

# THE TANGENTIAL IMPULSE WATER WHEEL IN CALIFORNIA GOLD MINING

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**Abstract:** The high pressure tangential impulse water wheel was born and developed in the unique California gold mining environment of the late 19th Century. Hurdy gurdies, the early simple hand-crafted wheels with flat or curved blades driven by jets of high pressure water, were the first efforts to drive mining machinery without using steam or classic overshot water wheels. Samuel Knight designed and manufactured a cast-iron water wheel with superior efficiency to the hurdy gurdy in 1875. This was followed by Lester Pelton's patent of 1880 which captured a most innovative concept: that the stream of water striking the wheel must be stopped by reversing its direction relative to the moving cup. Many competing wheels were developed including those of Donnelly, Risdon, Joshua Hendy, Dodd, Tutthill, Doble, Hug and others. The Pelton remained the dominant wheel in Northern California and this engineering breakthrough was exported worldwide. This paper, instead of discussing the impact of water power on California mining, could better be described as discussing the impact of California mining on the engineering of water power.

## Introduction

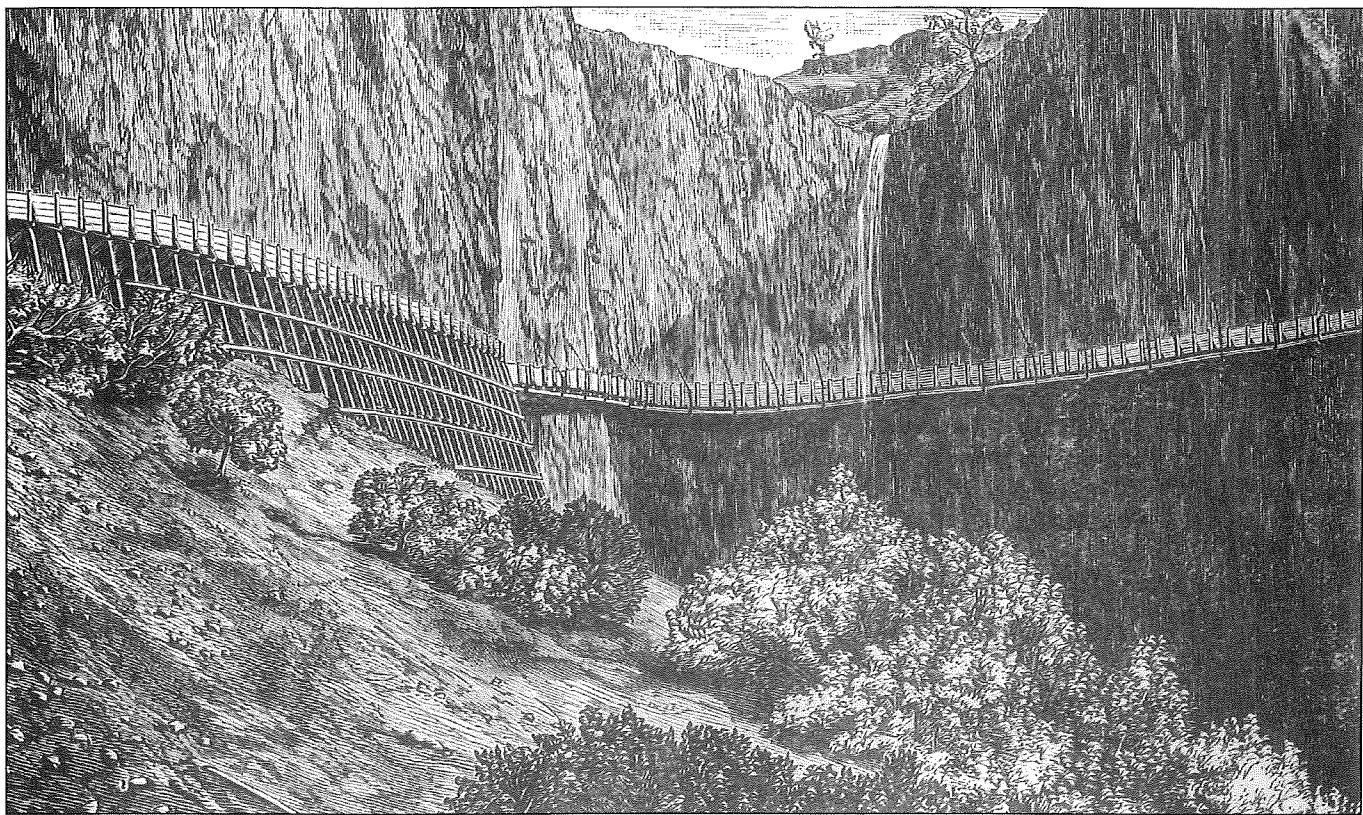
The 1848 discovery of gold in the Sierra Nevada Mountains of California and the subsequent development of a thriving hard rock gold mining industry gave birth to a revolution of high-head water power engineering and the development of the tangential impulse water wheel. These wheels were called tangential because the centerline of the water jet was a tangent to the circle of the wheel. They were impulse type because the power conveyed to the wheel was through the transfer of the kinetic energy of high velocity water striking the wheel.

The first hoards of gold seeking migrants to California depleted streams and river-beds of placer gold. Industrial America began to exploit the avenues of hydraulic mining for placer gold trapped in ancient riverbed gravels and hard rock mining for lode gold. Hydraulic mining was particularly fruitful in regions of Northern California where remnants of the ancient Yuba River gravels were deposited. The hydraulic mining method required abundant water volume delivered by nozzle under high pressure. This, in turn, fostered flume and ditch construction with the creation of high elevation reservoirs with high pressure water for sale by the miner's inch which is a flow rate of approximately 1.5 cubic feet per minute with no exact universal method for its measurement. This was a California unit of measurement and varied significantly between flume and ditch companies in their sale of water to customers. The construction of flumes and ditches was an engineering challenge in mountainous terrain where water from high elevation dam-created reservoirs would be transported distances up to 50 miles for delivery to the industrial site of use. When open water flow was maintained, a constant slope was mandated, such as a 12-foot drop per mile. Where a canyon needed crossing, the flume would be carried by trestle or would be converted to a closed, rivetted, wrought-iron pipe called an "inverted siphon". A flume and ditch system might be rated at several thousand miner's inches. Hydraulic mining was suddenly stopped by court order in the 1880s because of serious mud contamination of lower elevation streams and rivers in agricultural California. Selective sites for hydraulic activity were permitted for the next 30 years where construction of settling ponds would prevent river transfer of mud and debris. The major search for gold was now limited to hard rock mining for lode gold and, to a lesser degree, dredging for placer gold in lower-elevation river beds.

Most of the gold mines described in this paper were located between the elevations of 1000 and 4000 feet. The Sierra Mountains to their east rose to over 10,000 feet in many areas. With a melting snow pack providing summer water, reservoirs above the mines frequently made available water heads of over 500 feet. This slender row of gold mines along the western slope of the Sierra, extending over a distance of over 150 miles, defined what was known as the mother lode. Each mine, for the most part, represented a hard rock mining extension into the earth, below the outcroppings of gold-bearing quartz. Later, similar developments occurred in other parts of the state, other western states, Alaska and Mexico.

