PRIVILEGE AND RESPONSIBILITY

William Mulholland and the St. Francis Dam Disaster

By Donald C. Jackson and Norris Hundley, jr.

A few minutes before midnight on March 12, 1928, the St. Francis Dam gave way under the hydrostatic pressure of a full reservoir. During the early morning hours of March 13, some 38,000 acre-feet of water surged down from an elevation of 1,834 feet above the sea. Roiling through San Francisquito Canyon and the Santa Clara Valley in southern California, the flood wreaked havoc on the town of Santa Paula and dozens of farms and rural communities. By the time it washed into the Pacific Ocean near Ventura at daybreak some fifty-five miles downriver, more than four hundred people lay dead. Damage to property was in the millions of dollars. Considered the greatest civil-engineering disaster in modern U.S. history, it was the nation's deadliest dam failure ever save for the 1889 Johnstown Flood in Pennsylvania, which took nearly 2,200 lives. The St. Francis Dam tragedy engendered great public interest not only because of the deaths and destruction, but also because it involved the failure of a curved-gravity concrete dam, the design type then planned for the massive Hoover (Boulder Canyon) Dam on the Colorado River. The disaster prompted critics to urge reconsideration of that project—which was being vigorously promoted by Los Angeles civic authorities—as well as to call for renewed scrutiny of efforts by the city of Los Angeles (builder/owner of St. Francis Dam) to expand its municipal water-supply system. And it focused attention on William Mulholland, longtime head of the city's Bureau of Water Works and Supply and the official in charge of the failed dam's design and construction.[1]

Despite the absence of a prominent roadside marker located amidst the concrete remains at the dam site, the failure of the St. Francis Dam remains an enduring—almost mythic—story within the history of California and the nation.[2] Part of this tale's fascination derives from the sheer horror of the event. But much of it relates to the disaster's effect upon the reputation of William Mulholland, the engineer credited with building the 233-mile-long Los Angeles Aqueduct that delivered prodigious quantities of Owens River water from the Sierra Nevada into the southland starting in 1913. For good reason, the aqueduct is viewed as an essential component of the region's hydraulic infrastructure responsible for much of the growth and economic development associated with modern Los Angeles. In addition, the aqueduct is now (and was at the time of its construction) considered by many to comprise an audacious "water grab" allowing control over the Owens River to pass from Inyo County settlers into the hands of Los Angeles.[3]

Not surprisingly, the potent image of an engineer responsible for the city's controversial—yet incredibly important—water supply system being also responsible for a key storage dam that collapsed in horrible tragedy has etched itself into the historical consciousness of Californians and countless others. Those memories have attracted scholars, with two in particular shaping the public's current knowledge of the disaster and influencing its attitudes toward William Mulholland. Drawn first to the subject was Charles F. Outland, author of *Man-Made Disaster: The Story of St. Francis Dam*, a carefully crafted book. As a teenager living in Santa Paula at the time of the disaster, he witnessed firsthand the tragic aftermath of the flood. This experience later energized him to convey the impact of the disaster on Santa Clara Valley residents with moving, yet tempered eloquence. Though first published over four decades

Considered the greatest civil engineering disaster in California's history, the collapse of the St. Francis Dam took more than 400 lives in the Santa Clara River Valley during the early morning hours of March 13, 1928. Designed and built under the authority of William Mulholland, a legendary engineer in the history of Los Angeles, the dam incorporated more than 100,000 cubic yards of concrete into its massive structure. Left: A huge piece of concrete that toppled from the center/east section of the dam dwarfs human investigators.

Henry E. Huntington Library, Courtney Collection

Near right: *Salvage efforts underway near the remains of the Southern California Edison Company camp near Kemp, about fifteen miles downstream from the dam. Eighty-four men sleeping at the camp died when the flood from St. Francis Reservoir smashed through at 1:20 am on March 13.*
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Center: *Effect of the flood on a Santa Paula residence over thirty-five miles downstream from the dam site. The exact number of victims killed during the flood remains unknown but, according to Charles Outland, "any death figure over 450 or under 400 is unrealistic."*
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Far Right: *Remains of the Willard Bridge that crossed the Santa Clara River at Santa Paula. While the surge of water receded dramatically after about twenty minutes, at peak flow it extended for a distance of more than a half mile across the valley floor.*
DC Jackson/damhistory.com

ago in 1963 and then briefly revised and expanded in 1977, Outland's account remains the essential overall history of the tragedy. Arriving later to the topic was J. David Rogers, a geologist whose particular interest was in the mechanics of the dam failure and the physical causes of the collapse. His findings were set out in two articles, one published in 1992 and the other in 1995, and expanded upon in an interview published in 1997 and another longer interview published on the Internet in 2000 and also circulated in a CD format.[4]

Though the purposes and emphases of Outland and Rogers differed, their works generally reinforced one another's findings. The views of the two were not always in harmony, however, and that was nowhere more clear than in their attitudes toward Mulholland's role in the St. Francis disaster. On this point, Outland was straightforward and adamant: "In the final analysis, . . . the responsibility was his alone." Rogers was neither so unequivocal nor direct in his judgment, but he nonetheless believed that blame was misdirected. In the matter of the dam's collapse, the culprit was not Mulholland, he insisted, but excusable ignorance. Put another way, the problem lay not with Mulholland but with a "civil engineering community" allegedly lacking the geological and technical knowledge—specifically, lacking "a modern appreciation of uplift theory"—to build a safe dam in San Francisquito Canyon.[5] In adopting this perspective, Rogers pointedly defends Mulholland as a "rugged individualist" and avers that "we should be so lucky as to have any men with just half his character, integrity, imagination and leadership today."[6] In the last several years, Rogers's view of Mulholland's responsibility (or lack thereof) for the disaster has found its way into press coverage and public consciousness.

The *Los Angeles Times* greeted the publication of Rogers's first article in 1992 with the headline: "The Night the Dam Broke: Geological Look 64 Years Later Clears Mulholland and His Engineering Marvel in Tragedy That Killed 450." A year later Margaret Leslie Davis's *Rivers in the*

Desert: William Mulholland and the Inventing of Los Angeles described Rogers's "assessment" as an "exoneration" of Mulholland. So, too, did Ruth Pitman's *Roadside History of California* (1995): "Geological knowledge at the time the dam site was selected simply wasn't sophisticated enough. . . . Thus, more than fifty years after his death, Mulholland was exonerated." In essential agreement was Kim Weir's *Southern California Handbook* (1998): "The general condemnation of William Mulholland for the St. Francis Dam disaster went unchallenged until 1992" when Rogers "largely exonerated him." Also picking up on the seeming significance of Rogers's pronouncements was Catherine Mulholland—granddaughter of William Mulholland—whose biography, *William Mulholland and the Rise of Los Angeles* (2000), heralded Rogers as "masterfully" analyzing the disaster and credits him for "the apparent vindication of Mulholland."[7]

In this article, we do not offer a conventional recounting of the origins and aftermath of the disaster. Rather, we analyze key investigations into the cause of the collapse and relate these inquiries to those of Charles Outland in the 1960s and J. David Rogers in the 1990s, especially as they concern Mulholland's ostensible responsibility for the tragedy. In seeking to discern where such responsibility most reasonably resides, we also consider Mulholland's dambuilding practices in light of California's 1917 dam-safety law and within the context of professional civil engineering knowledge and norms of his day. For reasons suggested by Outland and because of additional evidence set out in this essay, we arrive at the judgment that William Mulholland was responsible for the St. Francis Dam failure.

PRELUDE TO DISASTER

The Los Angeles Aqueduct descends more than 2,500 feet from the intake dam near Independence to its entry into the San Fernando Valley at Sylmar. The biggest part of that drop comes when the aqueduct leaves Fairmount Reservoir and pierces the Sierra Madre escarpment separating the western Mojave Desert (or Antelope Valley) from coastal southern California. The five-mile-long

The St. Francis Dam lay in remote northwestern Los Angeles County (at upper right), but much of the land inundated by the flood was in Ventura County (center, lower left). Floodwaters surged southward down San Francisquito Creek for about ten miles before joining the Santa Clara River near Saugus. The torrent then churned west for over forty miles, passing through the heart of the Santa Clara Valley before reaching the Pacific Ocean just south of Ventura. Today, motorists on Interstate 5 (Golden State Freeway) cross the flood path just a short distance northeast of Magic Mountain theme park. By driving west from I-5 on State Route 126 it is possible to parallel the flood path that ravaged the farming community of Bardsdale and inundated low-lying areas of Fillmore and Santa Paula. Today, the Santa Clara Valley citrus groves that were laid to waste have long since been restored, but memories of "The Flood" remain strong among valley residents.

Reprinted with permission from Charles Outland, *Man-Made Disaster: The Story of St. Francis Dam* (Glendale, CA: Arthur H. Clark Col, 1977).

Above: *More than 75 years after the St. Francis flood swept through the Santa Clara Valley, the effects of the disaster on the landscape are not always easy to discern. As shown in this recent photograph, however, sharp-eyed observers traveling along San Francisquito Canyon Road can still see large concrete chunks that broke off the dam during the collapse.*

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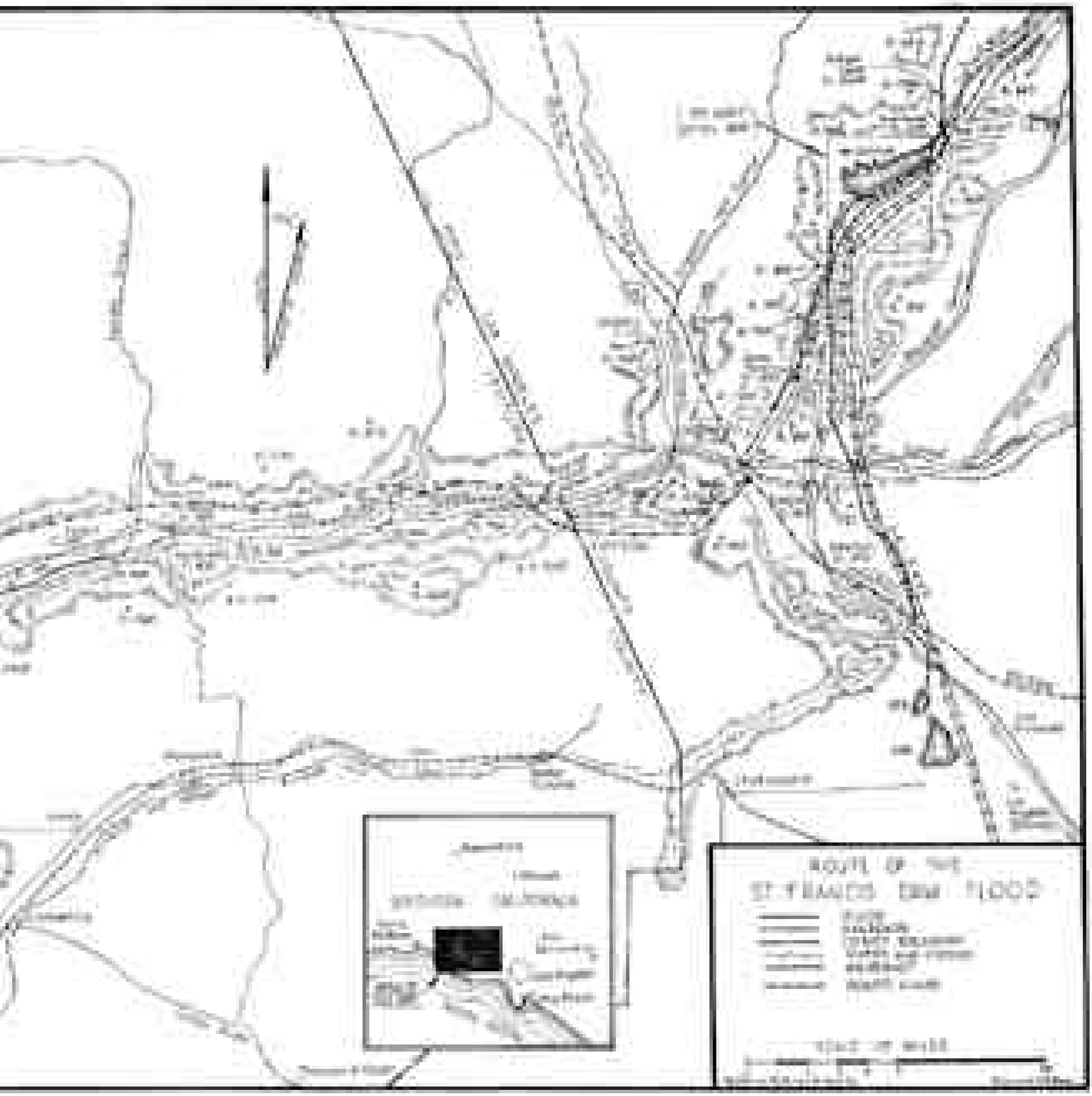

ROUTE OF THE
ST FRANCIS DAM FLOOD

Elizabeth Tunnel draws water from Fairmount Reservoir and feeds into San Francisquito Power Plant No. 1. From there, water flows south through a six-mile-long tunnel in the east canyon wall before dropping down to Power Plant No. 2 along the banks of San Francisquito Creek (from there, other tunnels extend the aqueduct to Sylmar about twenty miles farther south). About one and a half miles upstream from Power Plant No. 2 lies a broad, open area bounded by a narrow gorge at the southern end. This gorge and the flat expanse of land above it—which had been used by Mulholland for an aqueduct construction camp between 1908 and 1913—comprised the site of the St. Francis Dam and Reservoir.

