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COLORADO RIVER AQUEDUCT  
(Colorado Aqueduct)  
(Colorado River Aqueduct System)  
From Colorado River to Lake Mathews  
Parker Dam vicinity  
San Bernardino County  
California

HAER No. CA-226

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

REDUCED COPIES OF MEASURED DRAWINGS

PAPER COPIES OF COLOR TRANSPARENCIES

HISTORIC AMERICAN ENGINEERING RECORD

National Park Service  
1849 C Street NW, NC300  
Washington, DC 20240

HISTORIC AMERICAN ENGINEERING RECORD

COLORADO RIVER AQUEDUCT

HAER No. CA-226

**Location:** From Colorado River in vicinity of Parker Dam, CA to Lake Mathews in vicinity of Riverside, CA; Parker Dam vicinity, San Bernardino County, CA.

**Dates of Construction:** 1933-41

**Designers:** Frank E. Weymouth, Chief Engineer, Metropolitan Water District of Southern California; Julian Hinds, Assistant Chief Engineer, Metropolitan Water District of Southern California

**Contractors:** Various

**Present Owner:** Metropolitan Water District of Southern California

**Present Use:** Aqueduct

**Significance:** The Colorado River Aqueduct pumps water from the Colorado River through, over, and across mountains and desert in a 242-mile-long march to the coastal plain of Southern California. When completed, it was one of the longest water-conveyance facilities in the world. The aqueduct includes power lines, tunnels, siphons, covered conduits, open canals, dams, reservoirs, and five pumping plants, involving ingenious engineering solutions and newly-introduced construction equipment. The project also employed over 35,000 people during its eight-year span and as many as 10,000 at one time, making it southern California's single-largest work opportunity during the Great Depression. In 1995, the Colorado River Aqueduct was named a National Historic Civil Engineering Landmark by the American Society of Civil Engineers. Today, it is the major water supply for urban and suburban southern California.

**Historian:** J. Philip Gruen, August 1998

**Project Information:** This aqueduct was documented as part of the Colorado River Aqueduct Recording Project conducted by the Historic American Engineering Record (HAER) for the Metropolitan Water District of Southern California (Metropolitan) during the summer of 1998. The project was prepared under the general direction of Eric

DeLony (Chief, HAER). The architectural team included Supervisory Architect Andrew Johnston (University of California, Berkeley) and architects Chrysti Chun (Illinois Institute of Technology), Imola Kirizsan (ICOMOS, Romania), Sydney Mainster (University of California, Berkeley), Elizabeth Milnarik (University of Illinois, Urbana-Champaign), and Nina Shatberashvili (ICOMOS, Republic of Georgia). Project Historian was J. Philip Gruen (University of California, Berkeley). The photographer was Jet Lowe (Washington, D.C.). Additional drawings were provided by Christopher B. Brown (University of Washington) and Adam Maksay (Transylvania Trust Foundation, Romania). Engineer Allien M. Whitsett (Metropolitan Water District of Southern California) offered advice and technical assistance.

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## PREFACE

Many projects undertaken by the Historic American Engineering Record (HAER) begin with a minimal amount of information. This usually sends historians and architects scrambling for resources to prepare for the documentation process. Frequently, summer HAER teams spend twelve weeks painstakingly interpreting sites with little to draw upon other than a few physical remains and scattered references to the sites in contemporary trade journals and public records.

The HAER team working on the 1998 Colorado River Aqueduct Recording Project encountered few of these difficulties. The Colorado River Aqueduct is thoroughly documented from its inception to alterations made to the present day, and nearly all of the original historical reports, annual reports, magazines, specifications, drawings, newspaper articles, and photographs are preserved and catalogued by the Metropolitan Water District of Southern California (MWD)<sup>1</sup> in Los Angeles, California. Metropolitan made any and all of these materials readily available to our team for the purposes of the drawing set and this historical report.

Metropolitan's collection is extensive, and we soon realized that it was not feasible to provide a comprehensive summary of the material in a brief twelve-week project. Instead, our task was to condense the voluminous technical information contained in the documents into a digestible and comprehensible format.

To limit the scope of our project and to examine the Colorado River Aqueduct at an important moment in American engineering history, we chose to focus upon its principal construction phase (1933-41). But even by focusing on this eight-year period, the following written report and the drawing set does not -- and cannot -- contain the amount of technical information included in the specifications or the annual or historical reports. Instead, our work contains what we considered to be the most significant, or the most interesting, aspects of the design and construction process.

It should be noted that the aqueduct's significance extends both before and after its original

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<sup>1</sup>Abbreviations used throughout the text are as follows:

c.f.s. Cubic feet per second  
g.p.m. Gallons per minute  
hp Horsepower  
kv Kilovolt  
MWD Metropolitan Water District of Southern California  
PWA Public Works Administration  
RFC Reconstruction Finance Corporation  
WPA Works Progress Administration

construction period. Like any major water project in California, the Colorado River Aqueduct was (and is) bound up in the politics of water development -- it is considerably more than just its constituent concrete and steel parts. The aqueduct involved tens of thousands of workers, state and federal legislation, major dams, and a formidable desert landscape with which the planners and workers had to contend. The story of the aqueduct -- even one that focuses on engineering -- cannot be properly told without highlighting some of the stories that surrounded its construction and made the project a reality. These happenings are important stories in their own right, but not all of them are recounted in our documentation. When some of these issues are touched upon in the written report, footnotes direct readers to relevant sources for further research.

The construction of the aqueduct did not follow a neat, chronological pattern, moving west from Parker Dam on the Colorado River in 1932 and finishing at Cajalco Reservoir near Riverside in 1941. Instead, construction proceeded along many parts of the aqueduct simultaneously. While chronology is followed where possible or appropriate in our report and the drawing set, we thought they would be best organized by separating the aqueduct into its sections or parts. This is simply our method of organization; it is not meant to suggest that the construction of the aqueduct was envisioned as a series of parts rather than a complete unit. The order presented in this historical report is meant, for the most part, to cohere with the order presented in the drawings and, where possible, with that of the photographs. The researcher is thus encouraged to view the report, the drawings, and the photographs as a complete set, although there is information in the historical report that is not included in the drawings and the photographs, and vice versa.

Because the historical report and the drawings focus on the initial construction, the various features associated with the system are referred to by their original names. For example, Lake Havasu is called "Parker Reservoir," Hinds Pumping Plant becomes the "Hayfield Pumping Plant," Lake Mathews becomes "Cajalco Reservoir," Weymouth Filtration Plant becomes "Softening and Filtration Plant," and Hoover Dam is referred to as "Boulder Dam." To avoid confusion, the current names are often indicated in parentheses -- at least with the first reference.

We encountered some difficulty regarding tense shifts in the written text in the historical report and on the drawings, because the aqueduct functions today much as it did in the past. To reduce confusion, the past tense is used when the text refers specifically to the process as it was carried out *during* the aqueduct's construction. The present tense is employed when the text discusses general construction techniques or those parts of the aqueduct that operate today more or less as they did initially.

This report has benefitted from a number of individuals who offered their time and assistance. Engineer Allien M. Whitsett of the Metropolitan Water District of Southern California spent many hours with drafts of this text, questioning some of its claims and assisting

with the editing process. This report is the better for it. HAER Chief Eric DeLony and HAER Historian Rich O'Connor read early drafts of this report and offered timely and pertinent suggestions. Dora Lee and Dao Dang of Metropolitan's Central Library went out of their way to direct the author to hard-to-find sources and materials.

## CHAPTER ONE: CONTROLLING WATER

### Introduction

The Colorado River Aqueduct is part of a long and complex story of water development in the American West, a story that is part and parcel of the sustenance and growth of twentieth-century southern California. This story has been told in myriad ways over the years, and it will continue to be told as long as southern Californians divert water from its natural course to irrigate farmland or provide urban areas with water for commercial, industrial, or residential use. Many scholars have attempted to tell the entire story of water in the West -- including its political, economic, and legal aspects -- even if they focus their discussion on particular examples or case studies, such as the Los Angeles Aqueduct or Boulder (Hoover) Dam. Judged along these lines, the following report is decidedly less ambitious.

Too often, however, historians assume that the history of water in the west is decided in the courtroom or at the ballot box, and they neglect the importance of engineering and technology to this history. To explore the Colorado River Aqueduct as a work of engineering -- which it is -- helps to illuminate the story of the American West as a partly technological story. The importance of technology to the growth and expansion of the American West was apparent to settlers and to those who applied new technology to the American landscape in the nineteenth and early twentieth centuries, but this understanding of history has been mostly buried or ignored by historians of the American West in favor of other narratives.

The following essay points up the importance of American engineering to twentieth-century American Western history by examining the Colorado River Aqueduct: a little-studied, yet enormously significant, project.<sup>2</sup> The 242-mile-long aqueduct marches over largely untrammelled and treacherous desert terrain with approximately 237 miles of power lines, 92 miles of tunnels, 62 miles of concrete-lined open canals, 54 miles of cut-and-cover conduits, 29 miles of reinforced-concrete cylindrical inverted siphons, six reservoirs, five pumping plants, and

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<sup>2</sup> When the Colorado River Aqueduct has been studied by scholars, it has commonly been examined in either a political, legal, or economic context. These contexts are touched on in this report but not extensively analyzed. For more directed research examining the aqueduct along these lines, see Jerome W. Milliman, "The History, Organization and Economic Problems of the Metropolitan Water District of Southern California," Ph.D. diss., University of California at Los Angeles, 1956, or Kazuto Oshio, "Urban Water Diplomacy: A Policy History of the Metropolitan Water Supply in the Twentieth Century Southern California," Ph.D. diss., University of California at Santa Barbara, 1992.



four dams on its way to southern California's coastal plain.<sup>3</sup>

The difficulty of selecting the most cost-effective route from the Colorado River was the principal engineering problem, and this problem was noted frequently in the early literature issued by the Metropolitan Water District of Southern California (Metropolitan), formed in 1928 for the purposes of building and operating an aqueduct to provide water for southern California. The aqueduct's planners had to select a route that offered the lowest combination of construction costs, operating costs, and safety of construction and operation. This process alone took nearly seven years, while the aqueduct's actual construction took eight. Ultimately, Metropolitan settled on a route from the lower Colorado River that required the pumping of water.

The combination of the total height that water is lifted (1,617') and the aqueduct's 242-mile length was unprecedented, as was the aqueduct's initial design capacity of 1,500 c.f.s.<sup>4</sup> The vertical synchronous motors driving the pumps were the largest of these types of motors then constructed. The difficulties encountered during the construction of the Mt. San Jacinto tunnel received national attention, and engineers argued that it was one of the most difficult tunnel construction jobs undertaken in the history of engineering. Some of the equipment introduced and engineering techniques employed during the aqueduct's construction overall were celebrated for their ingenuity and ability to set standards for future projects of similar magnitude.<sup>5</sup> The Parker diversion dam was founded on bedrock 235' below the river's alluvial bed, making the dam the world's deepest. The Colorado River Aqueduct overall was the world's most technologically-advanced water conveyance system, and its construction was a major engineering achievement.

Yet the aqueduct is more than just a physical object attached to a series of facts and figures, slopes and formulas, equipment and materials. Its construction exists within the context of Depression-era America, and it is this context that provides much of the aqueduct's engineering significance. During this devastating economic crisis, the appearance and promotion of technological "progress" provided the American public with a renewed sense of hope, promise, and pride. The engineering accomplishments carried out during the project were emphasized in a

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<sup>3</sup> Most accounts of the aqueduct's total length, in addition to the length of its parts, round off the distance to the nearest whole number. Accounts vary, but the total length of the system is closer to 241.6 miles. This includes 92.1 miles of tunnels, 62.8 miles of lined canals, 54.4 miles of conduits, 28.7 miles of siphons, and the rarely mentioned 1.3 miles of total passage through the system's reservoirs, 1.2 miles of pump delivery lines, and 1.1 miles of unlined channel into the terminal reservoir.

<sup>4</sup> Including the distribution system, the aqueduct was originally 392 miles long -- thought to be the longest in the world. (Archaeological investigation has since revealed that a 360-mile-long gravity-fed aqueduct with tunnels and storage reservoirs was built by the Incas in the fifteenth and sixteenth centuries from the highlands of modern-day northern Peru.)

<sup>5</sup> "The Colorado River Aqueduct," *Engineering News-Record*, vol. 121, no. 21 (24 November 1938): 638.

deluge of publicity and promotional literature issued and inspired by Metropolitan, which tapped into and helped shape a growing American fascination with engineering and technology. This fascination was heightened by the 1930s construction of publicly-built massive concrete objects like Boulder (Hoover) Dam and other works erected by the U.S. Bureau of Reclamation, the Tennessee Valley Authority, and the Army Corps of Engineers in the 1920s and 1930s.<sup>6</sup>

Like any story of American technology, that of the Colorado River Aqueduct is also a very human story. It is a story of human solutions to engineering problems, and just as much a story of failure as one of triumph. Although planners envisioned the aqueduct well before the onset of the Great Depression (it was not envisioned as a federal make-work project), its construction spanned the worst years of the Depression and offered much-needed jobs during that time. During the eight-and-a-half-year construction period, over 35,000 people found work on the aqueduct, and, during the height of construction, as many as 10,000 workers at one time were on Metropolitan's payrolls or those of the numerous contracting companies who worked on the project. During the 1930s, it was the single-largest employment opportunity in southern California, and one of the largest in the United States.<sup>7</sup> At the same time, the project was not free from accidents, deaths, worker tension, or political conflict.

To assess the importance of the Colorado River Aqueduct is to see it in this human context, for therein lies its greatest significance. Historians of Technology David Nye and Henry Petroski (at different times and in different ways) have reminded us that machines, engineering, and technology are not abstract, autonomous concepts, but are shaped and invented by human action, drawing upon other human successes and failures of the past.<sup>8</sup> While some new equipment and techniques were developed to fill specific needs during the Colorado River Aqueduct project, most of the techniques executed during construction were based on their successful application or development on earlier projects. While different aspects of the aqueduct's engineering will be

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<sup>6</sup> For more on the Depression-era public works projects that sparked the American imagination, see Carl W. Condit, *American Building Art: The Twentieth Century* (New York: Oxford University Press, 1961), 231-73, Donald C. Jackson, *Building the Ultimate Dam: John S. Eastwood and the Control of Water in the West* (Lawrence, Kansas: University Press of Kansas, 1995), 245-51, or C.W. Short and R. Stanley-Brown, *Public Buildings, A Survey of Architecture of Projects Constructed by Federal and Other Governmental Bodies Between the Years 1933 and 1939 with the Assistance of the Public Works Administration* (Washington, D.C.: Government Printing Office, 1939).

<sup>7</sup> The scale of the work is noted in "The \$220,000,000 Metropolitan Aqueduct," *Fortune*, vol. 15, no. 4 (April 1937): 89. The editors of *Fortune* actually contended that the aqueduct was "the biggest engineering job ever tackled in the U.S.," but noted that the employment rolls for the proposed Grand Coulee Dam project might be larger. Indeed, considerably more people were employed during the Grand Coulee Dam construction.

<sup>8</sup> David E. Nye, *Narratives and Spaces: Technology and the Construction of American Culture* (New York: Columbia University Press, 1997); Henry Petroski, *To Engineer is Human: The Role of Failure in Successful Design* (1982, reprint. New York: Vintage Books, 1992).

discussed and analyzed here, its parts and its construction must be understood in this historical context.

### California Water Historiography

For much of the twentieth century, historians of the American West have aligned themselves alongside the theoretical fence erected by Frederick Jackson Turner in the late nineteenth century. Turner's "frontier thesis," which he laid out in an 1893 address, argued that the expansion and settlement of the American West revealed something positive and true about American character and democracy. The transformation of previously "savage" wilderness into a settled landscape, Turner argued, also transformed Europeans into Americans. Following Turner's lead, many historians have seen the history of the West as an important enterprise of expansion, settlement, and growth, where desolate and forbidding natural landscapes have been "conquered" by doggedly determined "pioneers" and brave "heroes" in the name of "progress."

While Turner wrote primarily about the Western landscape as it was shaped by agrarian settlement, others have applied that theory -- whether consciously or unconsciously -- to the landscapes of water. Thus, many scholars have seen the history of water in the West as a history of intrepid explorers and brilliant engineers who have helped "tame" natural "menaces" -- such as the "unruly" Colorado River -- and have thus contributed to Western settlement and growth.

Since the 1960s, however, this pristine picture of Western American history has been replaced by a different, darker interpretation. This history includes the roles played by Native Americans, Hispanics, and Chinese, and it has become popular to understand this history not as an accomplishment but as an ethnocentric story of conquest and ruthless Anglo-American domination. Where practitioners of this so-called "new" Western historical approach have dealt with issues of water, they have interpreted that history essentially as one of manipulation, greed, profit, and environmental devastation, seeing water viciously snatched away from its natural habitat and artificially re-routed to serve agricultural and corporate/big-city interests.<sup>9</sup> Under the critical lens of this methodology, engineers are regarded with suspicion, and scholars frequently point to their profit- and ego-driven ulterior motives.

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<sup>9</sup> The now-classic text exposing the inadequacies of the Turnerian approach to Western history is Patricia Nelson Limerick, *The Legacy of Conquest: The Unbroken Past of the American West* (New York: W.W. Norton and Company, 1987). Regarding Western water development as conquest and domination, see Donald Worster, *Rivers of Empire: Water, Aridity, and the Growth of the American West* (New York: Oxford University Press, 1985) or Marc Reisner, *Cadillac Desert: The American West and Its Disappearing Water* (1986, reprint. New York: Penguin Books, 1993).

It is not the purpose of this report to either align with or counter these approaches, although both should be taken into account to provide a more comprehensive picture of Western American water history. To be sure, works following the path of the "new" Western history should be applauded for requiring historians to confront large gaps in the history of the American West that have been excluded in favor of the patriotic and sanitized view put forth by much of the earlier literature.

Yet much of the "new" Western history judges the actions of individuals and events of the past with the standards of today's culture, where environmental considerations and conservation issues play a greater role in our assessment of water development in the West. In seeking to explore the aqueduct as a product of the state of American engineering and technology in the 1930s, it is perhaps more useful to attempt to understand it in its original context, where a different set of cultural conditions applied. But even as an example of water manipulation in the West, the Colorado River Aqueduct has been largely overlooked in the scholarly literature.<sup>10</sup>

### **Before the Aqueduct**

The 233-mile-long Los Angeles Aqueduct (1908-13), built to serve the water needs of a city with a population of two million people and to last forty to fifty years, has been afforded most of the attention because of the conflict it generated in the Owens Valley, because of the "land rush" that it may have inspired, and because of the conspiracy charges that surrounded the real estate speculation and subsequent development of the San Fernando Valley.<sup>11</sup> The Los Angeles

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<sup>10</sup> The most comprehensive source about the early history of the Colorado River Aqueduct is the first annual report published by Metropolitan, which contains considerable historical information in addition to engineering details. See Metropolitan Water District of Southern California, *Report for the Period July 1, 1938 to June 30, 1940* (Los Angeles: Metropolitan Water District of Southern California, 1940). Secondary sources, however, are much harder to find. There are few secondary sources that focus solely on the aqueduct and, in fact, most discussions of the aqueduct are included in texts encompassing a range of water issues. Among the more comprehensive sources with information about the Colorado River Aqueduct are Oshio, "Urban Water Diplomacy," 34-139 and Joel Schwarz, *A Water Odyssey: The Story of the Metropolitan Water District of Southern California* (Los Angeles: Metropolitan Water District of Southern California, 1991), 37-89. Other scholars who have discussed the Colorado River Aqueduct include Erwin Cooper, *Aqueduct Empire: A Guide to Water in California: Its Turbulent History and Its Management Today* (Glendale, California: The Arthur H. Clark Company, 1968), 81-100; Paul L. Kleinsorge, *The Boulder Canyon Project: Historical and Economic Aspects* (Stanford, California: Stanford University Press, 1941), 236-42 and 273-83; and Remi Nadeau, *The Water Seekers* (Garden City, N.Y.: Doubleday, 1950), 228-40.

<sup>11</sup> The attention afforded the Los Angeles Aqueduct included the production of the movie "Chinatown," an early 1970s film based loosely on the events surrounding that aqueduct's construction. That movie still grips the popular imagination regarding water supply systems in the West.

Aqueduct fits nicely with the current academic paradigm, fostered by practitioners of the "new" Western history, that views all water development as manipulation and conquest in the pursuit of capital accumulation. Thus, in books about water in California, the stories are usually about the Los Angeles Aqueduct, not the Colorado River Aqueduct; about the Boulder Dam or the St. Francis Dam, not Parker Dam; about Owens Lake or Mono Lake, not Parker Lake (Lake Havasu); and about engineer William Mulholland, not engineers Frank Weymouth or Julian Hinds. Some scholars have devoted entire books to the Los Angeles Aqueduct and its controversy; others have used it as the focal point around which they have constructed their arguments about water development in the West.

Even so, the fact that city officials in Los Angeles had to buy land and transport water from more than 200 miles away in Inyo County points up the scarcity of water in the region and reveals -- or at least implies -- some truths about the climate in the southern California region. Nearly all portions of this region experience average precipitation of 15" per year or less, dry as a desert. Annual rainfall fluctuates, however, and the area had experienced many years with an average above 20" prior to the construction of either the Los Angeles or Colorado River aqueducts. On the other hand, the region had also suffered consecutive years with an average rainfall below 10", and this constituted a drought. Studies revealing that the Los Angeles region had experienced long periods with little rainfall led William Mulholland and others to look beyond local water supplies as the region's population expanded exponentially in the late nineteenth and early twentieth centuries.

