William Mulholland: Father of the Los Angeles Municipal Water Supply System

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Abstract

William "Bill" Mulholland (1855-1935) a self-taught civil engineer, who at the zenith of his career was the highest paid public official in California and the most respected man in Los Angeles in 1926. His storied career came to an abrupt end with the catastrophic failure of the St. Francis Dam in March 1928. A native of Belfast, Mulholland took to the seas at age 15, and in 1878 took a job as a ditch tender for the Los Angeles Water Company. He rose through the ranks to supervise the drilling of wells and constructing a system of distribution. When the water company was absorbed by the City in 1902, Mulholland hired as the general manager of a metered municipal water system. He possessed a willingness to work in the field under difficult conditions and was a natural leader and problem solver, who brought all of his projects in on time and on budget. For Bill Mulholland and the hundreds of civil engineers whom he influenced, their challenge was that of harnessing nature to build a better world, providing the water that was essential to the growth of southern California. His crowning achievement was the First Los Angeles Aqueduct, constructed in 1906-13. With a gravity fall of 3,260 feet and a length of 233 miles, no one imagined that its delivery capacity would be found insufficient less than a decade after its completion.

FROM IRELAND TO LOS ANGELES

Most people raised in Los Angeles County are vaguely aware of the name Mulholland, because of Mulholland Drive which follows the crest of the Santa Monica Mountains. Those living in the Hollywood Hills may be aware of Mulholland Dam, the structure that retains Hollywood Reservoir, or the Mulholland Memorial Fountain in nearby Griffith Park. Bill Mulholland was a giant of his time, who, like the mythical Horatio Alger, who began his career as a common laborer, and capped it as Chief Engineer of Los Angeles water supply system from 1886 until 1929.

Born in Belfast, Ireland on September 11, 1855, but raised in Dublin from age 5, going by the nick-name "Willie." When he was seven, his mother died shortly after delivering her 6th child. Willie and his two brothers attended a local Christian Brothers School. Mulholland's father re-married three years later, and young Bill decided to took to the seas at age 15, during an age when Great Britain sported the largest merchant fleet in the world. Willie landed in New York as a journeyman sailor four years later (in 1874) and found seasonal employment in Michigan logging in the winters and as a sailor on Great Lakes freighters in the summers. In the fall of 1875 he met his younger brother Hugh at the home of their deceased mother's brother, Richard Deakers and his wife Catherine, who operated a dry goods business in Pittsburgh (Mulholland, 2000). Here they remained for almost two years, until their aunt and her six children booked passage on a steamer for California, departing New York on December 9, 1876 with Willie and his brother Hugh as stowaways. Discovered shortly before reaching Panama, the pair were unceremoniously dumped on the customs dock in Colon, where they were obliged to walk the 50 miles across Panama because they could not pay the $25 fare charged by the Panama Railroad (their aunt and her children took the train and continued onto Los Angeles).

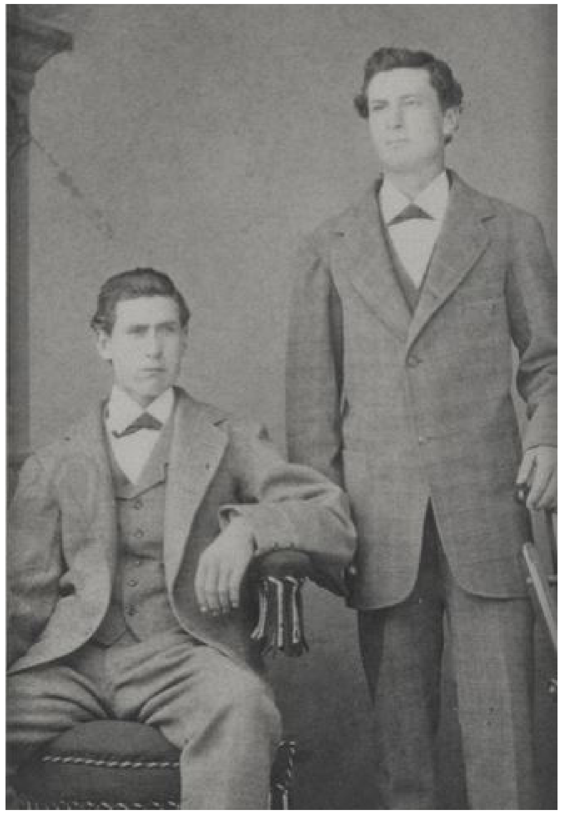

Figure 1. 1878 photograph of William Mulholland (standing) and his brother Hugh Patrick, who was 11 months younger (Catherine Mulholland Collection, CSUN Oviatt Library).

On the Pacific side, Willie and Hugh found a Peruvian naval vessel sailing north, who accommodated the pair in exchange for their shoveling bunker coal. They were left in the Acapulco, where they managed to secure passage to San Francisco, by working in a similar fashion. From San Francisco, the pair took made their way to Martinez, where they purchased a pair of horses and made the 400-mile overland trek top Los Angeles. When they arrived in January 1877 the city's population was almost 9,000 people and it was battling a smallpox epidemic.

The Pueblo of Los Angeles had recently welcomed the arrival of the Southern Pacific Railroad the previous September (1876), hastened by a local gold rush centered round Coso, in southwestern Inyo County (north of the Mojave Desert). The area also found itself in the throes of the worst drought of the 19th Century, which killed 400,000 head of cattle in southern California. His Aunt Catherine had lost three of her six children to sickness on their voyage from Panama to Santa Monica (Mulholland, 2000).

After a month of seeking work, Willie decided he had seen enough of this dusty, drought-ridden land, and decided to return to the sea. While walking to San Pedro he ran into Manuel Dominguez, one of the heirs to Rancho San Pedro, one of the largest Spanish Land Grants. Dominguez hired Mulholland to hand excavate artesian water wells in the coastal plain of is now Compton. At a depth of about 600 feet the workers encountered wood from a tree, as well as numerous marine fossils. These discoveries caught Mulholland's fancy, so he sought to learn more about geology and hydrology (Kahrl et al., 1979). At the Los Angeles Library he secured a copy a book on geology from the public library, which turned out to be Joseph Leconte's *Elements of Geology*, which had just been released (1877). Leconte was a Professor of Geology at the

University of California in Berkeley. His classic text remained in print for 17 years and was used by colleges across the United States. Mulholland would occasionally quote from it for the balance of his lifetime, much to everyone's amazement (Lippincott, 1941).

