PDHonline Course R135 (2 PDH)

Ethical Issues from the St. Francis Dam Failure

Instructor: J. Paul Guyer, P.E., R.A., Fellow ASCE, Fellow AEI

2020

PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

An Approved Continuing Education Provider

Ethical Issues from the St. Francis Dam Failure

J. Paul Guyer, P.E., R.A., Fellow ASCE, Fellow AEI

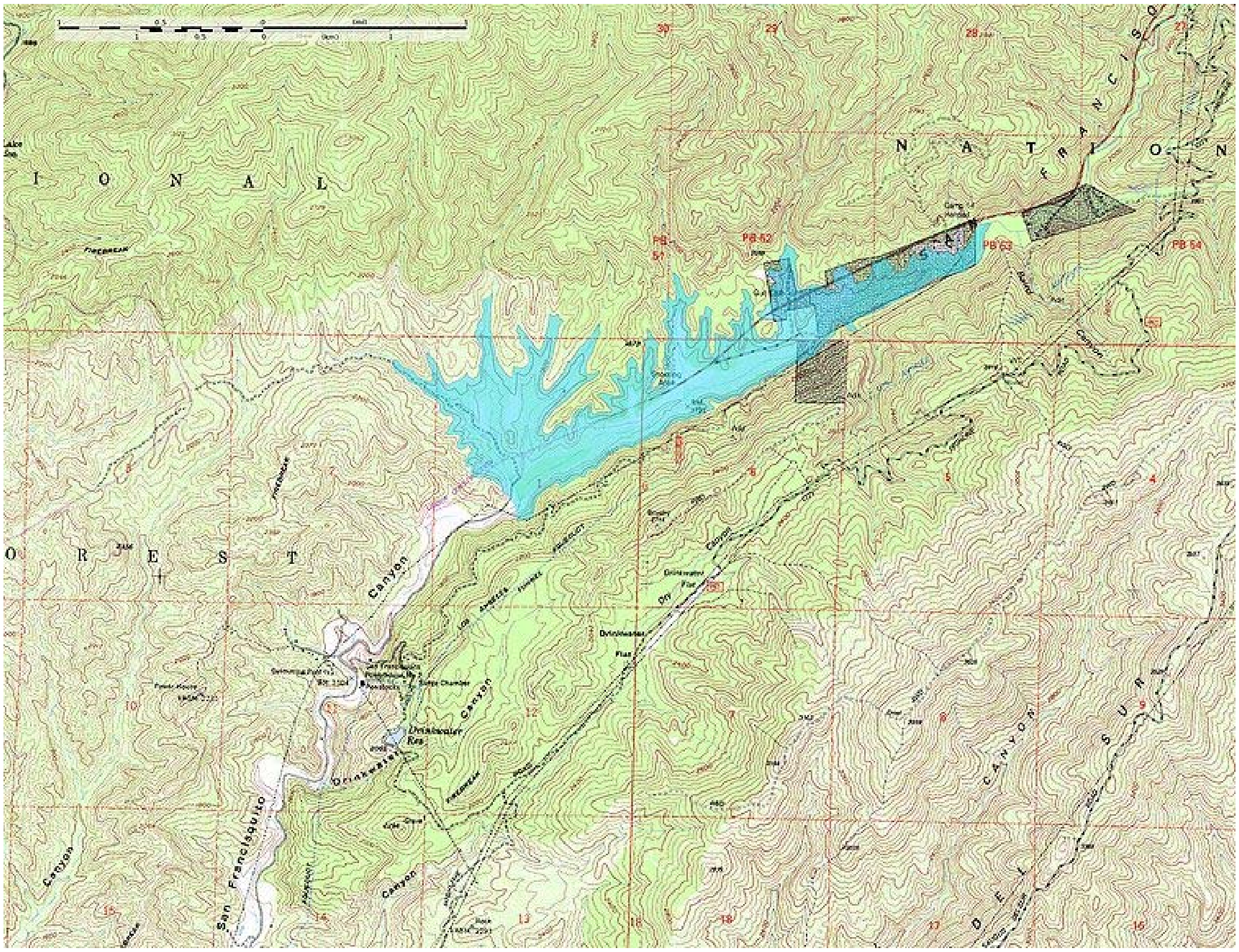
CONTENTS

1. INTRODUCTION

At 11:56 PM on March 12, 1928, the concrete arch St. Francis Dam was a key element of the Los Angeles (California) Aqueduct. It was designed and constructed by the City of Los Angeles' Department of Water and Power (LADWP) to create a reservoir to store water brought via the Aqueduct from the Owens Valley in east central California to serve the burgeoning city of Los Angeles. It was a concrete gravity arch dam located about 40 miles northwest of Los Angeles on San Francisquito Creek near the present day city of Santa Clarita, California.