Nevertheless, settlers in the region in the late eighteenth century were able to rely upon the intermittent rainfall and the local supplies provided by underground springs and the Los Angeles, Santa Ana, and San Gabriel Rivers and their watersheds -- which were prone to periods of either extreme aridity or sporadic flooding. Early Spanish settlers founded the *Pueblo de Nuestra Señora la Reina de Los Angeles* -- the old town of Los Angeles -- and claimed the "pueblo water right" as they diverted water from the Los Angeles River. This so-called water right, which communities in the southwestern United States traced back to rights protected under the 1848 Treaty of Guadalupe Hidalgo, generally favored the water needs of communities over private individuals. The city of Los Angeles in 1850 claimed such a right and the California courts backed it, granting the growing city exclusive rights to the water in the Los Angeles River and its 500-square-mile watershed.<sup>12</sup> This pueblo water right -- particularly where it concerns the city of Los Angeles -- continues to hold a central place in the debates about the Los Angeles water supply system today.

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<sup>12</sup> For a comprehensive account of the pueblo water right and its affects on the history of water rights in Los Angeles, see, for example, Norris Hundley, Jr., *The Great Thirst: Californians and Water, 1770-1990s* (Berkeley: University of California Press, 1992), 45-58.

Along the banks of the Los Angeles River, these settlers built earthen dams to divert water for irrigation and domestic use. The earliest documented aqueducts in southern California were open ditches (called *zanjas*) and water wheels that transported water from the river to residences and fields.<sup>13</sup> The most intensive use for the region's water came initially from agricultural development, but by the late nineteenth century, with a growing regional population requiring water for irrigation, domestic, and commercial use, the surface supply from the region's rivers was running low.

Settlers began tapping into the groundwater basins by digging wells. Some wells were pumped and others were artesian wells where water flowed up naturally from internal pressure to supplement the surface supply. In the early twentieth century, some of these wells yielded an aggregate of 300 c.f.s., but by 1930 nearly all of these artesian wells had ceased to flow. Most of them, in fact, had been replaced by electric motors and gas-driven pumps that had been available since the 1880s. By the early twentieth century, some of these wells could yield an average aggregate of 300 c.f.s.<sup>14</sup> Use of these artesian wells lasted well into the twentieth century, but their overall use had already begun to decline when electric motors and gas engines became commercially available in the 1880s. Electrically-operated wells, allowing for an easier and more efficient way to pump water, soon sprouted across the southern California landscape. By 1940, there were approximately 30,000 of these wells in the region.

Yet the abundance of these pumped wells suggests more about the need to supply a growing regional population with water than it does about securing a permanent water supply for the city of Los Angeles. Indeed, as early as 1892, with the city's population over 50,000 and its water supply under the control of the private Los Angeles Water Company, water from the Los Angeles River was disappearing and the underground water table in southern California was being depleted. The city's population doubled by 1900, and in 1902, voters approved a bond measure to form a public water company. William Mulholland, then superintendent of the private water company, joined the newly formed public water agency (the Los Angeles Bureau of Water Works and Supply, later called the Los Angeles Department of Water and Power) and began the search for more water -- a quest that eventually led to the construction of the Los Angeles Aqueduct. Mulholland's search and the political, economic, legal, and social legacy of the Los Angeles Aqueduct have been analyzed in some detail by scholars, and need not detain us here.<sup>15</sup>

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<sup>13</sup> Schwarz, *Water Odyssey*, 15-16.

<sup>14</sup> Metropolitan, *History and First Annual Report*, 14.

<sup>15</sup> For a sampling of books either about, or with large sections dedicated to, the Los Angeles Aqueduct, see Abraham Hoffman, *Vision or Villainy: Origins of the Owens Valley-Los Angeles Water Controversy* (College Station, Texas: Texas A&M University, 1981); Hundley, *The Great Thirst*; William L. Kahrl, *Water and Power: The Conflict over Los Angeles' Water Supply in the Owens Valley* (Berkeley: University of California Press, 1982); Nadeau, *Water Seekers*; Reisner, *Cadillac Desert*; or John Walton, *Western Times and Water Wars: State*

However, few of these scholars have discussed the engineering of the Los Angeles Aqueduct in much detail.<sup>16</sup> When the aqueduct has been analyzed for its engineering, it has been generally seen as an isolated engineering "wonder" in part because of its construction under difficult conditions with equipment and vehicles that, in retrospect, appear "primitive." Few scholars, however, have noted the rather modern technology that was used and the engineering connections between that project and the Colorado River Aqueduct.

The construction process of the Los Angeles Aqueduct was considerably more sophisticated than a frequently-published photograph of mules hauling sections of 36-ton siphons might indicate.<sup>17</sup> Power shovels, dredges, air hammers, blasting powder, and concrete were all used to facilitate construction of the 232-mile gravity-flow system -- a water system far larger than any that had ever been constructed in the United States. Workers blasted through mountains to bore 142 tunnels, including the difficult five-mile Elizabeth Tunnel near Lake Hughes, California, which took the duration of the project to construct. Concrete was used so extensively overall that the Los Angeles Bureau of Water Works and Supply built a mill in the limestone and clay-rich foothills of the Mojave Desert near the town of Monolith to produce Portland cement.<sup>18</sup>

While some of the methods of transport may seem antiquated relative to the trucks hauling materials and parts to sites along the Colorado River Aqueduct, many of these materials and parts were quite similar. Although the Los Angeles Aqueduct did not require any pumping plants, it was comprised of tunnels, open canals, siphons, conduits, and reservoirs in varying combinations to keep water flowing and to most effectively deal with the region's geology. Similar construction methods and problems experienced during the construction of the Los Angeles Aqueduct -- including tunnel floods -- reappeared some twenty years later further south.

Similarly, many of the same parts were used for the construction of the 110-mile Catskill Aqueduct to supply fresh water for New York City, built in two stages, from 1907 to 1927. The first stage, completed between 1907 and 1917, involved the construction of a 92-mile aqueduct with cut-and-cover conduits, steel-pipe inverted siphons, gravity and pressure tunnels, reservoirs, and distribution lines from a reservoir created by the damming of Esopus Creek. This stage also included the construction of a deep-rock tunnel 1,000' below the Hudson River. The second stage extended the system 33 miles north to another creek, requiring the ten-year construction of the 18-mile Shandaken tunnel. It is arguably the Catskill Aqueduct, and neither the Los Angeles

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*Culture and Rebellion in California* (Berkeley: University of California Press, 1992).

<sup>16</sup> The exception is Margaret Leslie Davis, *Rivers in the Desert: William Mulholland and the Inventing of Los Angeles* (New York: HarperPerennial, 1993): 33-86.

<sup>17</sup> This photograph, for example, is reproduced in *ibid.*, Nadeau, *Water Seekers*, 123; and Schwarz, *Water Odyssey*, 21.

<sup>18</sup> Schwarz, *Water Odyssey*, 22.

Aqueduct nor the Colorado River Aqueduct, that established modern water supply development and distribution practices.<sup>19</sup>

While the Colorado River Aqueduct is linked to both the Catskill Aqueduct and the Los Angeles Aqueduct in engineering techniques, the connections between the two California-based aqueducts went beyond engineering. It is also possible to make connections, as some scholars have, between southern California's water supply systems and its urban growth. The connections between the Los Angeles Aqueduct and the development of land in the San Fernando Valley has been frequently noted by scholars of urban history; similarly, it is possible (although more difficult) to make an argument linking the overall growth of urban southern California to the Colorado River Aqueduct.<sup>20</sup>

Furthermore, officials who went after Colorado River water knew that diversion from a federally-administered waterway, such as the Colorado River, would at least avoid the legal difficulties regarding land and water rights encountered during (and after) the construction of the Los Angeles Aqueduct. (The taking of water from the Colorado River, however, sparked new interstate controversies.) While there were proposals to take more water from the Owens Valley (in addition to those proposals to take water from streams feeding Mono Lake), investigations had failed to reveal the rightful owner of that water, and the city of Los Angeles did not want to

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<sup>19</sup> Ellis L. Armstrong, ed. *History of Public Works in the United States, 1776-1976* (Chicago: The Association, 1976). Chapter 8, "Community Water Supply," 223.

<sup>20</sup> While Los Angeles's population had swelled from 160,000 in 1906 when the first aqueduct was proposed to 970,000 with three times the area by 1924 -- the city's major population explosion came in the post-World War II years, coinciding with the arrival of a new water supply from the Colorado River. [Population figures taken here from House Committee on Irrigation and Reclamation, *Protection and Development of Lower Colorado River Basin*, 68th Congress., 1st sess., part 1 (1924), Testimony of William Mulholland, 97, and Oshio, "Urban Water Diplomacy," 31.] This is not intended to imply, however, that the arrival of Colorado River water into the Los Angeles basin was the principal cause for urban growth. Indeed, there were a number of other factors aiding growth, and the fact that the water was not immediately needed by the majority of the member cities upon the aqueduct's completion suggests that the arrival of Colorado River water was incidental to the area's expansion. The availability of this water may have been one reason for the area's growth in the postwar years, but it was one of many. A recent book by Greg Hise, *Magnetic Los Angeles: Planning the Twentieth-Century Metropolis* (Baltimore: The Johns Hopkins University Press, 1997), for example, argues that Los Angeles' postwar suburban expansion was due principally to the aircraft industry. The region, however, was also growing due to job opportunities offered in shipbuilding, housing construction, banking, tourism, and the entertainment industry. Nevertheless, the postwar population boom in Southern California eventually required more water than the Los Angeles Aqueduct was prepared to supply, and thus the Colorado River Aqueduct helped to supplement postwar expansion and sustenance. For a book that does tie Metropolitan directly to southern California's growth, see Robert Gottlieb, *A Life of Its Own: The Politics and Power of Water* (San Diego: Harcourt Brace Jovanovich, 1988).



get any deeper into the legal entanglements which it already faced in that area.<sup>21</sup>

Finally, the growth of the Los Angeles region since the importation of water from the Owens Valley went beyond expectations, and what officials had assumed would be enough water to supply the needs of the city for some forty to fifty years suddenly seemed to be barely enough to supply the existing population. By the early 1920s, a lingering drought had reduced the overall flow of water in the Los Angeles Aqueduct to nearly half capacity and the region's groundwater supplies were still apparently dropping.<sup>22</sup> While the Los Angeles region had not quite reached a crisis point, this situation nevertheless spurred city officials to look for another water supply.

### Necessary Legislation

It is impossible to pinpoint exactly when the search for another water supply began and who initiated it. Most accounts credit Mulholland as solely responsible for this, pointing to an October 1923 Colorado River trip he took with other engineers from the Los Angeles Department of Water and Power. The party apparently traveled to the Colorado River by train to determine whether that river would provide a reliable supply of water for urban use.

They also pondered the feasibility of pumping that water to the coastal plain -- the lower Colorado, below what is now Lake Mead, was well below the elevation of the sites of possible terminal reservoirs that could serve the southern California coastal plain, and well below the elevation of the intervening lands. An aqueduct would require massive amounts of electrical power to operate a pumping system to get water over and through the mountains to the Los Angeles region. This would be a far more costly undertaking than an entirely gravity-operated water supply system, like the Los Angeles Aqueduct. The trip was publicized by local newspapers that ran photographs of Mulholland and fellow engineer Henry Van Norman aboard a rowboat on the river, raising public consciousness about the need for another water supply while suggesting the desire to conquer this "wild" and "unruly" natural feature -- the Colorado

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<sup>21</sup> See the comments by William Mulholland in Senate Committee on Irrigation and Reclamation, *Colorado River Basin*, 69th Congress, 1st Session, part 1 (1925), 108, as noted in Kleinsorge, *Boulder Canyon Project*, 277-78.

<sup>22</sup> The depleting groundwater was a centerpiece of Metropolitan's campaign to generate support for the \$220 million bond issue needed to build the Colorado River Aqueduct. Graphics showing the depleting groundwater were featured frequently in brochures and movies produced by Metropolitan. Also see Frank E. Weymouth, "Introduction and Letter of Transmittal," in *Summary of Preliminary Surveys, Designs and Estimates for the Metropolitan Water District Aqueduct and Terminal Storage Projects* (Los Angeles: Metropolitan Water District of Southern California, December 1930): 1-2.

River.<sup>23</sup>

But it is more likely that Los Angeles city officials had begun considering an additional water supply as early as 1920. When Mulholland appeared before the House Committee on Irrigation and Reclamation in 1924, his trip was spurred by the drought that had plagued southern California since the early 1920s.<sup>24</sup> And while Mulholland spoke before the House Committee as an employee of the city of Los Angeles and stressed the city's needs ahead of the region as a whole, he mentioned both the city and the region at different times, noting that the water shortage was not merely a problem for the city of Los Angeles.

A new (Colorado River) water supply for the southern California coastal plain would also depend on California reaching agreement with the other states of the Colorado River Basin. This agreement, the controversial Colorado River Compact, divided the Colorado River watershed into an upper basin and a lower basin. The Upper Basin lies within the states of Colorado, New Mexico, Utah, and Wyoming. The Lower Basin lies within the states of Arizona, California, and Nevada. (Arizona, New Mexico and Utah each contain a small portion of the other basin.) The Compact addressed both mainstream and tributary waters; and the compact apportioned to each basin the consumptive use of 7.5 million acre-feet per year, with the Lower Basin given the right to additional consumptive use of 1 million acre-feet per year.<sup>25</sup> The representatives of the seven states executed the Compact in November 1922. The legislators of six of the states ratified the Compact within the following year; the Arizona legislature refused to ratify the Compact for decades.<sup>26</sup>

The Compact was approved by Congress with the passage of the Boulder Canyon Project Act in December 1928 over the protest of Arizona. The protest caused costly delays on the aqueduct project, particularly in the construction of Parker Dam (see Chapter 3).

California claimed the rights to 5.4 million acre-feet of this allocation, and in July of 1924, the city of Los Angeles filed a claim for 1.1 million of California's share.<sup>27 28</sup>

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<sup>23</sup> For information about this trip, see Kevin Starr, *Material Dreams: Southern California Throughout the 1920s* (New York: Oxford University Press, 1990), 158-59.

<sup>24</sup> That Los Angeles city officials had been searching for another water source since the 1920s is noted in United States Department of the Interior, Bureau of Reclamation, *Boulder Canyon Project Final Reports: General History and Description of Project*, Part 1 (Boulder City, Nevada: United States Department of the Interior, 1 December 1948), 129.

<sup>25</sup> Representatives from Arizona insisted that an additional one million acre-feet of water should be allocated to the lower basin. California and Arizona would later fight over the entitlement to this water.

<sup>26</sup> The conflicting claims are described in House Document No. 717, 80th Congress, 2nd Session, *The Hoover Dam Documents*, Washington, D.C., U.S. Government Printing Office, 1948, 103-105.

<sup>27</sup> Most of California's 5.4 million acre-foot allocation was used for agricultural purposes, mostly in the Imperial Valley, but W. B. Mathews (originally with the Los Angeles Department of Water and Power and later with

Much of the debate swirling around the compact was related to the concurrent proposal to build a dam at Boulder Canyon on the Colorado River -- a dam which California supported but many other states, seeing no benefit in its creation, did not. Mulholland's appearance in Washington D. C., for example, was specifically related to the first of four Swing-Johnson bills advocating this dam's construction. The bill, named for California Congressman Phil Swing (Imperial County) and California Senator Hiram Johnson, was first introduced into Congress in 1923. It called for a high dam at the Boulder Canyon location for the purposes of flood control and water "conservation" -- in this case, conserving it mostly to provide convenient water diversion for farmland in California's Imperial Valley near the U.S.-Mexico border. Moves toward introducing this legislation had been in the works since at least 1919.<sup>29</sup>

With an eye toward developing a water conveyance system that would require power to pump the water from the Colorado River, Mulholland claimed that Los Angeles would fail to obtain that power without the construction of this dam. The dam, he contended, would not only provide electrical power but had the further advantage of de-silting the notoriously turbid Colorado River water by capturing it first in a giant reservoir. According to Mulholland, the river in its current state was "wasting" a considerable amount of water by flowing naturally to the Gulf of California -- water that could otherwise be put to "beneficial" use.<sup>30</sup>

In speaking to the House Committee on Irrigation and Reclamation, Mulholland argued that Los Angeles faced certain doom if its water needs were not immediately addressed:

"...last year was a dry year, you will remember; and last year the supply from the Owens Valley dropped down to 270 c.f.s. Now that in the face of our rapid

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Metropolitan) was able to secure an annual allocation of 1.1 million acre-feet for Metropolitan.

<sup>28</sup> Arizona's protest led to the longest and most expensive court case over water in the nation's history. In March 1964 a U.S. Supreme Court decree apportioned 7.5 million acre-feet of Colorado River Water for use in California, Arizona and Nevada as 4.4, 2.8 and 0.3 million acre-feet, respectively. The byzantine political route taken by this compact is covered extensively by Norris Hundley, Jr., *Water and the West: The Colorado River Compact and the Politics of Water in the American West* (Berkeley: University of California Press, 1975).

<sup>29</sup> Schwarz, *Water Odyssey*, 38.

<sup>30</sup> House Hearings, 68th Congress, (1924), Testimony of William Mulholland, 99, 114, 116, 133, 136, 138. The idea of Colorado River water being "wasted" if its natural flow into the Gulf of California was not diverted for human consumption is common in the statements and the literature promoting the construction of the aqueduct. See, for example, Ralph L. Griswell, "Colorado River Conferences and Their Implications," *Annals of the American Academy of Political and Social Science*, vol. 148, no. 237, Part 2 (March 1930), 12; or Don J. Kinsey, "Purpose of MWD: Organization and Functions of the Metropolitan Water District," in *Metropolitan, The Great Aqueduct: The Story of the Planning and Building of the Colorado River Aqueduct* (Metropolitan Water District of Southern California, 1941), 12.

growth was a disturbing thing, especially so soon after our construction. But here comes another dry year, and even worse; so that at that time there is very slim promise of a supply from the Owens River, and the condition is absolutely alarming. And this committee has got to come to our relief and give us the means of a larger and more secure water supply, or we are ruined."<sup>31</sup>

The fourth Swing-Johnson bill was finally signed in December 1928 by President Calvin Coolidge, but what became known as the "Boulder Canyon Project Act" could not become effective until other water allocation issues were resolved. In June 1929 the Act was declared to be effective by President Herbert Hoover, launching a \$165 million program to build both the dam and the All-American Canal for the Imperial Valley near the international border. (The dam was built in Black Canyon, downstream of Boulder Canyon.)

While officials in southern California promoting a new aqueduct depended upon the electrical power provided by Boulder Dam, the Bureau of Reclamation, builders of Boulder Dam, also depended upon Metropolitan's promise to purchase about one-third of Boulder Dam power to prove that the dam project was economically feasible.<sup>32</sup>

Importantly, too, the construction of Boulder Dam provided a contextual link to the Colorado River Aqueduct that went beyond its function. Although the Boulder Canyon Project Act was approved before the onset of the Depression, the dam's erection during the early years of the Depression provided thousands of jobs and did eventually receive New Deal funding. Metropolitan's Board of Directors turned to New Deal-created funding from the Reconstruction Finance Corporation (RFC), which purchased Metropolitan's bonds to finance the aqueduct's construction; Boulder Dam's construction was also assisted by a large amount of funding from the New Deal's Public Works Administration (PWA).<sup>33</sup>

President Franklin D. Roosevelt made Boulder Dam the highlight of what could be called his "New Deal" world of dams --a world of large, concrete, publicly-built 1930s dams that also included Fort Peck Dam (Montana), Bonneville and Grand Coulee Dams (Washington), the dams

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<sup>31</sup> House Hearings, 68th Congress, (1924), Testimony of William Mulholland, 99.

<sup>32</sup> All costs of Boulder Dam (construction, operation and maintenance except for an allocation for flood control) with interest were to be recovered through the contract sale of electrical energy over a 50-year period. Metropolitan, its member cities Burbank, Glendale, Los Angeles, and Pasadena, and the Southern California Edison Co. were the initial energy contractees. In effect the people of Southern California underwrote Boulder Dam, making the project possible. As of 1987, the project was paid off with the California contractees paying 76 percent of that total.

<sup>33</sup> The PWA provided \$38 million of the nearly \$140 million Boulder Dam construction costs.

of the federally-backed Tennessee Valley Authority, and the Colorado River Aqueduct's diversion dam near Parker, Arizona.<sup>34</sup> While not quite as bulky as most of these dams, Parker Dam's width at the top is more than twice that of its base, and its deep 235' excavation to bedrock was an achievement in its own right.

The sheer mass of these dams, with their overwhelming amount of concrete and the national attention they inspired, may have also provided a much-needed psychological boost to an American population mired in economic woes. Donald C. Jackson has written that a "celebration of mass" became the dominant ideology associated with dam construction in the 1930s. The more material these dams required, he has argued, the more adulation they received.<sup>35</sup>

Although the immediate benefits of Boulder Dam would affect only a small portion of the American population, the American public at large was fascinated with this giant concrete arch dam. Tourists flocked to the narrow Black Canyon between Arizona and Nevada to watch the construction and kept coming after the dam was finished. The Bureau of Reclamation, in charge of building the dam, was not prepared for the hundreds of thousands of tourists who came to Boulder Dam during construction, but it *was* prepared for their post-construction visits: many parts of the dam's interior, for example, were designed specifically for their accommodation.<sup>36</sup>

While the massive amount of concrete in its arched form was enough to allow the Boulder Dam to function properly, engineers at the Bureau of Reclamation chose to embellish it as a monument to American engineering. Plaques and inscriptions to the dam's builders and those involved in funding its construction grace the roadway, and a memorial to those who died during construction, mosaics, and the imposing black granite winged human sculptures -- the "Figures of the Republic" -- call the attention of passersby on the Nevada side.

