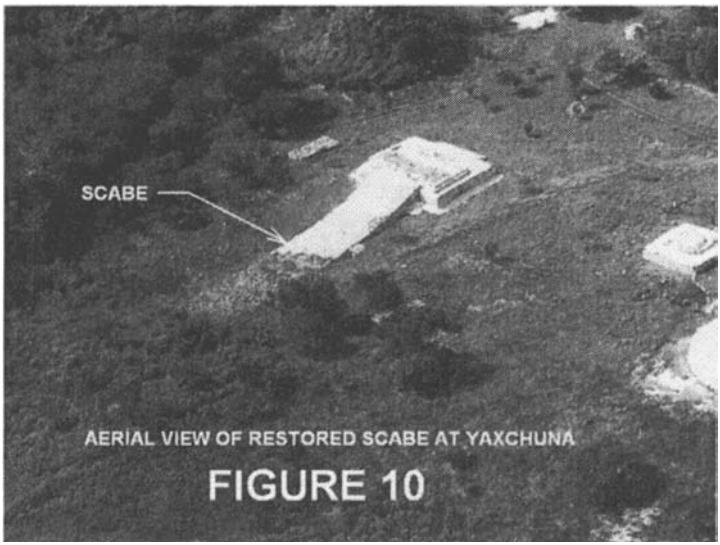
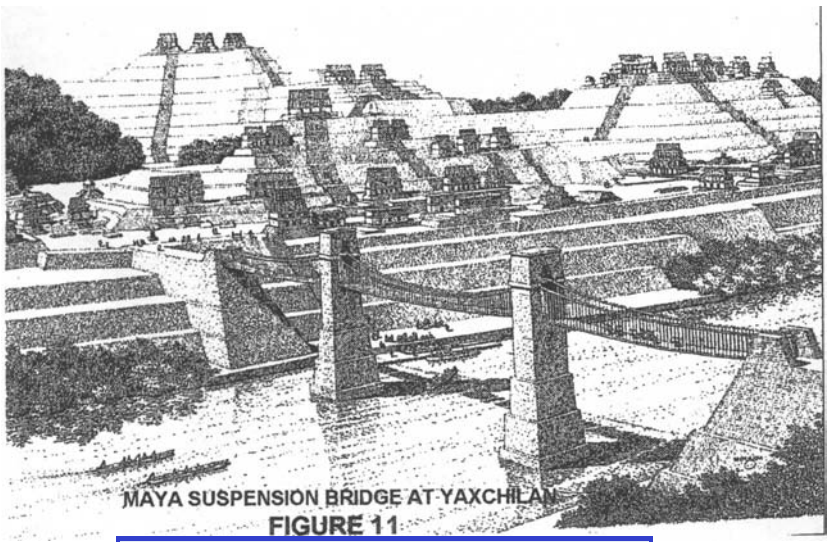


author (Figure 10).

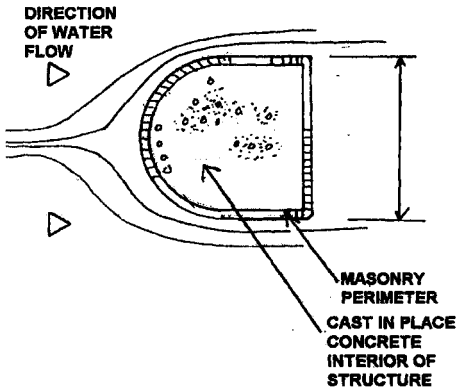
MAYA BRIDGE CONSTRUCTION

There are numerous short span bridges constructed by the Maya crossing streams. As previously discussed, surface watercourses are scarce and bridge construction was not widely employed. The exception to this was the long span bridge across the Usumacinta River at the city of Yaxchilan on the modern boundary between Mexico and Guatemala. This three-span long suspension bridge, with a 67-meter center span, was the longest bridge in the ancient world (Figure 11).



The city of Yaxchilan was located in a great ox bow in the river and was isolated by 15 meters of floodwater during the rainy season. The ingenious solution developed by the Maya engineers was to construct two tall stone and concrete towers in the river and construct a 106-meter long suspension bridge of hemp rope between the grand plaza of the city and the northern embankment. The bridge platforms were elevated above the 15-meter high floodwaters and provided an all weather access to the city. The high hills inside the oxbow of the river presented a natural fortress for the city and the ingenious bridge structure gave them the access to operate on a year around basis.

