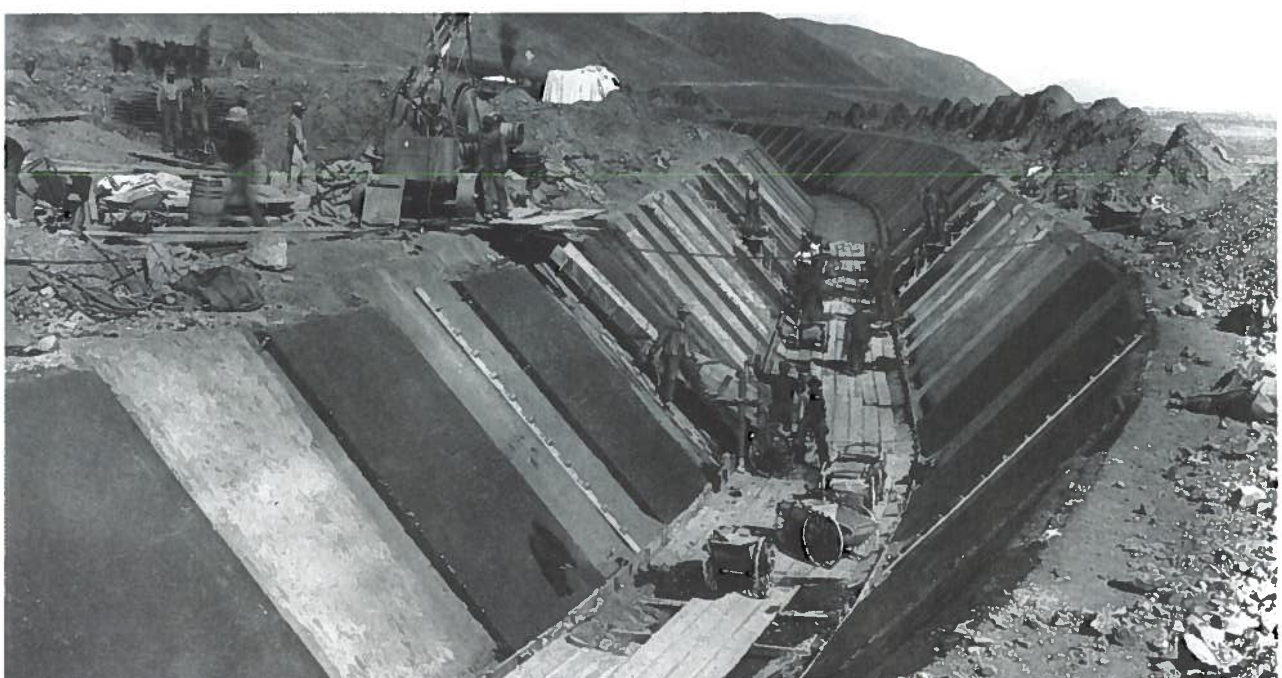
Simply preparing for construction was a large task. Some 225 mi of new trails and roads were needed to provide access to the aqueduct route. Crews installed 180 mi of water mains to supply the workers and make concrete production possible. They also built two hydroelectric plants to power the construction lighting and equipment. The city even made a deal with the Southern Pacific Railroad to construct a 120 mi railroad line roughly parallel to the future aqueduct for the transportation of supplies.

While surveying the aqueduct route, city engineers searched for local sources of the limestone and clay that would be needed to manufacture cement. They found an ample supply at a site in the Tehachapi Mountains, roughly halfway along the line of the aqueduct, and erected a large cement mill there that went on to spawn the factory town of Monolith. In other places workers mined deposits of tuff, or volcanic ash, which they blended with the cement to create a concrete mix similar to what had been used to construct the aqueducts of ancient Rome.

Between 1887 and 1907, the Irish immigrant William Mulholland rose from common laborer to the chief engineer of a $25-million project essential to the growth of the city of Los Angeles. The self-taught engineer proved capable of directing the efforts of thousands of workers covering a distance of more than 200 mi. Crews line the canal with concrete, *below*, on the eastern outskirts of the Sierra Nevada.