Mulholland's original plan for the aqueduct system did not include a reservoir at the St. Francis site.[8] But by 1922, with the city population three times larger than when the aqueduct was proposed and expected to be four times greater within a year, Mulholland decided that prudence called for additional water storage facilities. In the following year he developed plans for a reservoir and dam in San Francisquito Canyon. He selected the locale because of its proximity to the aqueduct right-of-way and because it would "provide emergency water supply against low years and against failure of the Owens River Aqueduct." He also claimed the proposed reservoir would enable the capture of "surplus water of the aqueduct used for power during the winter months" that was then "wasted into the Santa Clara and Los Angeles Rivers."[9] The St. Francis site was certainly suitable for storing a large quantity of water but, in other ways, the location was less than ideal. Specifically, water released into the reservoir from the aqueduct below Power Plant No. 1 could not subsequently be used to generate electricity at San Francisquito Power Plant No. 2. Another shortcoming was evidenced in the city's 1911 annual report on the aqueduct's construction, which described the rock along the eastern side of San Francisquito Canyon as "exceedingly rough, and the dip and strike of the slate [schist] such as to threaten slips."[10] Joseph B. Lippincott, Mulholland's chief assistant engineer during aqueduct construction,

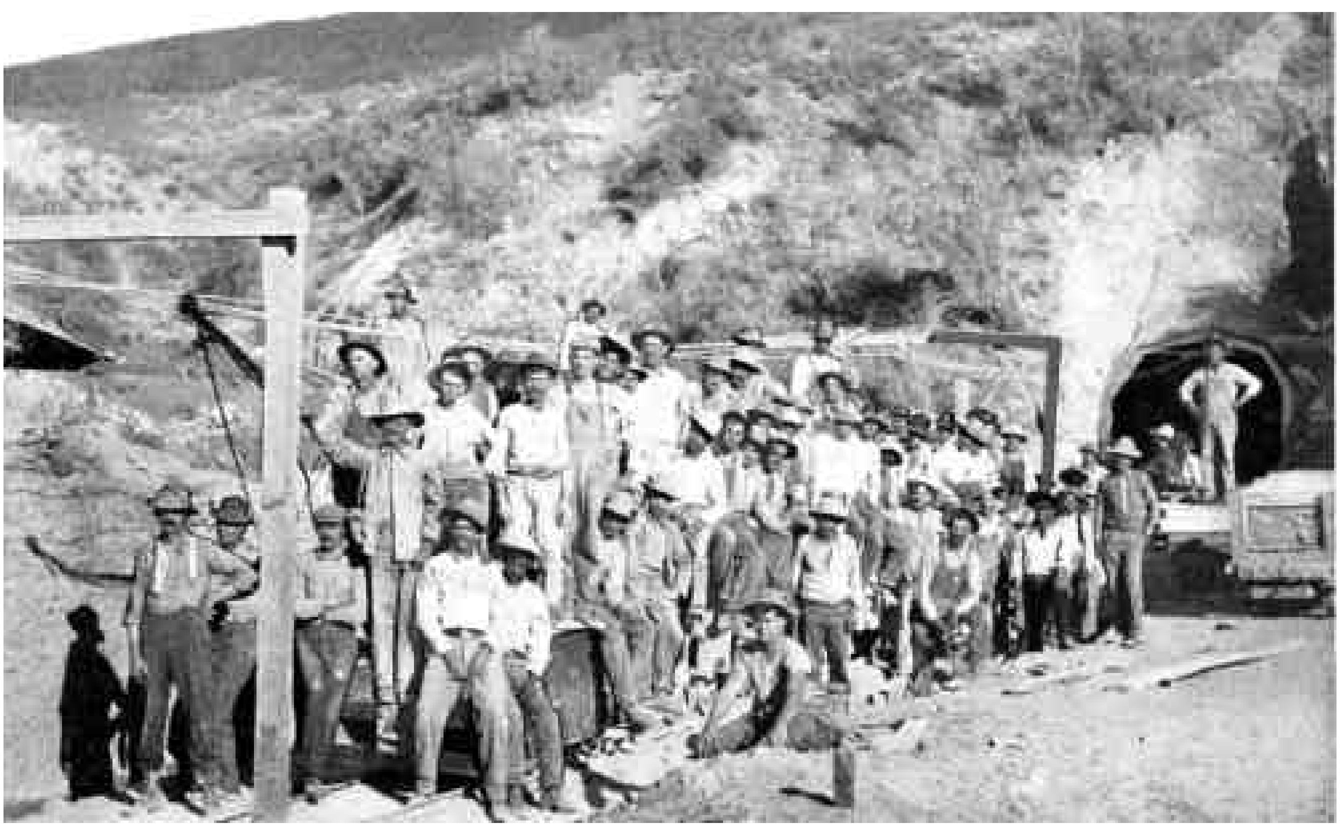
Left: *Extending across the barren expanse of the western Mojave Desert, the aqueduct carries water over 200 miles from the Owens River Valley to the city. This section is the Soledad siphon near Saugus, about ten miles south of San Francisquito Canyon.*
Joseph B. Lippincott Collection, Water Resources Center Archives

Right: *Workers posed in front of an adit, the entrance to the Los Angeles Aqueduct tunnel, being excavated deep within the east side of San Francisquito Canyon, circa 1911. Mulholland resorted to such expensive tunnel work in the canyon because of fear that the exposed rock on the canyon wall (fractured schist) would "slip" or give way if a "side-hill excavation" were made to accommodate an open cut canal.*
Julian Hinds Collection, National Museum of American History

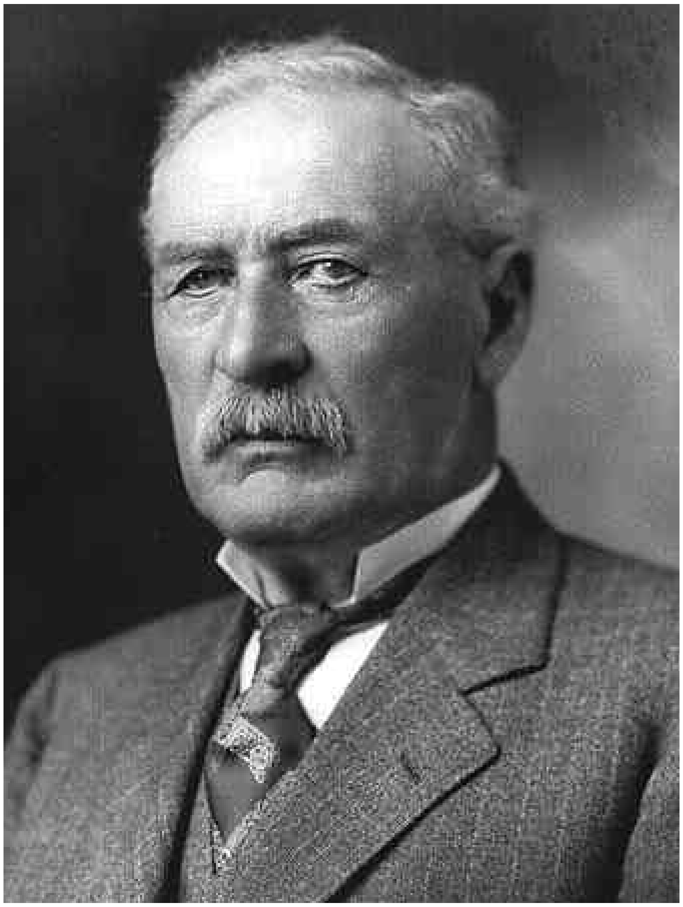
long remembered the difficult geological character of the east canyon ridge and, after acknowledging he had been "intimately connected with the driving of a series of tunnels for our aqueduct through the range of mountains on which the left or east abutment of the dam rested," later declared: "The rock that we encountered was a broken schist and a good deal of it expanded when it came in contact with the air and was what the tunnel men called 'heavy ground.' We had great difficulty in holding this ground [for the aqueduct tunnel] before it was lined with concrete."[11]

While the east abutment's faulty schist would later reverberate through the story of St. Francis Dam, it was the reduction in hydroelectric power capacity that prompted E. F. Scattergood, the city's chief electrical engineer, to criticize use of the St. Francis site for a major reservoir.[12] Scattergood's objections, however, held no sway over the authority allowed Mulholland by city political leaders to build the dam where and how he saw fit. Reinforcing Mulholland's control over the project was California's 1917 dam-safety law, which exempted municipalities from supervision by the State Engineer when building dams. Thus, when Mulholland chose to build, and subsequently enlarge, a concrete gravity dam at the St. Francis site, he could do so without substantive review by anyone outside his immediate control.[13]

Mulholland attained this authority after inauspicious beginnings. He arrived in Los Angeles as a twenty-two-year-old poor Irish immigrant in 1877. After a failed venture to find gold in Arizona, he returned to Los Angeles the following year and worked as a laborer tending ditches for the Los Angeles City Water Company. The president of the company rode by Mulholland's work site one day, noticed his single-minded attention to his job, and asked him his name and what he was doing. "It's none of your damned business!" growled Mulholland. Instead of responding with anger, the president rewarded him for his dedication by promoting him to foreman—an advancement that led to many others, including eventually superintendent and chief engineer. Unlike many of his peers such as Arthur Powell



Davis, John Freeman, and Charles E. Grunsky, who also attained prominence as civil and hydraulic engineers, Mulholland possessed no university training and was essentially self-taught, deriving the core of his hydraulic-engineering knowledge from on-the-job experience. He had a quick mind, a remarkable memory, and, apparently for much of his early career, an appetite to supplement his extensive practical work with knowledge gleaned from technical books and articles covering engineering and geology.[14]



Photograph of William Mulholland, circa 1920, a few years after completion of the Los Angeles Aqueduct, which brought him international fame as chief engineer in charge of design and construction.
Los Angeles Public Library

Mulholland had the respect of his superiors from the outset of his tenure as superintendent of the Los Angeles water system. Over the years he reported to a series of supervisory groups whose names and responsibilities changed but whose managerial authority was embedded in the city charter. Following Los Angeles's acquisition in 1902 of the privately owned distribution system and the hiring of Mulholland to continue as superintendent, the Board of Water Commissioners became his boss; then in 1911 the Board of Public Service Commissioners, created in anticipation of there being both a water and power system, succeeded to that role; fourteen years later—while construction of St. Francis Dam was underway—authority passed to the newly formed Board of Water and Power Commissioners.[15]

Mulholland's multiple superiors notwithstanding, he was in control. Practical considerations played a role, and paramount among them was the knowledge he brought to his job. When the city bought out the privately owned Los Angeles Water Company, little about the system and its operation existed on paper. Mulholland compensated for the omission by committing to memory the complex distribution system of pumps, ditches, hydrants, pipes, and valves. When challenged during the purchase negotiations, Mulholland called for a map and proceeded to identify details about the pipes in every city street. Those details were then corroborated by excavations. This impressive show of knowledge and bravado insured his continuation as superintendent—a superintendent whose knowledge automatically translated into power.[16]

Reinforcing Mulholland's control was the absence among the commissioners of engineers with training and practical expertise in the building of water-supply systems. The commissioners tended to be lawyers, businessmen, doctors, investors in real estate, and the like—"citizens [with] . . . part-time responsibilities," as Vincent Ostrom has noted, and unable to "undertake . . . [or] even assume the initiative in the formulation of policies."[17] Put simply, none of the commissioners possessed the credentials or knowledge to challenge Mulholland even if one of them had sought to do so—which none ever did. Their attitudes were epitomized by R. F. Del Valle, an attorney who served on the Board of Public Service Commissioners and later chaired the Board of Water and Power Commissioners. "Mr. Mulholland," observed Del Valle shortly after the St. Francis failure, "has had charge of the department ever since its inception. . . . During that time he conceived the construction of the aqueduct, built it, has built nineteen dams for the department, and during that whole time, the board has found that he has used the proper judgment, has been competent, efficient in every manner, and therefore the matter . . . as to whom he should consult or what he should do in detail has been left entirely to his judgment, because the board has had the utmost confidence, and has now, in his ability as an engineer."[18]

Members of his staff also ardently admired Mulholland. "The Chief was always resourceful, fearless, and never flustered in a pinch," recalled George Read, head of the water meter division and a member of the city water department's "old guard." Read further gushed, "I know that in being associated with him I learned to think more deeply, to appreciate more fully the wonders of nature, and to see the humorous side of life." Such admiration extended beyond his immediate coterie to the local citizenry. A reporter captured the public's infatuation and faith in Mulholland's judgment with an exaggerated boast: "If Bill Mulholland should say that he is lining the [Owens Valley] aqueduct with green cheese because green cheese is better than concrete, this town would not only believe the guff but take the oath that it was so."[19]

Mulholland had his critics, of course, with Owens Valley residents at the head of any list, but most people of Los Angeles likely agreed with engineer W. W. Hurlbut when he declared that "the public at large realizes . . . his untiring efforts in providing the city with the most essential element of its growth—nay, its very life blood." Among his staff, Mulholland's stature was such that, contemporaneously with completion of the St. Francis Dam, Hurlbut could avow in *Western Construction News*: "Since time immemorial every profession, every line of human pursuit, has had its outstanding character, its shining light, its great leader. In the profession of water works engineering there is an outstanding figure, a leader who . . . has proved to be a builder of an empire—an empire of unsurpassed progress in municipal development—William Mulholland." Heady praise, indeed, and praise reflective of a staff little prone to question the wisdom and directives of a larger-than-life (almost super-human) leader.[20]

GRAVITY DAM DESIGN

Still, in choosing the basic design for St. Francis in 1922–1923, the sixty-seven-year-old Mulholland did not prove particularly innovative or technologically adventuresome in opting for a concrete gravity dam. The modern form of such structures originated with French engineers in the 1850s and 1860s who (knowing both the weight of water and the weight of masonry) used mathematical analysis to proportion the dimensions of masonry gravity dams featuring vertical upstream faces. In simplest terms, these designs embodied a basic guiding principle: Place enough material (either stone masonry or concrete) in the dam so that the horizontal water pressure exerted by the reservoir would be insufficient to tip the structure over or push it downstream. This design technique resulted in the development of cross-sectional "profiles" for gravity dams that were triangular in shape and gradually widened in thickness from top to bottom (Note: because the cross-section of masonry gravity dams seemingly mimicked the shape of a