The Maya engineers constructed an efficient all weather lifeline that was a three span tension structure founded on masonry and cast-in-place concrete piers. The Maya engineers understood the importance of hydraulic shapes. The bridge piers are "D" shaped in plan with the curved face extending upriver into the oncoming water flow (Figure 12). The knowledge of scour was an important factor in this bridge design. The piers extended down to bedrock. Large flat stones were connected together to form the vase and the concrete structure was constructed upon the flat stone. These flat stones are in place today after over 1300 years of water flow.



PLAN: HYDRAULIC SHAPE OF BRIDGE PIER
FIGURE 12

REFERENCES

FITZSIMONS, N. (1995). "The Greatest Bridge Spans in the World from Earliest Times to the Present"

HARLOW, G. (1991). "Hard Rock," *Natural History Magazine*, August

MAUDSLEY, A. P. (1889). *Biologia Centrali-Americana,* Francis Robicsek

O'KON, J., et al. (1989). *Guidelines for Failure Investigation*, ASCE

O'KON, J. (1995). "Bridge to the Past," Civil Engineering Magazine, January

SCARBOROUGH, V. L. (1999). *Economic Aspects of Water Management in Prehistoric New World,* JAI Press

SCHELE, L., and MILLER, M. E. (1990).*The Blood of Kings*, George Braziller

SHARER, R. J. (1994). *The Ancient Maya*, Stanford University Press

STEPHENS, J. (1843). *Incidents of Travel in Yucatan*, Harper & Brothers

TATE, C. (1993). *Yaxchilan, the Design of a Mayan Ceremonial City*, University of Texas Press

The *Acequias* of San Antonio and the Beginnings of a Modern Water System

Dana Nichols

Abstract

In 1718 Spanish Missionaries established permanent settlements in San Antonio and immediately began constructing a system of irrigation ditches, or *acequias*, to divert water from the San Antonio River and San Pedro Creek to irrigate hundreds of acres of farmland. The *acequias* were so well built that the Acequia Madre, built between 1731 and 1745 still provides irrigation water for 400 acres of farms, establishing it as the oldest continuously working *acequia* in the country. This presentation will follow 300 years of water infrastructure in San Antonio and along the way touch on how important water is to a thriving community.

A City Born of Water

For the last century or so San Antonio, Texas, has relied upon the artesian wells of Edwards Aquifer for its water supply. The Edwards feeds the San Pedro and San Antonio springs which, until the middle of the 20th century, provided the base flow for San Pedro Creek and the San Antonio River.

In 1716 Spain and France were at war and the fighting carried over to the New World. The French controlled most of the gulf coast, including the mouth of the Mississippi River. Spain saw this as a threat to their holdings in New Spain and developed a three-pronged approach to securing their New Spain borders. The plan was unique in that rather than conquering and displacing the native population, the plan called for the natives to become the defenders of New Spain. Missions would be established to gather the natives to be converted to Christianity and missionaries would teach the principles of farming in preparation for establishing new colonies. Second, soldiers would establish a *presidio* (army post) near the mission to keep order. Finally, once native farmers had established settlements, Spanish colonists would come to these new settlements to begin new lives. In 1716 a Spanish *entrada* (expedition) was sent to east Texas to secure the French border and six missions and

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a *presidio* were established. The plan was working, but leaders shortly realized that they needed to establish a settlement half way between the border and the capital of New Spain, Mexico City.

Previously identified by Spanish missionaries as a desirable location for a settlement. Father Olivares and Don Martin de Alacon established Mission San Antonio de Valero (The Alamo) between the San Antonio River and San Pedro Creek in 1718. By 1731 there were six missions and a *presidio* in what today is the City of San Antonio. Early Spanish settlers knew that the successes of settlements were dependent on the success of farming and that in this semi-arid region this meant irrigated fields.

Acequias

The Spanish were well versed in the construction and use of large-scale irrigation systems, and these irrigation systems, or *acequias*, had been widely used in Spain since the Moorish conquest.

The primary water distribution system in the area was the *acequias*, or community water ditches. This extensive network of irrigation canals began with the first ditch, Pajalache or Concepcíon Ditch, which became operational about 1720 and remained in operation until 1869 when it was abandoned. The San Francisco de la Espada Mission *acequia* was built between 1731 and 1745 and remains in working order today. The *acequias* were supplemented by shallow wells and provided water for both irrigation and consumption.

In addition to the irrigation canals built by the missions, several public *acequias* and ancillary ditches were built in the San Antonio area to serve the *presidio* and the lands of the Canary Islanders at the Villa de San Fernando. Located in present-day downtown San Antonio, today this area is known as La Villita. The construction and maintenance of the *acequias* required considerable amounts of labor, and some of the larger canals took more than two decades to finish. Because of the relatively high cost of the *acequias*, the amount of irrigated land was limited, and competition for such land was strong. Much of the better land went to the Canary Islanders, who constituted the local political and socioeconomic elite.