A narrow window of time incorporated the enormous water power revolution that California mining provided. The period between 1865 and 1895 witnessed major changes in the power requirements and the engineering solutions of the mining industry. It is interesting to note that Joseph Glynn, F.R.S., in his third edition of *Power Of Water* (1869), though describing essentially every type of water wheel on the Earth, failed to mention the high head tangential impulse water wheel at work in the mines of California. These early hurdy-gurdy wheels, though working under hundreds of feet of head of water and driving major machinery, lacked the efficiency of the later manufactured Peltons, Knights and Risdons. At the elevation of these mines, the hills were lightly forested. Wood from these forests, used for building construction, mine timbering and for earlier steam engine fuel, became depleted. Other wood was costly to import. Power to run mine hoists, machine shops, water drainage, air compression, stamp mills and ore processing was greatly needed. The Empire mine in Grass Valley stopped using steam engines in 1886 and converted entirely to Pelton wheels to drive its stamp mill, air compressors, water pumping, hoists and machine shop. The Empire had required 20 cords of wood daily to fire its steam engines. This water power period at the Empire lasted only five years and was replaced in the early 1890s with electric motors and the power to run them. Most mines in California had converted to electric power by 1900.

Many mines with low water head availability used overshot water wheels or Leffel turbines. Mines with higher water heads, 50 to 500 feet, used self-styled hurdy-gurdys and later, manufactured tangential impulse water wheels. A common design for an early wheel might be a round central wood frame

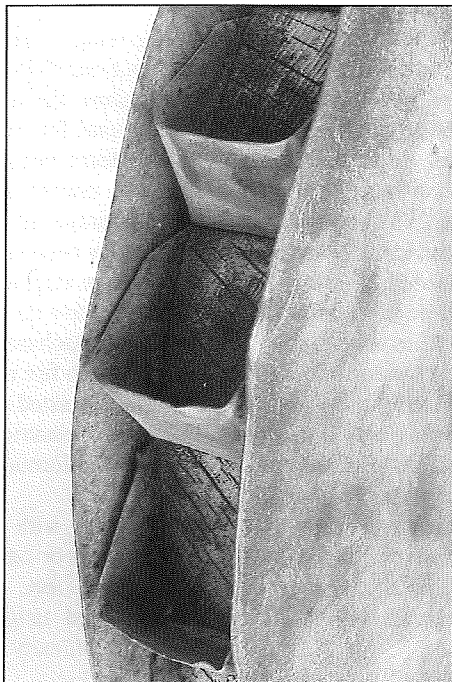
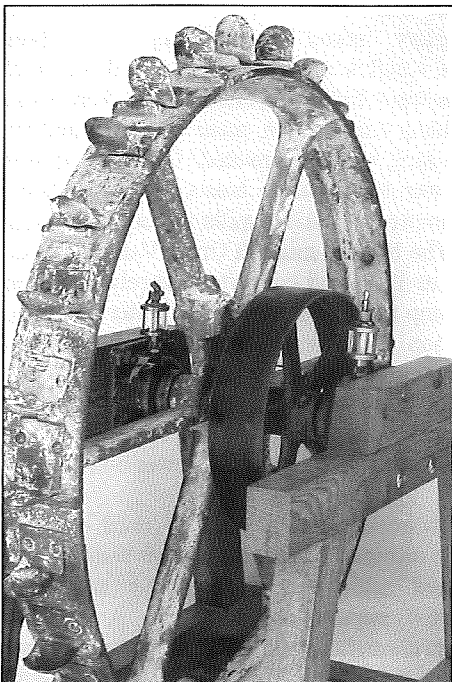


*Fig. 1. Bracket Flume, Butte County, California. 1888.*

on a steel axle with flat iron or steel paddles projecting radially at the periphery. The hurdy-gurdy paddles were later shaped like cups. Wagon wheels on occasion converted to hurdy-gurdys by local blacksmiths.

The first known manufactured product, an eight foot tangential wheel created at the Miner's Foundry in San Francisco, was known to drive a ten-stamp mill of 700 pound stamps with a head of only 80 feet in 1866. Wheels were divided into three basic categories, gravity, reaction and impulse types. The primary gravity wheel was the overshot, varying in size from 10 to 50 feet in diameter. Together with the turbine, it would be

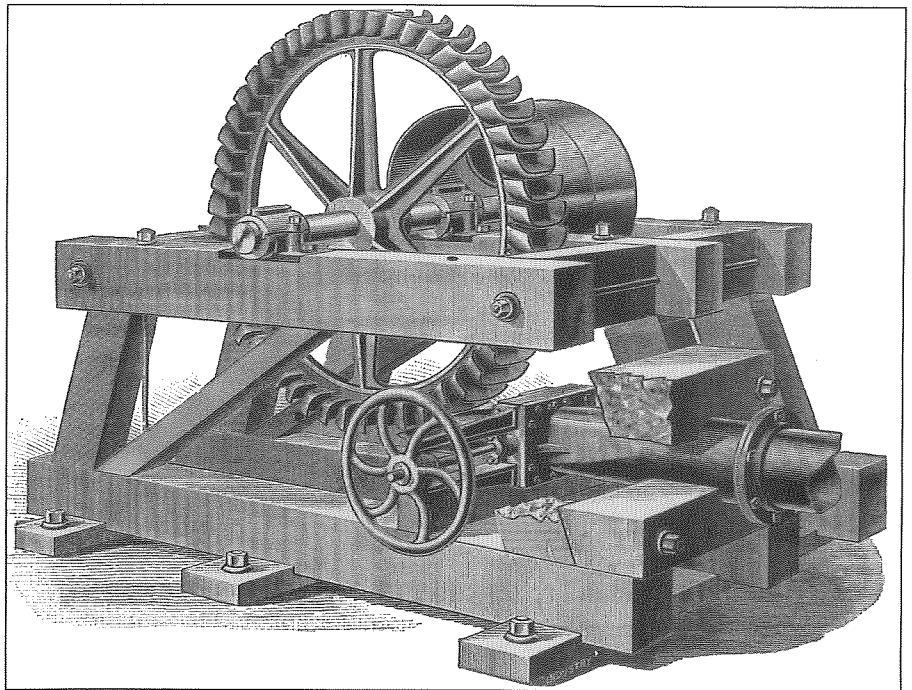
used with nearby river water, lifted by flume construction, in regions where elevated reservoir water was not available. The turbines were reaction wheels, best with high flow and low pressure. The tangentials were the impulse wheels, popular where high pressure water was available. It was the engineering development of these wheels from home crafted hurdy-gurdys to the definitive Peltons, Knights, Risdons, Donnellys, Joshua Hendys, Dodds, Tutthills and Hugs that make up the story of this engineering saga. It would be fair to rename this paper, "California Gold Mining History and the Creation of the Tangential Impulse Water Wheel". It was this unique engineering problem and the availability of high head water at the California mining scene which was responsible for the creation of this next generation of water wheels.