Completed St. Francis Dam and reservoir looking upstream (the east side of the canyon is on the right with the west side on the left). The curved gravity design is similar to that previously used for the Hollywood/Mulholland Dam, but the St. Francis design was built along a longer arc radius than its predecessor. In addition, the St. Francis design featured a long, shallow wing dyke running atop the west abutment ridge that was not required at the Hollywood site. Although the two dams were not identical, Mulholland's staff developed the St. Francis design as a direct outgrowth of the Hollywood/Mulholland design

Henry E. Huntington Library, Courtney Collection

human foot, the profile's "toe" was considered to be at the bottom of the downstream face, while the "heel" was at the bottom of the upstream face.) In terms of stability, it is important to appreciate that the amount of material necessary for safety in a gravity dam is directly proportional to the height of water impounded in the reservoir. Specifically, if a gravity dam is increased in height, its thickness must also be increased in order to maintain stability. To raise the height without widening the base is to court disaster.[21]

By at least the 1890s, engineers began to appreciate that water from a reservoir could also seep under a dam and exert pressure upward. This phenomenon of "uplift" (so-called because it tends to lift the dam upward) destabilizes gravity dams by reducing the structure's "effective weight," thereby lessening its ability to resist horizontal water pressure. Uplift can act through bedrock foundations that, in the abstract, are strong enough to bear the weight of the dam, but are fractured or fissured and thus susceptible to seepage and water saturation.[22] The deleterious effect of uplift upon a gravity dam can be countered in various ways: 1) excavating foundation "cut-off" trenches that reduce the ability of water to seep under the structure; 2) grouting the foundation (which involves pressurized injection of wet mortar into drilled holes), thereby filling underground fissures and impeding subsurface water flow; 3) draining the foundation and the interior of the dam through use of porous pipes, relief wells, and tunnels to remove seepage; 4) increasing the thickness of the dam's profile (and hence its weight) in order to counter the destabilizing effect of water pushing upward.[23]

Although generally amenable to mathematical analysis, concrete gravity dams require enormous quantities of material to insure stability. As a result, they can be quite expensive.[24] Nonetheless, many engineers consider such dams—if built properly—to be reliable structures. Additionally, they present imposing downstream facades, an attribute that engineers and politicians can value because of belief that it symbolically conveys a sense of both safety and civic achievement.[25]

While material suitable for an earth-fill embankment dam—a type which Mulholland had built numerous times before—was not readily available in San Francisquito Canyon, the precise reasoning that led him to choose a concrete curved-gravity structure for the St. Francis Dam remains uncertain.[26] In the period 1922–1923 Mulholland called for designs for two concrete gravity dams, the first for a site in the Hollywood Hills, about four miles from downtown Los Angeles (initially known as Weid Canyon Dam, then Hollywood Dam, and, finally, Mulholland Dam and Hollywood Reservoir), and the second for San Francisquito Canyon (the St. Francis Dam). The plans were similar, since Mullholland instructed that the Hollywood design be adapted to the St. Francis site. Still, no detailed descriptions of these designs were published in the technical press; in particular, our knowledge of the St. Francis Dam is fragmentary.[27]

In accord with protocol established during construction of the Los Angeles aqueduct, it appears that the initial design for the two dams was delegated to an assistant engineer/draftsman or an "office engineer" who reported to Mulholland.[28] At the Los Angeles County Coroner's Inquest that was convened to investigate the collapse of St. Francis Dam, Edgar Bayley, the assistant engineer for Hollywood Dam, described his role in developing a preliminary design ("the cross sectional transfer profile") for that structure.[29] But Bayley explicitly denied having any experience with concrete gravity dams and emphasized Mulholland's commanding role:

> Q. [By the coroner]: How many of this type [concrete gravity] dams have you designed and constructed?
>
> A. [Bayley] I have constructed none, have had nothing to do with the construction of any, except being that the Hollywood Dam complied with the profile we had to work by.
>
> Q. Didn't I understand that you are the man that designed the thing, the Hollywood Dam?
>
> A. No, I just testified that I had to do with

Mulholland Dam in the Hollywood Hills, a few miles west of downtown Los Angeles. Completed in 1924, Mulholland Dam (also identified at times as Weid Canyon Dam or Hollywood Dam) was the first concrete gravity structure built by Los Angeles under William Mulholland's authority. Work on St. Francis Dam commenced soon after completion of Mulholland Dam. Testimony at the coroner's inquest revealed that the design of the latter, with its stepped downstream face, served as a model for St. Francis Dam.

DC Jackson/damhistory.com

the design of the cross section profile of the design, with certain limitations.[30] The dam was designed between Mr. Mulholland and myself. Mr. Mulholland set the radius, picked the site, he picked the abutments. We made one or two little changes upstream to get a radial bond.

Q. Mr. Mulholland visited the site?

A. Picked it, considered it suitable for a dam.

Q. And that would be the place to put a dam, said, "I want you to draw me the plans and specifications for a gravity dam."?

A. No, no specifications were written, it was to be done by the department itself, certain dimensions to follow.[31]

Further underscoring Mulholland's overall authority was William Hurlburt, the office engineer involved with the design of St. Francis Dam.

Q. [By the coroner]: Now who designed the St. Francis Dam? Did you [Hurlbut] design it?

A. I did not.

Q. Did Mr. Mulholland design it?

A. It was designed under his instructions.

Q. Then, am I to understand that Mr. Mulholland designed the St. Francis Dam?

A. It was designed under his instructions.[32]

Not content with Hurlbut's responses, a deputy district attorney took over the questioning and doggedly pursued the nature of the design process, Mulholland's role in it, and the relationship between the designs for the Hollywood and St. Francis dams:

Q. [The deputy district attorney]: Do I get this correct: Is this the information you are trying to give the Coroner: that Mr. Mulholland designed the Hollywood Dam, that is, he said that he wanted a dam over there?

A. [Hurlburt]: He [Mulholland] gave instructions for a [Hollywood] dam to be designed with a gravity type section, according to the best engineering practice and it was assigned to Mr. Bayley to do that.

Q. And Mr. Bayley had prepared the blue prints in accordance with Mr. Mulholland's request for a dam?

A. He prepared studies in connection with that, and, as a result the drawings were made.

Q. And, then, when they wanted the St. Francis Dam, they got out the old drawings of the Hollywood and revamped them under your [Hurlbut's] instructions and sent them up there?

A. They got out the computations and the studies on the Hollywood Dam, and the matter was gone into with Mr. Mulholland and others at that time.[33]

Apparently satisfied, the deputy district attorney and other questioners turned to different issues. But despite a seeming desire to uncover the origins of the St. Francis design, participants in the coroner's inquest failed to investigate a critically important aspect of the dam's history: In what way did the design change during the construction process?

The exact dimensions of the dam built at St. Francis are now difficult to ascertain because of changes made during construction and because the precise nature of these changes was never reliably documented. In the wake of the collapse,

FACING PAGE: *Looking west across partially completed St. Francis Dam in July 1925. Buckets of wet concrete were hoisted up the wooden tower (center left) and then dumped into the tops of lengthy chutes. The chutes carried the concrete down to the specific part of the dam where construction was underway. This view illustrates that the structure was built as a monolith rather than —as was done with many other large gravity dams of the era—in discrete vertical sections separated by "expansion joints" spaced approximately fifty feet apart. The view documents the absence of drainage pipes along the length of the upstream face. And it reveals that only minimal excavation of the abutment foundations was carried out prior to the pouring of concrete.*

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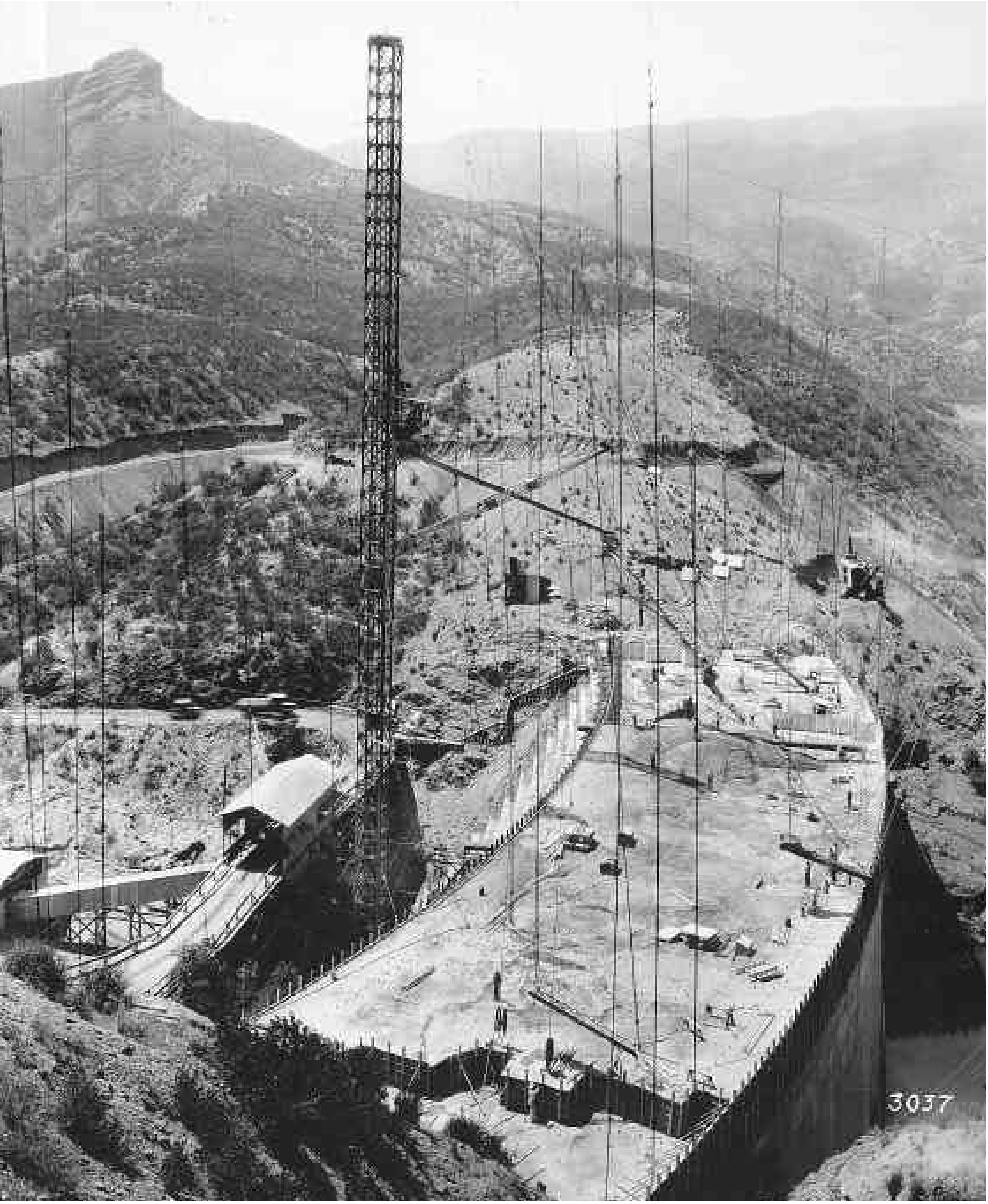
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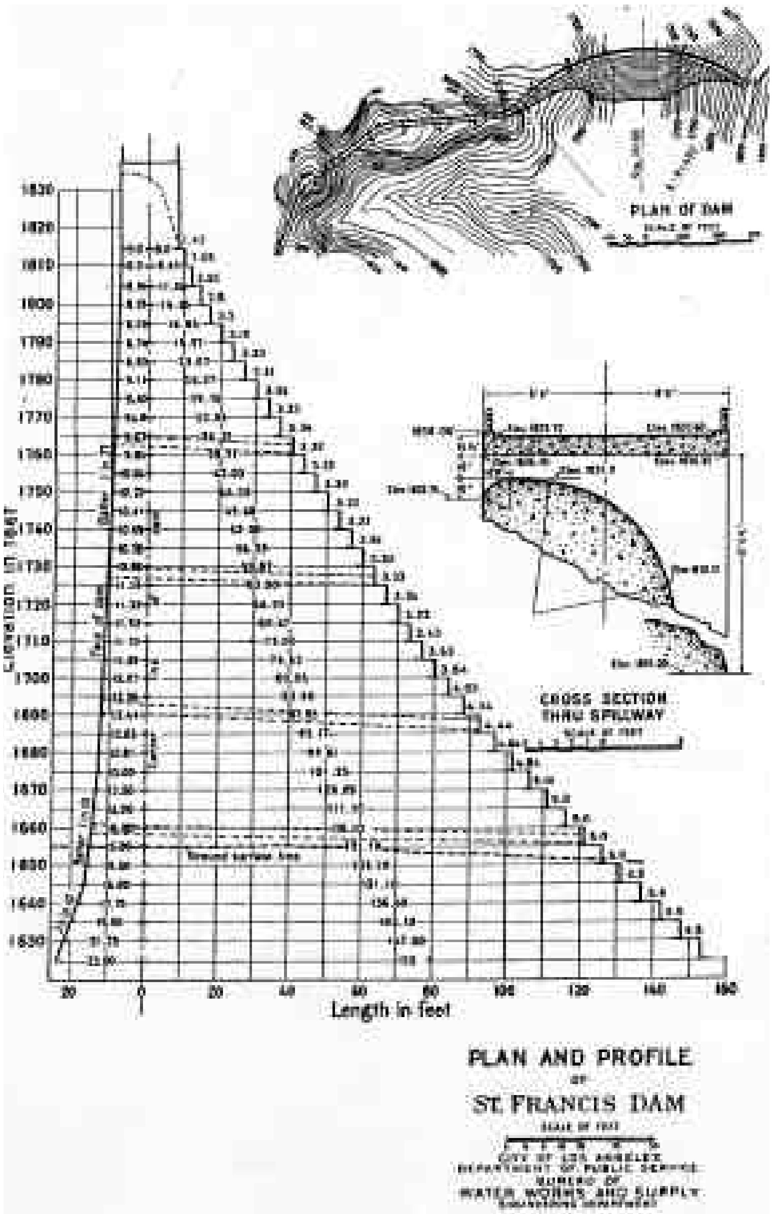

Above: *The "official" cross-sectional profile of St. Francis Dam as publicized by the Los Angeles Bureau of Water Works and Supply after the failure. Charles Outland's later comparison of this drawing with construction photos revealed that a significant portion of the dam's downstream "toe" had been omitted during construction, thus exacerbating the instability of the structure.*

Report, Governor's Commission, Plate 4

Mulholland and his staff distributed a drawing indicating a maximum height of 205 feet (extending from the deepest foundations at 1,630 feet above sea level to 1,835 feet at the spillway crest) and a maximum base width of 175 feet (this contrasted with a published report in 1926 indicating a maximum thickness of 169 feet).[34] A commission appointed by the California governor to investigate the disaster published this drawing in its report. For many years it was accepted as accurately documenting what would have been a very amply proportioned cross-section for the design. However, Charles Outland's subsequent research in the early 1960s revealed that the dam was significantly thinner at the base than the official drawing indicated.