In 1877-78 Willie and Hugh (Fig. 1) decided to try their luck at prospecting, and struck out easterly, for the Colorado River, along which dozens of new mining camps had sprouted up over the previous 15 years, mostly on the Arizona side. They found employment with one of the steamboat firms (Pacific & Colorado Steam Navigation Co. or the rival Colorado Steam Navigation Co) which operated out of Yuma, delivering essential goods from California and taking ore back east, on the Southern Pacific. At this time the village of Ehrenberg (across the river from present-day Blyth, CA) was the watery portal to wagon trains transporting ore to the nearest railhead at Maricopa, south of Phoenix. It was here that the two Irishmen decided to "work the placer deposits," which had been discovered in 1863 and worked over by numerous wildcaters. Their mining sojourn was interrupted by the Indian uprisings of 1877-78. When the American 6th Cavalry rode into the village warning its residents about the dangers of being caught alone outside of the village, the Mulholland brothers decided it was time to return to the Pueblo of the Angels, and so began a new chapter of Willie's life.

ZANJERO TO SUPERINTENDENT

When Mulholland returned to Los Angeles in the spring of 1878 he was 22 years old and looking for whatever opportunities he could find. He found a seasonal position with the privately-held Los Angeles Water Company as a deputy "Zanjero," or water ditch tender. His responsibilities centered around maintaining the city's main supply of water between Crystal Springs and the old downtown, centered around Olivera Street. Crystal Springs was where the William Mulholland Memorial Fountain was constructed in 1938-39, near the southeast corner of Los Feliz Boulevard and Riverside Drive. In 1878 the earthen ditch ran parallel to the Los Angeles River and required round-the clock maintenance whenever the weather became wet and the river rose, or during dry periods, when water could easily disappear into desiccation cracks. Young Mulholland, who now went by the sobriquet "Bill" or as the smaller Chicanos called him, "Big Bill," learned the craft of maintaining municipal water systems in an era accompanied by countless sources of organic debris and filth, without any municipal collection of horse droppings, garbage, or trash (Lippincott, 1941).

In the tradition of apprenticeship that typified that era, Mulholland found ways of educating himself through reading and interacting with others in his line of work. Much of his success came from his habit of reading technical literature and then applying those principles to the problems at-hand. His disdain for administrative work was typical of a field man, but seldom hurt him because he possessed a phenomenal memory. Mulholland was so serious about his work that one day when a man dressed in a business suit asked him some questions about what he was doing, he replied "None of your damn business!" It turned out that the man was one of the owners of the water company. Instead of being offended, he was impressed that Mulholland performed his duties as if he owned the company. Mulholland was gradually accorded more and more responsibility, and by the fall of 1886, was named superintendent of the L.A. Water Company. It was a position he would retain for the next 43 years.

During some torrential flooding in December 1889, the Los Angeles River overflowed its banks and cut a new channel that severed the brick-lined Zanja Madre (Mother Ditch) that conveyed water from Crystal Springs to the downtown business district, which included the train stations. The eroded sand filled the Zanja Madre conduit, which was 3.5 feet in diameter. Mulholland departed his home on Christmas Eve and remained engaged in supervising repairs for four days before returning home (Mulholland, 2000). No municipal hook-ups outside of the business district were disrupted during the holidays. Word of his good deed spread over the holidays, and a grateful water company awarded to him a gold watch at a company dinner, which he carried the rest of his life.

Two weeks after receiving his coveted gold watch, the 34-yr old Mulholland (Fig. 2) married Lillie Ferguson on July 3, 1890. She bore him five children before dying of cancer at age 47, on April 28, 1915. At the time of her death Mulholland had reached the peak of his professional career, having received an honorary doctorate from the University of California in Berkeley the previous June. The inscription on the diploma read "*Percussit saxa et duxit flumina ad terram sitientum*" (He broke the rocks and brought the river to the thirsty land). He never re-married.

The turn of the Century in 1900 brought about life-changing events for everyone connected with Los Angeles. Years after Mulholland's death his colleague J.B. Lippincott (1939) would recall:

> "*When the franchise of the Los Angeles City Water Co expired in 1898, a valuation of the property became necessary to determine the price to be paid for it by the City. The city employed a Board of Engineers, which included the writer [Lippincott], to present its case to the arbiters, and this Board called upon Mr. Mulholland, Manager and engineer of the company, for information.*
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> *As is frequently the case with people of fine memory, Mr. Mulholland's records were not perfect. After the Board of Engineers, as politely as it could, had expressed an opinion that these records were not sufficient for a proper valuation of the property, Mr. Mulholland asked, "Well, what isit that you want?"*
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> *Said one member of the Board: "The thing we want is a complete list showing the length of pipe, its size, character, and its age. We also want to know the number of gate valves and all about them, as well as fire hydrants and other structures connected with the water system*".
>
> *Upon hearing this sweeping request, Mr. Mulholland spread out on a drafting table a map of the city and gave from his memory the size, kind, and age of the pipe in every one of the city streets in which it was laid. He also designated the gate valves and hydrants. The Board expressed surprise in his memory, but stated that it did not feel that an inventory made in this way was adequate. Consequently, we indicated, with red circles on the map, 200 places throughout the city where we wished to have the [buried] pipe exposed to view.*
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> *Mr. Mulholland was not disturbed in the least over this request. In fact, he seemed rather pleased. He had the pipe dug up in the 200 places indicated; the Board of Engineers actually inspected and classified the condition of all the pipe exposed; and the inspection indicated that Mr. Mulholland's memory was correct in every particular. We thereupon accepted the complete inventory which he had prepared from memory.*
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> *When the city finally acquired the water company's properties in 1902, at a cost of $2,000,000, Mr. Mulholland was retained as manager of the system."*

Mulholland enjoyed a reputation as a working stiff who could get big things done (Taylor, 1982). He possessed a charisma unusual for an engineer, and his down-and-dirty working man perspective made him popular with construction workers, as well as water and power employees. At the zenith of his career he was the highest paid public official in California (Kahrl, et al, 1979). The personification of a field general, Mulholland he surrounded himself with talented engineers. The men he hired, such as Harvey Van Norman, W. W. Hurlbut, Edward Bayley, Charles Lee, and Ralph Proctor, were men not unlike himself: hard-working, to a large degree self-educated, and exhibiting a willingness to work under difficult field conditions.