Samuel Knight of the Knight Foundry in Sutter Creek, California, improved the low efficiency of the hurdy-gurdy by developing a deep cup, which drained easily. The cups were mounted closely together on the wheel and the water jet was shaped in a rectangular configuration, striking more than one cup at a time. The Knight wheel was patented in 1875 and was used widely in the mines of the four southern counties of this region. In 1873, two years before this, Nicholas Colman obtained a patent on his tangential wheel with a splitter partition similar to

*Fig. 2 (far left). Hurdy-gurdy from tractor wheel. (Photo: Robert Cross.*

*Fig. 3 (left). Hurdy-gurdy - sheet metal and wood*



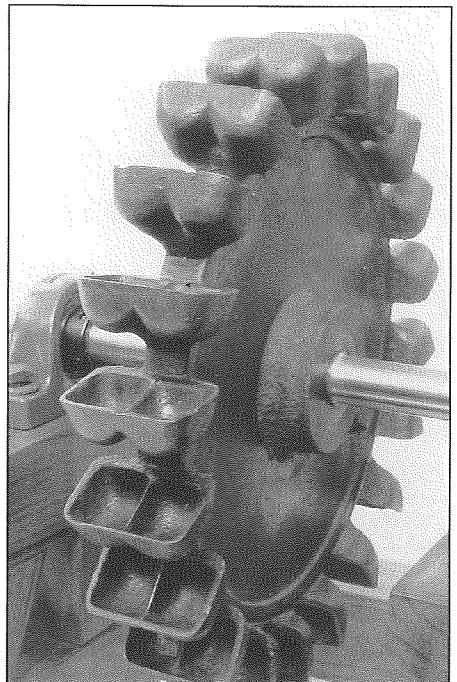
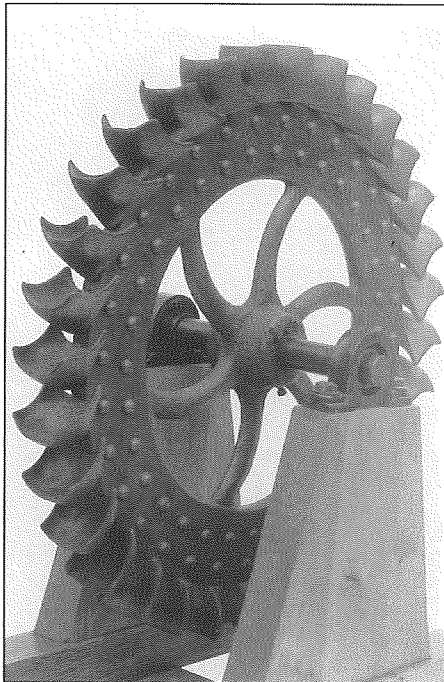
*Fig. 4. Hurdy-gurdy, based on a rope pulley. Fig. 5. Patented Knight water wheel, 1875.*

the later Pelton Wheel of 1880. The Colman patent apparently used a centre row of cups with a splitting partition and side cups to reverse the water jet. For reasons not fully understood, this wheel was never manufactured and the patent not recognized when the Pelton patent was granted in 1880. The Donnelly wheel, manufactured at the Sutter Creek Foundry, California, in 1882, had many of the same physical features of the Knight wheel with cups designed for better water escape on all sides and a "ship prow" shape of the underside of each cup to reduce splash drag. It was also popular in the southern counties of the mother lode. Unlike the Knight, the cups were always bolted on and therefore replaceable. The Knights were usually cast in one piece.

Lester Pelton, a fisherman and miner from 1850 to 1864 and a millwright and miner after this date, worked in Camptonville, California, a hydraulic and hard rock mining site in the northern portion of the mother lode. He experimented with hurdy-gurdys and with the Knight wheel. According to Durand of Stanford University (Durand 1939), while driving a rock-crushing stamp mill with a Knight water wheel, he encountered an accidental slippage of the key anchoring the wheel to its axle. The wheel, while turning, moved laterally along its shaft with a subsequent speeding of the stamp mill. He realized immediately that he had improved the dynamics of the wheel water flow. He realized also that he had, with the water striking the cup off-centre, created an undesirable lateral thrust. He worked with the design of a single cup with side-to-side flow, dual cups alternating left and right flow but settled on a single cup with a centre splitter partition. Most

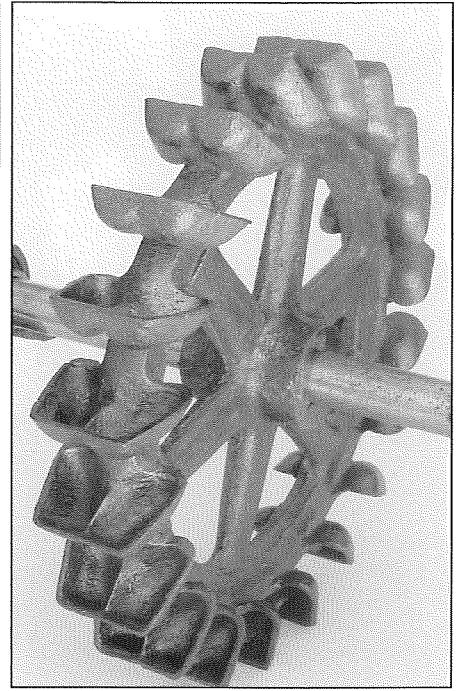
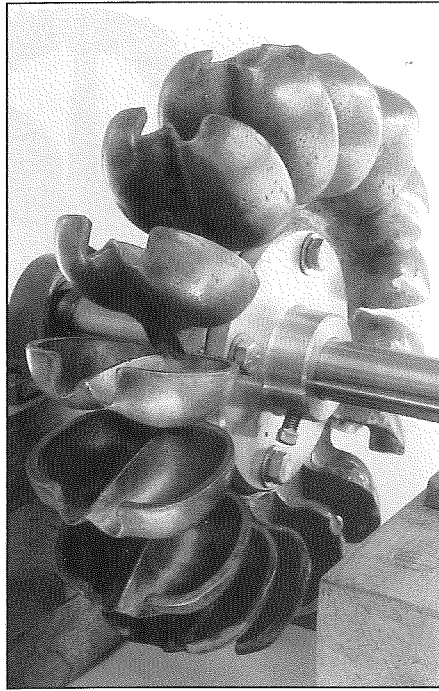
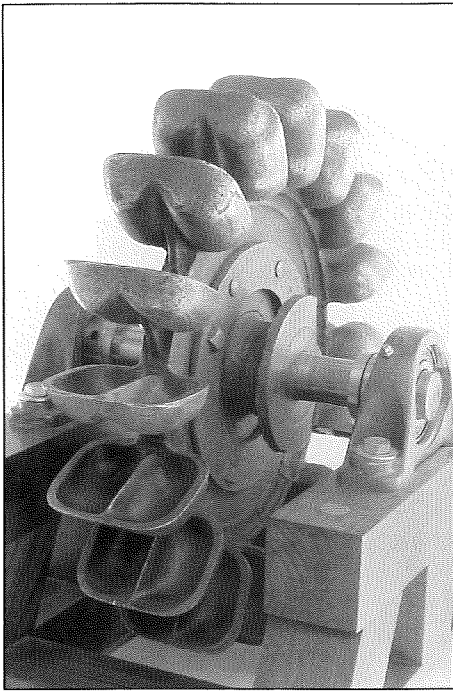
authors agree that he was totally unaware of the Colman patent. He patented his design in 1880 and immediately began producing wheels in Nevada City, California, at what became known as the Miners' Foundry. In 1883, a competition was held at the Idaho mine, Grass Valley, California. Four water wheels were tested against each other using a common water source of 368 feet head and Prony brake work loads. The Pelton won the competition clearly over the other wheels involved, Knight, Fredenburr and Taylor. The Pelton water wheel became dominant over its competitors and its production rose dramatically, finally outstripping the small Nevada City foundry's capacity.