In studying construction photographs, Outland discovered that the dam's base was about twenty feet less thick than indicated in the supposed "as-built" drawings. Moreover, in analyzing a series of pronouncements made by the city describing the size of the reservoir during the years 1923–1925, he discerned that the city had gradually increased the reservoir size. Specifically, in July 1923 the city publicized the size at 30,000 acre-feet, and a year later—shortly before concrete was poured—at 32,000 acre-feet. Then in March 1925 the reservoir capacity was reported

Facing page, top: *Looking toward the east abutment, summer 1925. In the left-center background, note the shallow excavation extending into the abutment and the lack of a cutoff trench near the upstream face.*

Henry E. Huntington Library, Courtney Collection

Facing page, bottom: *Spring 1927 view looking north across the almost-filled St. Francis Reservoir. This is a rare surviving image that focuses on the immense body of water impounded behind the dam. While the high-heeled model brought to the dam to pose for the Automobile Club of Southern California's photographer may appear out of place in such a prosaic setting, the photograph does help highlight how water stored in the reservoir was destined not to irrigate lemon groves in the Santa Clara Valley but, rather, to nourish the burgeoning municipality of Los Angeles.*

Automobile Club of Southern California

as 38,000 acre-feet (equivalent to about 11 billion gallons). In the abstract, raising the dam's height was not necessarily dangerous, but to fully assure safety, the base width would also need to be increased. The photographic evidence revealed that such a compensating increase had not occurred and that, in Outland's words, "the dam had been born with a stub toe."[35] Exactly what transpired on-site during construction of the dam will never be known, but little doubt exists that Mulholland chose to increase the reservoir capacity in a way that did not retain the dam's original height-to-width ratio. In so doing, he reduced the dam's stability and made it more vulnerable to the effect of uplift.

During construction, Mulholland incorporated few features into the design that would mitigate the effect of uplift. Across a distance of about 120 feet in the center of the dam site, he placed ten drainage wells. But for the remainder of the 600-foot long main section of the dam he did not grout the foundation, excavate a cut-off trench, or install a drainage system up the sides of the canyon walls. In concert with the raised height of the design, these omissions would prove to be fatal flaws.

Clearing of the dam site began in the fall of 1923, but the first concrete was not poured until August 1924. Construction proceeded for close to two years until the dam topped out in May 1926. After completion, the reservoir was not immediately filled, although it did come to within three feet of the spillway in May 1927. Nine months later, in February 1928, the water level came to within a foot of the spillway and, on March 7, 1928, the reservoir reached three inches below the spillway crest. It stayed at that elevation until late in the evening of March 12.[36] Then disaster struck.

THE INVESTIGATORS

The collapse of St. Francis Dam prompted the creation of several panels of engineers and geologists (sponsored by the California governor, the Los Angeles County district attorney, the Los Angeles County coroner, and the Los Angeles City Council, among others) to investigate the cause of the disaster.[37] Although the panels were not in unanimous agreement on all points, most quickly—perhaps hastily would be a better term—concluded that the collapse began in the red sandstone conglomerate beneath the western abutment. A new leak on the west abutment (others had been noted earlier) had been discovered on the morning of the day when the dam collapsed. As a result, Mulholland visited the dam less than eighteen hours before the collapse, but pronounced the leak not dangerous and felt no need to warn communities downstream of possible problems.[38]

Following the disaster, the governor's commission—responsible for a widely distributed report—and most other investigators perceived this new leak as comprising the key to understanding the collapse. The commission, it should be noted, believed that "the foundation under the entire dam left very much to be desired," but the west end emerged as the culprit. "The west end," stated the governor's commission, "was founded upon a reddish conglomerate which, even when dry, was of decidedly inferior strength and which, when wet[,] became so soft that most of it lost almost all rock characteristics." The softening of this "reddish conglomerate" undermined the west side. "The rush of water released by failure of the west end caused a heavy scour against the easterly canyon wall . . . and caused the failure of that part of the structure." There then "quickly followed . . . the collapse of large sections of the dam." The committee engaged by the city council concurred in ascribing the cause of the collapse to "defective foundations," with the failure "apparently" beginning in the "red conglomerate," but nonetheless acknowledged that "the sequence of failure is uncertain."[39]

The governor's commission and the City Council committee reached their conclusions within a week after initiating study of the failure (and less than two weeks after the collapse). Such haste produced no doubts. "With such a formation [the red conglomerate]," concluded the governor's commission, "the ultimate failure of this dam was inevitable, unless water could have been kept from reaching the foundation. Inspection galleries, pressure grouting, drainage wells and deep cut-off walls are commonly used to prevent or remove percolation, but it is improbable that any or all of these devices would have been adequately effective, though they would have ameliorated the conditions and postponed the final failure." As far as the commission was concerned, the poor quality of the foundation material on the west side of the canyon (and "defective foundations" generally) rendered all other issues—including uplift—irrelevant.[40]

On March 21, 1928, Los Angeles County convened a public coroner's inquest into the tragedy in which sixty-six people testified. Most appeared only once but some (including Mulholland) were recalled several times. On April 12 the coroner's jury issued its judgment on the dam's collapse.[41]

"After carefully weighing all the evidence," concluded the jurors, the dam failed for two fundamental reasons: "an error in engineering judgment" and "an error in regard to fundamental policy relating to public safety." The first error consisted of building the dam on defective "rock formations." Compounding these foundation problems was a dam "design . . . not suited to [the] inferior foundation conditions"—a design that, among other flaws, did not carry the dam "far enough into the bedrock" and that lacked precautions against uplift, such as "cutoff walls," "pressure grouting of the bedrock," and "inspection tunnels with drainage pipes" (except for "the center section"). The "responsibility" for these lapses in engineering judgment, stated the jurors, "rests upon the Bureau of Water Works and Supply, and the Chief Engineer thereof."[42] As for the error in public policy, the jurors laid that at the feet of "those to whom the Chief Engineer is subservient"—"the Department of Water and Power Commissioners, the legislative bodies of city and state, and to the public at large." If these groups had insisted on "proper safeguards . . . making it impossible for excessive responsibility to be delegated to or assumed by any one individual in matters involving great menaces to public safety, it is unlikely that the engineering error would have escaped detection and produced a great disaster."[43]

In their verdict, the jurors opined that the dam likely collapsed first on the red conglomerate/west side because a "preponderance of expert opinion favors the conclusion." Nonetheless, they expressed ambivalence about this judgment—they had heard testimony that the schist forming the east abutment was "a weak material, badly shattered, very susceptible to seepage of water, and to slippage along the planes of cleavage"—and hesitated to conclude that they fully understood "the exact sequence" of when and how the collapse occurred.[44]

A key reason for the jurors' ambivalence can be traced to the testimony of one of the last witnesses called before them. Halbert P. Gillette, president and editor of the journal *Water Works*, was decidedly unimpressed with reasoning that blamed the dam's failure on the softened red conglomerate at the western abutment—and he forcefully testified at the coroner's inquest on that point.[45] Soon after the inquest's conclusion he publicly aired his critique of the three seemingly official investigating committees—the governor's commission, the Los Angeles City Council committee, and the Los Angeles district attorney's committee. Declining to criticize Mulholland or the dam design, Gillette lambasted the investigating teams for hasty and faulty research and for concluding that the dam failed first on the west side. He also found no evidence to support the rumor of an explosion bringing the dam down (growing out of earlier dynamitings of the Los Angeles Aqueduct), but he did not discount the possibility of an earthquake playing a role.[46] Based upon his own field work and research (which convinced him that the red conglomerate was hardly as weak as publicly portrayed), he analyzed how the dam's fragments were distributed downstream and also analyzed data from triangulation surveys. Averring that "the schist on the east bank dips into the canyon in such a way that a slide could occur; and no one denies that slides of the schist did occur on such a scale as to destroy the east side of the dam," he convincingly demonstrated that the mechanics of an east abutment/first collapse sequence were the only ones to make sense of post-failure conditions at the site.[47]

Support for Gillette's contention that the schist on the east side failed first came from Charles H. Lee, a San Francisco hydraulic engineer retained as a consultant by the Los Angeles Bureau of Power and Light. In public lectures and an article published in June 1928 in *Western Construction News*, Lee concluded that "the immediate cause of failure" was "a slide at the east abutment." Unlike Gillette, however, he claimed that the subsequent collapse of the west abutment was "quite possibl[y] . . . a contributing . . . cause of failure." He also noted the possibility that these actions were accompanied by "uplift beneath the dam . . . being sufficient to produce cracking and failure." Lee dismissed with no comment the likelihood of an explosion or earthquake bringing down the dam.[48]

The most insightful and persuasive investigative reports on the mechanics of the St. Francis Dam collapse came from civil engineers Carl E. Grunsky and his son E. L. Grunsky and Stanford University geologist Bailey Willis. The elder Grunsky had gained prominence serving as the first San Francisco city engineer, a member of the Panama Canal Commission, a consulting engineer for the U.S. Reclamation Service, and in 1922 as president of the American Society of Civil Engineers. He also studied water-supply issues on behalf of farmers along the Santa Clara River (the major conduit for floodwaters coursing from the collapsed St. Francis Dam). His son, E. L. Grunsky, after acquiring an engineering education, worked with his father as a consulting engineer. Bailey Willis, with degrees in mining and civil engineering as well as "geological studies . . . directed primarily to the mechanical problems of rock structures," had accumulated a half century of engineering and geological experience in the United States and South America, including service as a geologist with the U.S.

Geological Survey and, most recently, as a professor of geology at Stanford University. Such qualifications (bolstered by the Santa Clara Water Conservancy District's existing professional relationship with Carl Grunsky) prompted the district to hire the Grunskys and Willis to investigate the dam collapse.[49]

Their investigations culminated in two reports (one by the Grunskys and the other by Willis) completed in April 1928. Willis's "conclusions and our own," observed Carl Grunsky, "were reached independently" and "are in substantial agreement." Both reports were subsequently published in *Western Construction News*, the Grunskys' in May 1928 and Willis's a month later.[50] In retrospect, the Grunskys and Willis

Top: *Construction view published by the Governor's Commission highlighting the fractured "schist" forming the east canyon wall. The dam's up-stream face is to the left, and the lack of a cut-off trench to help "key" the structure into the foundation is clearly evident. Moreover, no drainage pipes or wells were placed in this part of the structure. The wooden panels on the left comprise the "formwork" that held the wet concrete in place as it hardened.*
Report Governor's Commission, p. 47

Left: *Looking east across the dam site toward the east canyon wall, location of a huge landslide. The piece of the dam shown on page 8 appears in the foreground. Engineer Carl Grunsky and his son quickly perceived that the collapse was initiated at the east end of the dam and published their findings in May 1928 in* Western Construction News. *Halbert P. Gillette also recognized the logical impossibilities of the "west side first" failure theory and wrote a compelling critique published in* Water Works *in May 1928.*
DC Jackson/damhistory.com

demonstrated greater technical knowledge of the dam site and possessed keener analytical skills than any of the other investigators. Their efforts led to the identification of four major factors that, in combination, led to the disaster:

1) ***Unsuitability of the Foundation***: Foundations on both sides of the dam were deemed unsuitable, "but the critical situation developed more rapidly in the east abutment" where "the schist is . . . traversed by innumerable minute fissures, into which water would intrude under pressure and by capillary action."

2) ***Old Landslide***: The "east abutment was located on . . . the end of an old landslide."

3) ***Uplift and Collapse***: "When it [the old landslide] had become soaked by the water standing in the reservoir against its lower portion, it became active and moved." That movement resulted from "a great hydrostatic force under its [the dam's] foundation surface from end to end," which triggered the collapse of the east abutment.

4) ***Inadequate Design***: "The old slide against which the dam rested at the east . . . offered only insecure support to the dam, and this was rendered more precarious by the [dam builders'] adoption of a design which did not include adequate foundation drainage."[51]

Willis, as the geologist on this investigative team, most likely discovered the "old slide" (his report discussed it at the greater length and the Grunskys

In the aftermath of the disaster, geologist Bailey Willis recognized the existence of an "old slide" of schist that was reactivated by water seeping into the east canyon wall. In text superimposed over this photograph published in Western Construction News*, Willis called specific attention to the "outline of the old slide."*

Western Construction News, June 25, 1928

drew liberally on that discussion as well as on his analysis of the schist in their report). On the other hand, the Grunskys, as civil engineers, took the lead in describing the role played by "uplift," a condition of great concern to prudent dam builders of the era.