THE LOS ANGELES AQUEDUCT

After record-setting floods in the 1880s, drought conditions persisted in Los Angeles during the 1890s. The city's expanding population created an untenable situation for supplying sufficient water, especially for fire protection. In 1898 the Los Angeles City Water Company lost its franchise as the sole provider to the City of Los Angeles (Nadeau, 1993). The company was acquired by the City in February 1902, and after the series of interviews described earlier, William Mulholland was appointed Superintendent of Water Works. During his first three years he was given ample opportunity to demonstrate his skills and abilities as a water resources manager by rebuilding the City's outdated distribution network, cutting the water rates for domestic service in half, and turning a hefty profit of $640,000.

During its first year of municipal ownership a water audit revealed that Los Angeles citizens had consumed as much as to 26 million gallons per day (gpd). Mulholland began installing water meters to reduce consumption and increase operating profits, and the per capita usage was reduced to 200 gpd, which was considered an acceptable figure. But, it was a losing battle because of Los Angeles' increasing population. In 1899, while Fred Eaton was mayor, the City surpassed the 100,000 mark in population (reaching 102,479 in 1900). By 1904 that number had swelled to 175,000. To those charged with providing water, it was becoming apparent that the Los Angeles basin was incapable of supporting more than about 200,000 people with the water resources available from all sources within the Los Angeles River's watershed (by 1910 the City's population had increased three-fold in a single decade, to 319,198 people).

Mulholland's frustrations began to swell with the drought of 1904, when only 8.74 inches of rain fell on Los Angeles, about half of normal. Having exhausted the underground aquifers within the Los Angeles River watershed, he soon found himself enveloped in the political swirl of a full-blown water crisis. His water dilemma had been predicted by his mentor at the Los Angeles City Water Company, former City Engineer and Mayor Fred Eaton (Fig. 2). Mulholland had succeeded Eaton as Superintendent of the water company when Eaton became the L.A. City Surveyor and Engineer in December 1885. Eaton was re-elected to a second one-year term in December 1886, and again in 1889-90. During the drought of 1893-94, Los Angeles only recorded 6.7 inches of rain. As an adjunct activity of his City Engineer duties, Eaton had undertaken a search for alternative sources of water in the Sierra Nevada Mountains as far north as the Kings River, and east to the Colorado River (Nadeau, 1993). In 1892 or '93 Eaton scouted the Owens Valley as a water source and informed Mulholland of its favorable potential as a water source for Los Angeles. At that time the two disagreed as to whether an out-of-area water source would be necessary to meet demands during drought years.

Born in the Pueblo of Los Angeles in 1855, Eaton understood the bitter effects of extended droughts in the Los Angeles Basin better than all of the transplanted folks. Two out of every three years brings "below average precipitation" to Los Angeles because of the occasional sub-tropical deluges that impact the coast on average about once every three to five years. The precipitation cycles in 1861-62, 1883-84, and 1888-89 had been particularly severe spikes, such that "average" precipitation values were of little use or consequence for long-range planning, because they lacked the means of storing the excess runoff, or even encouraging its percolation into depleted coastal aquifers. In 1899 Eaton became the first native-born Mayor of Los Angeles, serving for two years. In 1899 Eaton became the first native-born Mayor of Los Angeles, serving for two years.

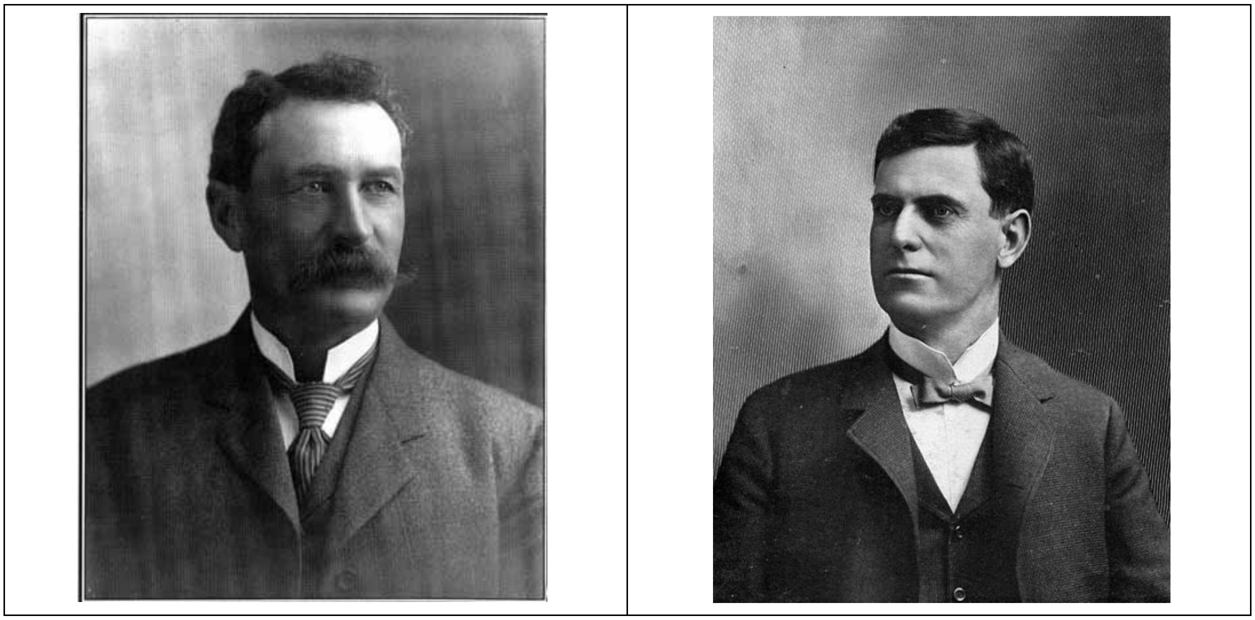

Figure 2. William Mulholland at left, and his mentor and colleague Fred Eaton, at right. In 1904-05 the two men conceived the idea of constructing an aqueduct ~240 miles long, linking Los Angeles to the Owens River emanating from the eastern escarpment of the Sierras.