At 11:57 PM it collapsed catastrophically, releasing 12 billion gallons of flood waters downstream that reached a depth of 140 feet with average velocities estimated at 26 feet per second. By 5:30 AM on March 13 flood waters reached the Pacific Ocean at Montalvo (near Ventura), California. The flood killed more than 450 people and was the worst civil engineering failure in U.S. history.

St. Francis Dam
(Attribution: U.S. Geological Survey Photographic Library)
Figure 1



Topographical Map of St. Francis Dam Reservoir
(Attribution: Wikipedian Kbh3rd)
Figure 2

2. WHAT HAPPENED

2.1 Height Increases During Construction

Construction of the St. Francis Dam was begun in 1924. Shortly after construction had begun it was decided to raise the height of the dam 10 feet, which would increase the storage capacity of the reservoir from 30,000 to 32,000 acre-feet. This height increase was adopted with only minor changes in the dam's design to accommodate the additional height, particularly with no increase in the width of the dam base. In 1925 when construction was about 50 percent complete a decision was made to increase the height of the dam an additional 10 feet to 195 feet, thereby increasing the reservoir's storage capacity to more than 38,000 acre-feet. The dam's new height increase required construction of a dike along the top of the ridge of the western abutment to prevent water from spilling over the ridge. Again, there was no increase in the width of the dam base.

2.2 Cracks Appeared

Throughout 1926 and 1927 temperature and contraction cracks, in some cases with accompanying leakage, appeared in the dam as the reservoir filled. The cracks and leaks were inspected and judged to be within expectation for a concrete dam the size of the St. Francis.

From late 1927 to March 1928 the reservoir filled steadily and without incident. In March the reservoir reached full capacity and the initial filling was concluded. In the same month, however, travelers on the road along the east shore of the reservoir reported cracks and a sagging in the roadbed near the dam's east abutment.

2.3 Leaks Observed

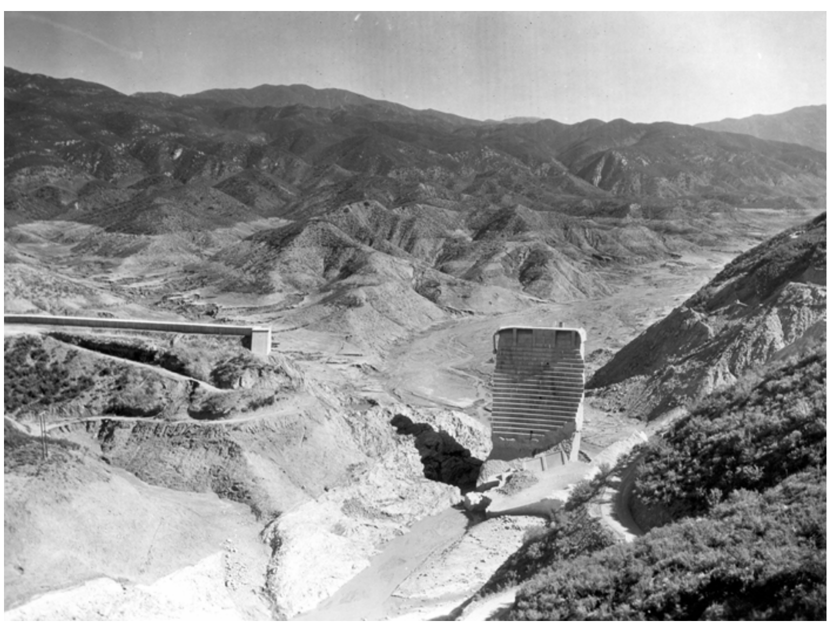
On the morning of March 12, the dam keeper discovered a substantive leak, reported it to LADWP management, and the leak was inspected by LAWPD management. It was concluded the leak was relatively minor and normal for a concrete dam, and the dam was pronounced safe by LADWP management.