The Grunskys expressed surprise that "no measures . . . have been noted, which would have reduced percolation into the hillside material under the dam." They also emphasized precautions that could have been implemented to combat uplift, such as "thorough hillside and foundation drainage . . . fortified with deep cut-off walls along or near the up-stream face." As a result, "at a full reservoir there was a great hydrostatic force under its [the dam's] foundation surface from end to end, relieved but slightly by a few weep-holes [located in the center of the canyon]. This hydrostatic pressure, the uplifting force of the swelling red sandstone at the west, and the horizontal and uplifting pressure of the slide at the east, lifted the dam . . . [and] broke it from its foundation."[52]

In early June 1928, the reports of the Grunskys and Willis were synopsized in the nationally dis-

The Hoover (Boulder) Dam shortly after completion in the mid-1930s. Built under the authority of the federal Boulder Canyon Project Act (aka "The Swing-Johnson Bill"). A key benefactor of the proposed dam would be the Metropolitan Water District of Southern California, a regional authority subordinate at the time to the political will of Los Angeles. Mulholland played an essential role in designing the district's Colorado River Aqueduct that would depend upon the Hoover (Boulder) Dam for water storage and for hydroelectric power (necessary to operate the system's huge pumps). After a long struggle, proponents of the Boulder Canyon Project Bill anticipated that it would be enacted by Congress in the spring of 1928. The collapse of St. Francis Dam came at a very inopportune time for these proponents and congressional approval of the project did not come until December 1928, a month after Mulholland resigned from the city's Bureau of Water Works and Supply.

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tributed *Engineering News-Record* under the headline "Sixth Report on St. Francis Dam Offers New Theories." This synopsis noted how the Grunksys had tied the failure of the east abutment to uplift and included Willis's description of the "old slide" on the "lower portion" of that abutment which "became active and moved." Except for an editorial article accompanying the synopsis that attempted unsuccessfully to reconcile the Grunskys/Willis reports with the investigative teams that posited a "red conglomerate/west side" failure mode, little public discussion or debate about the Grunskys/Willis findings subsequently appeared in the engineering press. Instead, the views of the governor's commission and others that ascribed the failure to the western abutment's conglomerate—and more generally to "defective foundations"—largely predominated prior to publication of Outland's book.[53] All of which raises the intriguing question: "Why?"

Given the explanatory power of the east side/uplift failure hypothesis, why did the investigating committees that quickly posited a "west side first" collapse theory decline to reconcile such findings with the analysis of the Grunskys, Willis, Gillette, and Lee? Outland insightfully answered such a question when he linked the St. Francis failure to the Boulder Canyon Project (or Swing-Johnson) Bill that was due for a vote in Congress in the spring of 1928. As Outland observed: "A worried, water-short southern California looked askance upon a proposed dam that would store seven hundred times more water than the late reservoir in San Francisquito Canyon. If Boulder Dam was to become a reality, this fear would have to be eased and quickly." Congressman Phil Swing, the principal advocate of the dam in Washington, D.C., felt the political heat and counseled the Boulder Dam Association to find ways of advocating the efficacy of high dams "without tying [St. Francis] too closely to [the] Boulder Dam project." And Arizona Governor George W.P. Hunt—a tenacious opponent of Boulder Dam—publicly connected that project with the St. Francis failure. "Governor Hunt knew a good thing when he saw it," observed Outland. "The truth of the matter was that the engineering world had been shaken, far more than it cared to admit, by the sudden catastrophe."[54]

Because of Mulholland's public association with the Boulder Canyon Project—he had testified before Congress in support of Boulder Dam in 1924, had taken a well-publicized trip down the Colorado River in 1925, and had traveled to Washington, D.C., in January 1928 to lobby for the bill—the Bureau of Reclamation had good reason to ease public disquiet concerning the curved gravity dam technology used at St. Francis.[55] Because of its precarious financial situation in the 1920s, the agency had much (besides prestige) riding on congressional approval for the proposed Boulder Dam.[56] Perhaps not coincidently, many engineers in the agency's employ, or closely associated with it as consultants, agreed to help investigate the St. Francis disaster. There was, in particular, A. J. Wiley, chairman of the bureau's Boulder Dam Board of consulting engineers, who served as chairman of the governor's commission and Elwood Mead, bureau commissioner and hence the agency's highest ranking official, who served as chairman of the City Council committee.[57]

The uncertain fate of the Boulder Canyon Project (not resolved until December 1928) most plausibly explains why these engineers—and other proponents of gravity-dam technology—evinced no interest in keeping the St. Francis Dam disaster in the public eye any longer than absolutely necessary. It also explains why they had no interest in modifying their conclusions after the Grunskys, Willis, Gillette, and Lee presented compelling critiques of the "west abutment failed first" theory. Finally, it helps explain why the governor's commission, a mere two weeks after the disaster, took pains to assure the public that "there is nothing in the failure . . . to indicate that the accepted theory of gravity dam design is in error . . . [or that] such a dam may [not] properly be deemed to be among the most durable of all man-made structures."[58]

Newspaper illustration depicting Mulholland's testimony at the Coroner's Inquest.
Henry E. Huntington Library, California Scrapbook No. 8

MULHOLLAND AND THE CORONER'S INQUEST

Though none of the investigative reports exonerated Mulholland, he was publicly hailed in the engineering press as a "big man" for his seeming forthrightness in accepting responsibility at the Los Angeles County coroner's inquest: "Don't blame anybody else, you just fasten it on me. If there is an error of human judgment, I was the human."[59] That acknowledgement did not come without reservations.

"We overlooked something here," Mulholland testified at the coroner's inquest in March 1928, but he never indicated what it might have been. Twice he seemed on the verge of offering an explanation—"I have a very strong opinion myself as to what was the approximate cause of that failure"; "I have a suspicion, and I don't want to divulge it"—but he backed off when invited by the coroner "to tell us." He may have believed that sabotage—similar to the dynamite attacks carried out against the Los Angeles Aqueduct by Owens Valley vigilantes in 1924, 1926, and 1927—caused the collapse. But, aside from a vague reference to the site being "vulnerable against human ag[g]ression" in his coroner's inquest testimony, there is no evidence to directly support such a supposition.[60] Regardless of what Mulholland may have thought to be the cause of the collapse, his granddaughter later insisted that, "in accepting responsibility, he did not thereby consider himself to blame for something that had occurred beyond his power."[61] But "blame," of course, was precisely the word that he applied to himself. A telling commentary on Mulholland's conception of "blame" emerges from the transcript of the coroner's inquest.

Acknowledging no engineering or geological reason for the St. Francis Dam collapse, Mulholland did conjure the possibility of psychic or supernatural forces. He would not build another dam "in the same place," he told the coroner, because it was haunted by a spirit opposed to human violation of the area. "There is a hoodoo on it." "A hoodoo?" asked the surprised coroner. "Yes," replied Mulholland, "it is vulnerable against human ag[g]ression, and I would not build it there." "You don't mean [to say] that because it [the dam] went out on the morning of the 13th?"

"Perhaps that," answered Mulholland, "but that is an additional hazard. I had not thought of that."[62] The coroner's jury quickly dropped the subject, leaving only conjecture as to what Mulholland meant by "a hoodoo" (and "human aggression," for that matter). But clearly the exchange did little to bolster confidence in his scientific or technical judgments.

No less disconcerting was Mulholland's assertion at the inquest that he had secured an outside inspection of the St. Francis Dam project similar to the state supervision mandated by the 1917 dam-safety law. "You had no inspection of the site by any state authority?" asked the coroner. "Yes sir," countered Mulholland, "the State Engineer [Wilbur F. McClure] examined the site, examined it carefully." This prompted a quizzical response from the coroner: "You are not required to have state inspection?" "No sir," replied Mulholland, "not with us, we are not required to." "Why did you call for state inspection when you didn't require it?" asked the coroner. "I am not a strict caviler about the law," responded Mulholland. "I like to comply as far as I can and go over the mark in conformity to the law, recognize there ought to be state inspection of such things, whether it is a municipality or not."[63]

At this point a member of the coroner's jury interrupted with a question that elicited a response which, even on its face, questioned Mulholland's claim that McClure's inspection had gone "over the mark in conformity to the law": "How much time did Mr. McClure spend?" asked the juror. "Didn't spend but half a day," answered Mulholland, "and he saw all there was to see in half a day, because there wasn't much to see." Moreover, in McClure's company "my men went around there, stumbled around there over the country."[64] The coroner intervened: "He didn't make any geological test?" "Don't know what you call it," replied Mulholland, "[he] looked [at the site] as I did, exposed rock . . . . I don't really know if he is a geologist or not." "Did he come at your request," asked the coroner, whose question immediately prompted a juror's follow-up question before Mulholland could respond: "With the specific object of examining the dam?" "Precisely," said Mulholland. "I don't like to be stubborn about things, I wouldn't think of telling him it was none of his business, I did insist it was his business." "Did Mr. McClure see the finished work?" asked the juror. "I think he has," answered Mulholland, "pretty sure he has been down here several times while they were working on it." In the midst of these questions and responses, Mulholland made an admission about his policy on consultants that came closer to the mark. "In general, for the last ten or twelve years, I haven't consulted with anybody, or but very few."[65]

Though Mulholland and his questioners speak as if McClure is alive, he had, in fact, been dead almost two years, having passed away in June 1926. Moreover, Mulholland's remarks leave unclear whether he was actually at the dam site during McClure's visit. His reference to the occasion is remarkably vague: "I think there was some little excavation, and my men went around there, stumbled around there over the country, and never had a word to say about it." Nor does the testimony reveal whether Mulholland ever talked with McClure about his visit.[66] Most importantly, Mulholland's description of McClure's actions offers scant support for any assertion that he had called for a "state inspection" going "over the mark in conformity to the law." Particularly untenable is the notion that the State Engineer's half day visit might constitute a substantive review comparable with those undertaken under formal authority of the 1917 dam-safety law.

For example, consider the review given to Littlerock Dam located only thirty-five miles east of the St. Francis site. This reinforced-concrete multiple-arch dam was built by the Littlerock Creek and Palmdale Irrigation Districts in 1922–1924 and—in stark contrast to the privilege afforded the city of Los Angeles—the farmers in these districts could not build their dam until obtaining explicit approval from the State Engineer. The approval process for the Littlerock Dam stretched over four years, beginning in 1918.

Aerial view looking down on Littlerock Dam in the San Gabriel Mountains of northern Los Angeles County, circa 1930. St. Francis Dam was located only about thirty-five miles to the west, but it was a world away in terms of the scrutiny given to its design and construction by the California State Engineer. Built jointly by the Littlerock Creek Irrigation District and the Palmdale Irrigation District in 1922-1924, the Littlerock Dam received no privilege of exemption from the 1917 dam-safety law. Instead, the design-approval process went on for more than four years before State Engineer Wilbur F. McClure allowed construction to begin.

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During that time State Engineer McClure engaged three outside engineers to review plans with his staff. He also called upon the advice of Joseph B. Lippincott, consulting engineer for the bond house that was to finance construction.[67]

McClure approved the plans for Littlerock Dam in May 1922. The following August his representative visited the site and noted that slight adjustments were being made by the contractor. He quickly reported to McClure that the contractor had been told to "suspend operations . . . until the changed plans were submitted to the State Department of Engineering and Irrigation for approval and action thereon." In addition, the contractor was informed "that the foundation would have to be cleared, viewed, and passed as satisfactory by a representative of the State Engineer before the actual construction of the dam could commence.[68] Two more site visits took place before McClure granted final design approval on November 4, 1922. Thereafter, a representative of the State Engineer visited the site regularly and reported on construction progress. Formal acceptance of the completed Littlerock Dam was made in a letter from McClure to the Littlerock Creek Irrigation District on June 5, 1924.[69]

Clearly, it would be specious to equate a half day's "stumbling around" at the St. Francis site with the authority exercised by the State Engineer over the Littlerock Dam. Mulholland's venture in obfuscation also contrasts sharply with the more forthright testimony given to the coroner by his chief assistant, Harvey Van Norman. "Do you know of any independent geologists or engineers who were called in consultation with regard to the selection of that site?" asked the coroner. "No, I don't," replied Van Norman."[70]

Instead of targeting Mulholland, post-collapse criticism generally focused on a legal system—specifically, the 1917 dam-safety statute—that allowed him to build St. Francis Dam without substantive outside review. Compounding that loophole was Mulholland's heroic stature among Los Angeles authorities who viewed him, in the words of the coroner's jury, as possessing "infallibility in matters of engineering judgment." With enactment of a new California dam-safety law in 1929 that eliminated the municipal exemption and with Mulholland's seeming willingness to accept responsibility for the disaster, the causes of and responsibility for the St. Francis collapse soon passed beyond the realm of overt debate or thoughtful reflection.[71] Things would not change until publication of Outland's book.

OUTLAND AND MULHOLLAND

In 1963 Charles F. Outland's *Man-Made Disaster* brought the tragedy back into the public eye.[72] Neither wild-eyed conspiracy fanatic nor Mulholland-hater, Outland resisted temptation to moralize or render judgment on emotional grounds. Interviewing as many witnesses as he could locate and examining many volumes of published and unpublished materials, he described how the dam came to be built, carefully documented the effect of the flood as it passed through the Santa Clara Valley in the pre-dawn hours of March 13, and analyzed the inquests and investigations that sought to discern the cause of the collapse. While evidence amassed by others, especially Willis and the Grunskys, informed his views, he did not simply parrot their findings.[73] Moreover, unlike the public pronouncements of earlier investigators, he assigned responsibility for its occurrence to more than weak foundations or to a legal system that allowed an individual to design and build a dam without outside review.