By 1904 the water situation in the Owens Valley began to change. In August of that year Eaton accompanied J.B. Lippincott and J.C. Clausen of the newly-formed Federal Reclamation Service on a tour of the Owens River watershed, which had been under study the previous year. Lippincott was a veteran water resources engineer in southern California, who had recently accepted a position with the Reclamation Service as their Southwest Bureau Chief. His assignment was to develop as many workable irrigation projects as possible, to bolster political support for the new reclamation agency and its guiding light, Frederick H. Newell (Hoffman, 1981). After a favorable reconnoiter of the Owens watershed, Eaton returned to Los Angeles and hurriedly began considering what Los Angeles might do to enter the competition for the waters of the Owens River. All of the Owen Valley lands then under study by Reclamation were held by the U.S. Department of Interior under the tenets of the 1902 Reclamation Act. If the City didn't move quickly, they would lose any chance of securing any legal claim to the water.

In late September 1904, Eaton returned to Owens Valley with Bill Mulholland, the pair keeping a low profile amongst the valley's residents. The purpose of their trip was to reconnoiter the feasibility of building an aqueduct to convey water from the Owens River across the Mojave Desert and Sierra Pelona Mountains to Los Angeles. Mulholland returned convinced that an aqueduct could be constructed.

In theory, the concept of an aqueduct utilizing gravity flow had numerous advantages over any of the competing rivers then under consideration. Owens Lake, the terminus of the river's natural flow, was at an elevation of 3560 feet above sea level, while downtown Los Angeles' elevation of just 300 feet allowed for a drop of more than 3,260 feet. After pouring over topographic profiles they decided to situate the aqueduct's intake 12 miles north of Independence near elevation 3900, and convey the water an incredible 233 miles southward. This would allow a hydraulic grade of over 15 feet per mile, more fall than any other aqueducts preceding it. The surplus hydraulic energy head meant that sag pipes (often referred to as inverted siphons in the media of the era) and pressure tunnels could be utilized to traverse difficult terrain.

A natural problem solver blessed with charisma, Mulholland could be very stubborn about principles. We can catch a glimpse of this character trait in the long-standing feud between himself and his mentor Fred Eaton, who had preceded him as Superintendent of the L.A. Water Company. It was Eaton who conceived the idea of capturing the waters of the Owens River and conveying this precious resource to Los Angeles. With inside knowledge that the citizens of Los Angeles might vote approve a future proposal to construct a mighty aqueduct to tap the Owens River, in March 1905 Eaton purchased 20,000 acres of land in the Upper Owens and Long Valleys from the Rickey Land & Cattle Co., for $450,000 ($22.50 per acre). Within a year and a half he sold 8,000 acres of his holdings to the City at cost ($22.50/acre), but retained 12,000 acres in Long Valley, which included the prime site for a dam that could retain a storage reservoir storing 260,000 acre-feet with a dam 140 ft high. For 25 years Eaton tried in vain to sell his Long Valley property to the City, initially for $750,000, or about $62.50 per acre. Eaton profiting at the public expense was not something a man like Mulholland could accept, and he exerted pressure to hold off on its acquisition. After Mulholland retired, the property went into foreclosure and the City purchased the land for $650,000 in December 1932. In 1938-41 the Department of Water & Power (DWP) constructed Long Valley Dam. Just 126 feet high, it retains Crowley Lake, the largest storage facility on the Los Angeles Aqueduct, capable of retaining 183,650 ac-ft

Feasibility studies. Mulholland asked the City's Board of Water Commissioners for $1.5 million to undertake engineering studies of the scheme (Kelly, 1916). These funds were quickly made available, a real testimony to Mulholland's credibility and the serious nature of the City's desperate need for water. In the spring of 1905, the Water Commissioners appointed a Board of Engineers to investigate all of the potential sources of additional water for the City. The panel was comprised of Mulholland, J.B. Lippincott and O.K. Parker (when Lippincott's contract with the Reclamation Service ended in 1906, he was hired by Mulholland as Assistant Chief Engineer of the Aqueduct). The panel's likely purpose was to demonstrate that the Owen River presented the best alternative, and the appointment of Lippincott had strategic significance, given his position with the Reclamation Service then overseeing studies of the Owens River (Hoffman, 1981). The alternatives including the San Gabriel River (283 mi^2), Santa Ana River (728 mi^2), Mojave River (211 mi^2) and the Kern River (2,345 mi^2). Conveying water from the Mojave or Kern Rivers would require tunnels of unprecedented length to transport water through Cajon Pass (for the Mojave) or either Tejon or Tehachapi Passes (for the Kern).

It was the Owens River that exhibited enormous potential. Its expansive watershed encompassed 2,604 square miles, and its water could be diverted southward from a much higher elevation than the any of the alternatives. The fact that Mulholland had never constructed hydraulic structures, such as pressure tunnels and sag pipes, never seemed to diminish his confidence that these things could be accomplished by a judicious review of the published literature on the subject.

The initial goal was to secure sufficient water to supply 390,000 inhabitants with an average per capita consumption of 150 gpd, requiring 58 million gallons per day (gpd). Though not nearly the capacity of New York's new Croton Aqueduct (capable of 340 million gpd), an aqueduct 233 miles long was without precedent. The longest of the numerous Roman aqueducts, at Marcia, had a length of just 58.4 miles.

Mulholland was a prodigious reader of the technical literature, and was very involved in the activities and publications of the American Waterworks Association (AWWA). In 1885-93 New York had succeeded in constructing a new Croton Aqueduct, which employed a near-continuous pressure tunnel, the first ever completed. Their aqueduct was 45 miles in length and used a sag pipe seven miles long and up to 420 feet deep to pass beneath the Harlem River. Massive steel sag pipes, steam-powered shovels, and gasoline powered tractors were recent technological triumphs that would allow for an Owens River aqueduct to become reality.