2.4 The Failure

Three minutes before midnight on March 12, 1928, the St. Francis Dam catastrophically failed. There were no eyewitnesses to the dam's collapse. A wall of water 125 feet high was quickly released and twelve billion gallons of water surged down San Francisquito Canyon in a dam break wave demolishing a downstream power station and destroying everything in its path. The flood traveled south down San Francisquito Canyon flooding parts of the present-day towns of Valencia and Newhall. The deluge then turned west into the Santa Clara River bed, flooding the towns of Bardsdale, Fillmore and Castaic Junction. The flood continued west through the town of Santa Paula and discharged the flood water and accumulated debris, including drowning victims, into the Pacific Ocean near the town of Montalvo, 54 miles away. When it reached the ocean at about 5:30 a.m. on March 13, the flood waters were about two miles wide and traveling at a speed of about 5 miles per hour. Bodies of victims were recovered from the Pacific Ocean as far south as the Mexican border.

Here is a link to a good online video about the failure that includes computer simulations of the flow of the dam break wave: (There is one factual glitch: One of the slides indicates leaks were detected on “March 22”; actually they were detected on March 12.)

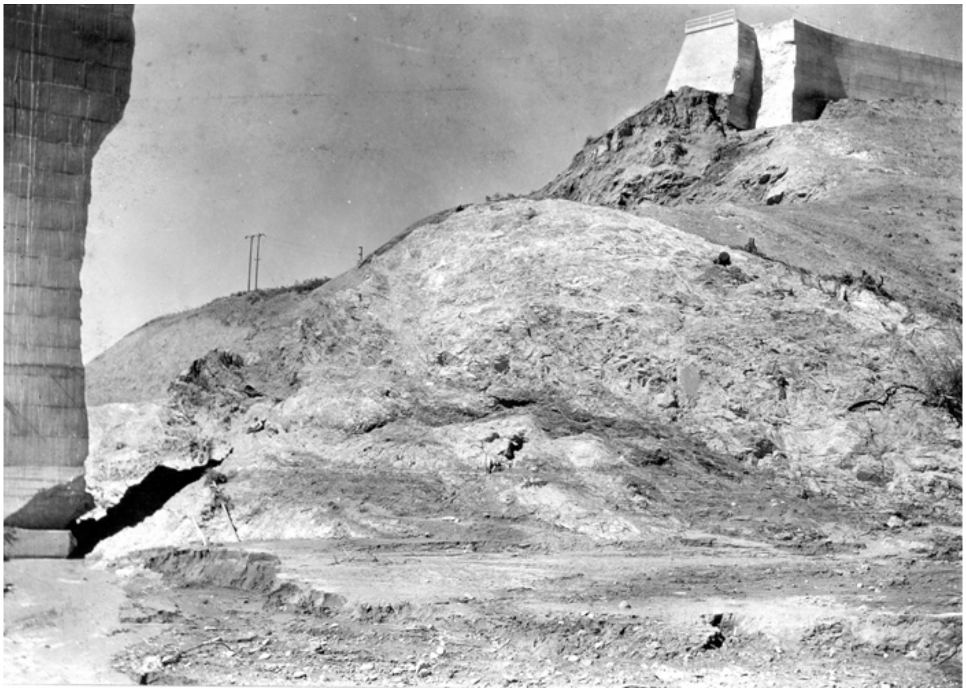
http://www.youtube.com/watch?v=3MdB_s6KhwA&feature=player_embedded#!



St. Francis Dam, March 17, 1928
(Attribution: U.S. Geological Survey Photographic Library)
Figure 3

St. Francis Dam, March 17, 1928
(Attribution: U.S. Geological Survey Photographic Library)
Figure 4

St. Francis Dam, Concrete Debris Blocks
(Attribution: U.S. Geological Survey Photographic Library)
Figure 5



St. Francis Dam, Former West Abutment
(Attribution: U.S. Geological Survey Photographic Library)
Figure 6

Remains of downstream powerhouse
(Attribution: U.S. Geological Survey Photographic Library)
Figure 7

Flood damage at Santa Paula
(Attribution: U.S. Geological Survey Photographic Library)
Figure 8