Like the Grunskys, Willis, Gillette, and Lee, Outland concluded that the dam collapsed first on the east side. "Ever since completion of the dam," observed Outland, "suspicious eyes had watched a leak on the western abutment, while all the time the real villain lurked seven hundred feet away in the mountain of schist." This was not to say that Outland believed the western abutment was a pillar of stability, for he considered it an "admittedly wet conglomerate" and unsuitable as a dam foundation. The east abutment, however, consisted of faulty schist at the point of contact with the dam and was vulnerable to saturation and the destabilizing effect of uplift.[74] Outland fixated on this schist—the "mountain of schist"—and insisted it was the "real villain."[75]

In actuality, Outland identified two villains—the schist and William Mulholland. Unlike the early investigators who focused on detailing the causes, mechanics, and sequence of the St. Francis Dam failure and said nothing about personal blame, Outland unhesitatingly named Mulholland the key figure in the tragedy: "In the final analysis, . . . the responsibility was his alone."[76] That appraisal in part derived from Outland's discovery of a report sent by Mulholland in 1911 to the Los Angeles Board of Public Works. While seeking a route for the Los Angeles Aqueduct, Mulholland and Lippincott (as noted earlier in this essay) encountered unstable, fractured schist within the east canyon wall of what would become the future site of St. Francis Dam. That discovery prompted a decision to avoid the faulty rock by locating "the [aqueduct] line . . . well back under the mountain" in a tunnel. "No one," stated Outland in *Man-Made Disaster*, "had seriously questioned the stability of the east abutment except the Chief, himself, at the time the aqueduct was being built many years before."[77] While Mulholland took precautions in 1911 to protect the long-term integrity of the aqueduct as it ran the length of San Francisquito Canyon, no comparable caution was evident when he later built the dam. Outland did not speculate on Mulholland's reason for this—and in later years the "Chief" offered no explanation of his own—but there was no doubt in Outland's mind that Mulholland should have been aware of the danger posed by the faulty schist forming the east canyon wall. "Construction photographs," noted Outland, "clearly record the fractural nature of the schist. . . . Unfortunately, it was so badly laminated that when stress was applied parallel to these lines of cleavage, it had little resistance to slippage. The east abutment of the dam possessed the strength of a deck of cards that is pushed obliquely on the table."[78]

An examination of construction photographs also played a critical role in Outland's discovery that "the dam had been born with a stub toe" and featured a base thickness about twenty feet less than indicated in design drawings. However, Outland downplayed this discovery by claiming that "Changes in plans after construction has started are nothing new or unique to the engineering profession [and] unforeseen contingencies often require modifications of the original designs."[79] Had the thickness of the base been properly proportioned in relation to the increased height, Outland's sanguinity would have been appropriate. A "stub toe" profile for an enlarged gravity dam, however, represented a far different —and much more dangerous—state of affairs. Although Outland did not appreciate the safety implications of the "stub toe" profile, his perceptive comparison of design drawings and construction photographs comprised a very significant finding that speaks directly to the cause of the St. Francis Dam collapse.

ROGERS AND MULHOLLAND

Matters largely rested with Outland's book until 1992 when geologist J. David Rogers published an article in *Engineering Geology Practice in Southern California*. Three years later he reached a wider audience by republishing that paper in the *Southern California Quarterly* in an expanded format but one essentially unchanged in its major arguments. Rogers's findings about the dam's collapse—the unsuitability of the site, the destabilizing effect of uplift acting on the structure, and a failure sequence initiated when water saturation reactivated an "ancient" (Willis had termed it an "old") landslide within the schist of the east abutment—echoed those already documented by the Grunskys and Willis. Given his background as a geologist it is not surprising that Rogers drew special attention to the ancient landslide comprising the site's east abutment. And general readers confronting his analysis might easily infer that such a slide would necessarily render any dam at the site to be unstable. But Rogers actually makes no claim supporting this inference. Instead, his contention—which is essentially what Willis had already reported in 1928—is simply that "the dam failure sequence was brought about by the partial reactivation of the paleomegaslide, within the schist comprising the east abutment."[80]

In a 1997 interview published by the Bureau of Reclamation, Rogers explained: "when ground or rock has slid in a landslide, it dilates or increases in volume [and] that increase in volume sets up a whole bunch of cracks, and water can go through those cracks quite easily." Thus, while the broken schist in the east abutment at St. Francis certainly made Mulholland's gravity dam more susceptible to the effect of uplift, it did not automatically or inevitably precipitate failure. Rogers specifically notes that "we know now there's over 100 major dams in the United States that have also been built against [ancient landslides]" and acknowledges that "they haven't failed yet . . . [because] the thing keeping those dams in place is the inherent redundancies of their design[s]."[81] In essence, Rogers affirms that if gravity dams erected atop ancient landslides are conservatively designed—that is, with "inherent redundancies," such as properly proportioned profiles, extensive drainage systems, cut-off walls, grouting, and similar measures—failure is hardly a foregone conclusion. Unfortunately, this affirmation is not something that is widely appreciated in the public arena where, instead, notions of Mulholland's supposed "exoneration" have gained far greater currency.

While Rogers praised *Man-Made Disaster* as a "definitive work," he differs with his predecessor in three important particulars, two of which consisted of criticisms of Mulholland not made by Outland.[82] The first instance was Rogers's censure of Mulholland for his "omission of any outside consultants to review the dam's design," a lapse that Rogers considered a "weak link in Mulholland's design process."[83] Rogers's second criticism of Mulholland dealt with raising the dam's height—accompanied by no compensating change in thickness—after construction commenced. Outland had discovered this while studying construction photographs, but he did not relate such alterations to structural safety. Rogers picked up on this omission, correctly pointing out that, in accord with standard gravity-dam theory dating to the mid-nineteenth century, raising the height was "potentially dangerous . . . in a gravity dam . . . that derives its stability through simple dead weight to resist the force imposed by the reservoir water. . . . Simply put," stated Rogers, "it is dangerous to attempt the heightening of a concrete gravity dam simply by increasing the crest height without a corresponding enlargement of the dam's base." Rogers's diagnosis was on target and he acknowledged that the maximum base width was only about 148 feet and not the 169 feet or 175 feet reported by the city in the 1920s.[84] Nonetheless, he neglected to stress how this egregious lapse in engineering judgment helped to explain the dam's collapse.

While Rogers acknowledged shortcomings of Mulholland that Outland had not perceived, he failed to consider fully: (1) how the St. Francis design compared with gravity-dam design as practiced in the teens and 1920s, especially in regard to measures taken to counter uplift; and (2) Mulholland's experience as a dam builder and the significance of his decision to proceed without outside review. These lacunae are of more than passing interest in the context of Rogers's third difference with Outland: Who, if anyone, was responsible? Outland had unhesitatingly concluded that the "responsibility" was Mulholland's "alone." Rogers not only made no such pronouncement but also roundly criticized the governor's commission—though, strangely, not Outland—for "assigning blame to an individual (Mulholland) in lieu of an organization or profession." To Rogers, fault lay in the ignorance of a profession, not with particular members of that profession. "Mulholland and his Bureau's engineers," stated Rogers, belonged to a "civil engineering community" that "did not completely appreciate or understand the concepts of effective stress and uplift, precepts just then beginning to gain recognition and acceptance." In short, the evidence that had proved compelling to Outland was, according to Rogers, trumped by "larger culprits": the absence of "a proper appreciation of uplift theory" and the need for "incorporation of solid engineering geologic input."[85]

Rogers's criticisms of Mulholland seem altogether appropriate, even if lacking in conviction and a clear appreciation of their larger significance. But Rogers's failure to address Mulholland's knowledge of the scientific civil-engineering practices and literature of his day and his neglect of Mulholland's dam-building record represent serious omissions. They become all the more

Top: *Aftermath of the dam failure at Austin, Pennsylvania, on September 30, 1911. After visiting the Austin site in October 1911, John R. Freeman and Arthur Powell Davis—two of Mulholland's engineering colleagues who had recently served with him on a consulting board for the Great Western Power Company—recognized the role of uplift in the Austin collapse.*

Bottom: *Homes destroyed by the collapsed Austin Dam. More than seventy people died (some early estimates were higher) when the wall of water surged through much of the town only about a mile below the reservoir site. As this photo shows, there was enormous property damage.*

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weighty in light of evidence that Rogers's assertions about uplift are not supported by the historical record.

UPLIFT AND EARLY TWENTIETH-CENTURY DAM DESIGN

At St. Francis, Mulholland placed ten drainage wells in the dam's foundation at the center of the canyon. In testimony offered at the coroner's inquest, Mulholland indicated that these drainage wells had been located in the streambed of San Francisquito Creek where "the rock was fissured."

> Q. [By a Juror]: Was this dam [St. Francis] under-drained practically for its entire distance?
>
> A. [Mulholland]: No, it was only where the rock was fissured, that is, those igneous rocks are always more or less jointed a little bit, and we find it usually and always expedient to drain them out so there will not be any up-pressure, taking that much pressure of the dam away. So we lead them out. Those drains are provided in every dam I have ever built.
>
> Q. At what intervals were these bleeders put in?
>
> A. About every fifteen or twenty or twenty-five feet.
>
> Q. Practically almost to the top of the dam, as you went along?
>
> A. No, the west end was a homogenous ground. There was no drain necessary in those. It was much tighter. It was about as hard as the other but tighter and more compact. The rocks—the fractured rocks, all the hard rocks in this country are more or less fractured and you can go to the mountains here and look at the granites on every hill side and you will see them fissured and fractured more or less, but they will carry water without doubt, but the prudent thing is to drain them out.
>
> Q. But the points of under drainage was [sic] put in where the rock was seen to be fractured?
>
> A. Yes.[86]

In essence, Mulholland acknowledged the possibility of uplift acting through the fractured schist. But—while professing that "the prudent thing is to drain them out" and that it is "always expedient to drain them out so there will not be any up-pressure"—he confined his attention only to the dam's center section. He ignored the possibility that, as the level of the reservoir rose, water would extend up the east canyon wall and then seep into the fractured schist foundation. Beyond placing drainage wells in the center section, Mulholland did little to counter the possibility of uplift acting on the St. Francis Dam. As essentially all engineers who investigated the disaster acknowledged, the canyon walls had not been drained, no inspection/drainage tunnel had been placed in the dam's interior, there had been no grouting, and the structure lacked a cut-off trench extending across the site.[87] Moreover, as Outland discerned, Mulholland had raised the dam's height but without widening the base. With this latter action, he exacerbated the destabilizing effect of uplift and necessarily increased the potential for disaster.

Rogers avers that "many engineers were just beginning to appreciate the destabilizing effects of uplift pressures in the late 1920s" and promotes the impression that uplift represented an esoteric, little-appreciated phenomenon when St. Francis Dam was built.[88] If the date given by Rogers had been 1910, such a perspective could be defended. However, for a decade prior to construction of St. Francis Dam, uplift had engendered widespread concern. The extent of this concern—and action taken in actual construction—warrants close attention because the effect of uplift on the stability of St. Francis Dam speaks directly to why more than 400 people perished in the early hours of March 13, 1928.

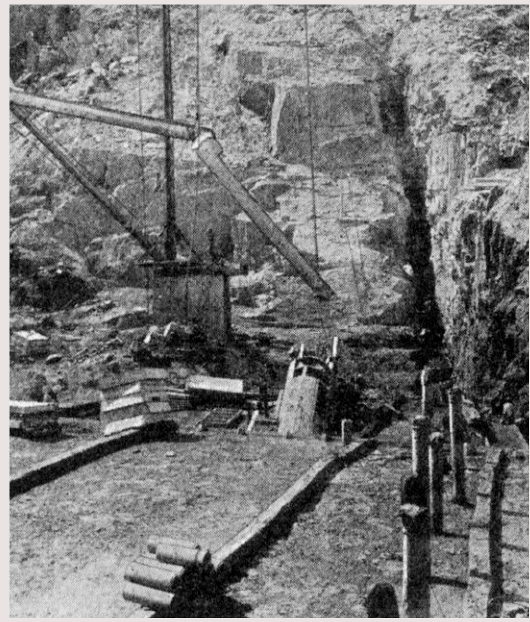
In the mid-nineteenth century uplift was not accommodated into gravity-dam design protocols.[89] Nonetheless, dam builders soon began to recognize the dangers posed by uplift and to develop measures to counter its effect. Most notably, concern about uplift prompted British engineers building Liverpool's Vrynwy Dam (a gravity structure completed in 1892) to incorporate drainage wells into its design, an action publicized in British engineering journals.[90] Not all civil engineers in the late nineteenth century—most prominently, Edward Wegmann, U.S. author of *The Design and Construction of Dams* (1888 and several subsequent editions)—paid heed to uplift. Thus, in 1904 Edward Godfrey could complain in *Engineering News* that "I find nothing in [books] on dams mentioning this floating tendency of the water which percolates under dams."[91] Four years later Godfrey reiterated his complaint, a critique obviated in 1910 when Charles E. Morrison and Orrin L. Brodie's *High Masonry Dam Design* directly criticized Wegmann for failing to account for uplift in gravity dam designs. As part of this, they asserted that "Present practice requires [that uplift]. . . be considered where a structure of great responsibility is proposed . . . ."[92]

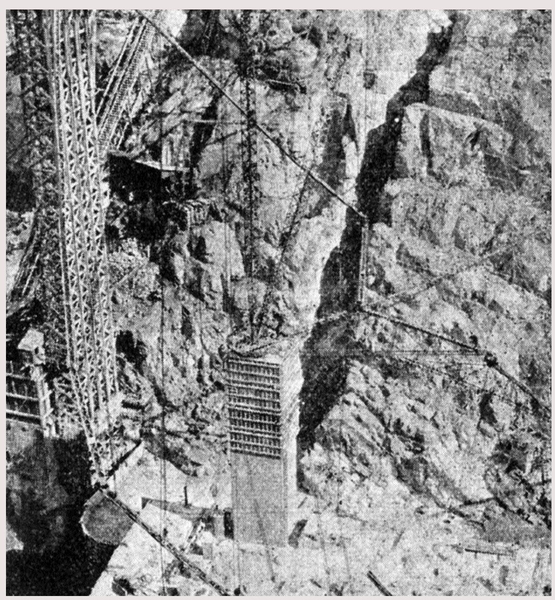
Apprehension about uplift intensified following the collapse of a concrete gravity dam in Austin, Pennsylvania, on September 30, 1911. Located about two miles upstream from town, the Austin Dam failed catastrophically, taking at least seventy-eight lives.[93] The calamity attracted great public attention and galvanized the American dam-building community to take action against the potentially disastrous effects of uplift. A leader in this effort was John R. Freeman, a prominent New England-based engineer who, in 1906, had served on the board of consulting engineers who reviewed Mulholland's plans for the Los Angeles Aqueduct.[94] A prominent advocate of gravity-dam technology, Freeman rushed to the site of the Austin tragedy and reported in *Engineering News*: "the cause that probably led to the failure of the Austin PA dam," he declared, was "the penetration of water-pressure into and underneath the mass of the dam, together with the secondary effect of lessening the stability of the dam against sliding." Freeman implored engineers to understand that "uplift pressures may possibly occur under or within any masonry dam and should always be accounted for."[95] At the time, Freeman was helping oversee construction of New York City's Ashokan (also known as Olive Bridge) and Kensico dams, two projects that—as *Engineering News* described Kensico Dam in April 1912—countered "upward water pressure" with foundation pressure-grouting and an extensive drainage system.[96]