The aqueduct as Mulholland designed it comprised several distinct sections. It began at its northern end with an intake structure feeding into an open, unlined canal excavated using steam shovels and running 24 mi through the valley of the Owens River. Upon reaching the Alabama Hills, a range of rugged rock formations on the eastern outskirts of the Sierra Nevada, the canal remained open but was lined with concrete for the next 37 mi. It then emptied into Haiwee Reservoir, the first and largest of the project's reservoirs. Below the reservoir, the water entered a closed conduit of cast-in-place concrete that conveyed it 98 mi through the western Mojave Desert.

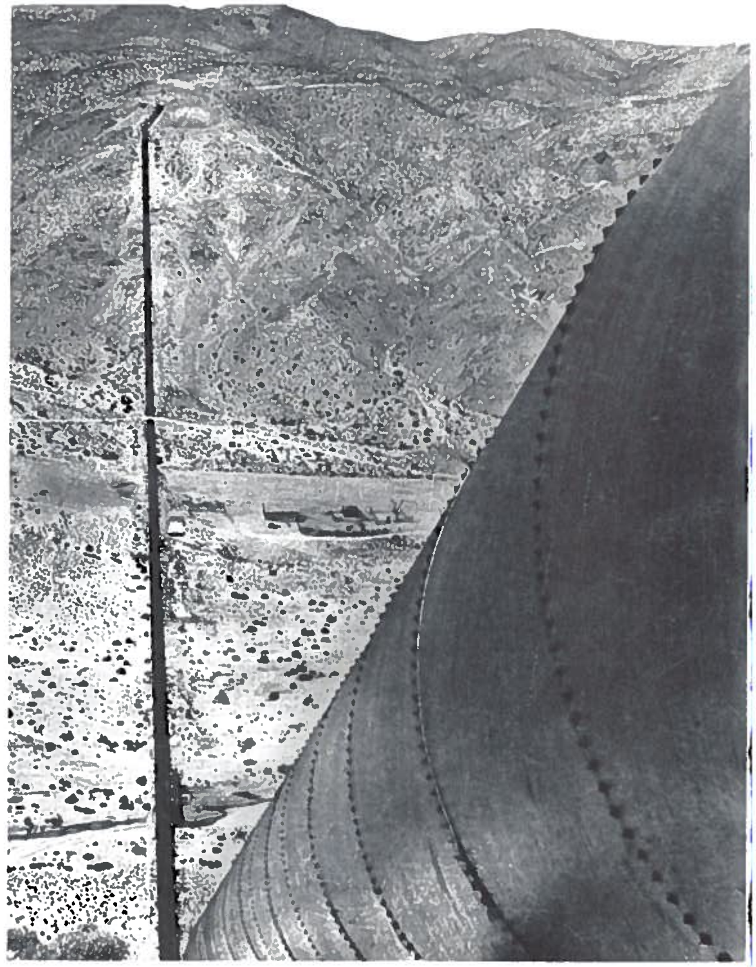
When at last the water reached the northern base of the mountains just north of Los Angeles, it entered a second reservoir and then passed into the 26,870 ft long Elizabeth Tunnel, which carried the water beneath the crest of the mountains. In San Francisquito Canyon, three hydroelectric plants converted the energy of the descending water into electricity. The