Here is a link to an excellent technical discussion of the soil mechanics issues that were at the heart of the St. Francis Dam failure:

http://web.mst.edu/~rogersda/st_francis_dam/reassessment_of_st_francis_dam_failure.pdf

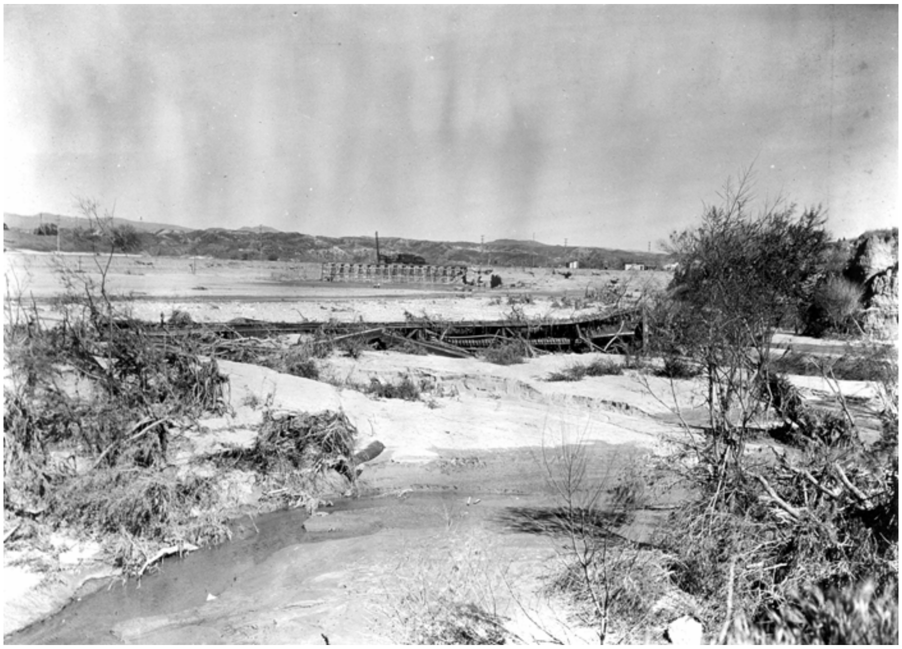
2.5 Aftermath

The dam broke into several large concrete blocks, some of which were carried almost 1/2 mile downstream, while the center section of the dam remained standing. The upright center section was subsequently demolished. The St. Francis Dam was not rebuilt, although Bouquet Reservoir in nearby Bouquet Canyon and Castaic Dam in the town of Castaic were subsequently built as replacements for the St. Francis Dam.

The exact number of victims remains unknown. The official death toll in August 1928 was 385, but the bodies of victims continued to be discovered every few years until the mid-1950s. Many victims were swept out to sea when the flood reached the Pacific Ocean and were not discovered until they washed ashore, some as far south as the Mexican border. The current death toll is estimated to be more than 600 victims.

The Los Angeles Coroner's Inquest concluded the disaster was primarily caused by the unsuitable soil conditions on which the eastern abutment of the dam was built, but which would have been impossible for the geologists of the 1920s to detect. Therefore, the inquest determined responsibility for the disaster lay with the governmental organizations which oversaw the dam's construction and the dam's designer and engineer, William Mulholland. Mulholland, however, was cleared of any charges since it was determined that neither he nor anyone at the time could have known of the instability of the rock formations on which the dam was built. The hearings also recommended, "the construction and operation of a great dam should never be left to the sole judgment of one man, no matter how eminent." It has also been suggested that raising the height of the dam 20 feet (as described above) during construction failed to recognize that accompanying design changes might be needed (such as increasing the width of the base of the dam).

Dislocated railroad tracks
(Attribution: U.S. Geological Survey Photographic Library)
Figure 9



Highway damage
(Attribution: U.S. Geological Survey Photographic Library)
Figure 10

Flood damage
(Attribution: U.S. Geological Survey Photographic Library)
Figure 11

3. THE HISTORICAL CONTEXT

This tragic engineering failure needs to be examined within the historical context of the rapid growth of Los Angeles, and what is known as the "California water wars." This confluence of powerful economic, social and technological challenges was the essence of this failure. And it was driven by the two fundamental ways people think and act….