Water rights were strictly controlled and were sometimes sold or bought separately from the land. Landowners were expected to help dig new irrigation ditches and to defray the expense of upkeep. Those who failed to comply with regulations to keep the canals in working order were subject to fines.

After the missions were secularized in the early 1790s, the city authorities undertook to oversee the distribution of water. City control was discontinued in the later half of the nineteenth century, and the remaining *acequias* were operated for a time as informal community enterprises or, in the case of the San Juan *acequia*, by an incorporated mutual company.

These ditches also began to serve as a *de facto* sewer system. Early San Antonians merely deposited their garbage and other wastes into the ditches where they were carried downstream.
In 1836, the San Pedro Ditch was reserved for drinking and cooking water only; penalties were established for using it for bathing or as a sewer. Although crude, this water and wastewater operation served the City's needs until 1866 when a severe cholera epidemic prompted real efforts to establish a satisfactory water supply system.

Surface Water to Ground Water - Brackenridge System
Many water development proposals were discussed and subsequently discarded over the years until the City finally entered into a water supply contract with J.B. La Coste and Associates on April 3, 1877. La Coste constructed a pump house near the headwaters of the San Antonio River in what is now Brackenridge Park. Water pressure operated a pump that lifted water to a reservoir near the old Austin highway on the present site of the Botanical Garden. This site was high enough for the water to flow by gravity into the distribution system.
In 1883 a new company, led by George W. Brackenridge, acquired the water system. Recognizing that the source of the springs was possibly a subterranean reservoir under high pressure, Brackenridge proposed that his firm purchase property along the river and drill a well. In 1889, the first artesian well was bored in what later became Brackenridge Park. Two years later an eight-inch discovery well was drilled to a depth of 890 feet at Market Street and the San Antonio River. By 1900, all of the system's water was obtained from artesian wells linked directly to the distribution system.

In 1905, George Brackenridge sold his interests in the water company to George Kobusch of St. Louis. At that time the name was changed to the San Antonio Water Supply Company. Shortly thereafter, Mr. Kobusch sold the business to a Belgian syndicate. While it was under foreign ownership, the water company was known as "Compagnie des Eaux de San Antonio" and was managed by the Mississippi Valley Trust Company of St. Louis, Missouri.

The City Takes Ownership
Partly to recover some of their financial losses from World War I, the Belgians sold the waterworks to a group of local investors in 1920. Contract and rate disagreements marred the relationship between the City and the new water entity. In 1924, the company demanded a rate increase, and since an agreement could not be reached, the new rates were put into effect and the City was enjoined from interfering. This situation prompted the City to issue seven million dollars in revenue bonds and purchase the system outright. On June 1, 1925, the utility became known as the City Water Board and its management was placed under the Board of Trustees appointed by the San Antonio City Council. At the time of the purchase pumping was an average of 25 million gallons a day serving 38,000 people.

During the Depression and the war years the City Water Board was able to keep pace with increasing demand without much difficulty. However, the post-war building boom and the impact of the 1950s drought significantly taxed the Board's capabilities. In the mid1950s the water operation utilized many widely scattered secondary pumping stations which were designed to serve immediately adjacent neighborhoods. These stations essentially operated independently and did not provide adequate system redundancy.

Water Planning – 1954-1991

A master plan for improvements was approved in 1954. During the 1960s, 1970s, and 1980s both the water and wastewater systems continued to expand as customer demand increased. In 1965, the City built a new wastewater treatment plant, and throughout much of this period the City Water Board was involved in negotiations or court actions involving attempts to secure a supplemental water supply. In 1979, a committee established by the City Planning Commission reported to the City Council that San Antonio should pursue the necessary federal and state permits to construct San Antonio's first surface water supply project known as the Applewhite Reservoir. Shortly thereafter, the Council passed a resolution directing the City Water Board to initiate the permitting process. The City Water Board received the necessary permits from the Texas Water Commission in 1982, and the U.S. Army Corps of Engineers in 1989. Construction on the Lake began a few months later.

On May 4, 1991, the citizens of San Antonio, by a narrow margin, voted to discontinue the Applewhite Project. In the following months the Board of Trustees of the City Water Board voted to sue the City over the legality of the election. Court action subsequently upheld the City's position and Applewhite construction was halted.