Figure 3. The independent Board of Engineers appointed to review Mulholland's scheme for the Los Angeles Aqueduct in the Owens Valley in 1906. From left, John R. Freeman, James D. Schuyler, Joseph P. Lippincott, Frederick P. Stearns, and William Mulholland.

Mulholland's earliest hurdles were securing the trust of the City's political base, then from bond measures passed by the electorate in June 1907. The enormity of the undertaking drew skeptics from the outset. Engineers, newspaper editors, and electric power interests pointed out the unprecedented scale of the project and Mulholland's lack of experience with such facilities, which were infinitely more complex than an ad hoc systems of buried pipes and some shallow wells in the Los Angeles River. These critics argued that the project was a desperate gamble, and that its failure could place the city in receivership.

Seeking to diminish as much criticism as possible prior to the $24 million bond election, the Water Commissioners appointed an Aqueduct Advisory Board, comprised of three nationally-known civil engineers: John R. Freeman, James D. Schuyler and Frederick P. Stearns (Fig. 3). They made an independent evaluation of the proposed aqueduct. The board reviewed the project's design feasibility, constructability, pricing and logistic requirements. The Board found the aqueduct "admirable in conception and outline" in their report released during the fall of 1906. Few engineers dared to criticize the project after the panel's review was released, due in large part to the clout and credibility of John R. Freeman, one of the principal consultants for New York's New Croton Aqueduct.

Final Plans and Construction. The aqueduct intake was intended to divert water from the Owens River at a pair of headgates about 12 miles north of Independence, at an elevation of 3714 feet (Fig. 4). Whenever Owens Lake filled to capacity, the overflow continued southward, sculpting the lower Owens Gorge, intermittently flowing through Rose Valley, across a series of lava dams at Little Lake, into Indian Wells Valley, which contains China Lake at its eastern end. It was in this channel just above the lower Owens Gorge waterfalls that Mulholland decided to build the principal storage and regulation reservoir, known as Haiwee Dam and Reservoir (Fig. 5). With a storage capacity of almost 60,000 acre-feet, Haiwee controlled discharge entering the covered sections and sag pipe crossings between the Owens Valley and Mojave.

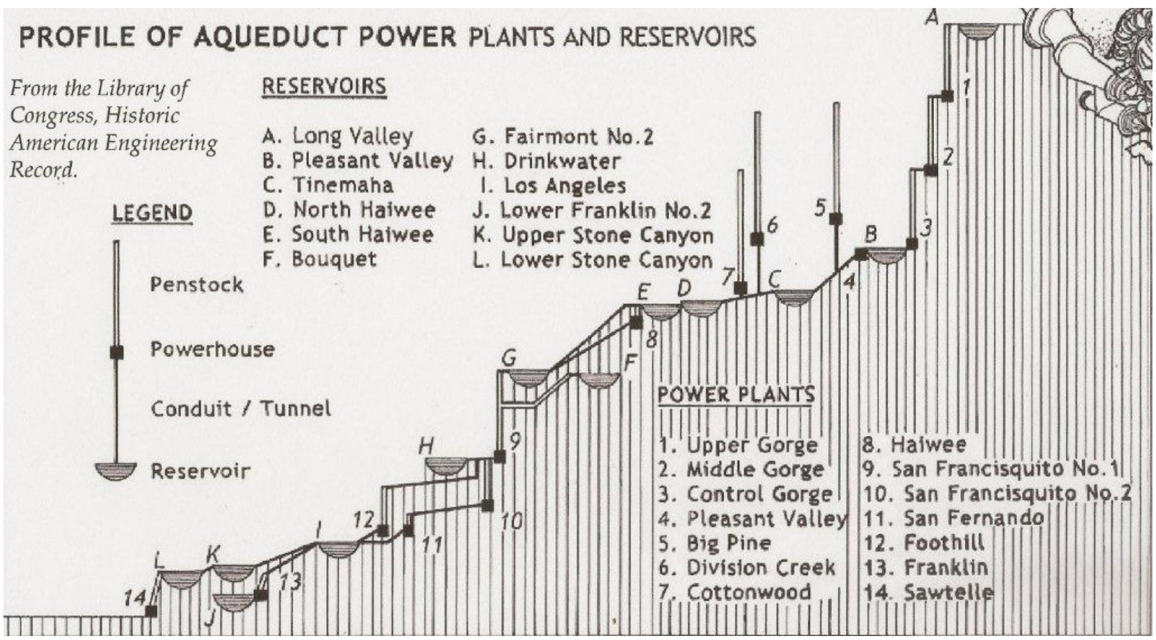

Figure 4. Profile of the Los Angeles Aqueduct, between Loing Valley Dam/Crowley Lake (A) and Sawtelle (14), just north of the downtown area (LOC-HAER).

From its intake north of Independence south to Haiwee the aqueduct was constructed mostly as an open channel. South of Haiwee the Owens Valley narrows and the crosses increasingly rugged country. In this area most of the aqueduct was built as a cut-and-cover box channel. The flatter sections were excavated using rail-mounted steam shovels and immediately lined with concrete. This system advanced at an average rate of about four miles per month. The life blood of the project was a standard gage rail line constructed by the Southern Pacific Railroad between May 1908 and October 1910, extending northward from Mojave to the Owens Valley. 320,000 tons of construction hardware would be carried along this line before the aqueduct was finished.

More than a million barrels of Portland cement was needed to line the canals, tunnels and cut-and-cover sections. J. B. Lippincott (1913) engaged in some local geologic studies and discovered requisite quantities of limestone for calcining cement at a location about 17 miles above Mojave, along the rail line crossing Tehachapi Pass. Originally called Aqueduct, the name was changed to Monolith in 1910. It became the largest cement plant in the United States, and continues in operation to present. The plant was also utilized for aggregate production, transporting all of the needed materials on the Southern Pacific Railroad to Mojave.