- *Linearly*, and
- *Non-linearly.*

3.1 Los Angeles' need for water

The water wars began when Frederick Eaton was elected mayor of Los Angeles in 1898, and appointed his associate, William Mulholland, the superintendent of the newly-created Los Angeles Department of Water and Power.

Eaton and Mulholland are said to have had a vision of a Los Angeles that would become far bigger than the Los Angeles of the turn of the century. The limiting factor of Los Angeles' growth was water supply. Eaton and Mulholland realized that the Owens Valley had a large amount of runoff from the Sierra Nevada, and a gravity-fed aqueduct could deliver the Owens water to Los Angeles.

3.2 Water rights and profit

At the turn of the century, the United States Bureau of Reclamation was planning on building an irrigation system to help the farmers of the Owens Valley. However, the agent of the Bureau is reported to have been a close friend of Eaton, so Eaton had access to inside information about water rights. Eaton bought land as a private citizen, hoping to sell it back to Los Angeles at a vast profit.

Eaton lobbied Theodore Roosevelt and got the local irrigation system cancelled. Mulholland misled residents of the Owens Valley, by claiming that Los Angeles would take water only for domestic purposes, not for irrigation. By 1905, through purchases, and alleged intimidation and bribery, Los Angeles purchased enough water rights to enable construction of the aqueduct. Some argue that Los Angeles paid an unfair price to the farmers of Owens Valley for their land. However, the sale of their land brought the farmers substantially more income than if they had kept the land for farming and ranching. None of the sales were made under threat of eminent domain.

The aqueduct was sold to the citizens of Los Angeles as vital to the growth of the city. However, unknown to the public, the initial water would be used to irrigate the undeveloped San Fernando Valley to the north, which was not at the time a part of the city. A syndicate of investors (again, close friends of Eaton, including Harrison Gray Otis) bought up large tracts of land in the San Fernando Valley with this inside information. This syndicate made substantial efforts on behalf of the passage of the bond issue that funded the aqueduct, including publishing articles favorable to the project in the *Los Angeles Times*, which Otis published.

3.3 Building and operation of the aqueduct

From 1905 through 1913, Mulholland directed the building of the aqueduct. The 223 miles Los Angeles Aqueduct, completed in November 1913 has been compared in complexity to building the Panama Canal. Water from the Owens River reached its terminal reservoir in the San Fernando Valley on November 5. The building of the San Francis Dam was begun a decade later….it's primary purpose being to store water for use in drought years.

3.4 Thus, the stage was set….

….for the St. Francis Dam tragedy. Strong political and economic forces were demanding the Dam's construction. There was a strong political will to overcome any technical hurdles that might arise. And this is where the human factors and ethical issues came into play.

4. THE HUMAN FACTORS

This tragedy is a case study in how people think and act with regard to a course of action to achieve an objective. Although a group or population of people may *overtly* express a common objective, individuals or sub-groups of individuals may have *covert* objectives.

The *overt* objective of Los Angeles' civic leaders was to provide Los Angeles with a safe and reliable water supply. As history now indicates, individual civic leaders may have had *covert* objectives intended to enhance their personal positions….such as by personal profit.

How these civic leaders reacted to this situation illustrates the proposition that people respond fundamentally in two different ways, which have been characterized as that of *linear thinkers* and *non-linear thinkers.*

4.1 Linear and Non-Linear Thinkers. The way people think and act has been said by psychologists and others to fall into two fundamental categories: *Linear Thinkers* and *Non-Linear Thinkers*. Some people undoubtedly have characteristics of both categories, but one or the other behavior pattern tends to dominate. Here is how these categories have been described.

4.1.1 Linear Thinkers. Linear thinkers are driven by rules. When presented with an issue, they apply recognized and accepted rules and reason logically to a conclusion that is driven by those rules. Engineers are classic examples of linear thinkers. Engineers are trained in engineering schools in the irrefutable laws of applied physics and they learn a methodology to apply those laws to engineering problems in order to arrive at a correct solution. In engineering practice engineers are intensely driven by rules, in the form of experiential knowledge incorporated into codes, regulations and accepted best practices. Engineers are not the only examples of linear thinkers. Medical doctors, scientists and accountants are some other linear thinkers. Here is a picture of how a linear-thinker gets from a problem (Point A) to a solution (Point B).