Pelton collaborated with a Mr. A. P. Brayton, general manager of the Rankin, Brayton and Co. of San Francisco and the manufacturing was moved from Nevada City to the newly created Pelton Water Wheel Company of San Francisco in 1888.



*Fig. 6 (centre). Donnelly water wheel, 1882. Fig. 7. Classic 1880 Pelton water wheel.*





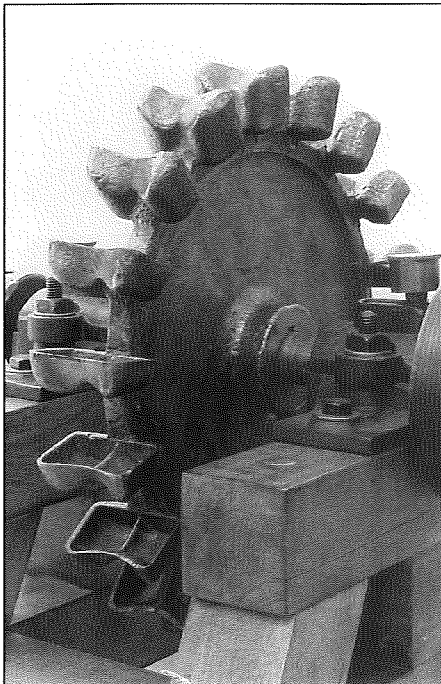
*Fig. 8. Early Pelton-Doble water wheel, 1898. Fig. 9. Classic Pelton-Doble water wheel, 1903. Fig. 10. Risdon water wheel 1895.*

The new facility was destroyed in the earthquake and fire of 1906 and moved the same year to a larger facility in San Francisco. The plant was closed in 1963.

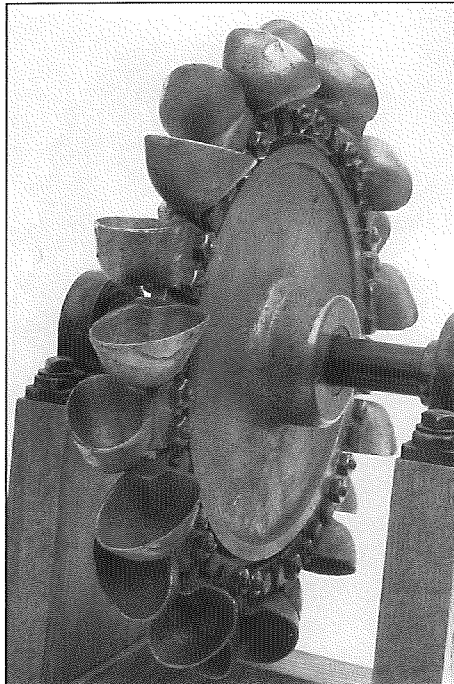
The significant breakthrough of Pelton's design was the division of the cup into two chambers divided by a wedge or splitter partition. The high pressure jet of water, sometimes exceeding 200 miles per hour, was aimed at the splitter partition. The high pressure jet of water, sometimes dividing the incoming stream into two portions, directing them laterally, and by the shape of the cup attempting to reverse their directions. This achieved two goals: (1) the clearing of the cup to prevent splash build up and (2) the reversal of the incoming stream imparting more energy to the wheel from the water jet. Since the cup, under load, is travelling at approximately one half the velocity of the

incoming jet, complete reversal of the water stream could result in water entering the tail race with zero velocity, depleted of kinetic energy. As one manufacturer described it: The ideal design allows the jet to strike the cup without turbulence and leave without velocity. In the flat paddle hurdy-gurdy, the water jet only partially conveys its kinetic energy to the cup. The water jet, after the collision, is still moving in the same direction at the speed of the paddle, approximately one half the velocity of the initial jet. The moving paddle cannot absorb all of the kinetic energy because the water maintains some of its nozzle velocity. Even before Pelton relocated in San Francisco in 1888, many other competitive foundries and machine shops chose to enter the water wheel market. These firms were already busy with the mining trade, producing hoists, stamp mills, ore carts, Cornish pumps, crushers, grinders, compressors and drills. It is