Along the western slope of Indian Wells Valley, a series of sag pipes (referred to at the time as inverted siphons) allowed the line to cross significant valleys (a total of 23 sag pipes totaling 11.4 miles in length). Eight of the sag pipes, comprising 2.7 miles, were 10 ft in diameter, while the rest were between 7.5 and 11.5 ft diameter. The sag pipes allowed the aqueduct traverse steeply-incised ravines emanating from the southern Sierras and Garlock fault zone. The largest of these was across Jawbone Canyon, about 20 miles north of Mojave (Fig. 5). Here the 7,000 ft conduit drops 850 feet. The siphons required huge sections of riveted steel pipe had to be fabricated in Pennsylvania steel mills and shipped via rail to Mojave, from where they were transported on wagon dollies pulled by 52-mule teams.

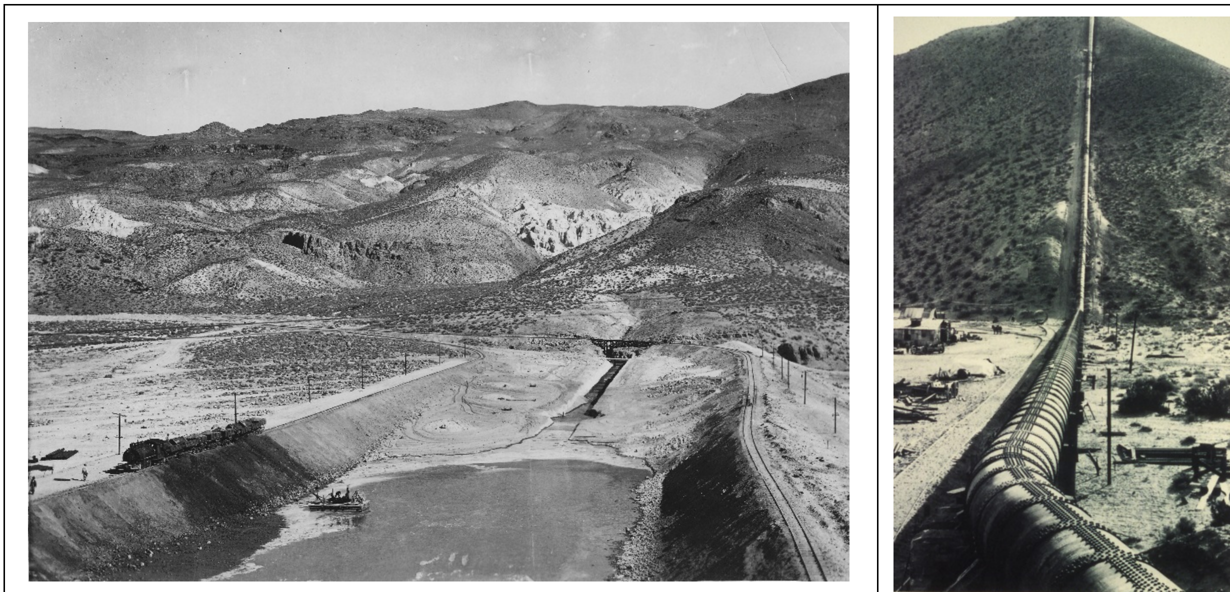

Figure 5. Left view shows Haiwee Dam under construction in 1911. All of Mulholland's embankment dams utilized hydraulic filling and puddling techniques, shown here. Right image shows the Sag Pipe crossing Jawbone Canyon, dropping and rising 850 feet (LADWP Archives).

When water was introduced into the sag pipes in early 1913, the line across Sand Canyon (10 miles south of Little Lake) began leaking and lifted up out of the canyon slope and become entangled in a landslide spurred by the seepage. This experience (understanding uplift forces) was a harbinger of things to come at St. Francis Dam 15 years later. Correcting these problems with the siphons added six months to the completion schedule.

Seismic hazards and the Elizabeth Lake Tunnel. Southwest of Mojave the aqueduct skirted the foot of broad alluvial fans emanating from the southern Tehachapi Range. The aqueduct crossed the western end of the Antelope Valley in a four-mile long sag pipe drops from 3100 to just below 2850 feet. A covered section then ran covered along the base of the Sierra Pelona Range, its escarpment controlled by the San Andreas fault. It was this section of the fault that spawned the January 1857 Ft. Tejon M7.9 earthquake, which witnessed up to 31 feet of right-lateral ground offset. This quake, along with the 1872 Owens Valley event, are two of the three largest earthquakes ever recorded in California.

The aqueduct required the excavation of 142 tunnels totaling 43 miles in length. The longest and most important of these was the Elizabeth Lake Tunnel, which passed beneath that body of water, a natural sag ponds in the San Andreas fault zone. The five-mile long tunnel was of rectangular section, measuring 10 by 12 feet, and conveyed water southward, between elevations 3030 and 2980. A hard rock tunnel piercing granite, the tunnel was advanced from either end simultaneously. On several occasions disasters loomed, especially in crossing the fault. The North Portal teams of drillers, blasters, and muckers was led by Big John Grey. His teams suffered numerous cave-ins and floods in the roughly 4,000 ft wide fault zone. In one instance Grey's brother Louis was trapped with four men in a cave-in combined with a wall of water, which almost drowned them. After digging furiously for 11 hours, the men were rescued (Taylor, 1982). In another case Mulholland had a 2-inch pipe pushed through a cave-in debris through which air, water, and hard boiled eggs were supplied to the trapped miner until he could be safely extracted (Davis, 1993).

Six million pounds of dynamite were expended in excavating the projects tunnels. Five lives were lost in blasting mishaps, including three men working in the Clearwater Tunnel on June 16, 1912. This was a remarkable record of safety at the time, given how many detonations were being handled each shift. Catherine Mulholland credits this to the use of the finest and most reliable blasting caps, which were imported from Germany (Mulholland, 2000).

Mulholland decided to employ a quota system for the Elizabeth Lake Tunnel. His quota was initially set at 4 ft per day, gradually increasing to 8 ft per day, with cash bonuses for exceeding the quota. This practice had an enormous impact of accelerating the project ahead of schedule. His miners were divided into north portal and south portal teams, which competed with one another. The South Portal crew led by William Aston set a hard-rock tunneling record of 604 feet in the month of April 1910. The next month the North Portal team achieved an advance of 567 feet, stunning given the fact that this group had to deal with the San Andreas fault zone, 400 feet beneath Elizabeth Lake (Mulholland, 1918).