Similar features, albeit on a smaller and less noticeable scale, also appear along parts of the Colorado River Aqueduct. This was probably not a coincidence, for the Bureau of Reclamation was responsible for the design of both Boulder Dam and Parker Dam, and Six Companies, Inc. -- the contracting company that built Boulder Dam -- was also ultimately responsible for the construction of the aqueduct dams at Parker, Gene, and Copper Basin.

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<sup>34</sup> The concept of a "New Deal world of dams" is borrowed here from Fred Pearce, *The Dammed: Rivers, Dams, and the Coming World Water Crisis* (London: The Bodley Head, 1992), 92. For a discussion of the 1930s as an era of "great dams," see Thomas P. Hughes, *American Genesis: A Century of Invention and Technological Enthusiasm, 1870-1970* (New York: Viking, 1989), 353-83.

<sup>35</sup> Jackson, *Building the Ultimate Dam*, 246-47.

<sup>36</sup> From 1934 to 1935, an estimated 750,000 people visited Boulder Dam. For more on Boulder Dam and tourism, see Joseph E. Stevens, *Hoover Dam: An American Adventure* (Norman: University of Oklahoma Press, 1988), 260-61; David E. Nye, *American Technological Sublime* (Cambridge, Mass.: The MIT Press, 1994), 138-40.

## CHAPTER TWO: PROMOTING WATER

### Selling Metropolitan

While the Boulder Canyon project was bandied about in Congress, Los Angeles region officials set to work creating legislation necessary to turn the aqueduct proposal into a reality. In September of 1924, "farsighted officials" of the Los Angeles Bureau of Water Works and Supply (a division of the Los Angeles Department of Water and Power) created the "Colorado River Aqueduct Association." This association was entrusted with the task of drafting a bill for the creation of a metropolitan water district that would sell bonds and carry out the construction of the aqueduct.<sup>37</sup> After Mulholland and others lobbied for three years, the "Metropolitan Water District Act" was passed by the California state legislature in May of 1927, allowing for the formation of metropolitan water districts that could "...incur bonded debt and to acquire, construct, operate and manage works and property, providing for the taxation of property therein..."<sup>38</sup> The Metropolitan Water District of Southern California, then, was a direct outgrowth of the Los Angeles Department of Water and Power, and functioned under its aegis until May 1, 1930, when funds and equipment became available for Metropolitan to exist on its own.<sup>39</sup> In 1925, the Los Angeles Bureau of Water Works and Supply, with Mulholland as chief engineer, began using \$2 million from a city bond measure for surveys to determine the best route for an aqueduct from the Colorado River.

The Metropolitan Water District of Southern California was created on December 6, 1928 with eleven member cities: Anaheim, Beverly Hills, Burbank, Colton, Glendale, Los Angeles, Pasadena, San Bernardino, San Marino, Santa Ana, and Santa Monica. Voters from each of these cities approved a ballot measure to join Metropolitan, and in August of 1931, Compton, Fullerton, Long Beach, and Torrance also joined, while Colton and San Bernardino dropped out.<sup>40</sup> This left Metropolitan with thirteen members, whose first priority was the construction of the Colorado River Aqueduct.

In 1931, the original 1927 act was amended to stress the "urgency" of holding a bond

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<sup>37</sup> Franklin Thomas, "Metropolitan Water Distribution in the Los Angeles Area," *Annals of the American Academy of Political and Social Science*, vol. 148, no. 237, Part 2 (March 1930), 6.

<sup>38</sup> *Statutes of California*, Ch. 429 (San Francisco: Bancroft-Whitney Company, 1927), 694.

<sup>39</sup> Weymouth, "Introduction and Letter of Transmittal," *Summary of Preliminary Surveys, Designs and Estimates*, 2.

<sup>40</sup> For details on the framework and operation of Metropolitan, see, for example, Oshio, "Urban Water Diplomacy," or Thomas, "Metropolitan Water Distribution."

election to build an aqueduct that would secure the "peace, health, and safety" of southern California citizens.<sup>41</sup> Metropolitan's primary mission was to supply "the area within its boundaries with water for domestic and industrial uses, and incidentally to provide a means of creating a water supply for such surrounding areas as later may find it advantageous to join in the enterprise."<sup>42</sup>

### Promoting the Aqueduct

The aqueduct, however, still had to await passage of the \$220 million bond issue before construction could begin. To assure its passage, Metropolitan, led by Don J. Kinsey (assistant to Metropolitan's General Manager and Chief Engineer Frank E. Weymouth), spearheaded a campaign to emphasize the aqueduct's necessity. Kinsey tirelessly promoted the aqueduct through articles, pamphlets, and speeches, continuously reiterating the "urgent need" for water and upholding the Colorado River as the only logical place where that supply could be found. The material produced by Metropolitan included the publication of numerous brochures, some of which were mailed to customers with their water bills, and the production of an early talking motion picture called "Thirst" that was shown in 200 area theaters.

A Los Angeles-based, Metropolitan-sponsored "Citizens Colorado River Water Committee," chaired by John G. Bullock of department store fame, was formed to promote the project, and branch committees were created in each of the member districts. Among other things, this committee published a newspaper, produced weekly radio programs accentuating the need to secure water for the purposes of "maintaining population and property values," hung banners across downtown streets, and distributed automobile windshield aqueduct stickers. Local newspapers, stressing employment opportunities, the belief that the project would be self-supporting, and the idea that it would not increase the tax burden, also backed the project. Mulholland knew the importance of the press in shaping public opinion; in his 1924 meeting before the House Committee on Irrigation and Reclamation, he claimed that he paid no attention to the press, but that a "man trying to do useful work... as he needs their help might go after [the press] and encourage them, and get away with it."<sup>43</sup>

By August of 1931, over 4,000 Los Angeles businesses were supporting the aqueduct and,

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<sup>41</sup> *Statutes of California*, Ch. 323 (Sacramento: California State Printing Office, 1931), 831-32.

<sup>42</sup> Julian Hinds, "Colorado River Aqueduct: The Need, Growth, Engineering Features, Financial Status, and Progress," *Colorado River Aqueduct*, 1st ed., (Los Angeles: Metropolitan Water District of Southern California, 1935), 1.

<sup>43</sup> House Hearings, 68th Congress, (1924), Testimony of William Mulholland, 109.

the day before the September 29, 1931 election, a reminder to approve the bond was printed on every bottle of milk delivered in Southern California. Later that day, the measure passed with a five-to-one margin in each of the member districts.<sup>44</sup>

Before construction could begin, however, Metropolitan had to find somebody to buy the bonds -- a difficult process because effects of the Depression were beginning to be felt by late 1931. To help get the aqueduct started, the RFC, a newly-created federal loan institution (part of Roosevelt's New Deal), made an initial commitment of \$40 million on the stipulation that Metropolitan's aqueduct would eventually pay for itself.<sup>45</sup> After some legal complications, the RFC eventually funneled the rest of the money to the aqueduct project.

### Surveys, Geology, and Route Selection

Although the bond measure authorizing construction was not approved until 1931, much of the legwork to determine the aqueduct's route had already been completed. In fact, Mulholland and others had initiated a large-scale mapping of the desert region which the aqueduct might traverse in October of 1923, when he pointed to the Colorado River as the still-untapped supply that could provide an adequate alternate water supply for Los Angeles. Prior to the 1920s, most of the area remained inadequately mapped, and surveyors, engineers, and geologists -- working originally for the Los Angeles Bureau of Water Works and Supply -- traversed over 25,000 square miles of rugged and barren desert to draw detailed topographic maps of the region and to build various structures to assist in testing the initially suggested routes. This process took seven years -- nearly the time it took to build the aqueduct itself.

The surveying process was crucial to the construction of the aqueduct; without an accurate

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<sup>44</sup> Only in Long Beach was there a close vote. The information about the bond issue promotion is from Nadeau, *Water Seekers*, 228-29, Oshio, "Urban Water Diplomacy," 99-101, Schwarz, *Water Odyssey*, 52-54, and a series of brochures, magazines, and other promotional material in the possession of the Communications Division of the Metropolitan Water District of Southern California. The written aqueduct boosterism continued during the project, perhaps to assure taxpayers that their money was going towards a worthy cause. Beginning in 1934, Metropolitan published a newspaper entitled the *CRA News*, which initially published semi-monthly, then monthly in 1938 as the aqueduct neared completion. Radio broadcasts also took place along various points of the project, such as the completion of the San Jacinto Tunnel and the first intake of water from the Colorado. Annual reports and five magazines were also published during the aqueduct's construction, highlighting the features of the aqueduct, the "need" for the water, and the history of the construction process. These publications included photographs, maps, graphs, charts, and drawings showing the different stages of construction, and 6,000 copies were given away locally and sent elsewhere in the United States and internationally.

<sup>45</sup> James H. Howard, "Financing," in Metropolitan, *The Great Aqueduct*, 13.



mapping of the region, engineers could neither determine the aqueduct's alignment nor its physical features, and it would have been impossible to estimate aqueduct costs, which would be borne by the taxpayers. An extraordinarily expensive bond issue would have had a difficult time earning voter approval. The varied topography of the region -- with mountains interspersed among the vast expanses of the desert landscape -- did not lend itself to the obvious selection of an aqueduct route. In all, surveyors investigated more than 100 different routes between 1925 and 1931 before settling on a route beginning near the Arizona town of Parker.

In the first years of the survey process, funding from Los Angeles water bureau revenues allowed for small teams of surveyors to spread out across the desert. The surveyors first pieced together already-existing United States Geological Survey topographic maps to estimate initial costs and determine locations for survey field offices. These maps, however, did not provide the detailed information necessary for designers to map an aqueduct route. When the bureau received \$2 million from a city-issued bond sale in 1925, the surveying effort was expanded.<sup>46</sup>

By 1926, hundreds of surveyors, using transits, rods, and chains, had taken over the vast expanse of the desert southwest -- from the Grand Canyon to Baja California. They made area maps on 20" by 30" sheets, working predominantly at a 10,000' = 1" scale, but providing larger-scale maps in areas that required greater detail.<sup>47</sup> They also produced a huge 25'-long relief map of the area.

Metropolitan publications issued during and after the aqueduct's completion noted the difficulty of the survey process. These sources emphasized that access to many areas was difficult, and that drinking water was scarce and often had to be hauled to the work sites. The occasional use of the new Model-T touring cars (with the earliest surveys) and Model-A wagons alleviated some of the difficulties, but without roads across most of the terrain, vehicular access to many of the areas was next-to-impossible.<sup>48</sup>

Many surveyors crossed the desert on foot carrying their bedding and supplies on their backs. At times, surveyors had to traverse the landscape with teams of horses hauling food, water, and equipment. Engineers camped in semi-permanent tents and quickly-constructed "fly camps" (short for "fly-by-night" camps), and the desert summers reached "the limit of human

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<sup>46</sup> This money was eventually reimbursed to the city of Los Angeles in 1935, once Metropolitan had taken over the aqueduct project. City voters, in June 1925, voted for the bond measure in an over five to one margin of victory.

<sup>47</sup> Metropolitan, *History and First Annual Report*, 53.

<sup>48</sup> The Los Angeles Bureau of Water Works and Supply, however, did construct approximately 115 miles of roads next to the southern slopes of the Little San Bernardino Mountains (through which the Coachella tunnels eventually extended) between 1925 and 1927 and a 16-mile road between Earp, California and the Parker Dam site.

endurance."<sup>49</sup> One source noted that the surveyors, to map the best route, kept heading for the mountain passes like "the wagon trails of the pioneers."<sup>50</sup> Surveyors grouped together in teams of four or five people comprised of a party chief, an instrument man, a rod man, and one or two chain men.

Surveyors used transits to take measurements and drove wooden stakes into the ground to mark spots which they had surveyed.<sup>51</sup>

The extreme conditions made route surveying difficult. Visibility between stakes was distorted because of heat waves rising from the desert floor. Measuring tapes would lengthen (expand) during the day's heat. Measurements were made at night and early in the day to take advantage of better work conditions. Tens of repetitions were made when angles and distances were measured to get an acceptable accuracy under the adverse conditions.

Much of the work was carried out using rather sophisticated equipment and technology. The widespread use of automobiles across the desert terrain was a major advancement over surveying methods in the past, even if some of this work was completed on foot and horseback in the early years of surveying. Surveyors also used aerial photography to provide complete coverage of possible locations for the power transmission lines and patrol roads in inaccessible areas. These photographs revealed a more desirable relocation site for the Intake pumping plant, thereby resulting in a reduction of costs.<sup>52</sup>

The surveyors also paid close attention to the accurate mapping of earthquake faults. Inactive faults were a landscape feature representing potential construction and operation problems, while active faults were to be avoided wherever possible. Between the Colorado River and the Coachella Valley --a distance of almost 200 miles -- surveyors did not discover any evidence of active faults. But the major San Andreas fault, running north-south through much of California, was impossible to avoid.

Surveyors first mapped the area that would have provided the most direct -- and shortest -- aqueduct route: a direct line running from the town of Blythe adjacent to the Colorado River to the southern California coastal basin. The river at Blythe did not, however, provide a reasonable

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<sup>49</sup> At times, summer temperatures as high as 128 degrees were recorded. See E. A. Bayley, "The Financial and Topographical Problems of the Colorado River Aqueduct Project," in C.A. Dykstra, ed. *Colorado River Development and Related Problems*, 32.

<sup>50</sup> Metropolitan Water District of Southern California, *Colorado River Aqueduct*, 5th ed., (Los Angeles: Metropolitan Water District of Southern California, 1950), 14. A photo of two surveyors with four horses in the desert is reproduced in Metropolitan, *The Great Aqueduct*, 25.

<sup>51</sup> Schwarz, *Water Odyssey*, 48.

<sup>52</sup> Metropolitan, *History and First Annual Report*, 245.

site for the construction of a diversion dam necessary to aid in the task of de-silting the extraordinarily muddy Colorado River. Infiltration galleries are the alternative to a diversion dam for desilting turbid river water. The galleries are essentially horizontal wells adjacent to and below the level of the river. Water pumped from the galleries is filtered by flowing through the natural sands in the river banks and bottom. Tests conducted by pumping a test gallery indicated that these sands were too "tight" to make infiltration galleries feasible. Surveyors looked elsewhere along the lower Colorado River for a suitable location to build a dam. They looked north to areas where routes could begin near the town of Parker, where a dam could be constructed and the aqueduct route could connect with a section of the route already charted from Blythe. They also looked south for possible diversion points along the U.S.-Mexico border.

All of the proposed lower Colorado River routes required the pumping of water, because the lower Colorado River was (and is) below the elevation of the terminal reservoir sites, and well below the intervening lands across which the water had to travel. Surveyors also determined that the mountain ranges standing between the lower Colorado River and the coastal plain would actually necessitate a *series* of pumps to transport the water -- each of which represented a perpetual annual operating cost.

To avoid these operating costs, surveyors, later joined by geologists and engineers, traveled to areas of higher elevation to find a gravity-fed route. These teams proposed gravity routes from sites as far north and northeast as the Grand Canyon and the mouth of the San Juan River in Utah. Proponents of the all-gravity routes contended that those routes eliminated the costly perpetual pumping and were thus more economical; those who favored the pumping routes argued that the use of pumps could permit a much shorter aqueduct, less costly to construct.

The reconciliation of these two views was what is called the Present Worth Method, an accounting procedure that calculates the amount of money that, if deposited in a time account at one time (say the end of construction) would exactly pay the projected annual costs of each future year, and have a zero balance at the end of the operating period (say the year that the last of the construction bonds is redeemed).

The procedure is used with the same interest rate as that of the construction financing bonds. The Present Worth of all future costs is added to the total construction cost for each alternative route. The alternative with the lowest combined cost is the least costly overall. The construction costs are paid from bond revenues; and bond interest, annual pumping costs, and future bond redemption are paid from future revenues.

Planning a gravity flow aqueduct starts with source and terminus locations, a design flow rate, and the shape of the intervening lands described on topographic map(s). An initial route is selected, conveyance components (canals, tunnels, siphons and conduit) are assigned to the

reaches of the route, initial sizes are assigned to each component, the hydraulic friction (head loss) and the construction cost of each component are calculated. The sizes of the components are adjusted such that the sum of the head losses is equal to the elevation difference between the two locations. Portions of the route may be realigned and additional routes sought, and all are analyzed in this manner. The lower cost routes become the preliminary routes that are then reanalyzed at greater detail. This exhaustive process continues until no additional feasible routes are suggested.

Using economic design methods for an aqueduct leads to specific shapes and relative sizes for the conveyance components. For each canal size, there is a matching tunnel size, a matching conduit size and a matching siphon size. The matching sizes are based on the cost per foot of head (C/F). For a minimum cost aqueduct, the C/F of all the components will be the same. The C/F is calculated for each size of each component. It is the incremental increase in cost to construct a given size component slightly larger, divided by the incremental reduction in the hydraulic friction (head loss) at design flow.

Planning a pumped aqueduct is similar to planning a gravity aqueduct *except* that in a gravity flow aqueduct, the total available head is the elevation difference between the terminus and the source; while in a pumped aqueduct the pumps can supply as much lift, and thus head, as the planners wish.

The C/F concept is used as for a gravity aqueduct with the C/F for a pumping plant, C/FP calculated as the incremental total cost of furnishing an additional one foot of lift, head, divided by the one foot of head. The incremental total cost includes construction costs and the present worth of all future annual costs. The overwhelming item in the incremental total pumping cost is the cost of the increment of energy to lift the water.

Once the C/FP is determined, the sizes for conveyances are fixed, planners select an initial route, conveyance components are assigned to the reaches of the route, the head losses are totaled and lifts are determined for the pumping plants, construction costs are estimated and present worth of annual costs are calculated and summed as the total cost of the route.<sup>53</sup>

Another factor is avoiding damage from desert rain storms. They can transform any arroyo in the desert into an instant raging torrent, sweeping obstacles before it and scouring new channels many feet deep. Canals, conduits and siphons could be breached and filled with debris if not protected by constructing training dikes to divert surface flows into existing channels and prevent the channels from meandering, and by crossing under the channels using deeply buried

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<sup>53</sup> "Aqueduct Design Methods," a personal communique. A. M. Whitsett, October 1998.

siphons.

But there were still other factors involved. None of the routes could avoid crossing mountain ranges requiring extensive amounts of tunnel construction -- the most costly and most dangerous aspect of any aqueduct's construction process.

Canals, conduits and siphons are constructed in open excavations into the surface of the earth. Their full length can be inspected in daylight and any area can be sampled before the start of construction. Tunnels are constructed in the dark. Only the ends (portals) can be inspected before the start of construction, and conditions along the tunnel's length are inferred from exposed rocks and a few tiny holes drilled from the surface into the tunnel's future path. True conditions are learned at the tunnel face as the work advances. In addition to the obvious risks of life and limb to the constructors, unanticipated geologic conditions can slow or halt the work. In a worse case scenario, the tunnel may be abandoned and excavated in another location. A year's delay in completion and a 50% cost overrun is possible, though not highly probable.

Potential damage from earthquakes had to be considered in all cases, and routes that could incur the least amount of damage (and, hence, the least risk of costly repair) stood a better chance of being chosen. The planners also considered the proximity of the aqueduct's route to existing transportation lines, which could reduce the overall costs of building new infrastructure to transport materials and workers to the construction sites. And finally, the planners tried to procure a route that traveled as much as possible over public lands, thereby reducing the costly purchase of privately-held land across which the aqueduct would travel. It was the combination of all of these factors that ultimately led to the selection of the final route.

With the establishment of Metropolitan by February of 1929, the process of recommending an aqueduct route fell to a new staff of engineers and geologists -- some of whom arrived at Metropolitan by way of the Los Angeles Bureau of Water Works and Supply. One of these engineers was Frank E. Weymouth, who came to Metropolitan as chief engineer in July of 1929 after serving briefly as the chief engineer of the Los Angeles organization. Weymouth and his staff took over the data already compiled by the surveyors and reduced the more than 100 possible routes to fifty-four by November of 1929, and then provided preliminary estimates and details. Most of the routes they recommended began along the upper Colorado River, and twenty-three of those were pump-operated routes from Black Canyon, the present-day site of Boulder Dam. Only twelve of the proposed routes would have operated on the principles of gravity flow, and all of these began along the upper Colorado River.

Weymouth's team submitted its report to a review board of consulting engineers appointed by William P. Whitsett, the chairman of Metropolitan's Board of Directors. Whitsett asked the consultants -- Thaddeus Merriman from New York City, Richard R. Lyman from Salt Lake City,

and A. J. Wiley from Boise, Idaho -- to solve what he defined as a basic "problem": to recommend the best of these routes that could deliver water "at the lowest possible cost," including cost of construction and cost of operation.<sup>54</sup> Less than one month later, the consultants offered their preliminary report and recommendations to the board of directors, their selection being made in coordination with Metropolitan geologist F. L. Ransome.