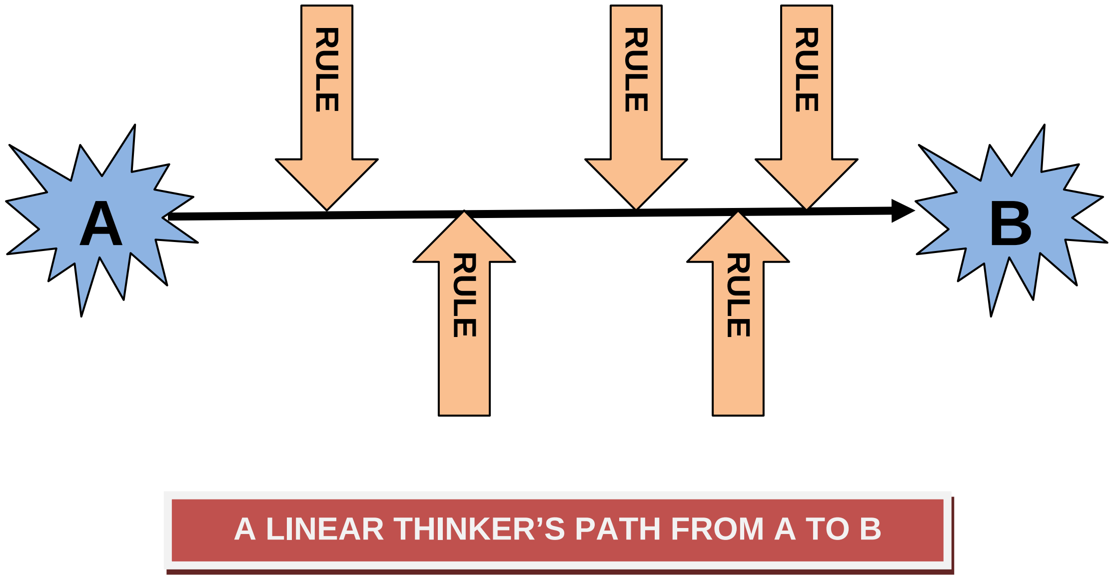


Figure 12

A linear thinker arrives at Point B by logical application of rules, not because Point B is a pre-determined goal. But this is not how non-linear thinkers get from Point A to, perhaps…. Point B….or Point C or Point D, depending on which is his or her goal.

4.1.2 Non-Linear Thinkers. Non-linear thinkers are not concerned about rules. They are concerned about getting from "Point A to Point C." Point A is the situation with which they are currently confronted and Point C is where they want to be. They are "goal-oriented." For example, if a non-linear thinker is currently a clerk in the mail room of a large corporation (Point A) his goal may be to become Chief Executive Officer of that large corporation (Point C). His goal is not to design a big dam (Point B). He wants to be Chief Executive Officer of that large corporation (Point C). Here is a picture of how a non-linear thinker gets from where he is now (Point A) to where he wants to be (Point C).