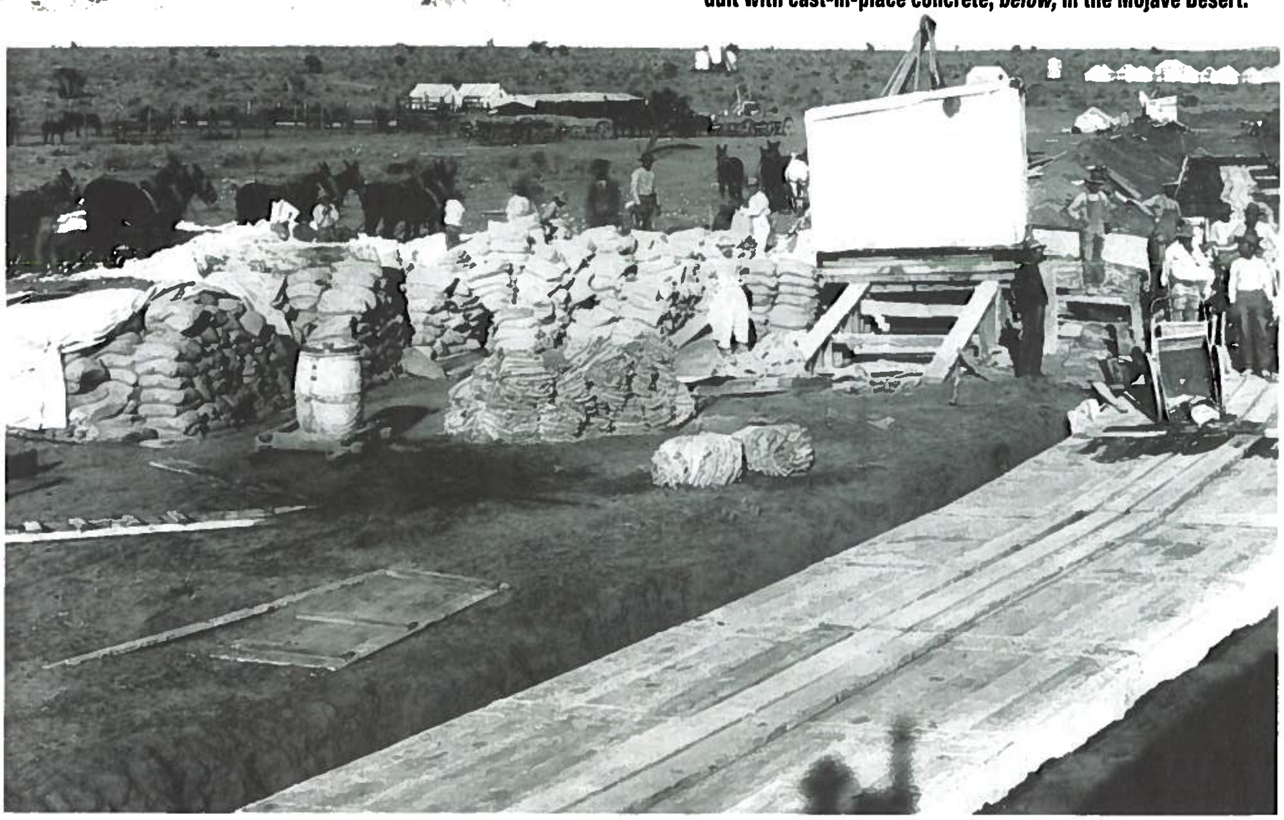
water was then collected in another reservoir and conveyed to a terminal reservoir in the San Fernando Valley. From there it would be distributed to the city.

The Elizabeth Tunnel was the longest of the 142 tunnels on the aqueduct. These conveyed the water a total distance of 43 mi, and there were an additional 9 mi of tunnels associated with the hydroelectric plants.

Mulholland understood that efficient tunnel construction would be of paramount importance in completing the project on schedule and within budget. To encourage speed, he set up an incentive system. For example, the men excavating the Elizabeth Tunnel were expected to progress at least 8 ft per day. If they exceeded this minimum, however, they would receive a bonus of 40 cents per man for each additional foot. The



Where the aqueduct had to cross deep canyons, Mulholland employed inverted steel pipe siphons, the most impressive of which was in Jawbone Canyon, *above.* Construction required hauling huge pipe sections up steep slopes, *left.* Workers cover the conduit with cast-in-place concrete, *below,* in the Mojave Desert.