The consultants quickly narrowed the fifty-four routes down to eight, only four of which they took seriously and all four of which (from Black Canyon, Bulls Head, Parker, and Picacho) required pumping as the water made its way to a proposed terminal reservoir, Puddingstone Reservoir, near Pomona. At the same time, the consultants considered four other gravity-flow routes, including an all-tunnel route from Black Canyon. They ruled these out because of their exorbitant costs, but nevertheless recommended that these routes be further investigated by Metropolitan engineers and geologists.<sup>55</sup>

Engineers and geologists headed back out into the desert during the next year to collect detailed information about the landscape over which these (and other) routes would cross, and Weymouth issued an extensive report to the board of directors in November of 1930, which he also forwarded to the consultants. The consultants, in turn, made a final report to the board of directors on December 19, 1930. Both Weymouth and the consultants recommended Route 74-B -- the "lower" Parker route --because it had the most favorable combination of construction cost, operating expense, and safety in construction and operation.<sup>56</sup> This route was formally adopted on January 16, 1931.

Weymouth's report explained the work performed by the engineers and geologists during the investigations, and it outlined the advantages and disadvantages of each of the routes his team had studied. In carrying out the investigations, Weymouth's team selectively studied six routes. Five of these (Parker, Picacho, Black Canyon, Bulls Head, and a Bridge Canyon all-gravity route which the consultants considered cost-prohibitive) had been suggested for further study by the consultants, but one of them -- an "All-American" route that would have diverted water from the Bureau of Reclamation's proposed All-American canal running through California's Imperial Valley -- was not specifically mentioned in the consultants' preliminary report.

Weymouth's report analyzed the Parker route first, noting its advantages, and pointed up that

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<sup>54</sup> Metropolitan, *History and First Annual Report*, 58. The consultants selected were all engineers who had worked previously on major water projects. One of them, Thaddeus Merriman, was the principal designer of the Catskill Aqueduct supplying New York City, at the time the nation's largest water supply system.

<sup>55</sup> Metropolitan, *History and First Annual Report*, 62.

<sup>56</sup> J.B. Bond, "Surveys and Estimates," in Metropolitan, *Summary of Preliminary Surveys, Designs and Estimates*, 39.

route's appeal by noting the disadvantages of the other five routes. Much of the route he recommended was the same as that adopted by the consultants, although it did not consider the pumping stations eventually constructed at Gene and Iron Mountain, the dams and reservoirs later built at Gene and Copper Basin, and the alternate Cajalco site eventually adopted for the terminal reservoir.

Weymouth's suggested route began with a combined diversion and power dam to create a large de-silting reservoir north of Parker, from which the water for the aqueduct could be taken in. The water, he wrote, would be lifted 539' before heading west through tunnels in the Whipple Mountains, where it would feed into 51 miles of either surface conduit or open canal. After these 51 miles, the aqueduct was to enter a tunnel in the Granite Mountains and then alternate between conduits, open canals, siphons, and a pumping plant (which became the Eagle Mountain pumping plant) to lift the water to its final elevation of 1,817'. At the base of the last pumping plant (Hayfield) was a dry lake bed which Weymouth suggested should be used for a large reservoir to regulate the aqueduct's flow or provide emergency water in the event of a breakage.

At that point, the route was to consist of tunnels and siphons running along the face of the Little San Bernardino Mountains (these became the Coachella tunnels) before it pierced Mt. San Jacinto with a tunnel. Emerging from the tunnel, Weymouth suggested that the route should be led to its terminal reservoir in "either of several safe and satisfactory routes." The Parker route, Weymouth argued, was best because it required less tunneling than the others and, as a whole, managed to avoid most major earthquake faults.<sup>57</sup>

Weymouth did not recommend the Black Canyon route, which would have been more costly because of its 300-mile length, much of which would require tunneling, and because the route had a higher pump lift than the Parker route. Weymouth eliminated the proposed route from the Bulls Head site in Nevada, fifty miles south of Black Canyon, largely because of its required 2,051' lift, which was considerably higher than that proposed for Parker. He did not recommend the 252-mile-long aqueduct diverted from the river near Picacho, on the California-Arizona border twenty miles north of Yuma, mostly because of its 1,997' lift and the fact that much of this route would have closely paralleled the San Andreas fault. Weymouth's team also looked at the possibility of a 271-mile-long aqueduct route taking water from the proposed All-American Canal and pumping it 1,888' to the coastal plain, but discarded that proposal because of the uncertainty of the canal's construction, its even greater proximity to the San Andreas fault, and the fact that a large section of the aqueduct would have been under the federal government's control. Weymouth also eliminated the proposed 316-mile-long Bridge Canyon all-gravity route because of its vast \$558 million construction cost (numerous tunnels would have been required,

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<sup>57</sup> Weymouth, "Introduction and Letter of Transmittal," in Metropolitan, *Summary of Preliminary Surveys, Designs and Estimates*, 8.

one of which would have been 89.5 miles long) and, like the Picacho and All-American routes, because it would have crossed hazardous fault zones in deep tunnels.

Weymouth's four-volume report, while certainly an influence on the process, was not the final word on the selected route. The decision was ultimately the responsibility of the engineering consultants, who were instructed by the Board of Directors to conduct an "independent study" of the routes and were reminded that they were in "no way" to be bound by the suggestions in the Weymouth report.<sup>58</sup> Given that they did not have the time to re-examine the sites, the consultants' final report nevertheless adopted much of the same information from Weymouth's report, including the final recommendation of the Parker route. There were, however, some differences between the two reports.

The consultants presented eight routes in their final report, some of which they suggested Metropolitan's engineers and geologists examine initially, and at least two others which had not been mentioned in the series of reports up to this time. In addition to the Parker, Bulls Head, Picacho, Black Canyon, Bridge Canyon, and All-American routes discussed in the Weymouth report, the consultants seriously considered a gravity-flow 850-mile-long aqueduct from the San Juan River in Utah requiring a 1,080' high dam and a 277-mile-long "Southern Sea Level" route diverting Colorado River water into a de-silting basin in Mexico, from which it would enter a 70-mile tunnel to San Diego before making its way up to Santa Monica with pumping located along its distribution lines. With the exception of the Parker route, the consultants eliminated all of these routes from consideration based either on excessive construction, operation, or maintenance costs, issues of safety or, in the case of the Southern Sea Level route passing into Mexico, political difficulties.

The consultants' final report, issued in December of 1930, stated that the Parker route was best because it passed through the "best terrain" and was relatively free from unusually long tunnels presenting safety hazards during construction. They also determined that the construction cost of the Parker route would be \$199,618,000 -- more expensive than the Picacho and All-American routes but less expensive overall because of its lower pump lift and, thus, cheaper operating costs.<sup>59</sup> And they noted that only along the Parker route was it practical to provide intermediate water storage in the event of imbalance or emergency shutdowns.<sup>60</sup>

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<sup>58</sup> "Board of Review Report," in Metropolitan, *Summary of Preliminary Surveys, Designs and Estimates*, 146.

<sup>59</sup> This figure did not include cost estimates for terminal storage (at Cajalco Reservoir) or the distribution lines, which the consultants estimated would bring the overall construction cost up to \$218,844,000. Metropolitan, *History and First Annual Report*, 111.

<sup>60</sup> Thaddeus Merriman, A. J. Wiley, and Richard R. Lyman, "Board of Review Report," in Metropolitan, *Summary of Preliminary Surveys, Designs and Estimates*, 162.



While adopting most of Weymouth's recommendations, the consultants noted that final surveys and geological test borings might require changes in the overall route and design of the aqueduct in order to reduce costs while maintaining safety. Finally, they suggested that the Parker route be subjected to more detailed examinations to determine the exact location and design of the aqueduct.<sup>61</sup> On January 16, 1931, Metropolitan's Board of Directors formally suggested the Parker route. Interestingly, there is some evidence that the site selected for the diversion dam was only a few miles from where William Mulholland had initially suggested it should be following his 1923 Colorado River expedition.<sup>62</sup>

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<sup>61</sup> Ibid., 154,

<sup>62</sup> Schwarz, *Water Odyssey*, 45.

## CHAPTER THREE: SENDING WATER

### Operations and Management

With Route 74-B -- the Upper Parker line -- now selected, engineers and geologists set to work with the final surveys to nail down the exact route and determine the parts to be used in each case. While most of the selected route and its parts were followed, surveys continued as engineers and geologists adjusted the route's specifics when necessary. As before, they had to pay close attention to overall cost. Among the major alterations that occurred following the route's selection was the abandonment of part of the route through the Granite Mountains when it was discovered they could not be easily penetrated.<sup>63</sup>

On June 18, 1932, an Act of Congress was approved, permitting Metropolitan free access to public lands needed for the aqueduct's right of way. This act also allowed Metropolitan to purchase additional land over which the power and telephone lines would travel and upon which roads, reservoirs, camp sites, and diagonal storm runoff "training dikes" would extend for a fixed price of \$15 per acre.<sup>64</sup> Metropolitan's acquisition of land for the route began in October of 1932, and by 1938, Metropolitan had paid nearly \$2 million to private owners for about 27,500 acres of land. The purchases overall spanned six counties in three states, including reservation land of the Native American tribes of the Chemehuevi, Mojave, Colorado River, Morongo, and Soboba.<sup>65</sup>

Engineers also had to determine the most economical design employing the aqueduct's parts: open canals, conduits, siphons, tunnels, reservoirs, dams, and pumping plants. The combination of these features for an aqueduct as large as the Colorado River Aqueduct was unprecedented in aqueduct construction, but their employment in an aqueduct project, as mentioned in chapter two, was not.

While pointing up the ingenious efforts of engineers and workers tackling various aspects of the Colorado River Aqueduct construction, Metropolitan did acknowledge that the parts used were generally those that had been successfully employed in similar projects in the past.<sup>66</sup> The aqueduct's dam and tunnel construction methods, for example, followed those previously used at

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<sup>63</sup> Schwarz, *Water Odyssey*, 75.

<sup>64</sup> Metropolitan, *History and First Annual Report*, 295.

<sup>65</sup> These included the counties of Riverside, San Bernardino, and Los Angeles in California; Yuma and Mojave in Arizona; and Clark in Nevada.

<sup>66</sup> Metropolitan, *History and First Annual Report*, 94-95.

Hoover Dam. Prior to the commencement of construction, a locating engineer employed on the aqueduct project noted that the design plans "so far considered" were quite similar to those of the Catskill Aqueduct.<sup>67</sup> Nevertheless, none of the previous aqueduct projects had been carried out on a scale comparable to the work that was about to commence in the southern California deserts.

But if the massive Colorado River Aqueduct project was to be carried out with any success, its construction process would require meticulous organization. The origins of the organization process came with Metropolitan's creation following the passage of the Metropolitan Water District Act in 1927, establishing a board of directors to hold ultimate responsibility over the managing of a metropolitan water district. The Metropolitan Water District of Southern California Board of Directors appointed Weymouth as general manager and chief engineer in charge of all administrative, engineering, and construction work on the aqueduct. Key engineering positions under Weymouth's direct control included that of the assistant chief engineer (responsible for office engineering and civil engineering design) and the positions of chief electrical engineer and distribution engineer.

Weymouth's appointment as Metropolitan's chief engineer in 1929 at the age of 58 followed twenty-two years as chief engineer with the U.S. Bureau of Reclamation. In that position, Weymouth had been in charge of construction for a number of dams, including the Arrowrock Dam in southern Idaho -- the world's highest dam until the completion of Boulder Dam. His recommendations to the Bureau of Reclamation were also instrumental in the selection of the Black Canyon site for Boulder Dam.<sup>68</sup>

Like Weymouth, Assistant Chief Engineer Julian Hinds came to the aqueduct project having been employed with the Bureau of Reclamation (he had begun there in 1910). In 1926, however, Hinds resigned from the bureau and spent four years in various jobs -- including one with the Los Angeles Department of Water and Power -- until he came to Metropolitan. Hinds also had a tremendous amount of dam experience. In fact, Hinds had been asked to oversee the design of the proposed dam in Black Canyon, but turned down that opportunity to work on the aqueduct.<sup>69</sup>

During the aqueduct's construction, Weymouth retained his principal office in Metropolitan's downtown Los Angeles headquarters building, while Hinds was in charge of the

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<sup>67</sup> E. A. Bayley, "The Financial and Topographical Problems of the Colorado River Aqueduct Project," in C. A. Dykstra, ed. *Colorado River Development and Related Problems*, 29.

<sup>68</sup> Stevens, *Hoover Dam*, 19.

<sup>69</sup> Among other projects completed while he was employed with the U.S. Bureau of Reclamation, Hinds was involved with the Elephant Butte Dam Project in New Mexico and the Yakima River Project in the state of Washington.

day-to-day construction operations from his office at the field headquarters in Banning. Specifically, Hinds was in charge of all construction operations and of all field engineering on the main aqueduct, although he reported to Weymouth.

While Banning was the central construction headquarters (it was also the location of the concrete and cement testing laboratory), the giant size and scope of the project required the establishment of subsidiary division headquarters. Six division headquarters were set up at various points along the route, each of which was run by a division engineer reporting to Hinds. Three of these division headquarters -- Divisions one, two, and three -- gradually became the sites of the Gene, Iron Mountain, and Eagle Mountain pumping plants, respectively. Division four was located at the Berdoo construction site, division five at the field headquarters area in Banning, and division six near the east portal to the Valverde tunnel. The "chief operator" of the entire aqueduct system was to be stationed at Gene.

Metropolitan's staff drew up the specifications and the contracts for work along the aqueduct, which the district divided up into various "schedules." (These schedules usually referred to a specific length of the aqueduct, which could include the construction of different parts of the aqueduct, such as siphons, canals, and conduits.) Prospective bidders were issued bidding packages -- including drawings -- for the work to be completed along each schedule, and they offered bids on these packages. Because some federal money from the RFC was used to initiate construction, the specifications forbade the use of any non-domestic materials and machinery.<sup>70</sup>

Metropolitan reserved work along the Coachella tunnels for its own workers in an attempt to relieve the "acute unemployment situation" in southern California as construction got underway. All workers -- whether working on Metropolitan's "force account" or under contract -- were required to hail from the member cities.<sup>71</sup> To be eligible, people from the member cities had to have been residents for at least one year, and Metropolitan required potential employees to perform a skills test to ensure a "high type of labor."<sup>72</sup> Many residents newly arrived to southern California discovered ways to claim residency despite their failure to meet the one-year limit.<sup>73</sup>

People hired to work on the aqueduct ranged from skilled engineers, craftsmen, teachers, lawyers, and doctors to unskilled laborers. Many of the laborers were trained on the job,

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<sup>70</sup> Metropolitan, *History and First Annual Report*, 272.

<sup>71</sup> *Ibid.*, 274.

<sup>72</sup> *Ibid.*, 306.

<sup>73</sup> Exceptions to the member-city-only employment rule were given to contracting companies who occasionally brought in their own men, or to Metropolitan when skilled men were needed for specific tasks. For more on the employment policy, see Metropolitan, *The Great Aqueduct*, 28-29, or Schwarz, *Water Odyssey*, 62.

learning, for example, to become muckers, drillers, or truck drivers. While Metropolitan limited its workers to eight hour shifts, they would sometimes work twelve consecutive days before receiving two days off, and construction often proceeded twenty-four hours a day.<sup>74</sup>

By 1938, over 150,000 people had applied for work at Metropolitan's labor employment office in downtown Los Angeles.<sup>75</sup> The project provided some relief to the unemployment problem in southern California by providing jobs to as many as 10,500 people at certain times during the eight-year construction period, and 35,648 people in all. It was without doubt the largest construction employment project carried out in southern California during the 1930s.<sup>76</sup>

### **Work Camps and Worker Morale**

To house all the workers, Metropolitan and the contractors built a number of construction camps along (or near) the route. These camps were usually built as close as possible to the work sites, although contractors working on a number of schedules along the route usually built one construction camp and transported workers to the various work sites. Because there were a variety of contractors -- in addition to Metropolitan's workers -- no two construction camps were exactly alike. Some were much larger than others (such as the Metropolitan-operated camps at Berdoo and Coachella) and included hospitals, libraries, and recreation halls. Others, such as the Walsh Construction camp in the Whipple Mountains northwest of Gene, offered little more than the essential dormitories, supervisor's headquarters, and a mess hall. Workers at camps like these were required to drive off-site for most of their non-work related activities.

The organization of Metropolitan's construction staff followed a standard pattern, resembling -- at least in its hierarchical spatial organization -- many American nineteenth-century company towns. Because of the remoteness of much of the aqueduct work and the need for employees to be stationed at a single site for long periods of time, living quarters had to be built to house the workers, engineers, field managers, and plant operators. Workers were housed in one- or two-story dormitories built of two-by-fours and plaster board with no ornament. Metropolitan did not provide air conditioning for the early one-story versions, but noted that

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<sup>74</sup> Schwarz, *Water Odyssey*, 66. For more on employment, see N. F. Jamieson, "Employment," in Metropolitan, *The Great Aqueduct*, 28.

<sup>75</sup> Metropolitan, *History and First Annual Report*, 304-05.

<sup>76</sup> Metropolitan, "Main Aqueduct Completion Ceremony," (Program), 14 October 1939; "The \$220,000,000 Metropolitan Aqueduct," *Fortune*: 90. Among other major American engineering efforts undertaken in the 1930s was the construction of the Boulder Dam (over 5,000 workers overall) and the enormous Grand Coulee Dam (over 70,000 workers). Unlike the Grand Coulee Dam project, however, the Colorado River Aqueduct was not initiated as a federal make-work Depression-era project.

there was "room for each man to sleep on the porch if he wished."<sup>77</sup> The district boasted of the quality of the kitchens, mess halls, and food served to the workers.

Meanwhile, camps provided for the division engineers were single cottages made from "first quality" plaster board. Permanent houses of frame or stucco construction with air conditioning and electrical heating were built for the plant operators. The field headquarters in Banning was the most palatial of all aqueduct construction-related buildings, with its tiled roofs, mission-style architecture, and manicured lawn.

Managing the workforce was a formidable task, given the aqueduct's magnitude and the numbers of workers employed at different times during its construction. Many of these workers had to be trained to use the specialized equipment, and ninety percent of those hired had never worked underground. Weymouth, nevertheless, was given a tremendous amount of credit for fostering an "esprit de corps" among his staff and the workers.<sup>78</sup> To build worker morale, Metropolitan established recreational facilities, organized athletic programs, and built libraries at the project's largest work camps.<sup>79</sup> Metropolitan also lauded its camp hospitals and safety procedures, noting that each division engineer was responsible for reducing accidents to a minimum. To encourage the enforcement of safety regulations, Metropolitan awarded pennants each month to the camp with the best safety record. In addition, camps often displayed signs noting Colorado River Aqueduct construction "speed records" that its residents had set.

Workers also managed to enjoy themselves in their hours away from the work camps. Among other activities, workers spent many of these hours in taverns. Those who worked on the aqueduct in the vicinity of Indio frequently attended a bar named the Jackhammer, while those who were building parts of the aqueduct at or near Parker Dam could be found at the Tunnel Tavern along the "MWD Highway" between Earp and the Whipple Mountains.<sup>80</sup> Those who worked along the aqueduct's westernmost stretches often sought out "gaudy amusement" in the towns of Riverside, Banning, or San Bernardino, although many of them lived in the nearby towns and returned home to their families at night.

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<sup>77</sup> Metropolitan, *Colorado River Aqueduct*, 5th ed., 24.

<sup>78</sup> *Engineering News-Record*, vol. 121, no. 21:, 637-38. For the "esprit de corps" fostered by Weymouth, also see Arthur Taylor, "Significance of Colorado River Aqueduct Water Supply to Southern California," *Western City Magazine* (June 1936).

<sup>79</sup> Metropolitan, *History and First Annual Report*, 307.

<sup>80</sup> Regarding the Jackhammer, see Schwarz, *Water Odyssey*, 69. The Tunnel Tavern was apparently important enough that Metropolitan's photographer took a picture of it for the official collection of construction photographs. See "'Joint' on MWD Hwy. Between Earp and Whipple," Negative no. 1-1-71 (25 November 1934), Metropolitan Water District of Southern California, Photographic Collection. Other bars frequented by aqueduct workers included the Owl and the Paradise. See Lynn Davis Smith, "End of a Chapter," in Metropolitan, *The Great Aqueduct*, 67-68.

It was a different situation in places like Indio, further out in the desert. One article noted that in those places, Saturdays may mean "whooping celebrations with rock-drilling contests and barrels of beer for prizes, and honky tonks with gambling and girls."<sup>81</sup>

### Construction Infrastructure

With the bond issue approved and the organization of operations settled, the path was clear for the beginning of construction. However, because much of the aqueduct's route was located in desolate areas far from roads and other facilities required for living or the necessary construction work, a tremendous amount of preparatory work had to be completed -- or at least begun -- before the aqueduct itself could be built. On January 1, 1933, two months before workers for the Wenzel and Henoch Company began construction at the San Jacinto tunnel, Metropolitan's district forces began to grade over 150 miles of new roads and erect 454 miles of high-voltage power lines, 1,206 miles of telephone lines, and 199 miles of water supply lines that included pipes, wells, pumps, and water tanks, in preparation for the massive construction job ahead.<sup>82</sup>

This construction infrastructure system, crucial to the project's successful completion, was essentially completed one year after its inception. It was built in segments, scheduled to precede the contractors' needs. Metropolitan elected to build those segments of this infrastructure that would support multiple contractors. Metropolitan then charged the contractor for the use of power and water. A critic claimed that this allowed Metropolitan to profit.<sup>83</sup> To the contractors, this charge was another cost of construction to be included in the bid price to Metropolitan. To Metropolitan, the infrastructure was less costly due to the economies of scale, the total construction time was minimized, and the charges discouraged waste of power and water. Contractors working on isolated works were required to build their own roads and utilities to facilitate construction.