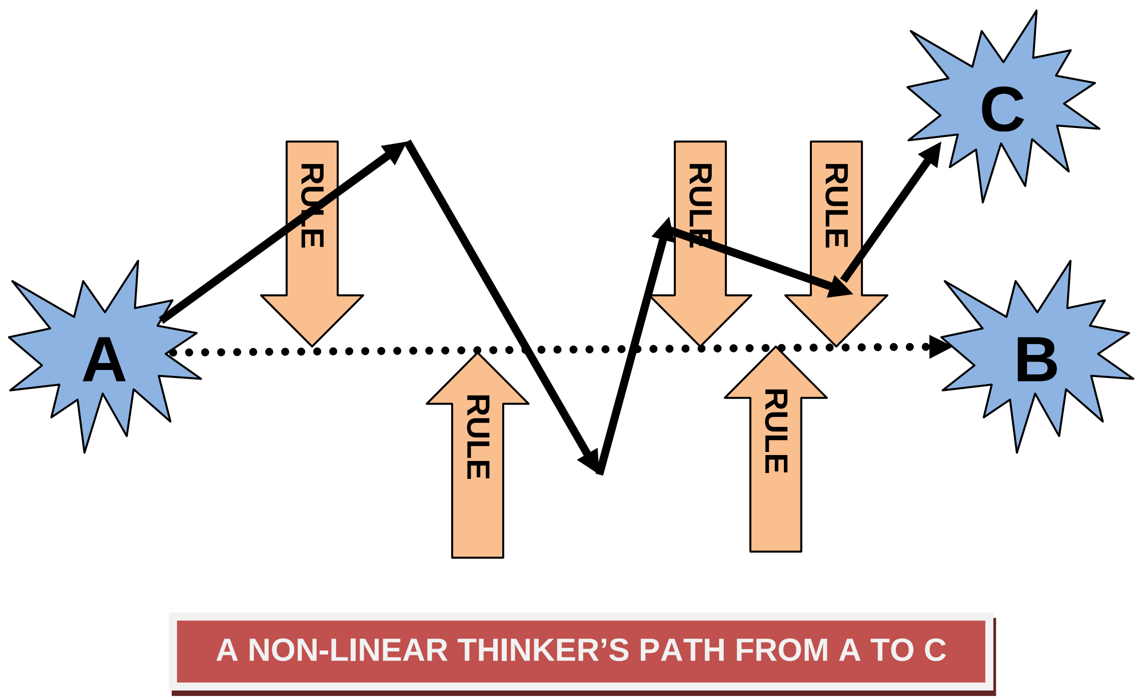


Figure 13

4.2 What Motivates Public Policy Makers? Public policy makers….elected public officials, public officials appointed by elected public officials, and higher level civil servants whose careers are driven by appointed and elected officials….are classic non-linear thinkers. Other examples are retail merchants, advertising executives, and performing artists.

Public policy makers are goal oriented. Their goal is usually either to (a) get re-elected/re-appointed to the office or position they now hold or, more likely, (b) to get elected/appointed to a higher office….a "higher" office being one of greater power, authority and prestige. Their "Point A" is their current position and their "Point C" is the position to which they aspire. And they will do whatever is necessary to move from A to C.

4.3 The Key Public Policy Makers for St. Francis Dam. The key public policy makers driving the construction of the Los Angeles Aqueduct and St. Francis Dam were Frederick Eaton and William Mulholland. Were they linear or non-linear thinkers…. or some combination thereof? And how might these characteristics have shaped their actions, which led to the St. Francis Dam failure?

4.3.1 Frederick Eaton. Eaton was the principal political force behind the Los Angeles Aqueduct. Born in Los Angeles in 1856, into a prominent Pasadena family, he was the Mayor of Los Angeles from 1898 to 1900. He is reported to have “taught himself engineering” and was the superintendent of the Los Angeles City Water Company by age 19 in 1875. As head of the Water Company, in 1878 Eaton first hired William Mulholland as a ditch-digger for distribution canals from the Los Angeles River to the city. While Mayor, he created the Los Angeles Department of Water and Power, and appointed Mulholland as superintendent and Chief Engineer. Together, they planned and developed the Los Angeles Aqueduct, which was completed in 1913. Eaton is said to have used inside advance information about the aqueduct project to the financial advantage of himself and his associates, at the expense of the city of Los Angeles. He died in 1934.

4.3.2 William Mulholland. Mulholland has frequently been characterized as a “civil engineer.” But it is unlikely he would be described as such by current professional standards. Without meaning to lessen his many accomplishments as a public agency manager, by today’s professional standards he would probably be characterized as an “engineering technician.”

Mulholland was born in Ireland in 1855. At the age of 15 he ran off to sea. In 1872 he left the sea and ultimately immigrated to the United States, arriving in Los Angeles in 1877. After arriving in Los Angeles he accepted a job digging wells. After a brief period in Arizona where he prospected for gold and worked on the Colorado River, he obtained a job from Frederick Eaton as Deputy “Zanjero” with the newly formed Los Angeles Water Company (LAWC). (In southern California during the Spanish and Mexican administrations water was delivered to “Pueblo de Los Angeles” in a large open ditch, the Zanja Madre. The man who tended the ditch was known as a zanjero.) In 1898, the Los Angeles city government decided not to renew its contract with the LAWC. Four years later the Los Angeles Department of Water was established and mayor Frederick Eaton arranged for Mulholland to be appointed its head.

Mulholland, who was described as a “self-taught engineer”, laid the foundations that would transform Los Angeles into today's metropolis. In furtherance of that goal and under his direction, the 233-mile Los Angeles Aqueduct was completed in 1913 to bring water from the Owens Valley to Los Angeles.