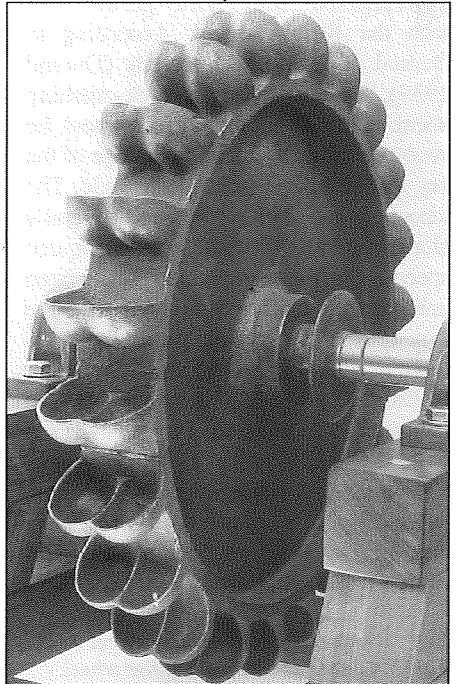
*Fig. 11. Dodd water wheel, 1891.*





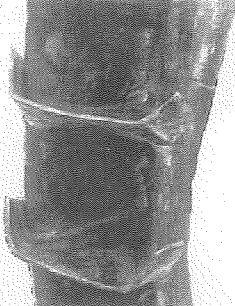

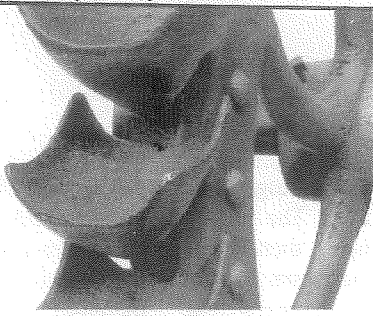
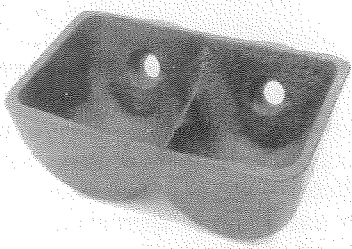
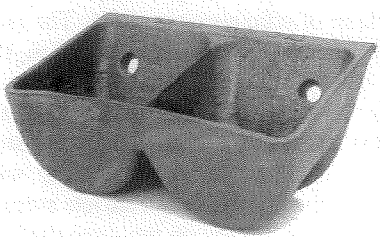
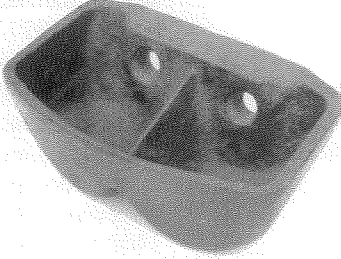
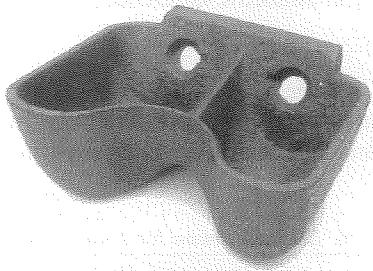
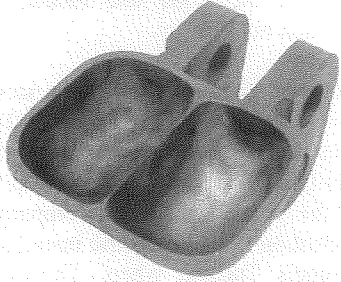
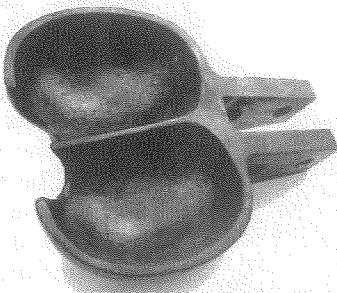
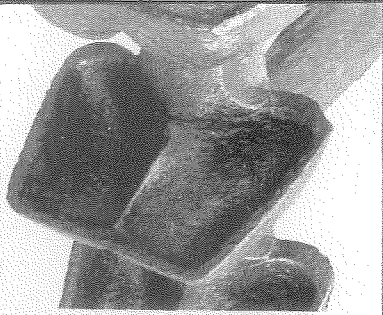
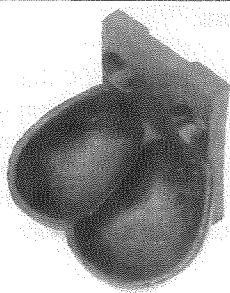
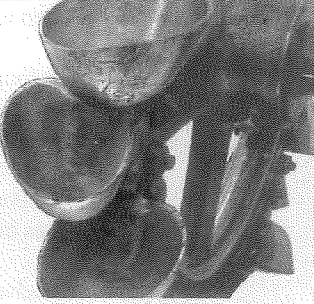
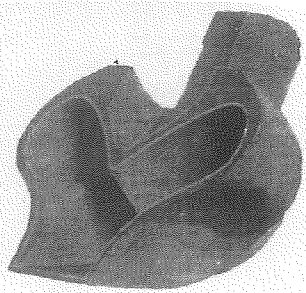
*Fig. 12. Tutthill water wheel, 1895.*



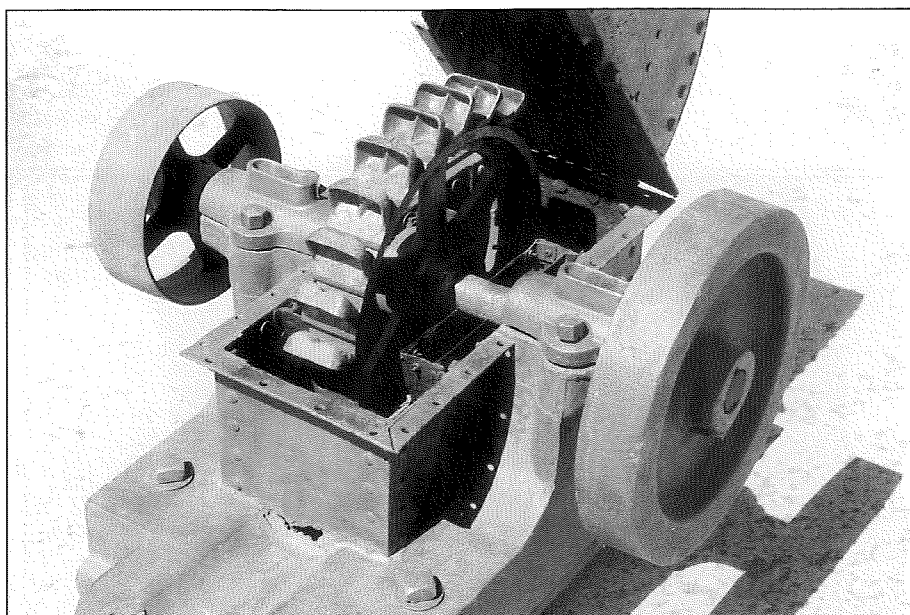
*Fig. 13. Joshua Hendy water wheel.*





 <p><b>Hurdy-Gurdy #1 ca 1865</b></p>	 <p><b>Hurdy-Gurdy #2 1870</b></p>	 <p><b>Hurdy-Gurdy #3 ca 1870</b></p>
 <p><b>Knight 1875</b></p>	 <p><b>Donnelly 1882</b></p>	 <p><b>Classic Pelton 1880</b></p>
 <p><b>Pelton Modification #1 1890</b></p>	 <p><b>Pelton Modification #2</b></p>	 <p><b>Pelton Modification #3 and Dodd Sigmoidal 1891</b></p>
 <p><b>Pelton Doble #1 1898</b></p>	 <p><b>Pelton Doble #2 (Ellipsoidal) 1903</b></p>	 <p><b>Risdon 1895</b></p>
 <p><b>Joshua Hendy</b></p>	 <p><b>Tutthill 1895</b></p>	 <p><b>Hug 1897</b></p>