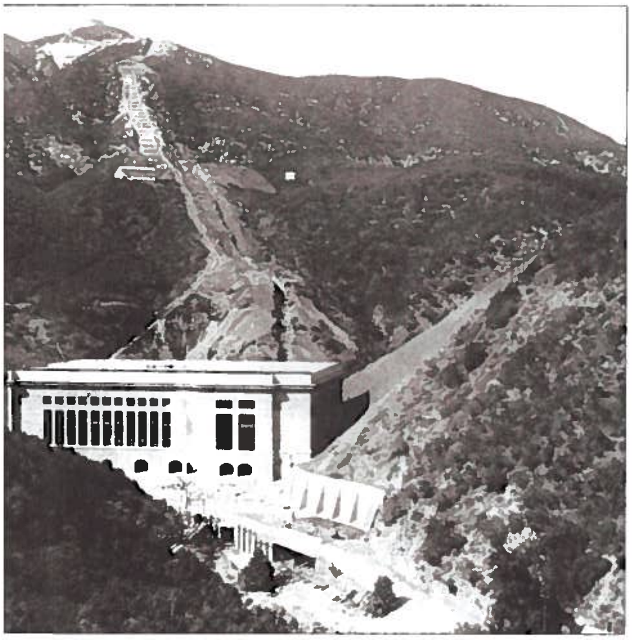


Mulholland understood that efficient tunnel construction would be of paramount importance in completing the project on schedule and within budget. To encourage speed, he set up an incentive system.

system worked. The 10 ft wide by 12 ft tall horseshoe-shaped, concrete-lined tunnel was completed on February 28, 1911, or 450 days ahead of schedule. In their final construction report, city officials noted proudly that the Elizabeth Tunnel crew had driven through 604 ft of hard rock in a single month (April 1910), setting a new American record for work done using nothing but hand drills, dynamite, mules, and railcars.

Where the aqueduct had to cross canyons that were particularly deep and wide, Mulholland used inverted steel pipe siphons, which made up 12 mi of the aqueduct route. The siphons typically were formed of riveted steel pipe, although in some locations concrete was used to reduce costs where the water pressures were relatively low. The most impressive of these structures was the 8,095 ft long pressure siphon across Jawbone Canyon, which plummeted 850 ft to the floor of the canyon before ascending the opposite canyon wall. The siphon pipe varied from 7.5 to 10 ft in diameter, and its walls were up to $1\ ^1/_8$ in. thick. The longest siphon, however, was in Antelope Valley. Its length was 21,800 ft, including 15,600 ft of steel pipe.

Construction officially began on October 1, 1908. The project was completed five years later, on time and under budget. In a ceremony on November 5, 1913, some 40,000 spectators gathered at the lower end of the aqueduct and celebrated as the waters of the Owens River poured out at their destination for the first time. When it was time for Mulholland to present the aqueduct to the city, he uttered just five words: "There it is. Take it."



Hydroelectric plants, *above left*, were included in the project to generate electricity. Some 40,000 people attended the opening ceremony, which was held on November 5, 1913, *above right*.

Not everyone cheered. Those living in the valley of the Owens River bitterly opposed the diversion of water from their homes and farms. But there was no going back. The aqueduct fueled the growth of the booming metropolis, which soon needed even more water. The original aqueduct was extended north to the Mono Basin in 1940. The following year marked the opening of another aqueduct delivering water to Los Angeles, this one from a completely different source—the Colorado River. And in 1970 yet another aqueduct opened, roughly parallel to the first, bringing even more water from the Sierra Nevada.

The legacy of the first Owens River–Los Angeles Aqueduct is controversial in that population growth is intensifying competition for water resources in California and, indeed, throughout the American West. What is not controversial, however, is the enormity of this engineering achievement. Designed to deliver 260 million gpd, the Owens River–Los Angeles Aqueduct was the first aqueduct ever to supply water to a metropolitan area on such a large scale, and it was accorded landmark status in ASCE's Historic Civil Engineering Landmark Program in 1971. In this, the aqueduct's centennial year, its contribution to the prosperity of Los Angeles is worth celebrating.

—JEFF L. BROWN

Brown

Jeff Brown is a contributing editor to Civil Engineering.