Each phase of the construction infrastructure program was a difficult process, involving hundreds of workers. Prior to the grading of roads, for example, only "devious wagon trails" existed over most of the aqueduct's 242-mile distance.<sup>84</sup> Many of these were "scratch" roads

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<sup>81</sup> "The \$220,000,000 Metropolitan Aqueduct," *Fortune*: 93.

<sup>82</sup> Much of the infrastructure built for construction later became a permanent part of the aqueduct system and the physical desert landscape of southern California. The roads built for construction, for example, still provide most of the access to the various points along the aqueduct. Some of them became part of the state highway system.

<sup>83</sup> J. L. Burkholder, "Construction Program and Management," *Engineering News-Record* vol. 121, no. 21 (24 November 1938): 662.

<sup>84</sup> *Ibid.*, 659.

built during the survey process, created by simply clearing away boulders and brush. These roads were not sufficient for the constant transport of materials and workers to and from division headquarters and rail depots, so Metropolitan began grading lengthy stretches of road near the aqueduct's eventual route, with extensions to connect with the six division headquarters and camps. Following grading, Metropolitan's workers laid a 3" top layer of oil-treated material upon a base of natural roadbed material to create 20'-wide roadways. The longest stretch was built from Desert Center to Earp, near Parker Dam.

With no available surface supplies of fresh water along the entire route from the Coachella Valley to the Colorado River, district forces also built and operated an extensive water supply system to provide water for drinking and to assist the construction process. Water was used, for example, to cool the workers and the machines, to wash the aggregate at the contractor-built batching plants, and to mix and cure the concrete. Part of what was, in essence, a "miniature aqueduct" involved the tapping of fourteen underground wells and the installation of electric pumps to pump that water into thirty-five storage tanks.<sup>85</sup> Water stored in these tanks could be discharged into the 199 miles of 4" to 8"-diameter water pipelines built to transport it to the work sites.

The power lines built during this phase of construction provided electricity to operate many of the machines used to build the aqueduct and to light the tunnels. Although power from Boulder Dam and Parker Dam would eventually operate the aqueduct's pumping plants, contractors needed an immediate power source to proceed with construction. There were a number of pre-existing power plants owned by private power companies located near much of the route, but Metropolitan determined that it would be more cost-effective to purchase power from a single existing generating station of the Southern California Edison Company at Colton, near San Bernardino, and then build its own transmission system extending from there. This system consisted of 196 miles of 66,000-volt lines, 258 miles of 33,000-volt lines extending from it, and five power substations. The 66,000-volt transmission lines stretched east and southeast from Colton to five 6,000-kva substations at Lakeview, Cabazon, Fan Hill, Hayfield, and Granite. At those points, the 66,000-volt power was transferred to 33,000-volt transmission lines and then sent to seventy-two local distribution stations along the route. Some of this power was used to operate the electric pumps of the wells. Finally, over 1,000 miles of telephone lines were erected for the use of the district's field forces and for contractors employed on the job.

Metropolitan's workers and contractors also benefitted from pre-existing railheads of the Southern Pacific or Santa Fe Railroad at Earp, Rice, Freda, and Indio. Much of the equipment and supplies needed for construction, including reinforcing steel, structural steel, plate steel,

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<sup>85</sup> O. J. Schieber, "Construction Water," in Metropolitan, *The Great Aqueduct*, 24.



cement, lumber, and copper was sent by rail from major urban centers, unloaded at the railheads, and then transported by truck to the construction sites.<sup>86</sup>

The use of these railheads points up the national scope of the aqueduct project.<sup>87</sup> While almost all concrete work was performed on-site, for example, the cement needed for this work usually had to first be brought by rail to the various railheads and stored in central storage bins before it was brought by trucks to the batching plants near the construction site.

In fact, most of the equipment and materials needed for aqueduct construction were manufactured off-site in factories and then shipped to the desert for use along the aqueduct. Many of the pipe manufacturing plants from which the district purchased material were located in Los Angeles and Long Beach, but other materials were shipped from as far away as New York City, Cleveland, and Pittsburgh.<sup>88</sup> In addition, the contracting companies hired for work along the aqueduct hailed from all over the United States -- from Boston to Milwaukee, Minneapolis to Denver, and New York to Boise -- and they often transported some of their own key workers and equipment to the desert.

### **Parker Dam and Reservoir**

The consultants' selection of the Parker Route advocated the construction of a diversion dam across the Colorado River below the mouth of the Bill Williams River, about 16 miles northeast of Parker, Arizona. The dam was needed to raise the level of the river up 72' to 450' above sea level to provide adequate storage capacity (717,000 acre feet) for the purposes of silt removal and regulation.<sup>89</sup> Raising the level of the Colorado River by means of a dam -- while a costly endeavor -- nevertheless reduced the costs that would have been required to build nearly 100' of additional intake pipes leading from an intake pumping plant that would necessarily be located at

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<sup>86</sup> In certain cases, materials were sent from the railhead to the construction sites by railway company-owned trucks.

<sup>87</sup> The importance of the railroads to the aqueduct's construction was highlighted in promotional material. See Metropolitan, "Water for Thirteen Cities," (souvenir booklet) for the "Water Exhibit" at the California Pacific International Exhibition in San Diego, California (Los Angeles: Metropolitan Water District of Southern California, 1935), or Union Station Celebration Committee, "Railroads Build the Nation," (booklet), for the opening of Union Station, Los Angeles (Los Angeles: Union Station Celebration Committee, 3-5 May, 1939).

<sup>88</sup> Metropolitan did, however, erect its own fabricating plants at Indio and Freda to bend and weld steel into the proper shape for the aqueduct's siphons.

<sup>89</sup> The reservoir created by Boulder Dam provided the initial silt-removing function along the Colorado River. The Parker Dam reservoir's silt-removing function was to remove the silt that had collected below Boulder Dam. A 1957 survey of Parker reservoir found that siltation reduced the initial capacity by 69,000 acre-feet.

the river surface, to pump the water up the additional 78', and to erect and operate "clarification" works at the point of diversion so that the volumes of Colorado River silt did not enter the system.<sup>90</sup>

While Metropolitan advanced the funds for construction of Parker Dam through its \$220 million bond, the U.S. Bureau of Reclamation designed and built the dam.<sup>91</sup> Six Companies, Inc. offered the low bid for construction and began working in August of 1934. This giant company, comprised of a consortium of major contracting companies, was qualified to take on the job: its workers were currently in the process of completing Boulder Dam.

Like any dam construction, the erection of Parker Dam was complicated and time consuming, and it will only be summarized here.<sup>92</sup> Engineers knew that the Parker site was a suitable site for a dam because of excellent foundation conditions, but they also knew that reaching the foundation would be challenging -- it was 235' below the river. Engineers, however, also knew that the difficulty of excavating and constructing Parker Dam would be considerably reduced once the water was first impounded 150 miles to the north at Boulder Dam, so work on Parker Dam did not begin until 1934 -- just prior to the initial impoundment of water behind the newly-created Boulder Dam on February 1, 1935.

To begin Parker Dam's construction, the river had to be diverted around the site. Following some preliminary work, Six Companies subcontracted the diversion tunnels construction to J. F. Shea and Company, one of its constituent contracting companies building Boulder Dam, and then later subcontracted all Parker Dam construction work to the company. J. F. Shea and Company was allowed to transport much of the same equipment it had already used at Boulder Dam to assist with the Parker Dam construction.<sup>93</sup>

Before it set to work on the diversion tunnels, J. F. Shea and Company first built a construction camp on the California side and access roads to the site. Plans for the tunnels called for two parallel 29'-diameter tunnels to be driven through solid rock -- one 1,759'-long and the other 1,704'-long -- designed to handle a flow of 30,000 c.f.s. This capacity was thought to

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<sup>90</sup> Metropolitan, *Summary of Preliminary Surveys, Designs and Estimates*, 5.

<sup>91</sup> Parker Dam and its reservoir are owned and operated by the Bureau, but their operating costs, at least originally, were provided by Metropolitan. To aid in financing of the dam construction, the district benefitted from a \$0.5 million grant from Federal Emergency Administration of Public Works -- a division of the Public Works Administration (PWA).

<sup>92</sup> For a more complete account of the Parker Dam construction, see Metropolitan, *History and First Annual Report*, 208-17.

<sup>93</sup> Donald E. Wolf, *Big Dams and Other Dreams: The Six Companies Story* (Norman: University of Oklahoma Press, 1996), 54-55.

handle any flood flow from the Bill Williams River, and it was tested during a 1937 flood.<sup>94</sup>

Because Parker Dam was to span a federal waterway and the boundary between the states of California and Arizona, federal legislation authorizing its construction had to be in place. The state of Arizona, in addition to its refusal to ratify the 1922 Colorado River Compact, actively opposed the construction of Parker Dam as well as Boulder Dam. The United States Congress, interestingly, had failed to specifically authorize the construction of Parker Dam.

Trouble started early, when Arizona officials noted that the workers had begun test drilling on the Arizona side of the river in February of 1934. Arizona Governor B. B. Moeur was informed of this activity and ordered a small squad of the Arizona National Guard to monitor activity and report on "any encroachment on the Arizona side of the river."<sup>95</sup> By the time workers had begun erecting a temporary wooden trestle bridge across the river to reach the diversion tunnel construction area on November 10, 1934, Governor Moeur ordered over 100 armed troops to the Parker Dam vicinity to physically prevent further construction.<sup>96</sup> Three days later, the United States Secretary of the Interior halted the construction and moved the Parker Dam situation into the courts. On February 13, 1935, the Secretary acquired a temporary restraining order against Arizona that permitted construction to continue, but on April 29, 1935, the United States Supreme Court dismissed the United States' application for an injunction against Arizona from interfering with the construction of Parker Dam on its side of the river. The Court's ruling was based on its finding that construction was not authorized by Congress. This problem was rectified with the passage of the Rivers and Harbors Act on August 30, 1935 -- which included a specific passage allowing construction of the Parker Dam to resume -- allowing construction to continue.

By September of 1936, J. F. Shea and Company had completed the diversion tunnels and water, with the help of temporary cofferdams built near the tunnel portals, began pouring through on October 22, 1936. Prior to the completion of the diversion tunnels, workers began excavating dam abutments and, once the tunnels were complete, built cofferdams made of riverbed material excavated from the dam site.<sup>97</sup> Then, initially using dragline cranes and dump trucks, and later cableways and "skips" to haul away material as work proceeded below what had been the Colorado River, workers dug a total of 235' down through silt and gravel before they reached

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<sup>94</sup> Metropolitan, *History and First Annual Report*, 209.

<sup>95</sup> Nadeau, *Water Seekers*, 223.

<sup>96</sup> While much light has been made of the events surrounding the Arizona National Guard and the so-called "Arizona Navy" (a ferryboat initially involved in the conflict) the disputes between Arizona and California over the dam and the rights to water from the Colorado river were not a joke. For humorous anecdotes about the "Arizona Navy" and the conflict over Parker Dam construction, see Nadeau, *Water Seekers*, 222-27; Reisner, *Cadillac Desert*, 258-59; or Schwarz, *Water Odyssey*, 71-73.

<sup>97</sup> These cofferdams, built to the north and south of the dam site, survived a flash flood in February 1937.

bedrock on July 23, 1937. The excavation process involved numerous complications caused by inflows of water, requiring the installation of de-watering pumps. It was the deepest dam excavation ever.<sup>98</sup>

Only six days later, J. F. Shea and Company began placing concrete for the dam and cooling it by allowing water from the upstream side of the Colorado River to run through pipes embedded in the dam. This process was assisted by the construction of a cooling tower and circulating pumps. The concrete dam is 100' thick at the base, gradually tapering to 39' at the top. By April 1938, the dam's concrete placement, which continued through the night, was far enough along to close the diversion tunnels, and in July, the dam was complete.

Parker Dam was designed and constructed under the general supervision of Chief Engineer Raymond F. Walter of the Bureau of Reclamation, but Jack L. Savage, the bureau's chief design engineer, who was also involved in the design of Boulder Dam, was more directly involved with the overall design. Three different Bureau of Reclamation construction engineers directly oversaw construction. Savage's design featured a concrete arch dam with an 856' crest length. Arch dams had been used in ancient Rome, but had been revived for major American dam projects in the early twentieth century.<sup>99</sup>

The dam's most significant visual features are five 50' x 50' steel spillway gates in the body of the dam which are controlled from the continuous concrete gatehouse embellished with fifteen windows. These features lend a streamlined appearance to the dam which is complemented by the tapered and fluted light standards along the roadway. The overall design is a representative example of a series of streamlined dams completed by the Bureau of Reclamation in the 1930s, and its upper portion is nearly identical to the gate structure for the Alcova Dam and Reservoir on the North Platte River in Wyoming (1938), also designed by the Bureau of Reclamation -- albeit on a smaller scale.<sup>100</sup>

Parker Dam's overall construction also included a powerhouse on the California side and penstock tunnels to divert water to operate the four 30,000 kilowatt generators, although construction of the powerhouse and its associated features was not begun until 1939. Under a 1933 agreement, half the power generated at Parker Dam belongs to the Bureau of Reclamation,

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<sup>98</sup> It is unclear whether Parker Dam remains the world's deepest dam. It held this title at least until 1961, when a Bureau of Reclamation publication listed it as the world's deepest. While its depth is significant, only 85' of the dam's overall 320' height extends above the original river bed. See United States Department of the Interior, *Reclamation Project Data* (Washington, D.C.: United States Government Printing Office, 1961), 599. Note that reference no. 1 is an update of the 1961 document which did not claim it was the world's deepest. However, this claim is made in reference no. 3.

<sup>99</sup> Jackson, *Building the Ultimate Dam*.

<sup>100</sup> See the photo of Alcova Dam and Reservoir in Short and Stanley-Brown, *Public Buildings*, 520.

while the other half belongs to Metropolitan. While most of the power driving the pumps along the aqueduct comes from Boulder Dam, workers installed a 69-kv line from Parker Dam to the Gene switchyard and put it into service in 1947.

### **230-kv Power Transmission System**

While Boulder Dam and the other massive concrete dam projects of the 1930s captured the imagination of the American public, they also served the very practical function of providing hydroelectric power. With the construction of Boulder Dam at Black Canyon underway, Metropolitan was assured of more than enough power to run its pumps at their initial capacity, and the aqueduct needed that power to pump water to urban southern California as much as the Bureau of Reclamation needed Metropolitan's money to help cover Boulder Dam construction costs. The construction of Parker Dam would eventually provide additional power, but it was not immediately necessary.

Power from Boulder Dam arrived originally in the form of one 230-kv (230,000-volt) transmission line strung south through Searchlight, Nevada to a switching station at Camino, California, 23 miles west of Needles, California. This power was supplied from two 82,500-kilowatt generators at Boulder Dam. At Camino, the line split into two principal 230-kv branches, one of which went to the Gene pumping plant and the other which turned west to provide power for the pumping plants at Iron Mountain, Eagle Mountain, and Hayfield. A smaller, 69-kv power line extension from Gene meanders two and a half miles over the Whipple Mountains to provide power for the Intake pumping plant.

The power system associated with the aqueduct was an essential aspect of the aqueduct's anatomy, although much of it was not physically in the vicinity of the aqueduct. This system not only included the ubiquitous steel towers from which the high-voltage 230-kv aluminum and copper conductors were strung, but also the towers for the 69-kv line from Gene to Intake; switch racks and switch houses at Boulder Dam, Parker Dam, and the five pumping plants; and a principal switching station near Camino. Metropolitan determined that the construction, operation, and maintenance of the power system would be monitored from Camino, and they required the contractor to set up the workers' camp there as well.

The Camino camp was modest in comparison to the camps near some of the tunnel projects, in part because considerably fewer workers were needed to construct the power system. The Newbery Electric Corporation earned the contract to build nearly 150 miles of telephone lines and poles to parallel the power lines and connect with the telephone lines and poles already alongside the aqueduct. The Newbery Corporation completed its work between September, 1935

and May, 1936.

Construction of the aqueduct's power system, like that of the aqueduct itself, required the grading of many miles of new dirt roads to facilitate the construction process. These roads originally were constructed between January and May of 1934; 250 miles of them were improved beginning in February of 1937 and transformed into permanent aqueduct patrol roads.

Construction of the five different types of steel transmission towers and the power lines they supported began in December of 1935. The average tower weighs 10,200 pounds and is capable of supporting a maximum span of 1,710.' The largest of the towers weighs 14,800 pounds and is 70' tall.<sup>101</sup> All of the towers are rooted in reinforced concrete footings to protect against high winds and potential corrosion caused by high levels of alkali dust.

The lines (or conductors) used through most of the system are composed of a composite cable that includes twenty-six aluminum wires wrapped over a core of seven galvanized steel wires.<sup>102</sup> These conductors are supported by strings of thirteen 10" porcelain insulators. Over the high-alkaline Danby Dry Lake bed between Camino and Iron Mountain, the conductor is composed of fifty copper wires stranded in two layers over a twisted copper I-beam supported by strings of seventeen insulators.

Fritz Ziebarth of Long Beach earned the contract to build the transmission towers, the aluminum and copper conductors, and the porcelain insulators, and, together with Metropolitan, to construct facilities for workers at the Camino Switching Station site. At the Camino work camp, Ziebarth trained different crews to handle the erection of the towers and the stringing of the lines, although there was some crossover between the crews.

After the grading of roads, construction proceeded in February of 1936 with the excavation of the concrete footings at different points in the Danby Dry Lake area. Ziebarth's workers used mechanical "excavators," explosives, and compressed-air tools to excavate for the concrete footings, most of which were completed by May 1, 1936. After this point, specially-trained work crews began erecting the towers. The company purchased the steel for the towers from steel-making plants in San Francisco. The crews worked first from the Camino switching station southwest through the Danby Dry Lake bed, completing between twenty-four to thirty-one towers per week during "favorable" weather conditions, which did not normally include the summer months when the temperature was (and is) typically higher than 95 degrees. By the end of 1936, however, towers stretching from the Boulder Dam through Camino down to the Iron Mountain pumping plant were complete, and those stretching to Gene were nearly so.

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<sup>101</sup> Metropolitan, *History and First Annual Report*, 244.

<sup>102</sup> Metropolitan, *History and First Annual Report*, 244.

The hanging of insulators and the stringing of conductors followed the erection of the towers, although crews did not build all of the towers along the system before stringing the conductors. Each tower was designed to carry three conductors, which required the use of "tractors" pulling the conductors through the tower and applying proper tension on the lines by means of a power-driven winch. The tractors were also used to pre-stretch the cables to 12,000 pounds to test their durability in the event of severe weather, and then returned to their normal 7,500-pound tension.<sup>103</sup>

While work -- particularly work involving the pouring of concrete -- along all parts of the aqueduct was routinely halted during the summer months, power line workers encountered severe winter weather during the early months of 1937, which prevented the erection of towers and the pouring of concrete on account of freezing. Once the weather permitted construction to resume, Ziebarth's workers assembled along the western portion of the system to build towers and string conductors from Iron Mountain to Hayfield. The crews finished building the towers by May of 1937 and stringing conductors by July 19, 1937 -- five months ahead of schedule. Metropolitan's forces built the smaller, 69-kv line from Gene to Intake, beginning work in March of 1937 and completing it on December 8, 1937.

Remaining to be completed were the switch racks, transformers, and switch houses at the pumping plants; the Parker Dam standby loop; and the terminal transmission span from the Boulder Dam switch rack. Various contractors carried out construction of the electrical stations at the pumping plants in addition to the pump houses, reservoirs, sand traps, and other miscellaneous structures built in conjunction with the plants. Each of these electrical stations included a steel switch rack with oil circuit breakers which received the power from the 230-kv high-voltage lines, step-down transformers, and a switch house that distributed electricity to operate the pump motors, the camp lighting, and other local needs. These structures were all completed at the various pumping plants by early 1939.

When the Bureau of Reclamation completed a short transmission span extending from the Boulder Dam switch rack to Metropolitan's transmission lines, the power system was ready to set the pumps in motion and pump water to urban southern California.

### **Pumping Plants**

As soon as the route was chosen, engineers knew that they had to construct a fairly elaborate

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<sup>103</sup> Ibid., 247-48.

pumping system to lift the water a total of 1,617' from the reservoir created by Parker Dam over the mountains to a level where it could flow, by gravity, to the coastal plain.<sup>104</sup> Because the terrain over which the aqueduct crosses (east of Shaver's Summit near the Hayfield plant) drains to the Colorado River, it was considered impractical and nearly impossible to construct one pumping plant near Intake with enough power to transport the water all the way to Cajalco Reservoir, however convenient that configuration might have been from an operating standpoint.

Even by dividing the overall pumping into five segments, the 1,617' height, combined with the eventually projected need to pump 1,500 c.f.s. of water at approximately 375,000 hp, combined to make the aqueduct project a complex and difficult pumping project. The aqueduct's planners noted that there were other water conveyance systems requiring more horsepower, larger capacities, or higher single lifts, but in America in the 1930s, there was no instance where pumps had been built to combine the high lifts and high capacities required to transport Colorado River water to the Southern California coastal plain.<sup>105</sup>

A number of pumps at each of the stations was deemed necessary to operate the pumping plants along the route, and the size of the pumps (and the amount of electrical power) depended upon the required lift. Originally, four pumping plants were planned along the route, but a plant at Iron Mountain was added when the Granite Mountains could not be easily tunneled through. This adjustment only required a small amount of additional lift (144'), which is why the Iron Mountain pumping plant has the smallest pumps along the system. Hayfield, with the largest lift (441'), necessitated the largest pumps. Falling somewhere in between were the pumps required at Intake (291'), Gene (303'), and Eagle Mountain (438'). Engineers determined that there would be nine pumps at each plant so that the aqueduct could operate at partial capacity. Eight pumps would pump full capacity, and the ninth pump would be a spare.