Municipal power generation. Around three miles past the south portal of the Elizabeth Lake Tunnel the aqueduct drops almost 900 feet, into upper San Francisquito Canyon. At the toe of this erosional escarpment the City's fledgling Bureau of Power & Light (BPL) constructed San Francisquito Powerhouse No. 1 in 1916-17. The aqueduct then passed through a series of tunnels excavated in the Pelona Schist along the southeastern side of the canyon, well above the valley floor. A second powerhouse was completed in 1920, where the aqueduct drops another 485 feet, to the floor of lower San Francisquito Canyon. The two drops in San Francisquito Canyon were the highest along the 233 mile path of the aqueduct. With this humble beginning, BPL grew to become the largest publically-owned utility in the nation.

From S F Powerhouse No. 2 the aqueduct re-entered the southeast canyon wall as a continuous tunnel, passing into Dry Canyon. The line then crossed Dry Canyon and entered tunnels passing through the hills east of what is now Santa Clarita, then crossing Bouquet Canyon and the Santa Clara River in Soledad Canyon using 10-feet diameter sag pipes. About a mile south of

Soledad Canyon the line enters another tunnel piercing the San Gabriel fault, before turning south-east, utilizing sag pipe crossings of Quigly and Placarita Canyons. The last tunnel was between Placarita Canyon and south front of the western San Gabriel Range, just east of [San] Fernando/Fremont Pass. Here the mountains were lifted abruptly along the Santa Susana thrust. San Fernando Reservoir was constructed between 1911-1917, about a mile south of the Cascades, the aqueduct's southern portal. Construction began in October 1907 and was essentially completed in May 1913, at cost of $24.6 million.

Completion. Approximately 30,000 people had gathered to watch the first Owens water flow down the open channel aeration cascade at the mouth of Fernando Pass on opening day, November 5, 1913. At the time of its completion it was the longest aqueduct in the world. It could transport 258 million gallons of water every day, all by power-free gravity flow. The hydroelectric power generated in San Francisquito Canyon would eventually pay for the entire project. It was a project that dominated western newspapers for six consecutive years, and was an accomplishment which drew notice the world over. Mulholland's Los Angeles had done something no other major city had accomplished previously: they had constructed a water supply infrastructure capable of sustaining anticipated growth ahead of their burgeoning population base. This was without precedent in all of human history. At the time of its completion (1913) nobody believed that Los Angeles would ever displace San Francisco as the State's largest, wealthiest, and most populace city.

The aqueduct's completion brought a unceasing stream of praise to Mulholland. Newspaper editors urged Mulholland's candidacy for Mayor, and the University of California bestowed an honorary doctorate upon him in June 1914. But, Mulholland had little interest in politics, and crowds roared with laughter when, in response to a question about his possible candidacy, he responded: "*Gentlemen, I would rather give birth to a porcupine backwards than be mayor of Los Angeles*" (Nadeau, 1993; p. 49). His humorous response was the quintessential personification of the "Chief," his nom de guerre within the Bureau of Waterworks and Supply (Van Norman, 1935).

Short-term Impacts. The pueblo's thirsts were quenched, at least for a while. Between 1900-1920 the City's population quintupled, to 576,000. From 1918 onward the City was growing in excess of 100,000 people per year. During the initial efforts to secure Owens River water in 1906, President Theodore Roosevelt had intervened on the issue over the abandonment of the Reclamation Service's plan for the Owens Valley. Roosevelt had sided with the City on the grounds that no water from the aqueduct would be ever be offered to private interests for resale as irrigation water outside of the City's limits. This alerted the real estate speculators who had purchased land in the semi-arid San Fernando Valley north of Los Angeles proper. These speculators began pushing for annexation of the valley between 1914-1923, which quadrupled the land area of Los Angeles, to 407 mi^2 (in 1913 only 3,000 acres had been under cultivation in the valley, but by 1917, that figure had jumped to 75,000 acres).

ANOTHER DROUGHT

During the aqueduct's first year of operation Los Angeles received 23.65 inches of rainfall, about 160% of normal. But, precipitation levels began falling soon after the November 1918 World War Armistice. The 1918-19 water year was a near-record low, only 6.67 inches of rain. This gave everyone a scare, but relief soon came with two successive years of above-average rainfall. The post-war land boom was in full blossom when a series of abnormally dry years commenced in

1922-23, when only 9.59 inches of rain fell. This was followed by 6.67 inches in 1923-24, and 7.94 inches in 1924-25 (the average annual precipitation from 1877 to present has been 14.93 inches). Los Angeles had never seen a 3-year cycle of drought. The effects of the drought stretched into the Sierras. By the spring of 1923 Haiwee Reservoir was at an all-time low (8,000 of its 58,500 acre-feet of capacity). During the three year drought of the early 1920s San Fernando Valley ranchers used about 45% of the aqueduct water, with their portion increasing each month. Mulholland suddenly had another water crisis to deal with.

Mulholland had engineered the aqueduct to serve 50 years of anticipated growth, but he had underestimated the rate of expansion and the seasonal flow fluctuation of the Owens River. At the height of the 1922-25 drought, the Owens River flow dropped to 262 cubic feet per second (cfs), about half of the aqueduct's capacity of 485 cfs (the average flow prior to the drought had been 355 cfs). The San Fernando Valley ranchers were drafting up to 277 cfs, more than all aqueduct's base flow. As the drought wore on, Mulholland was obliged to steadily reduce the rancher's share of the aqueduct's discharge. Worried about their livelihoods, the ranchers began exerting political pressure for more water.

Under pressure from the new Board of Public Service Commissioners to alleviate the water crisis, the newly formed Bureau of Water Works and Supply (BWWS) attempted to acquire additional Owens River watershed, upstream of the 1913 intake. They initially targeted ranches with established water rights and irrigation ditches drafting flow from the Owens River, above the City's intake. Ranchers soon got word of "impending sales" and held out for higher prices, while local merchants feared for their futures if ranchers sold out and moved away.