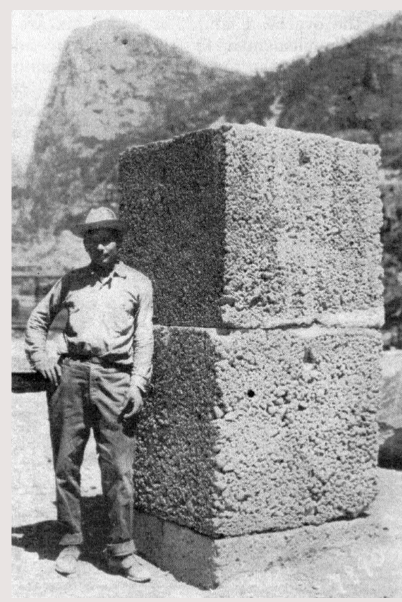
Also taking the Austin failure very seriously was Arthur Powell Davis, chief engineer (later director) of the U.S. Reclamation Service, who believed that the failure of Austin Dam "was caused by an upward pressure on the base of the dam." After visiting the disaster site, Davis expressed concern about the possible effect of uplift on the service's Elephant Butte Dam, a concrete gravity structure more than two hundred-feet high to be built across the Rio Grande in southern New Mexico.[97] The agency soon approved a design for Elephant Butte that included extensive grouting, placement of a drainage system along the length of the dam, and a deep cut-off trench. The service's close attention to the Elephant Butte foundation was documented in engineering journals and Davis's 1917 book, *Irrigation Works Constructed by the United States Government*, which described a "variety of precautions . . . adopted to prevent percolation under the [Elephant Butte] dam, and to relieve any upward pressure that might develop there."[98] For the service's 354-foot high concrete gravity Arrowrock Dam built in 1913–1915 near Boise, Idaho, Davis could similarly report: "In order to prevent leakage in the foundation of the [Arrowrock] dam, a line of holes was drilled into the foundation just below the upstream face of the dam to depths of 30 to 40 feet. They were grouted under pressure . . . [and] another line of holes was drilled to serve as drainage holes to relieve any leakage under the dam. These were continued upward into the masonry and emerged into a large tunnel running the entire length of the dam. The success of the Arrowrock drainage system was described in 1930 by C. E. Grunsky, who pointedly related it to the St. Francis collapse: "My visit to this dam [Arrowrock] was made at a time when the reservoir was filled. The func-

OTHER CURVED GRAVITY DAMS: IN CONTRAST TO ST. FRANCIS . . .

The Arrowrock, Exchequer, and O'Shaughnessy (Hetch Hetchy) dams were concrete curved-gravity dams built prior to or contemporaneously with the St. Francis Dam. Significantly, all of them incorporated features to alleviate the effect of uplift that extended far beyond Mulholland's efforts at St. Francis. These photos, including views published in the nationally prominent *Engineering News-Record*, graphically testify to construction practices absent from the St. Francis Dam.







Arrowrock Dam

Top, Left: *Downstream side of Arrowrock Dam, built in 1913–1915 by the U. S. Reclamation Service across the Boise River in southern Idaho. Constructed under the general authority of Arthur Powell Davis, the design featured grouting and drainage of the foundation along the full length of the structure.*

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Top, Center: *Construction view at Arrowrock showing drainage pipes running along the upstream face.*

Joseph B. Lippincott Collection, Water Resources Center Archives

Top, Right: *Interior view of Arrowrock Dam showing the interior inspection/ drainage gallery. The St. Francis design lacked any comparable drainage tunnel.*

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Exchequer Dam

Middle, Left: *Circa 1926 construction view of Exchequer Dam in the Sierra Nevada foothills near Merced, California. This photo shows how "expansion joints," spaced fifty feet apart, divided the dam's concrete into a series of vertical components. No expansion joints were incorporated into the St. Francis design, and major cracks in the upstream face exacerbated the effect of uplift on Mulholland's dam.*

Charles Derleth Collection, Water Resources Center Archive

Middle, Center: *1925 construction view showing the cut-off trench and drainage pipes (left foreground) at Exchequer. Compare this to photos on pages 21, 23, and 26 and it is evident that, in terms of abutment drainage up the canyon walls, the Exchequer design significantly exceeded what was done at the St. Francis site.*

Engineering News-Record, May 28, 1925

Middle, Right: *Detail view showing (along the left edge of the dam) the row of drainage pipes extending the length of Exchequer Dam's upstream face.*

Charles Derleth Collection, Water Resources Center Archives

O'Shaughnessy (Hetch Hetchy) Dam

Bottom, Far Left: *Circa 1925 "before and after" photos of Hetch Hetchy Valley and O'Shaughnessy Dam in Yosemite National Park. Like Los Angeles, San Francisco was exempt from California's 1917 dam-safety law and chief engineer M. M. O'Shaughnessy built the dam without the approval or scrutiny of the state engineer. On his own initiative, O'Shaughnessy incorporated into his design measures to counter uplift that far exceeded what Mulholland did at St. Francis.*

DC Jackson/damhistory.com

Bottom, Left Center: *1922 construction view of O'Shaughnessy Dam showing cutoff trench extending up the canyon wall.*

Engineering News-Record, June 8, 1922

Bottom, Right Center: *Two of the 1,600 porous concrete drainage blocks placed in O'Shaughnessy Dam. The photo appeared in* Engineering News-Record *in September 1922 and would have been easily accessible to Mulholland and his staff as they prepared the St. Francis design.*

Engineering News-Record, September 21, 1922

Bottom, Far Right: *1922 photograph showing how the porous drainage blocks were placed in the cutoff trenches extending up the canyon walls at O'Shanghnessy Dam. Chief engineer M.M. O'Shaughnessy is shown at left in front of the blocks.*

M. M. O'Shaughnessy Collection, Bancroft Library tioning of the weepholes was noticeable. In some cases the flow from the gooseneck outlet pipes amounted to several thousand gallons per day. If there were no drainage of the foundation there would be great likelihood of a large uplifting force such as that which, at the St. Francis Dam, contributed to its failure."[99]

After the agency became the Bureau of Reclamation in 1923, concern about uplift continued. For example, Black Canyon Dam in southern Idaho, a 184-foot high concrete gravity structure completed in 1924, featured two rows of grout holes "drilled into the bedrock along the upstream edge of the dam along its entire length. . . . [A] row of drainage holes was drilled 8 feet downstream from the second row of grout holes. . . . The water from them is carried to a tile drain embedded in the concrete parallel with the axis of the dam." In case anyone missed the point, *Engineering News-Record* declared: "The purpose of this drainage system is to collect and lead off any water that might accumulate and to prevent an upward pressure under the dam."[100] After leaving the Reclamation Service in 1923, Davis became chief engineer of Oakland's East Bay Municipal Utility District where his concern about uplift became manifest in the Llana Plancha (later Pardee) Dam. This concrete curved-gravity structure featured foundation grouting and an extensive drainage system running up both canyon walls. Construction started in 1927 and the design was illustrated in *Engineering News-Record* the same week that the St. Francis Dam collapsed.[101]

Freeman, Davis, and the Reclamation Service were hardly alone in drawing attention to the perils of uplift in the aftermath of the Austin Dam failure. In 1912, C. L. Harrison brought together the views of twenty engineers on the subject in a *Transactions of the American Society of Civil Engineers* article where, as Harrison summarized: "Each of the twenty discussions presented on the subject recognizes the existence of uplift."[102] The next year, *Engineering News* described field tests in Germany that confirmed the existence of uplift pressures. This prompted Edward Godfrey to proclaim: "the results of these experiments further emphasizes [sic] what the author has said before: It is a crime to design a dam without considering upward pressure."[103]

Authors of technical books also addressed the perils of uplift and Chester W. Smith's *The Construction of Masonry Dams* (1915) included a ten-page section describing how cut-off trenches, foundation grouting, and drainage systems could ameliorate the effects of uplift.[104] The 1916 edition of Morrison and Brodie's *High Masonry Dam Design* (retitled *Masonry Dam Design Including High Masonry Dams*) began with a fifteen-page discussion of uplift that described "several ways in which upward pressure may be cared for," including use of a foundation cut-off trench, "adding a sufficient section to the dam to offset the upward pressure, and . . . providing drainage wells and galleries to intercept all entering water."[105] A year later, William Creager's *Masonry Dams* (1917) emphasized the need to counter uplift in the aptly titled chapter, "Requirements for Stability of Gravity Dams." In addition, references to uplift appeared throughout the book.[106] "The methods of design described [in *Masonry Dams*] and the assumptions recommended," Creager advised readers, "represent present conservative practice, and correspond to a proper degree of safety for the average enterprise, and where considerable damage to property and loss of human life would result if failure occurred."[107]

By 1916–1917, serious concern about uplift on the part of American dam engineers was neither obscure nor unusual. Equally to the point, in the early 1920s, Mulholland's placement of drainage wells only in the center section of St. Francis Dam did not reflect standard practice in California for large concrete gravity dams. Earlier, in 1916, when Hiram Savage developed plans for two municipally owned concrete gravity dams near San Diego, he followed the lead set by the Reclamation Service. His designs for Lower Otay Dam (completed in 1917) and Barrett Dam (1922) called for grouting and drainage wells along the length of the structures and for a cut-off trench (containing a "continuous 12-[inch] sub drain") to run the length of both dams.[108] In northern California, the Scott Dam (also known as Snow Mountain Dam), built by the Snow Mountain Power Company across the Eel River in 1922, featured "grouting below the cut-off wall" as well as a network of under-drains to "carry off seepage water. . . . The drains under the dam consist of porous concrete tile . . . . Lines were laid parallel with the axis of the dam and on 15-ft. centers under the entire structure."[109] In California's Central Valley in the mid-1920s, the Merced Irrigation District constructed Exchequer Dam, a large concrete-curved gravity structure that featured a cut-off wall and an extensive drainage system running up both canyon walls.[110]

San Francisco, the only municipality in California that compared in size and wealth with Los Angeles (and a city that also benefited from the dam safety law's "municipal exemption"), began construction in 1919 on a large water supply dam in the Sierra Nevada. The concrete curved-gravity Hetch Hetchy Dam (later renamed O'Shaughnessy Dam after the project's chief engineer) featured an extensive drainage system consisting of 1,600 porous concrete blocks and a cut-off trench running up both canyon walls. The dam reached an initial height of about 330 feet in 1923 (it was extended to 430 feet in 1938) and, as detailed by *Engineering News-Record* in 1922, "the porous concrete blocks are placed in the bottom of the cut-off trench for its full length, and also in vertical tiers."[111] The Hetch Hetchy Dam's extensive drainage system—designed and implemented *before* 1924—clearly bore scant resemblance to Mulholland's minimal effort to counter uplift at St. Francis Dam.

Contemporary measures, like those taken at Hetch Hetchy/O'Shaughnessy and at other gravity dams in California to provide for drainage up the canyon walls of a dam site, did not escape attention at the coroner's inquest. The issue prompted frank comments in the testimony of M. H. Slocum, the construction supervisor at Exchequer and Scott dams and a participant in the foundation preparation and early concrete placement at Hetch Hetchy.

> Q. [By the Coroner]: In your opinion, how could undermining of the foundation [of St. Francis Dam] have been prevented?
>
> A. [Slocum]: On other work of such a character with which I have been connected, it has been done by putting in drainage holes, connected up to a drainage gallery which intercepts the water practically at the upstream base, taking away the uplift and letting it run off downstream without any pressure.
>
> Q. [By a Juror]: Is it common practice to run the drainage lines you are speaking of pretty well up the sides of the hills?
>
> A. Drainage galleries in Exchequer, Hetch-Hetchy, [and] Snow Mountain run to all intents and purposes to the top of the dams, clear to the top.
>
> Q. Have you ever seen or heard of a dam which you considered to be a safe and properly designed dam, which didn't provide some means of draining up the sides?
>
> A. I have been to a great many dams, and to my memory I can't remember of any that haven't had drainage, drainage galleries in them of the gravity type, not of strict arch type, this [St. Francis] was a gravity type.[112]

Additional evidence could be cited to demonstrate the awareness of America's dam-building engineering community, prior to the St. Francis disaster, of the threat posed by uplift and of the extensive measures taken to offset its effect.[113] But the material presented here justifies the observation in 1927 of noted engineer Fred Noetzli: "conservative engineering requires that gravity dams be designed for uplift." It also underscores that such conservatism was hardly an anomaly by the 1920s.[114] Why Mulholland ignored the tocsin sounded by numerous engineers—both in print and in practice—over the dangers of uplift remains a mystery. After all, he was supposedly a voracious, self-schooled devotee of technical information.[115] But labeling the rationale for his actions as somehow mysterious does not excuse them. Many American dam builders of the teens and 1920s understood the importance of countering uplift with measures that went far beyond the meager steps taken at St. Francis Dam. Mulholland stood apart from his contemporaries on this crucial issue of safety and the results proved tragic.