To reduce overall costs, engineers wanted to maximize the efficiency of the aqueduct's pumps. In coordination with hydraulic experts at the California Institute of Technology (Cal Tech) in Pasadena, Metropolitan built a pump testing laboratory at Cal Tech and conducted tests at various speeds and heads and under different operating conditions on sample pumps for two years before specifying pumps for the plants.<sup>106</sup> When Metropolitan put the pumps out to bid, companies offering bids were required to adhere to specifications determined by the tests conducted at Cal Tech, and to provide a model pump for further testing. Metropolitan's Chief Electrical Engineer J. M. Gaylord claimed that its testing laboratory resulted in pumps of

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<sup>104</sup> The hydraulic grade reaches a maximum elevation of 1,807' at the top of the Hayfield lift.

<sup>105</sup> See, for example, J. M. Gaylord, "Pumping Plants," in Metropolitan, *The Great Aqueduct*, 51.

<sup>106</sup> The Cal Tech laboratory also served as a test area for other equipment in connection with the pumping system, such as pump inlet passages and valves.



“unprecedented” efficiency.<sup>107</sup>

The pumps at each of the plants are single-suction, single-stage vertical centrifugal pumps set below the level of the water to reduce the risk of cavitation and to insure self-priming. The synchronous motors, meanwhile, are located above the highest inlet water level to avoid flooding. Each of the motors is a vertical, three-phase, 60-cycle, 6,900-volt synchronous motor, enclosed and water cooled. In the event of repair, inspection, or to minimize surge pressures in the event of a power loss, a rotary plug valve inserted between the individual pumps and the discharge lines can be closed without disrupting the operations of any other pumps. Each pump sends water through 6'-diameter discharge branch pipes, encased in concrete, that extend about 100' from each of the plants. Each group of three pipes converges at a special branch where they meet a single 10'-diameter delivery line made of welded steel. The delivery line carries water up the hill until it meets the mode of conveyance that transports it through mountains and across desert to the next plant or reservoir. Each of these lines includes a shut-off gate near the top to halt the flow of water, if needed for repair or maintenance.

While this general configuration holds true for all pumping plants, there are differences in detail at the individual plants. At Intake, for example, water enters the pumps through “trash racks” constructed to prevent the intake of unwanted matter from Parker Reservoir into the system; at the other plants, water enters through steel intake manifolds. Because the plants at Iron Mountain and Eagle Mountain include de-silting and storage reservoirs, selector valves at those plants can be opened or closed depending upon whether operators desire to pump water from the aqueduct or from the reservoirs. Selector valves and a trash rack were also built at Hayfield, but they have never been used because the natural dry lake to be filled had far higher seepage than predicted. At Intake, Gene, and Eagle Mountain, the delivery lines meet pressurized conduits or tunnels, requiring surge chambers to absorb the oscillations resulting from a sudden shutdown of the pumps. At Gene, an additional surge chamber is included near the pump inlet because the intake to the pumps is through a considerable length of closed pressure conduit. Surge chambers are not needed at Iron Mountain and Hayfield because their delivery lines meet gravity-flow tunnels.

The size of the synchronous motors, because of the different lift requirements at the various plants, also varies. The largest motors, each operating at 12,500 hp, are at Eagle Mountain and Hayfield. The Intake and Gene plants have 9,000 hp motors, while those at Iron Mountain, the smallest lift, are 4,300 hp. Initially, each of the pumps was built with bronze impellers; today the impellers are made of stainless steel. The method of construction at each of the various plants also differed depending upon the geological conditions, although each contractor built an incline

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<sup>107</sup> J. M. Gaylord, “Large Pumps of Unprecedented Efficiency,” *Engineering News-Record* (24 November 1938): 673-76.

railway to facilitate construction of the delivery lines and surge chambers.

The pumping plants were initially built at approximately one-third capacity. The aqueduct's planners had determined that the most sensible configuration, considering factors of economy, practicability, and demand, was to first build each of the plants with three pumps, each with a 200 c.f.s. capacity. Nevertheless, they designed the plant buildings to allow for an eventual expansion to the full capacity of nine pumps.<sup>108</sup> When the aqueduct increased its capacity in the mid-1950s, more pumps were added and the pumphouses were extended to their current size.<sup>109</sup>

The construction of the pumping plants required more than just testing and installation of the pumps and motors. Each group of three pumps, for example, was designed to feed into one discharge (or delivery) pipe at each plant. Because the system was not expanded until the 1950s, each plant initially included only one delivery line. To control the pumps, contractors built a main control room in each plant, with recording meters indicating the amount of water in the aqueduct and the reservoirs, and controls that allowed pump operators to turn on or shut off pumps when necessary.

The buildings themselves had to be built large enough to accommodate the pumps. This required the construction of a large open floor for the installation of the motors, and access to a lower floor (or, in the case of Hayfield, two lower floors) to work on the impellers, casings, and valves. Construction of these buildings began shortly after contractors excavated the site. In most cases, contractors worked on the pump houses before working on the electrical switch houses or the delivery lines, although work often proceeded on many parts of the pumping plants simultaneously.<sup>110</sup> Contractors also used a variety of equipment to complete this work, including tractors and carryall scrapers.

Large portions of the aqueduct were under construction before work began on the construction of the pumping plants, the first specifications for which were issued in October of 1935 for the construction of the plants at Intake and Gene. Each contract required the construction of the pump houses and many of the appurtenant structures, including reservoirs, inlet structures and manifolds, delivery lines, sand traps, and switching stations and transformers. Winston Brothers Company and William C. Crowell offered the low bid and were awarded the

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<sup>108</sup> The 200 c.f.s. capacity for the pumps was slightly more than was necessary to build the pumping plants at one-third capacity.

<sup>109</sup> Actually, the pump houses were initially built to accommodate five pumps, although only three were installed. In 1951, with the first expansion, two more pumps were added to bring the number of pumps to five. With the final expansion in the mid-1950s, the buildings were extended and four pumps were added to bring each pumping plant up to full capacity.

<sup>110</sup> Metropolitan, *History and First Annual Report*, 234-42.

contract to build Intake and Gene; Wood and Bevanda that for Iron Mountain; the L. E. Dixon Company for Eagle Mountain, and the L. E. Dixon Company together with Case Construction Company, Inc. for Hayfield. These companies, in turn, subcontracted their work to a number of other companies. The pumping plant buildings and their surrounding structures, including the electrical switching stations, the delivery pipes, and the surge tanks were all built under contract. Metropolitan was in charge of installing the pump machinery, motors, and electrical and control equipment.

The plants were built following the designs offered by Metropolitan architect Daniel Elliot, who designed all the pumping plants in addition to the filtration plant along the distribution system.<sup>111</sup> These buildings were designed in a stripped-down or "starved" classical fashion, where typical elements of classicism -- columns, capitals, arches, and so on -- are represented without much elaboration; a style loosely mirroring many public buildings built around the country in the 1930s, including major American dams and other industrially-related structures.<sup>112</sup> This style drew upon the classical past but abstracted rather than mimicked it. It did not represent a radical break in the parade of twentieth-century American architectural styles, but it could nevertheless be considered architecturally "modern" in its efforts to employ elements from the past and abstract them.<sup>113</sup>

The classicism at the pump houses was articulated through the symmetrical, yet stylized, representation of triumphal arches, scrolls, and Doric pilasters on the entrance facades, and on the pilasters and light fixtures on the interior. The use of this relatively progressive architectural vocabulary by Metropolitan suggests that the district desired to identify its aqueduct and, thus, itself, with other major American monuments of the 1930s.

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<sup>111</sup> Elliot's design aesthetic may have been partly shaped by the experience he had gained working in the offices of Gilbert Stanley Underwood before being hired by Metropolitan in 1932. Among other buildings, Underwood designed the San Francisco Mint in this stripped-down classical style.

<sup>112</sup> Because of its association with Depression-era architecture, this architectural style is also sometimes called "PWA Moderne" or "WPA Moderne." It has also been called "New Traditionalism" or, more generally, "Art Deco."

<sup>113</sup> Some critics have argued that the employment of past styles in new guises indicates a type of "post-modern" architecture, and that architectural modernism implies a radical break from past styles. If one subscribes to such theories, the modernism employed by Elliot was not necessarily a formal modernism; that is, it was not a radical break from the past. But this style responded to modernist ideas in its neglect of *direct* quotations from past styles and details. See Richard Guy Wilson, "Modernized Classicism and Washington, D.C.," in Craig Zabel and Susan Scott Munshower, eds., *American Public Architecture: European Roots and Native Expressions* (University Park, Pennsylvania: The Pennsylvania State University, 1989): 272-303.

## Aqueduct Canals

The concrete-lined open canals carrying the Colorado River water through the desert comprise the aqueduct's most consistently visible component, and from the air, the canals are the only part of the aqueduct that can be easily detected.

Contractors built the canals, comprising about 62 miles of the overall aqueduct, across the giant, yet gently-sloping, alluvial fans west of the Whipple Mountains and Hayfield. The canals wind across the desert floor to maintain a constant slope of .00015 (0.79 of a foot per mile), designed to transport water at 4.5 feet per second.<sup>114</sup> Because they neither required extensive excavation nor tremendous amounts of costly steel, the canals were the least expensive part of the aqueduct's conveyance to construct per linear foot. They were also the least expensive part of the anatomy to operate, because they required the least slope for operation and thus required the least pump lift. Engineers therefore built the open canals wherever possible along the route.

However, canals could not be constructed everywhere. Where the surrounding landscape was susceptible to flash floods and debris flows, canals became siphons or conduits. In other areas, tunnels were bored through mountains in order to provide the necessary slope.

A variety of contractors bid for canal work, but usually in conjunction with siphon and conduit construction. There were no companies that specialized in canal construction per se, and three companies -- Barrett & Hilp and Macco Corp, Utah Construction Co., and Aqueduct Construction Co. -- built canals, conduits, and siphons. All of the canal work was subcontracted, and these contracts were awarded on October 19, 1934. The C. W. Wood and M. J. Bevanda Company began the first excavation on November 27, 1934.

Canal construction first involved excavation of the existing surface soil. Tractors and bulldozers were used to clear, brush, and level the way for the use of draglines, which then cut into the earth to excavate the soil as closely as possible to the canal's eventual prism shape. Contractors frequently employed draglines with 50' to 90' booms to perform most of this work, but the tougher soil required drilling and explosives.<sup>115</sup>

While the draglines could excavate the basic final shape of the canals, they could not carve them out to precise specifications, which were 55'-1-1/2" in total width across the top, 20' wide at the base, and 11'-8-1/2" deep. Contractors initially trimmed the prism to final shape by hand, but in an attempt to reduce costs and time, Clyde Wood of the Wood and Bevanda Company introduced a giant motorized steel apparatus that was able to perform the final trimming process

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<sup>114</sup> Metropolitan, *Colorado River Aqueduct*, 3d. ed., 14.

<sup>115</sup> Metropolitan, *History and First Annual Report*, 178-79.

in one operation. The machine -- called a "canal trimmer" -- moved along rails on either side of the trench and performed so successfully that by the fall of 1935, all contracting companies working on canals built similar machines to facilitate construction.

While no company devised a machine to quickly and easily complete the next phase of construction -- the placing and tying of reinforcing steel along the slopes and the base of the canal -- the Wood and Bevanda Company devised another ingenious machine to ease the process of lining the canal with concrete. This machine -- the "canal liner" or "canal paver" -- resembled the canal trimmer because it had the same dimensions as the sides and bottom of the canal. But instead of trimming soil, it distributed concrete from a hopper and placed and leveled concrete to the final dimensions as it moved along tracks on the canal berms. The concrete was then hand-troweled to provide a smooth appearance, treated with sealing compound to prevent excessive drying and cracking, and whitewashed to avoid solar overheating and cracking. Using these machines, workers could place over 530' of concrete lining per eight hour shift -- a remarkable improvement over the non-mechanical hand-operated method.

Even though the trenches are more than 10' below the ground surface, the canals still had to be buffered and protected from potential flooding and other conditions. Contractors thus constructed dirt embankments and dikes alongside the canals, and dikes running diagonally away from the canals on their uphill side. All of these features are designed to divert potential floodwater. These dikes direct floodwater over the siphons, where it can then flow across the desert floor.

Sand traps are also built into the canals to collect large debris and coarse sand that could block the siphons. These smaller traps complement larger ones built at Iron Mountain, Eagle Mountain, and Hayfield to settle fine sand that could damage the pumps. At four points along the canals, radial gates can be closed and "wasteway" radial gates opened to divert the entire water flow into naturally-existing drainage channels in the event of emergency. Finally, a 6'-high fence with barbed wire lines the entire length of the canal on either side. While contractors completed sections of the canals at different times, all canal work was substantially complete by late July of 1937.

### **Aqueduct Conduits**

Where the aqueduct's route had a steeper cross-slope or was thought to be subject to extensive flooding, erosion, or severe blowing-sand conditions (as between the Whipple Mountains and Hayfield), engineers built concrete "cut-and-cover" conduits. Conduits also comprise much of the conveyance from Hayfield west to Cajalco Reservoir. Canals could have

been built there but would have been subject to the infrequent but heavy rains that periodically occur in the San Jacinto and Perris Valleys.<sup>116</sup>

The conduits are essentially 16'-high concrete arched structures placed upon an invert slab. In most cases, the conduits are cut fairly deep into the earth and covered with backfill (hence their "cut-and-cover" name). Unlike the canals, no sections of the conduits are visible above the ground. But as in the canals, flow in the conduits is driven solely by gravity. The conduits' slope is greater than that of the canals: east of the San Jacinto tunnel, the slope is .00045, or 2.376' per mile, and west of the tunnel, the slope increases to .00056, or 2.957' per mile.

Because of their placement below ground level (all conduits along the system are a minimum of 3' below the surface, and the construction of the deepest conduits required extensive trench excavation) the conduits are not subject to much damage from floods, although their construction required considerably more excavation than that of the canals. Draglines and other equipment were first used for excavation and then the lower layer of the conduit, upon which the inverted slab would be placed, was trimmed and rolled, often with ten-ton rollers.<sup>117</sup> With excavation completed, contractors worked first on the 18'-10"-wide invert, which involved the placement of rebar, the pouring of concrete, and finishing by hand-troweling. The sides of the invert that would receive the arch were intentionally roughened by air and water jets before the concrete had completely settled to prepare for the placing of the concrete.

Once the invert had cured, contractors began setting the steel form works for both the inside and outside of the conduit arches, and placing the reinforcing steel. The interior formwork was mounted on tracks and could be moved ahead when one section of the concrete pouring was complete. Similarly, a truss bridge-like gantry outside the conduit operated on tracks and could be conveniently moved ahead after completing its job. The concrete was placed continuously by means of a variety of machines, including hand-pushed "buggies," hoists, conveyors, and power-driven hopper cars.<sup>118</sup> After this was complete, contractors stripped the formwork, applied sealant and whitewash to the exterior, and gave the interior surface a fourteen-day curing treatment with water spray or mist. Finally, contractors poured earth back into the trench to cover the conduit, leaving only a few spaces along the length for access from above.

Arch construction proceeded simultaneously with invert work, although invert work was usually kept a few hundred feet in advance of the arch.<sup>119</sup> By working both parts of the conduit's construction simultaneously, contractors managed to complete between 175' and 200' of work

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<sup>116</sup> Ibid., 178.

<sup>117</sup> Metropolitan, *History and First Annual Report*, 192.

<sup>118</sup> Metropolitan, *Colorado River Aqueduct*, 3d. ed., 51.

<sup>119</sup> Metropolitan, *History and First Annual Report*, 194.

per day for most days. All conduit work, like the canal work, was subcontracted.<sup>120</sup>

### Aqueduct Siphons

Where the aqueduct's route crosses drainage courses, ravines, and other natural depressions, its conveyance system is comprised of reinforced-concrete "pressure pipes" or inverted siphons comprising 28.7 miles or 12 percent of the aqueduct's total length. There are 144 inverted siphons along the aqueduct, ranging between 175' and approximately five miles (26,400') in overall length, and in operating head between a few feet and 153'.

Three basic types of siphons appear along the aqueduct -- double-barrel circular pipes, a single circular pipe, and a triple-box structure. The choice of which type of siphon to build in each instance was heavily directed by its local conditions, which determined its cost.<sup>121</sup> The most common of these (making up 80 percent of the length of the siphons) are the double-barrel siphons, with a typical diameter of 12'-4". These double-barrel siphons link canals, conduits, and tunnels, and were built whenever a long siphon was needed or when the operating head (pressure) was greater than 25'. The first barrel only was built to carry half of the aqueduct capacity (750 c.f.s.) with the initial construction. Provision for constructing the second, parallel barrel included transition connections and bulkheads, and over excavation through rock reaches.

Where shorter siphons with lower head were needed between conduits and tunnels, a single-barrel circular siphon with a 16' diameter was used. The cost of the transition structures needed at either end of the double-barreled siphons prevented their use in these instances. Single-barrel siphons are similar in overall form to the double-barrel siphons, but each pipe was built at full capacity (1,500 c.f.s.). These large siphons are the least common of the three types, and comprise only nine-tenths of a mile of the overall siphon distance. The segments vary in length from 175' to 435'.

As a connection between the canals, engineers determined that the construction of triple-box siphons -- each box with a height and width of 9'-9" -- was most economical. Each of the boxes has a capacity of 500 c.f.s., and the three of them can handle a full-capacity flow of 1,500 c.f.s. There are eighty-one siphons of this type, comprising 5.57 miles of the overall siphon distance and varying in length from 260' to 610'.

All of the siphons are made of cast-in-place reinforced concrete (monolithic) construction,

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<sup>120</sup> The conduits between the Coachella tunnels were built by Metropolitan forces.

<sup>121</sup> Ibid., 197.

with the exception of a 660' long, 12' diameter siphon in Little Morongo Canyon, which was pre-cast in short sections off-site as an experiment and then lifted into place by the dragline cranes. This experimental pre-cast pipe was something of an engineering "innovation" along the aqueduct, and its successful application at Little Morongo Canyon inspired engineers to use pre-cast pipes widely along the distribution system.

Engineers determined that monolithic concrete pipes were most economical, but they were also somewhat inflexible and, in the event of an earthquake, were susceptible to significant damage extending over a considerable length. To minimize these potential hazards, engineers intentionally "broke" the siphons every 20' with joints in the areas west of the Coachella Valley where the aqueduct crosses major earthquake faults -- along the Casa Loma siphon, the Big Morongo siphon, and the San Andreas siphon. The joints could thus minimize the extent of a rupture to a 20' length by transmitting shear but no tension, reducing overall repair costs and time of construction.

Siphon construction was more complex than that of the conduits or canals, in part because of the necessary initial placement of heavy full-circle steel reinforcement, and also because of the steep slopes of the landscape over which the siphons crossed. While contractors performed most of the work in various schedules along the aqueduct, Metropolitan furnished the concrete aggregate and fabricated the steel reinforcement cages for all circular siphons in its shops at Indio and Rice, and then had them transported by truck, or rail and truck, to the construction sites.<sup>122</sup>

The construction process for the siphons, like those for the canals and the conduits, first involved excavation to a reasonable depth. In certain cases, particularly across the San Jacinto Valley, the proximity of groundwater to the surface had resulted in soft earth, and contractors were required to solidify this foundation by adding crushed rock.<sup>123</sup> Once excavation was complete, workers secured small reinforced concrete blocks at evenly-spaced intervals along the excavated slope to prepare for the lowering of the pre-made circular steel reinforcement cages.

With these in place, workers erected collapsible steel forms inside the cages to ready the structure for the pouring of concrete. Concrete was then fed through hoppers atop the exterior forms, and workers often stood atop the sections of formwork to help guide them into place. Following this, concrete was poured in a continuous operation between bulkheads of varying length. Contractors also built manholes at "regular intervals" to allow for siphon access from above. Following construction, all siphons (with the exception of the Eagle Mountain siphon)

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<sup>122</sup> Metropolitan built only the Fan Hill experimental siphon (to test the quality of the concrete), a short section of the Casa Loma siphon with its connection to the San Jacinto tunnel, and those siphons between the Coachella Tunnels that were part of Schedule 17.

<sup>123</sup> J. B. Bond, "Siphons," in Metropolitan, *The Great Aqueduct*, 33.



were backfilled, the excess material spread over the right-of-way or used to build up head walls or embankments along the canals.

Special conditions existed at Eagle Mountain, where engineers had designed a half-mile siphon to crawl over the mountain ridge instead of through it. A section of the steep and rough mountain prevented access by trucks and other vehicles, so the Three Companies, Inc. contracting company, working on that schedule, installed a cableway to lower reinforcing steel, forms, concrete and other equipment into the trench. Because it is carved into rock, the Eagle Mountain siphon did not require backfill.

Box siphon construction was somewhat easier. Once the concrete invert was placed and hand-troweled, the steel forms were moved into position to allow for the completion of the walls and the top slab.