*Fig. 14 Evolution of tangential impulse turbine cup designs.*

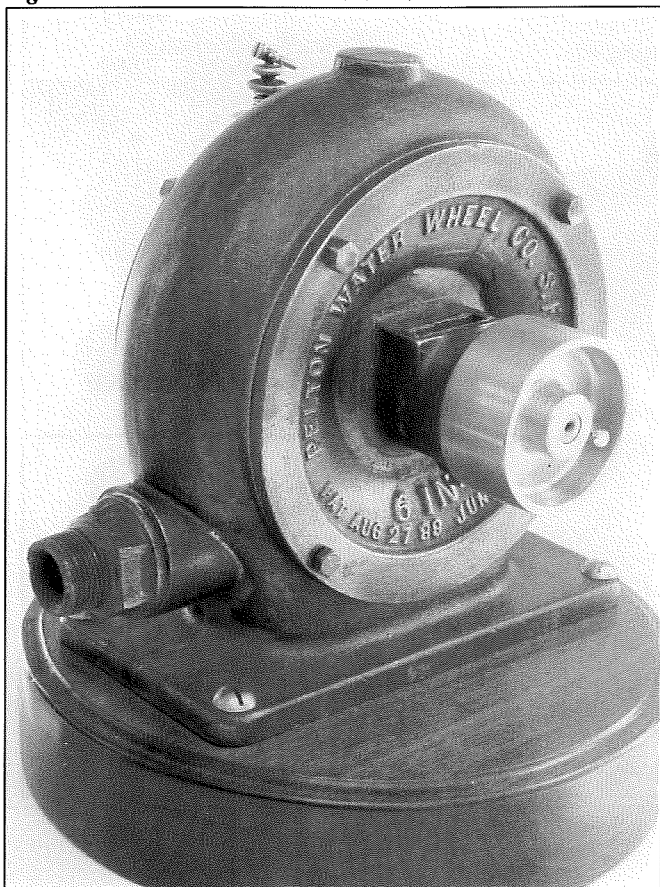


*Fig. 15. Shrouded classic Pelton water wheel.*

not well established but it is assumed that patent infringements and cooperative business ventures both occurred. The Risdon Iron Works of San Francisco made Knight wheels, then Pelton wheels and finally, in approximately 1895, their own Risdon wheel with design modifications from the Pelton patent. The Joshua Hendy Foundry made water wheels similar to the Pelton yet with distinctive differences.

All of these cups included the splitter partition. Pelton worked competitively and cooperatively with the Abner Doble Hydraulic Engineering Company who made beneficial changes

*Fig. 16. Six inch Pelton No.1 water motor.*



to the Pelton line. The Doble Company after a few years improved the efficiency of the cup, first, with rounded corners of the rectangular cup and in approximately 1903, with a new "ellipsoidal" design. Doble is also credited with better control of the water flow through a highly effective needle nozzle and better governor control of the runner velocity. In 1912, the two companies merged as the Pelton Water Wheel Company with William A. Doble, son of Abner, as chief engineer. The Pacific Iron Works of San Francisco produced the Dodd water wheel with patents in 1888, 1890 and 1891. The latter two patents included deep indentations of the peripheral wall and were designated Dodd "Sigmoidal" cups. The Pelton Company also made cups similar to these during this period with a deep indentation of the peripheral wall. The late-on-the-scene Tutthill,

patented in 1895 by the Oakland Iron Works, used alternating left and right cups and claimed higher efficiency than the Pelton, an efficiency of 85%. They attributed their success to the energy lost by the splitter partition of most of their competitors, including of course, Pelton. The still later Hug Water Wheel Company of Denver, Colorado, with a radically different cup shape, maintaining a different type of splitter, patented their wheel in 1897. Their claim of efficiency was 86%. The largest wheels installed included an 18 feet diameter wheel in 1895, which was displaced almost immediately by a thirty feet diameter wheel at the North Star Mine in Grass Valley, California. Later, in 1900, a thirty three feet wheel was installed at the Morning Mine in Mullan, Idaho. This latter wheel, revolving at 80 RPM, was driven by two separate jets averaging 1400 feet head. Two eleven feet Peltons on the same shaft were driven by water at 140 feet head. The 18 feet and 33 feet wheels were built by the Pelton Water Wheel Company of San Francisco and the 30 feet by the Cobb and Hesselmeyer Company, equipped with Risdon buckets.

By 1890, 280 Pelton wheels had been installed in the western United States; Knight in the same year, claimed 300. By 1898, 900 Peltons were listed in the United States and by 1909, 10,000. The Knights, Tutthills and Risdots never kept up with the Pelton output through the years. The Pelton company, in later years, directed its production to hydroelectric installations with emphasis on the Francis Turbine wheel. During the pre-electric gold mining period, the Knight and Donnelly were slightly more popular in the southern mother lode area and the Pelton more popular in the northern.

A colourful snapshot of the mining industry of California in the year 1888 is provided by the California State Mineralogist in his Eighth Annual Report to the Governor. The following are examples taken from the mineralogist's report. These have been selectively chosen as examples of water power utilization in the mines of the four southern counties of the mother lode.

#### **Amador County**

(1) Empire Mill, Plymouth, one five feet Donnelly wheel with 561 feet head and 75 miner's inches flow drove an 80 stamp mill, 750 pounds per stamp.

(2) Loyal Lead Mine, Drytown, one eight feet Knight with 260 feet head and 26 miner's inches drove a 10 stamp mill, 700 pounds per stamp.

(3) Kennedy Mine, Jackson, two six feet Knights drove the south hoisting works; two five feet Peltons drove the north hoisting works; one five feet Pelton drove a 40 stamp mill, 850 pounds each; two twelve inch Donnellys drove blowers and grinding wheels; two three feet Peltons drove 16 Frue concentrators, average head, 190 feet, total flow rate, 245 miner's inches.

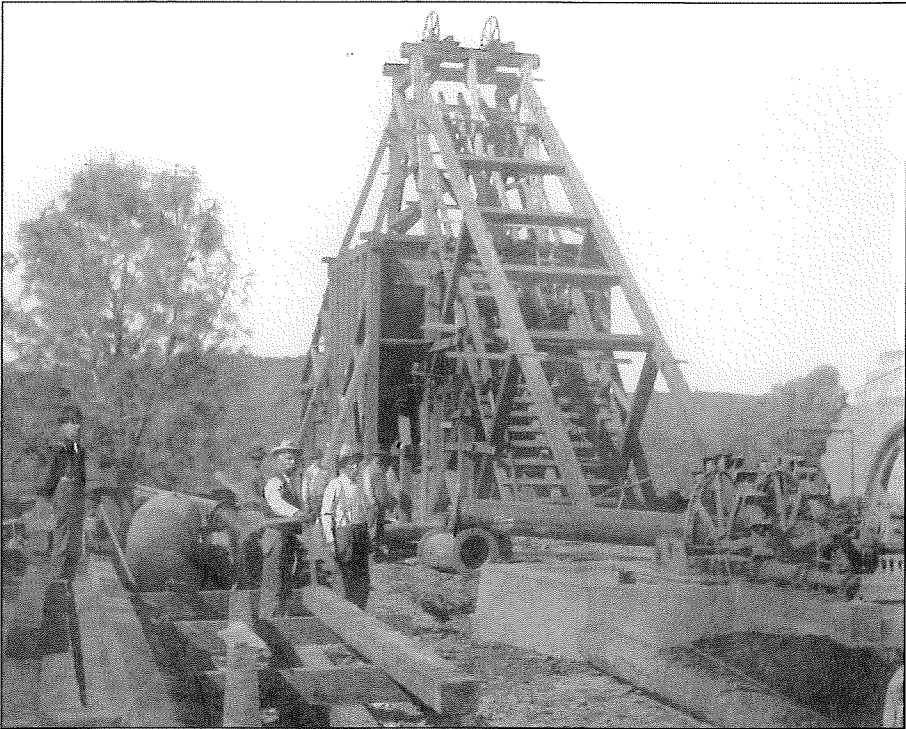
(4) Mammoth Mine, Jackson, one six feet Knight at 750 feet head, 70 miner's inches, drove a 10 stamp mill, 750 pounds each