MULHOLLAND: PRIVILEGE AND HUBRIS

William Mulholland was often admired for his ability to meet complex challenges, but he was not inclined to seek the counsel of his peers. His go-it-alone approach at St. Francis did not accord with the common practice of dam builders and the organizations financing construction to consult with outside experts. When, for example, John Freeman set out in 1909 to design Big Bend Dam in northern California for the Great Western Power Company, he secured the services of Arthur Powell Davis and Mulholland as consultants on the project. Two years later, the same company engaged the highly respected engineers James Schuyler and Alfred Noble to review John Eastwood's design for the nearby Big Meadows Dam.[116] Similarly, in 1916–1917, while planning construction of the municipally owned Lower Otay and Barrett dams in San Diego County, Hiram Savage sought the advice of well-known dam engineer A. J. Wiley.[117]

Outside of California between 1907 and 1916, New York City relied upon a panel of engineering consultants to help design the Catskill water supply system (including the Ashokan/Olive Bridge Dam); the Miami Conservancy District (a model for the Tennessee Valley Authority) engaged a group of consulting engineers in 1913 to review designs for flood-control dams in central Ohio;[118] and the Reclamation Service (later Bureau) initiated a policy in 1903 requiring dam designs and other projects to be reviewed by "engineering boards."[119] In April 1928, the bureau rushed to remind the public and fellow engineers of this policy: "The recent unfortunate failure of the St. Francis Dam in California," announced the bureau in *Engineering News-Record*, justifies "special mention of the extensive geological and engineering investigations that preceded the approval of the site and designs for the Owyhee Dam" that included three geologists and three engineers not on the bureau staff.[120]

Significantly, Mulholland himself had on at least one occasion recognized the value of outside review. In 1912 he requested Arthur P. Davis to visit the Lower San Fernando Dam site. His reason for doing so is telling, because the explanation could apply with equal force to later dams for which he sought no outside review. "I requested or rather suggested to the Board of Public Service Commissioners," Mulholland told Davis, "that an engineer be employed to examine the proposed San Fernando Dam [site] when it is stripped in order to clear them of any charge that might be brought in the future of having proceeded with the work without competent advice." Here, Mulholland advocated a principle that he thereafter largely ignored.[121]

There were other reasons for Mulholland to have recognized the desirability for seeking outside review of his dam projects. In 1918 his work had attracted public scrutiny after the partial collapse of the earthfill Calaveras Dam. That incident involved a major section of hydraulic fill that "slipped" upstream into the reservoir and required a major reconstruction effort to rectify. Mulholland had supervised the dam's construction starting in 1913 as a consulting engineer for San Francisco's privately owned Spring Valley Water Company. The failure was especially embarrassing since Calaveras was an earthen-hydraulic fill dam, a type that Mulholland had significant experience in building. Indeed, Rogers—apparently unaware of the Calaveras fiasco—places Mulholland among the "founding fathers" of this construction technique.[122] Michael M. O'Shaughnessy, the engineer responsible for San Francisco's Hetch Hetchy project, visited the Calaveras site in 1913, soon complaining to John Freeman about Mulholland's "sloppy" and "slipshod and crude" construction methods. Even more pointedly, O'Shaughnessy opined that Mulholland and his assistant were "so intensely conceited that they imagine all they might do should be immune from criticism."[123]

Prior to the St. Francis failure, Mulholland also ignored sharp professional criticism from Frederick Finkle, an engineer who, a few years before, had publicly rebuked him for using faulty cement in the Los Angeles Aqueduct. Even discounting the fact that it emanated from an earlier detractor of his work, this critique should have given Mulholland pause. In 1924, Finkle visited the St. Francis site at the request of the Santa Monica Anti-Annexation Committee and soon criticized "defects of design and foundation materials" as well as "unfavorable" geological conditions. The latter was supported by tests revealing the propensity of the red conglomerate to dissolve when submerged in water. Finkle also described the structure's base as "insufficient" and "not in accordance with sound engineering practice." His eerily prescient apprehensions—"I would hesitate to recommend a concrete dam on such a foundation"— found their way into the local press along with his prediction: "This dam, if kept full for any length of time, . . . will unquestionably fail."[124] Finkle's warning came prior to the dam's construction but, perhaps because Mulholland dismissed Finkle as some kind of biased naysayer, he ignored it and made no effort to seek significant, independent review of the St. Francis project.

Rogers acknowledges that Mulholland's "omission of any outside consultants to review the [St. Francis] dam's design" was a "weak link in [his] design process." But he fails to see any connection between the dam's collapse and that "weak link." Moreover, he neglects Mulholland's inexperience in building concrete dams. O'Shaughnessy did not miss the connection and seven months after the St. Francis failure, he bluntly told California State Engineer Edward Hyatt: "Los Angeles made an error in committing its policies of high concrete dam construction to one man, whose previous experience had been confined to building low head, hydraulic filled dams. . . . This was no justification for entrusting him with the design and construction of a high head masonry dam, hence they [Los Angeles] are now paying the bill."[125]

Rogers, in a published interview, also confounds his own judgments about Mulholland's competence by reversing course and indicting "the Chief" for flaws that he (Rogers) had previously rejected or ignored. Mulholland's "Achilles heel," states Rogers in the 2000 interview, was "his thriftiness," his ability "to build enormous projects at a fraction of the cost [that] any other public agency was able to achieve," a practice that explains "why his services were sought by so many." His parsimony, explains Rogers, "led to many aspects of dam design that were omitted from St. Francis, which might have saved the dam from failing. These included items such as seepage cut-offs, foundation keyways, grout curtains, additional uplift relief, expansion joints, inspection gallery, geologic evaluations, and any manner of external consulting, outside his own BWWS [Bureau of Water Works and Supply] staff."[126]

Such criticism stands in contrast to Rogers's contentions in his two articles that Mulholland and the dam-building profession "did not completely appreciate or understand the concepts of effective stress and uplift, precepts just then beginning to gain recognition and acceptance."[127] Which way would Rogers have it—that the St. Francis Dam disaster was due to Mulholland's parsimony, which led him to omit technologies for countering uplift; or that it was due to his ignorance of those technologies and their value as "inherent redundancies" (to borrow Rogers's phrasing) in countering uplift?[128] While we appreciate Rogers's descriptions of the mechanics of the dam's collapse—as we do the analyses of the Grunskys, Willis, Outland, and others whose earlier findings he affirmed—his ventures into the historical interpretation of Mulholland and the St. Francis Dam disaster possess far less cogency.

REQUIEM FOR MULHOLLAND?

Unlike Outland's dispassionate, yet moving, account in *Man-Made Disaster*, Rogers specifically sought to rescue Mulholland's reputation and correct what he perceived as injustices done to the "Chief" in the wake of the dam's collapse. He expressed that goal candidly in his *Southern California Quarterly* article under the heading "Requiem for Mulholland":

> we should be so lucky as to have any men with just half his character, integrity, imagination and leadership today. Big Bill Mulholland was the kind of rugged individualist that [sic] made great things happen, but his style of standing on principle would never be seen as "politically correct" in the style of today's committee-sitting, bean counting, lawyer-consulting, image-conscious compromisers. Mulholland would sooner "give birth to a porcupine backwards" than to have to work inside air conditioned buildings sitting in padded chairs with people of compromising principle.[129]

In this article we offer a distinct counterpoint to Rogers's perspective. We also take issue with any notion that Mulholland's conduct in raising the height of St. Francis Dam without increasing the base's thickness—or his failure to design the dam in accord with the same appreciation for uplift as practiced by his contemporaries—can in any way be countenanced as somehow "standing on principle."

Significantly, evidence suggests that Mulholland actually was treated rather gently following the dam's collapse. Not kindly disposed toward him, of course, were residents of the Santa Clara Valley as dramatically reflected in the sign erected by one woman in her front yard: "KILL MULHOLLAND!" Moreover, his granddaughter has recalled that "threats were made against his life, and he lived with an armed guard around his home." But his professional colleagues did not publicly pillory him. The Los Angeles Board of Water and Power Commissioners rejected demands for his immediate dismissal and he stayed on as Chief Engineer for several months until resigning in November 1928. Even then, the city retained him as a consultant at a salary of $500 a month, a post he held till his death seven years later.[130]

Public honors continued to come his way and city officials in April 1928 invited him as a guest of honor at a luncheon celebrating the new Los Angeles City Hall. He declined, but invitations continued to arrive, including one (not accepted) to the White House ceremony in December 1928 where President Calvin Coolidge signed the Boulder Canyon Project Act into law. An invitation that he did accept came in 1933 from the Los Angeles Water and Power Commission, which honored him "for producing a supply of water in the City of Los Angeles adequate for the uses of a population calculated on an unprecedentedly rapid basis of increase." There were also tributes, like that in 1933 from *Western Construction News*, which honored him "as a man of history and the maker of Los Angeles." They continued even after his death in praise-filled obituaries and other accolades, some making no mention of the St. Francis Dam collapse. Despite the honors coming during the years prior to his death in 1935, Mulholland withdrew from the public and fell into melancholy. He apparently anguished over the devastation wrought by the St. Francis flood and took little solace from those who remembered him as a "big man" and a person of "sterling quality" for accepting responsibility for the disaster.[131]

Many prominent engineers avoided public comments that might cast aspersions on or disturb the "Chief," but their private thoughts could be less than supportive. Consider what Arthur P. Davis wrote to John Freeman following a visit to the dam site on March 19, 1928. Emphasizing that his comments were to be held in confidence, Davis observed that conditions "all pointed to the vital necessity of preventing any percolation into the foundation" and he bemoaned the lack of a "deep cut-off trench," "deep grouting," and "adequate drainage wells." Making specific reference to the Elephant Butte, Ashokan/Olive

Prior to March 1928, "The Chief" was a dominant figure in western water development. For example, in this circa 1924 publicity photograph Mulholland (on the left) leads a group of engineers on a visit to the future site of Hoover (Boulder) Dam. Following the St. Francis Dam disaster, his colleagues largely refrained from direct public criticism and, after he resigned from the city's Bureau of Water Works and Supply in November 1928, they treated him with great personal respect. But his professional reputation was shattered and never again would he play a significant role in the planning or execution of any major hydraulic engineering projects.

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Bridge, and Arrowrock dams, he went so far as to say that, "had provisions existed [at St. Francis], as established by recent practice . . . [at] many other existing dams, the accident might have been avoided."[132]

J. B. Lippincott wrote to Freeman in March 1928 about the disaster, prefacing his remarks with the admission: "I have been very careful to avoid discussing this in any public way because of my old friendship and respect for Mr. Mulholland." But this public reticence did not prevent him from acknowledging the problematic character of the "broken schist" encountered in San Francisquito Canyon during construction of the Los Angeles Aqueduct. "The foundations on which the dam was built were not good," he admitted, adding: "It is my understanding that the dam had little of anything under it in the way of a drainage system."[133] In reply, Freeman confessed that he, too, was avoiding public discussion of the disaster: "I have been careful . . . to say nothing [to newspaper reporters] regarding the Los Angeles dam which could come back to hurt Mulholland." He followed this disclosure with candid criticism of Mulholland for his habit of not consulting independent experts: "[he] does not appreciate the benefit of calling in men from outside to get their better prospective [sic]

For more than a year after floodwaters laid waste to the Santa Clara Valley, the center section of the St. Francis Dam remained in place, an imposing (if unintentional) monument to the tragedy. In 1929, a curiosity seeker at the site fell to his death, prompting the city to dynamite the concrete monolith into a less visually provocative mass of rubble. While the dam itself seemingly could be erased from the landscape of San Francisquito Canyon, the horror of the flood in the collective memory of the Santa Clara Valley—and California as a whole—has proved far more enduring.

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and their independent point of view."[134] To another colleague, Freeman reinforced the point: "This [St. Francis Dam] site plainly required many precautions that were ignored, and while I have the highest personal regard for my good old friend William Mulholland, I can but feel that he trusted too much to his own individual knowledge, particularly for a man who had no scientific education."[135]

RETROSPECT

The St. Francis disaster quickly spawned a new California dam-safety law that eliminated the municipal exemption. After 1929, all the state's non-federal dams came under the authority of the Department of Public Works and the administrative oversight of the State Engineer (later assumed by the Division of Safety of Dams).[136] Many people believe that the 1929 law created regulatory mechanisms responsible for saving thousands of lives. A case in point was the near-collapse of Mulholland's Lower San Fernando Dam during the 1971 San Fernando Valley earthquake. "If it had not been for the [storage] restrictions imposed by the Division of Safety of Dams," states engineer Irving Sherman, "the water level in the reservoir might have been ten feet higher than what it actually was—in which case the [hydraulic-fill earthen] dam would have been overtopped and at least partially washed away." Instead, "the 80,000 people downstream . . . were temporarily evacuated until after the danger had passed."[137]

But regulation is a double-edged sword, and the development of innovative dam technologies was not necessarily advanced by the 1929 law. While gravity-dam design may have escaped stagnation, the new law proved enormously burdensome to hoped-for advances in multiple-arch dam technology and, in California, did much to eliminate the technology from the realm of acceptable design.[138] Of course, the sad truth is that the St. Francis Dam design did not draw upon any innovative advances in dam technology that might somehow have unwittingly fostered failure. Far from it, for in terms of large-scale concrete gravity dams of the 1920s, Mulholland's St. Francis design was, to borrow a phrase from architectural history, a *retardaire* structure. It suffered not from creative innovation but from an egregious lack thereof.

More than any other person, Mulholland shaped Los Angeles's water policy and laid the foundation for the modern city. When he resigned in 1928 the city's oil, motion picture, real estate, and tourist industries were booming; the Department of Water and Power had become the most powerful municipal agency in the United States; and Los Angeles was in the vanguard of a host of southern California cities embarking on a new phase of water-seeking that would reach to the Colorado River. But such achievement had not come without great human, psychic, and economic costs—among them the collapse of a dam in the remote reaches of the upper Santa Clara Valley that took more than 400 lives.

Despite equivocations, denial of dangers that he knew—or reasonably should have known—existed, pretense to scientific knowledge regarding gravity-dam technology that he possessed neither through experience nor education, and invocations of "hoodoos," William Mulholland understood the great privilege that had been afforded him to build the St. Francis Dam where and how he chose. Because of this privilege—and the decisions that he made—William Mulholland bears responsibility for the St. Francis Dam disaster.[139]

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