While water issues garnered the most attention, wastewater continued to be a demanding subject. During the 1970s and 1980s the City continued to upgrade its waste water facilities. The oldest treatment facility which had utilized Mitchell Lake for sludge disposal was closed and the lake, a long known favorite bird watching location, also known for its distinctive odor to a generation of San Antonians, was no longer used for treatment. Mitchell Lake was declared by the City Council as a bird refuge in 1987. Today it is owned by the San Antonio Water System and is on long-term lease to the National Audubon Society. It is presently known as the Mitchell Lake Audubon Center.

In 1989 the City of San Antonio asked the State Legislature to create a district devoted to reuse of the municipality's effluent. The bill was signed by the Governor on June 16, 1989. In 1991, the District applied for a permit to divert water from the Leon Creek Wastewater Treatment Plant for reuse purposes. The City Water Board opposed that action due to its possible impact on the Applewhite permit.

San Antonio Water System (SAWS)

The controversy brought on by competing water agencies as well as the Applewhite challenge prompted the City Council to vote in December 1991 to dissolve the 66-year-old water utility and establish a single utility responsible for water, wastewater, stormwater, and reuse. The refinancing of $635 million in water and wastewater bonds made the merger possible. A new entity, The San Antonio Water System (SAWS) became a reality on May 19, 1992.

Sources:

Handbook of Texas Online, s.v. "," http://www.tsha.utexas.edu/handbook/online/articles/AA/ruasg.html (accessed January 9, 2007).

H_2O University – Tools for Educators; San Antonio Water System Education Department; http://www.saws.org/education/h2o_university

THE MACHINE OF MARLY
WATER SUPPLY FOR VERSAILLES

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Abstract

The city of Versailles sits 130 to 140 meters above sea-level, surrounded by wooded hills. In 1661, Louis XIV decided to construct his palace in Versailles. The main problem that was facing the engineers was to supply water to the king's palace and its gardens and fountains. The king wanted the water to be furnished continuously. Due to the palace location, supplying water to the site was like a dream and even the several links between the nearby ponds and reservoirs were becoming inefficient. Two brilliant engineers "Arnold de Ville" and "Rennequin Sualem" started the construction of the "Machine de Marly" that was considered the biggest hydraulic system ever built. This machine was able to deliver water from the Seine River at an elevation of 162 meters and pumped nearly five thousand cubic meters of water a day. This gigantic machine solved the problem for several years until the 19th century when it was destroyed because of inefficiency.

Historical background

In 1661, Louis XIV acceded to the throne of France and got as a heritage from his father the late King Louis XIII, the Versailles Domain, which consisted only of a big swampy forest with a very modest mansion constructed with bricks and stones and used as a "hunting relay" for post horses.

Instead of living at the Louvre Palace in Paris as his father did before, King Louis XIV decided to settle down in Versailles, far from the rebellious population of the capital. For the splendor of his region, he started building a gigantic palace "The Chateau de Versailles" aiming to be considered as the Symbol of his Kingdom. The design of the Chateau included several interesting features among them very large irrigated landscape gardens.

Besides the importance of the architecture, the key feature of the Palace was the hydraulic planning which includes very large irrigated landscape gardens supplied by basins with water delivered through fourteen hundred fountains containing 1400 water jets linked together by a 30 km pipe network. This hydraulic system constituted a nightmare for the chief architect of the kingdom since the Versailles neighborhood was very scarce with water resources and the water consumption for the landscaping would be above 7000 m^3 per hour. The main difficulty facing the engineers was how

were they going to supply water for the gigantic construction and the fourteen hundred fountains? (One solution is in Figure 1.)

Figure 1 Overview of the Proposed Machine of Marly (Source: Pendery 2000)

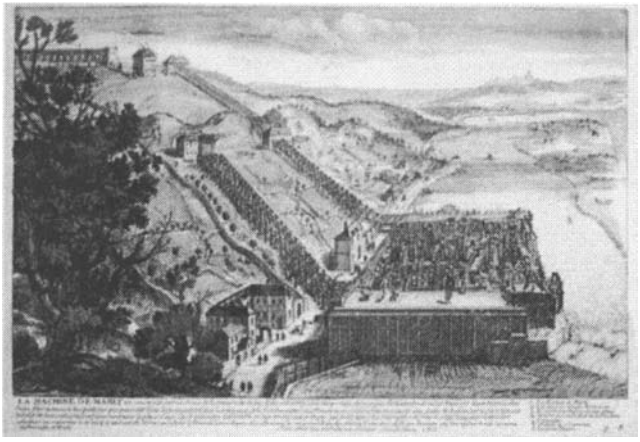

Figure 2 Map Showing the Versailles Hydraulic Projects (Sources: Monnier 2003)