4.3.3 Linear/Non-Linear Thinkers? Eaton and Mulholland strongly evidenced non-linear thinking characteristics. High level elected and appointed public officials are classic non-linear thinkers. Few succeed in these capacities without being non-linear thinkers and goal-oriented. And clearly the visions of a future Los Angeles metropolis and of one of the largest and most complex water resources projects in history were world-class objectives for which both strove.

But Eaton and Mulholland also had lesser levels of linear thinking characteristics. Both had some level of technical competence and linear thinking characteristics. But they were not trained professional engineers and their technical skills might appropriately be described as those of “engineering technicians.”

It would be fair to describe them as dominant non-linear thinkers, with lesser linear thinking characteristics. And this was the fatal combination that led to the St. Francis Dam failure. Their strong goal orientation, to develop the Los Angeles Aqueduct and the St. Francis Dam, overrode the rule-based approach required for prudent completion of major engineering projects.

5. ETHICAL ISSUES

The Coroner’s inquest found that the failure of the St. Francis Dam was due to:

- Unsatisfactory soil conditions at the site

- Failure to compensate for the additional 20 feet added to the height of the dam
- The design and construction overseen by only one person (Mulholland)

Here is how the ethical issues presented by the St. Francis Dam failure might be described.

5.1 Inadequate Technical Leadership. The project was closely controlled and directed by Mulholland with support from his mentor Eaton. Eaton has been described as having “taught himself engineering” and Mulholland as a “self-taught engineer.” Investing responsibility for major engineering projects in “self-taught engineers” is questionable, if not irresponsible. If society does not accept “self-taught physicians”, “self-taught nuclear physicists” or “self-taught airline pilots” it is difficult to understand how it can be reasonable for “self-taught engineers” to be in control of major engineering projects where risks of personal injury and property damage are often great.

Shortly after the failure, Mulholland publically accepted that the blame was his alone. Knowledge of the science of soil mechanics in general was sparse at the time, and knowledge of soil conditions at the site was limited because of insufficient exploration and testing. Appropriate rules-based technical leadership, which is the essence of professional engineering training, would have had to conclude that the theoretical and experiential knowledge base available for the project was inadequate to build the dam, at least without substantial additional research, exploration and testing. Instead, goal-based leadership (“get the project built”) controlled and the dam was constructed.

5.2 Insufficient Diversity of Technical Input. The record indicates Mulholland was dominantly if not completely in control of the project and there was little diversity (i.e. involvement of additional professional engineers) in decision-making. Particularly when the theoretical and experiential knowledge bases are as sparse as they were at the time the St. Francis Dam was designed and constructed, diversity of technical input should be strongly encouraged. That is, multiple qualified professional engineers should have been involved in the decision-making process through internal reviews and outside consultations.

6. LESSONS LEARNED.

Hindsight is, of course, a wonderful thing. The civil engineering professional has learned much from the St. Francis Dam failure both technically and procedurally. There are, however, lessons that should be restated and carried forward to future projects.

6.1 Substantive engineering projects and programs must be controlled by competent engineering professionals. There will be times with all engineering projects and programs when the state of technical knowledge (both theoretical and experiential) can conflict with project goals ("get the project done"). These conflicts need to be controlled and managed by engineering professionals with appropriate training and experience. Engineering professionals responsible for a project must have full and final authority on all engineering decisions.

6.2 Those in control of substantive engineering projects and programs must have professional training and experience; technical experience is insufficient. Professional training and experience is essential because it teaches a rule-based approach to engineering projects, not merely a selection of technical rules. The St. Francis Dam failure is a clear example of project leadership that had insufficient professional training and experience (i.e. self-taught engineers).

6.3 Engineering professionals should have training and experience in implementing substantive engineering projects and programs in an environment in which non-linear thinkers may be influential or even dominant. Engineering professionals need training and experience in working within organizations (companies and agencies) where goal-orient non-linear thinkers are influential or even dominant. They need the inter-personal skills that are essential to implementing substantive engineering projects and programs that fall prudently within the scope of available theoretical and experiential knowledge. These skills can help to prevent the ascension of unqualified persons to positions of control over engineering decisions.