### **Aqueduct Tunnels**

Workers ran into some difficulty during canal, conduit, and siphon construction, but tunneling produced by far the biggest challenges for aqueduct engineers and workers. Because tunneling is expensive and dangerous, it was avoided wherever possible. In most cases, however, the numerous mountain ranges lying between the Colorado River and the coastal plain were unavoidable. In other cases -- particularly in the Little San Bernardino Mountains between Thermal and Big Morongo canyons, through which the Coachella tunnels penetrate -- tunneling proved most economical because the rugged mountain topography did not permit surface line construction. Engineers knew, too, that tunneling presented the most challenging of the construction tasks, given that the interior geology of mountains could not be accurately predicted and that miles of work would have to be conducted deep inside mountains with limited access from the outside. In the San Jacinto and Valverde tunnels, for example, interior water flows caused unforeseen problems during construction.

Tunnels comprise the bulk of the aqueduct's conveyance anatomy. Some 92.1 miles of twenty-nine separate tunnels (38 percent of the overall aqueduct) extend through mountains as the aqueduct proceeds from the Colorado River to Cajalco Reservoir.<sup>124</sup> The longest of these is the 18.3-mile-long East Coachella Tunnel, but the most difficult by far to construct was that through Mt. San Jacinto, which is briefly outlined in the next section. The completed tunnels show a remarkable consistency: all, with the exception of the Bernasconi and Valverde tunnels,

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<sup>124</sup> There were thirty-eight tunnels in all, including those of the distribution system.

are of horseshoe shape, are 16' high x 16' wide, and are lined with concrete with a minimum thickness of 6" on the sides and 9" in the arch.<sup>125</sup> Like the conduits and canals, engineers designed the tunnels to handle the full capacity flow of 1,605 c.f.s., even though that flow was not initially needed. All tunnels, with the exception of those leading from Intake, Gene, and Copper Basin, are designed to handle gravity flow.

The construction process followed what had become standard tunneling practice by the 1930s, although machines were introduced in certain cases when conditions necessitated their use.<sup>126</sup> This practice, in a simplified manner, required excavation by drilling, blasting, construction of supports, mucking and clearing, and concrete lining. But it was never that simple. Each tunnel of the aqueduct presented its own difficulties, usually based on the geological conditions of the mountains being penetrated.<sup>127</sup>

Tunnel miners generally began the excavation by blasting the mountain at certain points. In most cases, these points were from the entrances, or portals, at either end. In some cases, however, the tunnel was constructed by first accessing it from points above, through vertical shafts or inclined adits, and then working through to the portals at either end. For the first few hundred feet of most tunnel construction along the aqueduct, workers excavated the top heading of the tunnel arch first, followed by the lower, or "bench" portion -- usually a few hundred feet behind. But as construction proceeded, the improvement of existing equipment proved to be more effective in completing this portion of the job.

To begin excavation, contractors installed railroad tracks at the face of each mountain and placed either battery-powered electric locomotives or trolleys with drilling carriages atop them. These drilling carriages, or "jumbos," could hold five to eleven compressed-air drills and had the ability to excavate the "full face" of the tunnel in one process. In other words, these machines could excavate the tunnel to slightly larger than its general dimensions in one overall operation. Except under certain geological conditions that prevented their effectiveness, all contractors blasting tunnels later adopted these machines for excavation.

In the early phases of tunnel construction, workers used hand-powered drills, but faster automatic-feed drills were introduced shortly thereafter and rendered the hand-fed drills largely extinct during most phases of construction. The jumbos were capable of drilling up to twelve holes at once, each about 1-1/2" in diameter, from 5' to 11' deep into the rock. After drilling as

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<sup>125</sup> The Bernasconi and Valverde tunnels have a 15'-3"-diameter

<sup>126</sup> Metropolitan, *History and First Annual Report*, 150.

<sup>127</sup> To discuss these differences and to discuss all the different tunneling practices worked out along the aqueduct is beyond the scope of this report. Metropolitan's *History and First Annual Report*, 146-77, details this process extensively.

many as seventy-two holes into the face, workers loaded the holes with powder and blasted them with the aid of an electric detonator connected to the construction power supply. The detonator was arranged with "caps" that could ensure staggered, yet organized, order to the explosions, blasting rock from the tunnel's center before proceeding to blast the top, sides, and bottom. This method of "full face" construction, apparently initiated only a few years earlier during construction of the Boulder Dam diversion tunnels, marked the death knell for the old "heading-and-bench" method. Following drilling and blasting, the locomotives moved the jumbos out of the way and ventilation blowers blew fresh air to clear the heading of dust, smoke, and noxious gases caused by the explosions.

Where the tunnels bored through hard, tightly-packed granitic igneous rock, this excavation process could sometimes continue without the erection of supports. But in most cases, supports were needed to prevent cave-ins and falling rock. These supports were usually of timber construction, although steel supports were used in situations where more support was needed. In the instances where the material through which the bored tunnel was alluvial in origin (sand, gravel, and clay) -- such as that encountered during the construction of the Whitewater and Morongo No. 2 tunnels -- full support systems were needed. Following completion of excavation, workers would prepare the tunnel for the placing of concrete to ensure the water's smooth flow.

But a considerable amount of rubble still remained on the tunnel floor, and muckers (usually cranes attached to a conveyor belt) and muck cars were needed to remove it and haul it away from the tunnel's working face. Contractors worked hard to develop machinery that could speed this conventionally slow process. One of these ways was the procuring of larger, faster, and sturdier muck cars and locomotives with electric motors up to 60 hp. Another was the introduction of the variety of "carpassers" -- devices to let a full muck car at the tunnel face pass around a train of empty cars on a single track.

One of these carpassers was the "California Switch," a moveable double-rail track that could be arranged to slide atop the regular track. The California Switch allowed one muck car to haul rubble away along one side while an empty car moved into position to collect the next batch. Another device used to quicken the mucking process was the "grasshopper" machine, a two-level structure resembling a steel truss bridge that moved along a wide track. The grasshopper included a track on its upper level capable of holding empty muck cars which could be lowered, when necessary, to receive the muck. The cars could then exit along the regular track below the steel truss. Some contractors also used an older, crane-operated method, where a compressed-air crane hoist known as a "cherry-picker" lifted an empty car next to or above the track to permit a loaded car to pass by or underneath.

To prepare the tunnels for lining with district-tested concrete, in most cases contractors

moved a 20' to 30' collapsible steel formwork mounted on a moving carriage. The concrete was commonly brought into the tunnels in a dry state by specially designed batch cars from a batching plant located just outside the tunnel entrances. In some cases, the material had to be shipped from commercial pits in cities because of the lack of adequate local deposits.<sup>128</sup>

Upon reaching the formwork, workers mixed the concrete with water and then poured the combination into the forms by pneumatic or pump-type machines, the latter known as "pumpcrete" machines. These machines could handle drier concrete than the air machines, and could shoot the concrete into the top of the forms and then move ahead as that concrete flowed down into the foundations and filled the arch. Following this process, these machines would be used for "grouting" -- filling the voids between the formwork and the rock with concrete. After the arch concrete was cured by fourteen days of continuous water spray, the forms were taken down. Finally, contractors used machines to line the inverted floor with concrete, although no formwork was needed.

Despite the introduction of this new equipment, construction still proceeded excruciatingly slowly along the tunnels relative to the rest of the project -- it took five and a half years to construct the 13-mile San Jacinto Tunnel, for example, while 13-mile stretches of other aqueduct features could be constructed much more rapidly. But tunneling is a naturally slow process, and, in fact, the rate at which many companies advanced the aqueduct's tunnels was considerably faster overall than any major tunneling project known at that time. Some contracting companies working on the aqueduct were busy setting tunneling records. Metropolitan engineers estimated that contractors would be able to complete an average of 4' to 5' of tunnel excavation per eight hour shift (this included drilling, blasting, mucking, and placing supports), but the overall average, due to the introduction of fast equipment, brought that up to nearly 6' per shift. The average was much higher in tunnels free from water and "bad ground" -- that is, in mountains whose geological conditions were ideal.

### **Mt. San Jacinto Tunnel**

While the completed tunnels appear similar in overall design throughout the project, the workers encountered varying levels of difficulty and different conditions depending upon which part of the aqueduct they were working. Although it was not the longest tunnel of the system, the most difficult tunnel to construct was the 13-mile tunnel through Mt. San Jacinto, California's third-tallest mountain at 10,831'. Like the Elizabeth Tunnel of the Los Angeles

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<sup>128</sup> This was the case for the west portion of the San Jacinto tunnel and the Bernasconi and Valverde tunnels. Metropolitan, *History and First Annual Report*, 156-57.

Aqueduct, engineers knew the Mt. San Jacinto tunnel would have the greatest distance between access points of all aqueduct tunnels (8.23 miles), and that the time needed to build the tunnel would determine the time needed to complete the entire aqueduct.<sup>129</sup> This distance necessitated the sinking of two shafts from above. The expected difficulty and time needed to construct the tunnel was also the reason it was the first part of the aqueduct's anatomy to be sent out for bids, which were received on November 29, 1932.

The project was fraught with problems from the beginning. After the bids had been received, the low bidder failed to qualify and the bid was then awarded to the Wenzel and Henoch Construction Company of Milwaukee, the second-highest bidder. Wenzel and Henoch began construction on March 17, 1933, first excavating the shafts at Potrero and Cabazon and the heading from the west portal. The construction of the shafts alone was as time consuming and as difficult as the construction of the tunnel itself. The Potrero shaft in particular required the excavation of a nearly 800'-deep shaft into the mountain to deliver and take out workers and materials as necessary. But it was not merely the depth of the shaft that was a problem. Only 130' from the surface, workers sinking the Potrero shaft encountered internal water flows where the shaft crossed an earthquake fault. It was a sign of things to come.

In July of 1934, with the sinking of the Potrero shaft complete, workers boring the tunnel from the west portal encountered the same fault. This time, over 7,500 g.p.m. of water, accompanied by 1,000 cubic yards of detritus, rushed into the tunnel and rose to a depth of 647' in the Potrero shaft, forcing workers to clamber 796' up ladders to safety. As water was being pumped out nearly two months later, one of the discharge pipes broke and water flooded the shaft once again, this time to a depth of 540'. Although this water was finally cleared in November of 1934, workers boring the tunnel from the west portal encountered yet another fault and water flooded the shaft for a third time.

In February of 1935, Metropolitan fired the contractors and hired its own workers to complete the job. To alleviate further trouble, Metropolitan's workers installed electrically-operated pumping equipment in chambers located at the bottoms of the shafts and excavated the 5,452' horizontal Lawrence adit to speed construction. To scout the adit line for potential water flows, workers dug two smaller parallel "pioneer" tunnels slightly ahead of the main adit. To remove rock and other material from the adit, Metropolitan experimented with new mucking techniques.

Metropolitan's forces encountered some problems during construction, but finished the San Jacinto tunnel on schedule. The "holing through" of the tunnel on November 19, 1938 marked

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<sup>129</sup> Metropolitan, *Colorado River Aqueduct*, 3d Edition, 38.

the ceremonial completion of the 242-mile-long aqueduct. In celebration of the tunnel's completion, the entire issue of the November 24, 1938 *Engineering News-Record* was dedicated to the aqueduct.

### Dams and Reservoirs

While providing the lowest combined costs of construction and operation, the Parker route also contained excellent natural sites for intermediate water storage. In addition to the dams and reservoirs at the beginning and end of the system (Parker and Cajalco), two more dams and four more reservoirs are associated with the system. Water is not only stored in the reservoirs, it is also conveyed through them. Because they are part of the conveyance system, the reservoirs make up a total of 1.3 miles of the overall aqueduct distance.

An arguably more crucial function of the reservoirs (and the dams that help create them), however, is water regulation. Although Parker Reservoir serves the purposes of silt removal and to raise the level of the Colorado River, the intermediate reservoirs help to regulate and equalize the flow of water along the system. In addition, the reservoirs at Gene and Copper Basin -- quite close to Intake -- can remove silt that may result from any local flood flows into Parker Reservoir.<sup>130</sup> The reservoir at Gene holds 6,300 acre-feet, while Copper Basin holds 24,200 acre-feet. Three of these large intermediate storage reservoirs were originally planned, but only Copper Basin and Gene (commonly called "Gene Wash") became realities.

A giant 86,500 acre-foot reservoir -- more than three times the capacity of Copper Basin -- was planned for the Hayfield (Hinds) plant because of a naturally existing basin, but it never materialized. It was intended that water from the open canals leading to the Hayfield plant from Eagle Mountain could either continue to the Hayfield pumps or be discharged into the Hayfield Reservoir, but as workers filled the reservoir, the water disappeared into the porous subsurface soil, and the reservoir was abandoned.

The low bidder for dam construction at both Copper Basin and at Gene Wash was the Six Companies' J. F. Shea Company, which was already building Parker Dam. Because of the proximity of the dam sites to the company's already-existing construction camp near Parker Dam, no additional living quarters were necessary.

The specifications for the work at Gene Wash and Copper Basin called for two thin

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<sup>130</sup> W. E. Whittier, "Reservoirs," in Metropolitan, *The Great Aqueduct*, 47. These "local floods" would probably come from the Bill Williams River.

concrete-arch dams, 138'-high and 210'-high, respectively, above bedrock. Each dam has a 5' crest. The crest length is 430' at Gene Wash and 254' at Copper Basin.<sup>131</sup> The otherwise drab appearance of these dams is made dramatic by their natural settings in narrow red-rock canyons. At Gene Wash, J. F. Shea and Company also built a concrete ogee spillway and two small rolled earthfill dikes. Construction for the Gene Wash dam began in 1937 and was completed by June 1938. At Copper Basin, the specifications also required a concrete ogee spillway dam. The major work at Copper Basin began in May of 1937 and was completed in June of 1938.

The dams are not only similar in appearance, but also in method of construction. Concrete aggregate for the dams came from the Parker Dam aggregate plant. Trucks hauled the aggregate to the dam sites, where it was mixed with cement and then placed in buckets dangled from high-line cableways strung across the rocks before pouring began. To cool the concrete after pouring, refrigerated water was pumped through steel cooling pipes placed horizontally every five feet. This water was intended to cool the concrete down to the desired temperature of 50 degrees after placement, and to prepare the concrete for grouting the construction joints.

Smaller forebay reservoirs at Iron (100 acre-feet) and Eagle Mountain (112 acre-feet) were built to regulate inequalities in the flow or reduce water losses in the event of a partial or complete shutdown of the pumping system. These small reservoirs did not require dams, but they did require the construction of concrete-lined reservoir basins -- unlike the natural storage areas at Gene Wash and Copper Basin.

### **Cajalco Reservoir**

The completion of the San Jacinto tunnel marked the completion of the original aqueduct, but the west portal of the tunnel is not the westernmost section of the 242-mile system. From that portal, water flows through twenty more miles of conduits, siphons, and tunnels -- in addition to a small stretch of unlined canal -- before reaching the aqueduct's terminus at the Cajalco Reservoir (Lake Mathews). The reservoir, about ten miles southwest of Riverside, California, was built originally to hold 100,000 acre-feet of water.<sup>132</sup> Like the other reservoirs on the system, Cajalco Reservoir is a safeguard against unexpected flow interruptions.

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<sup>131</sup> The crest length was originally planned to be 220' at Copper Basin.

<sup>132</sup> When completed, the reservoir actually had a 107,000 acre-foot capacity. Cajalco Reservoir is also considered the beginning of the distribution system, because water stored in the reservoir is eventually sent through the outlet tower into the outlet tunnel. If it is considered the beginning of the distribution system, the small stretch of canal leading into Cajalco Reservoir becomes the aqueduct's terminus.

The reservoir, however, also provides seasonal storage to meet the fluctuating demands of Metropolitan's member cities. Because the aqueduct at full capacity has a constant discharge of water, this reservoir and others along the distribution system were required to help balance that constant flow, the day-to-day or seasonal demand from the member cities, and potential shutdowns for operation and maintenance.<sup>133</sup> The Cajalco site was selected because its 1,405' elevation above sea level allowed for all-gravity flow to the member cities, its stable granite foundation revealed no earthquake faults, and engineers knew it would allow for future expansion to an ultimate capacity of 225,000 acre-feet.<sup>134</sup>

The creation of the Cajalco Reservoir required the construction of a dam across the existing Cajalco Creek on the reservoir's west side, a dike on its north side, the excavation and lining of a diversion tunnel and an outlet tunnel, a spillway with a discharge channel, an outlet tower, and a small suspension bridge. The Griffith Company of Los Angeles was awarded the contract to build everything -- with the exception of the suspension bridge -- on August 16, 1935. The company completed the large reservoir project nearly two and a half years later, in February of 1938.

Of the reservoir's features, the dam and dike required the lengthiest construction time. The dam and dike were built of earthen materials mostly from the reservoir site. Their embankments required 3,092,000 and 3,857,000 cubic yards of fill material respectively. Foundation excavations were excavated to competent material before the embankments could be started. The excavation for the dam was 65' deep. The excavated material was stockpiled, and much of it was reused in the embankments. The remainder of the earthy materials was obtained from quarries within the reservoir site. Importing materials from more distant off-site quarries would have increased the project costs.<sup>135</sup> Material excavated for the dam and dike material was by 2 1/2-yard shovels, and thirty ten-yard trucks were used for hauling the material to and from the area. Tractor-drawn "sheep's-foot" roller units weighing 30,000 pounds each were used to compact the earth. Water from hoses and sprinkler trucks was applied to each six-inch layer as the embankment was built to ensure a moisture content that would facilitate compaction of the material. Compaction is one of the critical elements ensuring the strength and stability of an embankment. In keeping with much of the aqueduct work, Metropolitan maintained an on-site soil testing laboratory to test the soil for moisture, compaction, and percolation. Finally, Griffith Company workers placed an 8" slab of reinforced concrete on the upstream slope and a concrete wall at the base of the slab for added reinforcement and protection on both the dam and the dike.

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<sup>133</sup> Metropolitan, *History and First Annual Report*, 222.

<sup>134</sup> R. B. Diemer, "Wholesale Distribution to Member Cities," *Engineering News-Record*, vol. 121, no. 21 (24 November 1938): 680. At an earlier stage, it was thought that the terminal reservoir should have an ultimate storage capacity of 300,000 acre-feet.

<sup>135</sup> Metropolitan, *History and First Annual Report*, 225.



The outlet tunnel -- a 2,348'-long, 14'-diameter tunnel -- connects to the distribution system. It was designed originally to connect Cajalco Reservoir only to the high line, but was modified later to connect the reservoir with all distribution lines west of Cajalco. The Griffith Company built a diversion tunnel to divert Cajalco Creek storm water during dam construction, and plugged it when the project was complete. The spillway and the concrete-lined discharge channel leading from it were designed to protect against the greatest possible flood in the 40 square miles of drainage area tributary to the reservoir.<sup>136</sup>

The contract also mandated the construction of a 145'-tall outlet tower on the reservoir's northwestern side. This outlet tower, much like those of Boulder Dam before the creation of its reservoir, originally had a striking presence because much of its shaft was visible with the reservoir partially filled. Today, with the reservoir at full capacity, only the uppermost portion, with its castellated top, extends above the water's surface.<sup>137</sup> The circular reinforced concrete tower has a 20' diameter, and is equipped with fifty hydraulically-operated control valves at ports on six different levels. The tower was originally connected to the land by a small steel suspension bridge, built by the Kyle Steel Construction Company of Los Angeles, to provide access for the tower's maintenance and operation.<sup>138</sup>

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<sup>136</sup> Metropolitan, *History and First Annual Report*, 227.

<sup>137</sup> The tower was actually heightened when the capacity of the reservoir was increased.

<sup>138</sup> Today, the bridge is a two-span steel truss bridge. Metropolitan also built a number of roads around the reservoir, some of which became a part of the Riverside County road system.

## CHAPTER FOUR: DISTRIBUTING WATER

### Distribution

Leaving Cajalco Reservoir, water from the Colorado River officially enters the gravity-fed distribution system bringing water to the boundaries of each of the member cities.<sup>139</sup> From there, the member cities connect their own municipal pipelines to bring the water to homes, businesses, and industries.

The original distribution system was 156 miles long, comprised of one principal "high line" (the "Upper Feeder") at a relatively high elevation in the foothills of the San Gabriel Mountains. Three distribution pipelines extended from this high line, ultimately bringing water to the member cities at the lowest elevations: Santa Monica, Torrance, and Santa Ana. The purpose of the high line, like that of the distribution system as a whole, was to meet the current and projected water needs of the member cities, and to facilitate the addition of pipelines to future member cities.<sup>140</sup>

The anatomy of the distribution system is somewhat different than that of the aqueduct, for there are no pumping plants, no open canals, and no covered conduits. In fact, the distribution system is an almost all-pressure system, with pressure and gravity tunnels, pipes, siphons, reservoirs, and dams. Furthermore, following the successful execution of the pre-cast reinforced concrete pipe experiment along the aqueduct, nearly all of the pipes used along the distribution were also of pre-cast reinforced concrete. At the time, Metropolitan distribution engineer R. B. Diemer claimed that the approximately 36 miles of pre-cast pipe built into the high line represented the most extensive use of large-diameter pre-cast pipe ever employed on a construction project.<sup>141</sup>

In addition, the distribution system had to be extended into already-existing city streets in many of the member cities. Because of the high cost of right-of-way purchases in this area, in many cases it was actually less expensive to locate the distribution lines along city streets than to enter into negotiations with private landowners.<sup>142</sup> Where the high line passed through the cities

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<sup>139</sup> If one includes the distribution pipelines, the Colorado River Aqueduct is actually 398 miles long.