**Calaveras County**

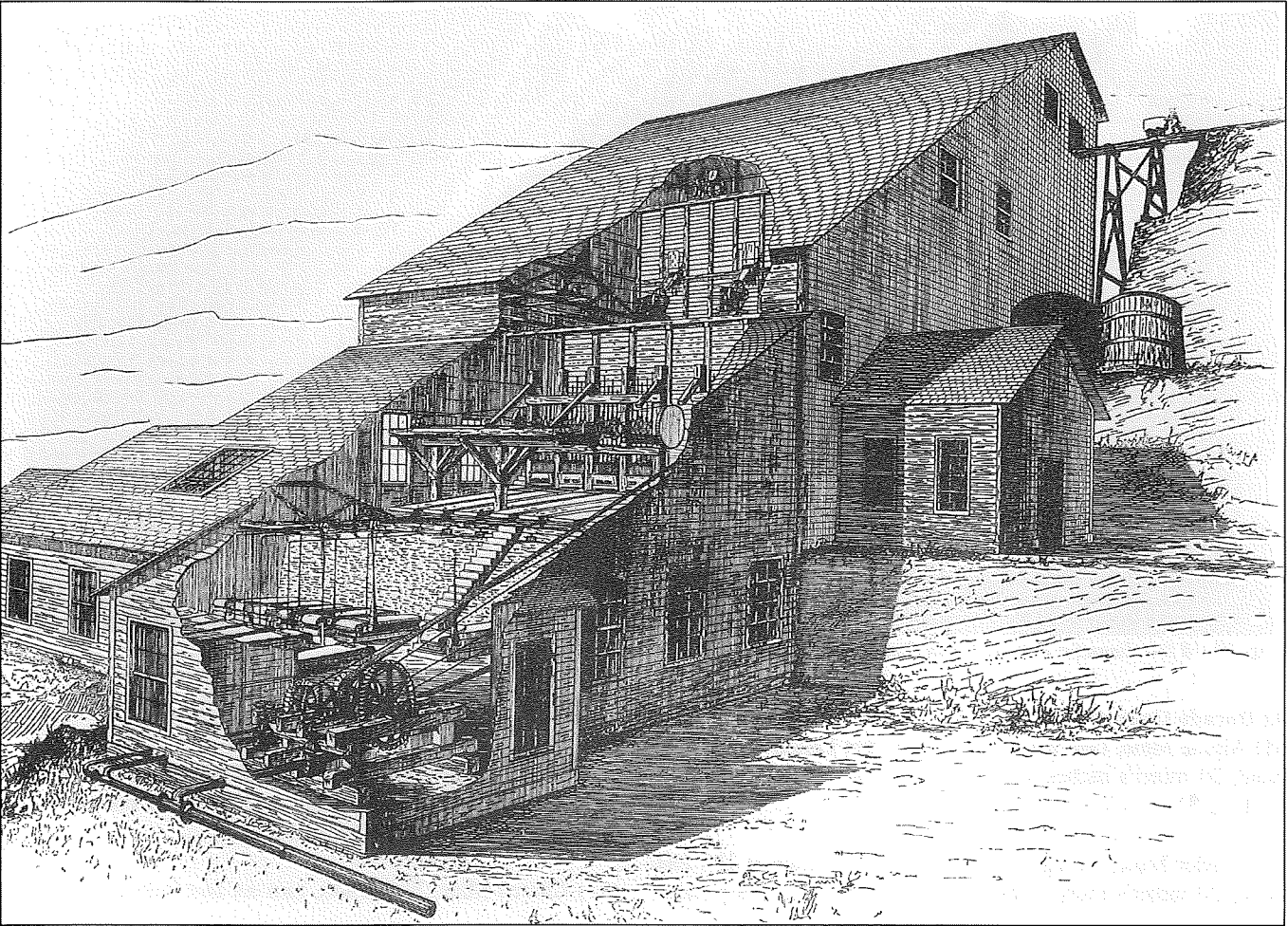
(5) Ilex Mine, Rich Gulch, one six feet Donnelly, 500 feet head, drove a 40 stamp mill, 850 pounds each; three Peltons, 6, 5 and 3 feet diameter and a one foot Knight wheel, 500 to 700 feet head, drove two hoisting works and miscellaneous machinery, 200 miner's inches.

(6) McCreight Mine, Angels, one 40 feet overshot wheel, 76 miner's inches, drove a 10 stamp mill, 650 pounds each.

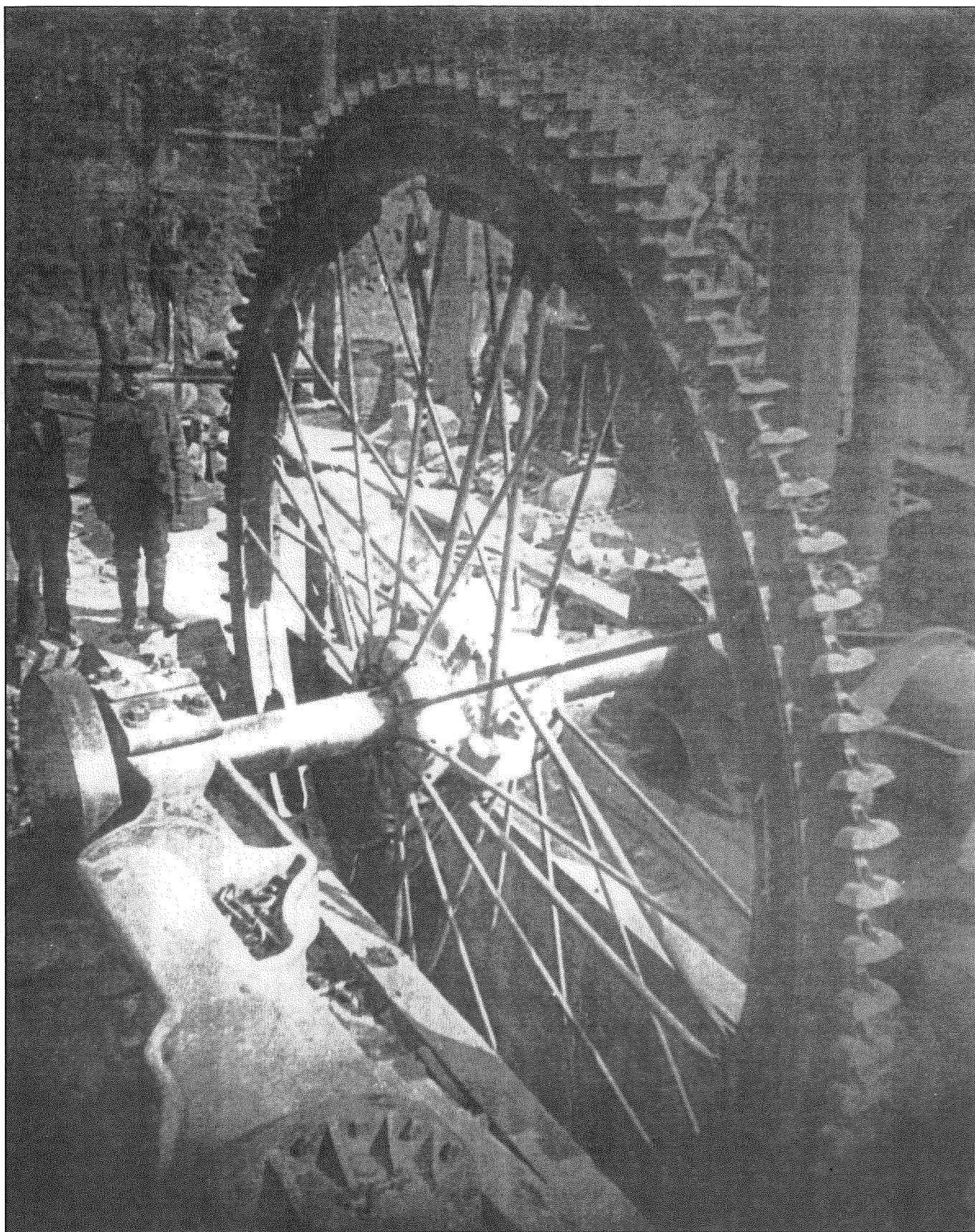
(7) Suffolk Mine, Angels, three overshot wheels, 24, 28 and 40 feet diameters, 40 miner's inches, drove a five stamp mill, 600 pounds each.