The City's agents began purchasing some of the key tracts, spending more than $3 million in 1924 alone. Those whose lands abutted the riverbank with established irrigation ditches commanded the most attention. For all their hasty purchases, BWWS received almost no additional water. In mid-1923 the residents of Big Pine became more proactive, taking a construction camp hostage and throwing city's equipment into the Owens River. After attempts by San Fernando Valley ranchers to purchase Owens water fell through, the first dynamiting of the aqueduct began in May 1924. This war of occasional sabotage and the attention-grabbing publicity it brought to newspapers continued through the 1920s and beyond.

MORE RESERVOIRS

For a practicing engineer like Mulholland, the city's water crisis of the early 20s was easily remedied by "sorting out the numbers." In the near term, the simplest solution was to construct more reservoir storage, so surplus flows of the Owens could be stored during wet years. More ominous was the revelation that the entire flow of the Owens River could not meet revised growth estimates for the Los Angeles area. The aqueduct had been constructed with the largest storage capacity at Haiwee, with a maximum capacity of 58,500 acre-feet. Fairmont Reservoir at the head end of the Elizabeth Lake Tunnel had a capacity of just 7,500 acre feet. The combined storage of the two reservoirs represented only 112 days of mean base flow, hardly enough to meet the shortfalls. In addition, both reservoirs were situated north of the ominous San Andreas fault. A repeat of the 1857 Ft. Tejon quake could be expected to sever the Elizabeth Lake Tunnel, severing access to the vast majority of their storage until the tunnel could be repaired (Lawson, 1914, p.15; Mulholland, 1918).

South of the San Andreas fault, there was Dry Canyon (1140 acre feet), [Lower] San Fernando (then 11,000 acre feet), Chatsworth 2 and 3 (9,850 acre feet); Upper Franklin Canyon

(123 acre feet); Silver Lake (2,162 acre feet), Bellevue (107 acre feet); Elysian (166 acre feet); Buena Vista (40 acre feet); Solano (17.5 acre feet); Hazard (8 acre feet), Mt. Washington (0.9 acre feet); Highland (61 acre feet); Garvanza (2.3 acre feet); San Pedro (26 acre feet) and Wicks [Rowenna] with 93 acre feet; for a total storage capacity of 24,796 acre feet, only 27% of the City's then-available storage.

With their dream of building Long Valley indefinitely on-hold, BWWS water bureau worked feverishly through the early 1920s to design and construct additional storage facilities, all within close proximity of Los Angeles and south of the San Andreas fault. What resulted was a second generation of reservoir construction, aimed at completing 67,000 acre feet of additional storage, increasing local storage capacity by almost three-fold.

TABLE 1
DAMS BUILT BY L. A. BUREAU OF WATERWORKS & SUPPLY (1921-26)

Reservoir Name	Height	Dam Type	Reservoir Capacity acre-feet	Years of Construction
Lower Franklin	96 feet	hydraulic fill & rolled earth	1,050	1921-22
Stone Canyon	147 feet	rolled earth	8,000	1921-24
Upper San Fernando	82 feet	hydraulic fill	1,850	1921-22
Lower San Fernando	raised 7 feet	rolled fill	additional 3,800, to 14,670	1924-25
Encino	135 feet	hydraulic fill	3,229	1921-24
Sawtelle	34 feet	rolled earth	103	1923-24
Ascot	73 feet	rolled earth	219	1925-26
Hollywood	200 feet	concrete gravity	7,500	1923-25
St. Francis	195 feet	concrete gravity	32,000	1924-26
Total added capacity			57,751	by mid 1926

Construction began on Stone Canyon Dam in the Santa Monica Mountains above what is now Bel Aire Estates in 1921. A tabulation of the major reservoir projects in the early 1920s is provided in Table 1. Though significant in scale, the reservoir construction program would come too late to save the San Fernando Valley crops during the 1923-24 season, when the drought returned after a brief respite, the year previous. This ambitious program of capital works improvements received an infusion of funding between 1921-26. To accomplish this goal, five new reservoirs were built and two existing structures enlarged. Of the 57,751 ac-ft of additional storage, 41,576 ac-ft of storage was lost with the failure of the St. Francis Dam in 1928 and the lowering of Hollywood Reservoir behind Mulholland Dam in 1931. Much of these losses were offset by the completion of Bouquet Canyon Reservoir in 1934, with a capacity of 36,505 ac-ft.

RETIREMENT

In the 1924 BWWS annual report, Mulholland stated that it was his desire to construct reservoir storage sufficient for 32,000 ac-ft, a year's supply of water for Los Angeles. This was the St. Francis Dam in San Francisquito Canyon, constructed in 1924-26. It failed catastrophically near Midnight on March 12-13, 1928, 10 days after its reservoir pool was topped off. This brought about a somewhat abrupt end to Mulholland's storied professional career, which is described in a companion article of this volume, titled "Who designed the ill-fated St. Francis Dam?" (Rogers, 2017).

The dam's failure hastened the selection of nearly a dozen independent assessments of the likely causes of the dam's untimely demise (Committee Report, 1928). Mulholland testified that he thought there was some sort of "hoodoo over the dam," and that "he had his suspicions" about what might have triggered the collapse, but he would not air these publicly (LA Co Coroner, 1928). BWWS hired San Francisco geophysicist Frank Reiber, a blasting expert. Reiber constructed an elaborate physical model of the dam, and during his testimony made some sound observations about the physical evidence. He "*thought that the initial break occurred when the reservoir level "was down 18 or 20 ft, maybe less, and from an eastward flow or when the water was at 35 or 40 ft from a westward flow."* Rieber stopped short of blaming the tragedy on explosive charges.

During the Coroner's Inquest Mulholland told the jurors "*Don't blame anyone else, you just fasten it on me. If there was an error in human judgment, I was the human*." With that admission, Mulholland's culpability ceased being a newsworthy item. After all of the inquiries and assessments were completed, Mulholland retired as Chief Engineer and General Manager of BWWS in November 1929. He died peacefully on July 22, 1935, at age 79. Despite his human shortcomings, no person likely did more to grow Los Angeles than William Mulholland, C.E.

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