<sup>140</sup> R. B. Diemer, "Distribution," in Metropolitan, *The Great Aqueduct*, 41; Metropolitan, *Colorado River Aqueduct*, 3d Edition, 22.

<sup>141</sup> Metropolitan, *Colorado River Aqueduct*, 3d. ed., 55.

<sup>142</sup> R. B. Diemer, "Wholesale Distribution to Member Cities," *Engineering News-Record*, vol. 121, no. 21 (24 November 1938): 682.

of Pasadena and Sierra Madre, Metropolitan dug tunnels some 30' - 70' below the surface so as not to greatly disturb existing infrastructure.

From the Cajalco Reservoir outlet tunnel, water is sent north towards Fontana and then west to Eagle Rock along the high line, which consists of 10.3 miles of welded steel pipe, 35.7 miles of pre-cast concrete pipe, 0.3 mile of cast-in-place concrete siphons, and 15.7 miles of 10'-diameter circular tunnels -- the longest of which was the 6.1-mile Monrovia tunnel number three. The 10.3 miles of steel pipe includes a section over the Santa Ana River, where the line is carried on a three-span steel truss bridge with five approach spans.

Metropolitan purchased the already-built Morris Dam and Reservoir (1934) from the city of Pasadena to provide 38,000 acre-feet of storage along the high line.<sup>143</sup> This 245'-high, 1,160'-long structure is the only concrete gravity dam on either the distribution system or the 242-mile-long aqueduct, and it includes a "drum-gate" spillway on its north side. After passing the Morris Reservoir but before reaching Eagle Rock, water is distributed to the cities of San Marino and Pasadena. A line to Orange County (the "Orange County Feeder") serving the cities of Fullerton, Anaheim, and Santa Ana, branches off the high line in the city of La Verne, upstream of Morris Dam.

At Eagle Rock, the distribution system branches into two principal feeders: the Santa Monica and the Palos Verdes. The Santa Monica feeder passes through (and distributes water) to the member cities of Glendale, Burbank, Beverly Hills, and Santa Monica. The Palos Verdes cross feeder flows south to the 1,000 acre-feet capacity Palos Verdes Reservoir near San Pedro, with laterals taking water to the member cities of Los Angeles, Compton, Torrance, and Long Beach.

The Palos Verdes Reservoir was built by enlarging a pre-existing natural basin, lining it with reinforced gunite, and equipping it with an inlet/outlet tunnel and an outlet tower.

Construction of the distribution system began late in 1935. Contractors involved with making the concrete pipe for the distribution system built fabricating plants to manufacture pre-cast concrete pipes in 12' sections near major construction areas at Rochester, Claremont, and Baldwin Park. Each of the fabricating plants included machinery for forming the steel reinforcement cages, a concrete mixing and placing plant, and curing yards, where the pipes were stored vertically for three days and then rolled into a horizontal position and kept continuously wet by an automatic sprinkler for another eleven days.

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<sup>143</sup> The Morris reservoir was constructed as the Pine Canyon Reservoir.

These pipe sections were laid into trenches excavated for their placement by a variety of machines, the most common of which were either cranes extending from steam-operated stiff-legged derricks mounted on girder bridges, or cranes extending from electrically-operated through-truss bridges. Both of these gantries moved along rails as the cranes lowered the sections of pipe into the trenches. Steel pipes for the high line, on the other hand, were largely manufactured in Los Angeles shops and placed into trenches with electric cranes.

### **Filtration and Softening**

Before the water is distributed to the member cities, it is treated at the Softening and Filtration Plant (Weymouth Filtration Plant). This plant, which includes a large administration building next to the settling basins and other equipment involved in the water treatment process, is located along the high line in the city of La Verne between Cajalco Reservoir and San Dimas. Originally, the large plant complex dominated its surroundings, set as it was amidst orange groves at the foot of the San Gabriel Mountains. Today, the administration building rises above sprawling residential development on all sides.

The plant's original presence in the landscape and its exterior architectural detail point up its vital importance to the overall water distribution process. While the de-silting reservoirs and sand traps located along the system served to remove some of the unwanted particles in the water (the water had the tendency to attain the characteristic of "hardness" in its long journey from the Rocky Mountains over limestone, gypsum, and other calcium- and magnesium-rich materials).<sup>144</sup> To reduce the hardness of the water (from 300 parts per million to between 85 and 100 parts per million), and to make it more suitable for drinking and other municipal and industrial uses, Metropolitan commissioned the construction of a water filtration plant.

The water filtration and softening process at Weymouth is complex, and a detailed summary is beyond the scope of this report.<sup>145</sup> Nevertheless, it is worth pointing out that the overall process at the plant was and still is divided into two major steps: filtration and softening. The filtration process is intended to remove the last traces of solid matter, such as mud, organic matter, and plant and animal life. The softening process reduces the amount of calcium and magnesium that contributes to the water's hardness. The treated water is then sent back into the water mains of the distribution system. The two processes together can loosely be called water "treatment."

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<sup>144</sup> Julian Hinds, "Operation," in Metropolitan, *The Great Aqueduct*, 65.

<sup>145</sup> For a more detailed explanation of the Weymouth Filtration Plant process, readers are directed to W. W. Aultman, "Water Softening and Filtration Plant," in Metropolitan, *The Great Aqueduct*, 61.

Raw water entering the plant from the Colorado River Aqueduct is first mixed with lime to remove some of the calcium bicarbonate. The mixed water then moves to the flocculating basins to settle any of the matter still suspended in the water, and then continues through a tunnel to square open settling basins for water clarification. In the clarifiers, or settling basins, special equipment is used to remove sludge, and filters are employed to remove any unsettled matter.

Following this process, most of the now-filtered and partially softened water is sent through a process to remove the magnesium and calcium sulfates that contribute to the water's hardness.<sup>146</sup> The water originally entered another building with twelve softener beds consisting of a material resembling white sand known as "zeolite." The zeolite had the ability to replace the calcium and magnesium sulfates in the hard water with its non-hardness-forming sodium content.<sup>147</sup> A regeneration process, involving the application of salt, allowed for the zeolite to be recycled and used again. The salt was then piped out of the system, and the remaining clear water solution sent back to the distribution line's high line.

The chemical process of filtration and softening took place in grand surroundings, as Metropolitan may have decided that its major engineering efforts could be most readily appreciated by the public in a sprawling complex with references to California's settlement history.

Because it was located in La Verne, the filtration plant was also considerably more accessible to larger numbers of the public than any of the pumping plant buildings. The softening and filtration plant's administration building, in particular, was intended as a major public showpiece, equipped as it was with a lecture room seating approximately seventy people for the purpose of explaining the filtration process without disrupting the work being carried out in the laboratories above.<sup>148</sup> Metropolitan estimated that between 5,000 and 10,000 people would visit the filtration plant annually, and thus designed the plant in part to cater to this expected population.

To provide the appropriate imagery for the water filtration plant (including the administration building with the offices and testing laboratories, in addition to the zeolite building), Metropolitan retained architect Daniel Elliot, who had already provided designs for the pump houses. Unlike his understated designs for the pumping plants, Elliot's filtration plant was relatively flamboyant, incorporating architectural clues from the California Missions and from Renaissance Spain.

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<sup>146</sup> Some of this water is sent back to the head house where adjustments are made for chlorination and pH correction.

<sup>147</sup> Aultman, "Water Softening and Filtration Plant," in Metropolitan, *The Great Aqueduct*, 61.

<sup>148</sup> Ibid., 62.

Most detailed was the four-tiered, stepped-back entrance facade of the reinforced concrete administration building, with its decorative columns on either side of a gabled pediment below a red-tiled roof. These decorative entrance facades are common to many Spanish-built churches and missions in what later became Mexico and the United States in the sixteenth through eighteenth centuries. The entrance to the building is flanked by arcades on both sides. Tiled fountains decorate the landscaped grounds, and the top of the building includes a terra-cotta tiled cupola incorporating Moorish detail. The interior includes a rotunda with the district's seal appearing as a large mosaic on the floor (the seal also appears below the gabled pediment on the facade). Terra cotta tiles also appear in patterns on the floor throughout the building; these patterns reference a Native American symbol for water.<sup>149</sup> Some of these features, with the exception of the arcades, appear on the zeolite building to the south of the Administration building.

Architectural historians have traditionally grouped buildings such as the Softening and Filtration Plant, with its imagery recalling the California Missions and other buildings from the lengthy period of Spanish settlement in the Americas, under the rubric of "Spanish Colonial Revival."<sup>150</sup> This term is frequently used to describe a building's formal elements, but is less frequently explored as an architectural idiom intended to incorporate the ideals and myths of an imagined past in architectural form.

At the Softening and Filtration Plant, as in so many buildings both public and private erected in southern California in the late nineteenth and early twentieth centuries, the California missions are recalled only abstractly, and the overall composition includes references borrowed from other periods and cultures, such as Moorish Spain and classical Greece and Rome.<sup>151</sup> These hybrid references to the architecture of Spanish California and "Old World" Europe allowed Metropolitan to perhaps make more genteel the chemical process of water treatment, while legitimizing Metropolitan's purpose as a water provider by referencing past civilizations through architectural form.

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<sup>149</sup> Anne M. Cole, term paper written for Professor Carrott. May, 1987. Paper in the possession of Metropolitan Water District of Southern California, Public Affairs Division.

<sup>150</sup> See, for example, David Gebhard, "The Spanish Colonial Revival in Southern California," *Journal of the Society of Architectural Historians* vol. 26 (May 1967): 131-47; Rexford Newcomb, *Spanish Colonial Architecture in the United States* (New York: 1937); or Karen J. Weitz, *California's Mission Revival* (Los Angeles: 1983).

<sup>151</sup> Architect Myron Hunt designed a number of eclectic "Spanish Colonial Revival" buildings in this fashion in early twentieth century southern California, including Riverside's Mission Inn and the campuses of Pomona College, Occidental College, and the California Institute of Technology. See Kevin Starr, *Material Dreams: Southern California Through the 1920s* (New York: Oxford University Press, 1990).

## EPILOGUE: CELEBRATION, EXPANSION, AND REFLECTION

When the first water trickled into the city of Pasadena on June 17, 1941, the completion of the original phase of Colorado River Aqueduct construction was finally at hand. The moment was acknowledged with a ceremony -- one of many held at different times and in different locations during the eight-year construction of the Colorado River Aqueduct. These celebrations and ceremonies, often accompanied by the installation of permanent bronze plaques, served to provide a visual tribute to engineering during the construction process. The plaques included one at the Palos Verdes Reservoir marking the end of the distribution system, an elaborate set of plaques at the Cajalco Reservoir observation area, and a plaque honoring the transition structure between the San Jacinto Tunnel and the Casa Loma Siphon -- the last piece of the aqueduct to be completed.<sup>152</sup> CBS radio crews were on hand for a number of the ceremonies.

Indeed, this was an important era for the engineer, and Metropolitan -- with its general manager doubling as the chief engineer -- emphasized the importance of the engineer through these tributes and through its literature. During the initial stages of the aqueduct's construction, Metropolitan adopted a heroic portrait to symbolize the Colorado River Aqueduct project. This drawing showed the water's path from the Parker Dam in the Arizona desert to its final destination in a triumphant-looking Los Angeles, represented by a neatly-cropped citrus grove at the foot of City Hall. At the drawing's center, a confident engineer stood next to his surveyor's instrument.

Not everything during this project was idyllic. Although Metropolitan sold the public on the idea that water was desperately needed to save southern California from drought, there was no

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<sup>152</sup> The permanent bronze visual tribute to Metropolitan's engineering accomplishments was accompanied by a photographic, paper, and film tribute. Metropolitan frequently included photographs of engineers, workmen, and equipment braving the desert conditions in the promotional material it distributed during construction. In addition, Metropolitan promoted the project through the display of photographs and aqueduct models at various buildings around the Los Angeles region, including the Biltmore Hotel, the Pan Pacific Auditorium, the Los Angeles Public Library, the Pasadena City Schools Museum, the Long Beach Municipal Auditorium, the Automobile Club of Southern California, and the downtown Bullock's Department Store. At the "Water Exhibit" in the San Diego International Exposition of 1935 and 1936, Metropolitan featured one of its topographical models of the project and distributed a four-color map of the route. An aqueduct movie called "The Thirteen Golden Cities" was also released on December 14, 1938, shortly before the aqueduct's completion. The movie was shown in theaters and schools both within and beyond the district cities, and viewed by over an estimated 900,000 people. In August of 1939, Metropolitan produced a four-color lithograph of the aqueduct's route and reproduced 150,000 copies for public distribution. In both 1939 and 1940, Metropolitan included a float in the New Year's Day Tournament of Roses Parade, featuring a woman standing astride a paper tunnel spilling forth paper water.

immediate need for the water when it became available in 1941. The water shortage predicted by Mulholland did not occur, and when the first Colorado River water was delivered to Pasadena in November of 1941, it merely supplemented an already abundant supply augmented by rainy seasons that had filled local water reservoirs above and below ground.<sup>153</sup>

In its first five years of service, an average of only 27,000 acre-feet of the aqueduct's 430,000 acre-feet annual capacity -- a mere six percent of the capacity -- was ordered by the member cities. Of this amount, the city of Los Angeles took no more than ten percent, while its citizens were taxed for over fifty percent of the overall operation.<sup>154</sup> Nor did the aqueduct use all thirty-six percent of the power it purchased from the generators at Boulder Dam. Many taxpayers were outraged, and economists were quick to criticize the aqueduct for being built too soon.<sup>155</sup> It was not until the 1960s that all of the Colorado River water was needed -- and even then, Los Angeles never took more than ten percent because the extension of the Los Angeles Aqueduct to Mono Basin provided an adequate supply for the city.<sup>156</sup>

Beyond the economic and political problems, there were also construction difficulties. The San Jacinto tunnel construction was not only difficult, but it also claimed a number of lives. While Metropolitan boasted that its close attention to safety procedures prevented the normal percentage of accidents and deaths on a project of the magnitude of the Colorado River Aqueduct, an estimated fifty-four people died during construction, in addition to over 100 construction-related car accidents. Furthermore, in the six-year period from 1933 to 1939, about 3,500 people were admitted to camp hospitals for medical and surgical conditions.<sup>157</sup>

Other problems encountered by Metropolitan during construction included a landowner on Metropolitan-purchased land near Cajalco Reservoir who complained that his 1,000 acres of

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<sup>153</sup> Cooper, in *Aqueduct Empire*, 90 argues that the citizens of the "Southland," up to about 1960, used more water from underground wells than any other source.

<sup>154</sup> Kahrl, *Water and Power*, 403.

<sup>155</sup> See, for example, Jack Hirshleifer, James C. De Haven, and Jerome W. Milliman, *Water Supply: Economics, Technology, and Policy* (Chicago: University of Chicago Press, 1960), 135-46.

<sup>156</sup> Hundley, *The Great Thirst*, 229. Numerous scholars have argued, however, that the history of water development in Los Angeles has been about securing future, rather than immediate, needs. And most of the boosters, including Mulholland, probably knew this; in Mulholland's 1924 appeal to the House Committee on Irrigation and Reclamation, he explained that the demand for water "does not at present exist; but it is a rapidly growing demand; and it is easily conceivable that it can amount to [the prospective demand] within ten years' time." Thus, Metropolitan was able to sell the aqueduct project by playing on the ideas of immediate water need (even if it knew this water was not immediately needed), and it could acknowledge its own foresight when that water was needed in later years.

<sup>157</sup> Metropolitan, *History and First Annual Report*, 299.



land was unjustly taken (he sued for \$4 million).<sup>158</sup> In August of 1937, Metropolitan confronted an affiliate of the Committee for Industrial Organization -- the International Union of Mine, Mill, and Smelter Workers -- that had organized at San Jacinto. After Metropolitan refused to comply with the union's requests for recognition as the sole bargaining agency in charge of hiring at the tunnel's construction, among other demands, 984 union workers walked off the job.<sup>159</sup> Violence, related to the strike, flared up briefly in October of 1937.

There were also non-Metropolitan-related problems. Workers building the Intake and Gene plants for the Winston Brothers Company and William C. Crowell struck in April of 1937 for more than four months. In early February of 1936, a fire claimed lives and obliterated a dormitory at the J. F. Shea and Company's camp near Parker Dam.

Yet with the bombing of Pearl Harbor and the U.S. entry into World War Two just six months after the aqueduct's completion, these events, and perhaps the aqueduct as a whole, were mostly forgotten. Ironically, it was the war that drew attention back to the aqueduct, as the city of San Diego needed water to supply its industries feeding the war machine. While the construction of what became the "San Diego Aqueduct" -- a pipeline extending from the west portal of the San Jacinto tunnel built by the United States' eleventh Naval district -- was not actually completed until 1947, its construction marked the first of many changes to the Colorado River Aqueduct over the next twenty years.

As Metropolitan planners had predicted, the total number of member cities did not remain at thirteen for long. In 1942, the Orange County cities of Newport Beach, Dana Point, and Brea voted to join Metropolitan, and during a seven-year drought from 1944 to 1953, a number of cities, formerly part of smaller municipal water districts, also joined the parent organization. One of these cities was San Diego, which, together with other cities in its region, joined Metropolitan as part of the San Diego County Water Authority in 1946. To meet the needs of its growing membership, in 1951 Metropolitan initiated a \$51 million system expansion, including the addition of two pumps and one delivery line to each of the pumping stations and some pipeline additions to the distribution system.

But in 1952, the Central Basin Municipal Water District, consisting of more than thirty cities and one million people, also became a part of a growing Metropolitan, as did the cities of Riverside, Corona, and Elsinore. These additions nearly doubled Metropolitan's size, and they

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<sup>158</sup> "The \$220,000,000 Metropolitan Aqueduct," *Fortune*: 92. Metropolitan noted that it had to resort to condemnation proceedings in two instances to secure right of way along the distribution lines through "some of the finest developed citrus land in southern California." Metropolitan, *History and First Annual Report*, 297.

<sup>159</sup> Metropolitan, *History and First Annual Report*, 170-71.

spurred the planned expansion of the aqueduct to full capacity.<sup>160</sup> In 1952, Metropolitan's Board of Directors voted to place a \$200 million bond issue before voters to expand the system -- a bond measure that passed by an eleven-to-one margin.

Along the original aqueduct, the expansion consisted of the installation of four more pumps and another delivery line to each of the pumping stations, the construction of the "second barrel" of siphons (twelve miles of siphons to parallel the originals), the raising of the Cajalco Reservoir dams to provide for 182,000 acre-feet of storage, and another 230-kv power line running from Hoover Dam to the Camino switching station. Along the distribution system, the expansion included more than one hundred miles of additional pipes and tunnels, an additional 1,500 acre-feet of storage at the Garvey Reservoir near Monterey Park, the expansion of the Softening and Filtration Plant to twice its original capacity, and the erection of another treatment facility near Yorba Linda in Orange County.

While the increase to full capacity was not immediately needed when this flurry of construction finished in the mid-1950s, the aqueduct was operating at full capacity by the late 1950s. By 1965, Metropolitan included twelve municipal water districts (incorporating a number of cities) and a county water authority to go along with its thirteen member cities -- serving over nine million customers.<sup>161</sup> By 1998, more than sixteen million people were served by the Metropolitan Water District of Southern California.

Tied up in the ongoing feud with Arizona over the rights to Colorado River water, the story of the Colorado River Aqueduct post-1941 is, arguably, more a story of politics than it is one of engineering.<sup>162</sup> Indeed, with the exception of the 1950s expansion (most of which was planned with the original construction and did not involve radically new construction techniques) and the continued expansion of the distribution system, little has been done to the original 242-mile-long Colorado River Aqueduct since its Depression-era construction, other than anticipated routine and major maintenance and the ubiquitous information automation upgrades.<sup>163</sup>

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<sup>160</sup> Erwin Cooper, *Aqueduct Empire*, 99.

<sup>161</sup> *MWD Annual Report* June 1965, Table 3, p. xxxvi.

<sup>162</sup> The political story referenced here has to do with the machinations involved as cities and districts have attempted (or resisted) joining Metropolitan, and the *Arizona v. California* case that dragged on for years and eventually required Metropolitan to look to the State Water Project for an additional supply of water. Parts of these stories are outlined in Cooper, *Aqueduct Empire*, Robert Gottlieb, *A Life of Its Own*, and Hundley, *Water in the West*.

<sup>163</sup> Among the major projects that have been associated with Metropolitan since the 1940s is the Eastside Reservoir Project, under construction as of this writing. This reservoir is intended to provide an additional 800,000 acre-feet of storage capacity -- including water to supply the entire southern California region served by Metropolitan for six months in the event of an earthquake or other major disaster.

A walk through the pumping plants today is somewhat of a time warp -- nearly everything appears today as it did in the 1930s, or at least as it has since the plants were expanded in the 1950s. Unlike the completely automated systems running the aqueducts of the Central Arizona Project and the State Water Project, that of the Colorado River Aqueduct is still essentially a manually-operated system, and plant operators at each of the five pumping plants maintain a twenty-four hour vigil to keep the water flowing and the supply balanced.<sup>164</sup> Perhaps unintentionally, the few changes made to the aqueduct since its original construction have left it in an arrested state of preservation -- a testimony to the extraordinary engineering effort carried out in the desert during the 1930s.

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<sup>164</sup> This has begun to change in recent years. The Eagle Rock control center now tracks the flow of the water throughout the entire system by computer, and improvements are in store to upgrade the entire system to full automation.

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