*Fig. 17 Head frame with two Pelton wheels, Empire Mine, Grass Valley, California.  
Fig 18 (below). Forty-stamp mill, tangential impulse water-driven, California 1880.*







*Fig. 19. 18 feet diameter Pelton, North Star Power House, Grass Valley, California.*

#### **El Dorado County**

(8) Alpine Mine, Georgetown, one four feet Pelton at 280 feet head, 20 miner's inches, drove a ten stamp mill, 1000 pounds each.

(9) Taylor Mine, Georgetown, one four feet Pelton at 220 feet head, 20 miner's inches, drove a ten stamp mill, 750 pounds

each.

(10) Gopher Mine, Kelsey, two Knight wheels, six feet and one feet ten inches diameters at 320 feet head, 71 miner's inches drove a 20 stamp mill, 750 pounds each.

(11) Church Mine, El Dorado, two six feet Peltons at 475 feet

head, one drove a ten stamp mill, 850 pounds each, and one drove a Cornish pump, 14 miner's inches total

(12) Oregon Mine, Placerville, one 8 feet hurdy-gurdy at 250 feet head, using 25 miner's inches, drove a ten stamp mill, 750 pounds each.

(13) True Mine, Placerville, one eight feet hurdy-gurdy at 450 feet head, ten miner's inches, drove a ten stamp mill, 550 pounds each.

**Tuolumne County**

(14) Patterson Mine, Tuttletown, one six feet Knight at 230 feet head, 64 miner's inches drove a 20 stamp mill, 800 pounds each.

(15) Gem Mine, Jamestown, one 32 feet overshot at 60 miner's inches, drove a ten stamp mill, 650 pounds each.

(16) Heslep Mine, Jamestown, one 50 feet overshot at 263 miner's inches drove a 25 stamp mill, 850 pounds each.

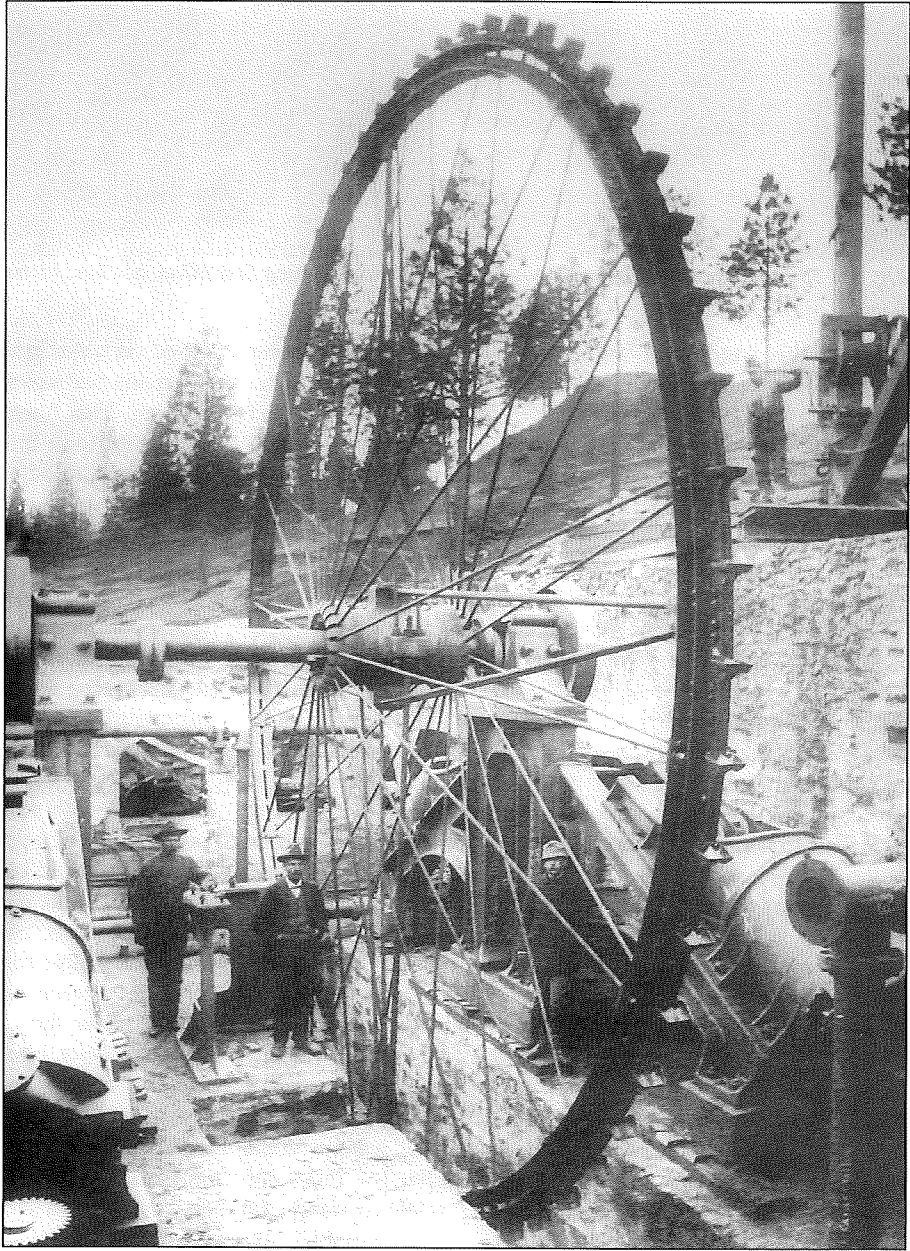
In general, this region of four counties may have favoured the Knight and Donnelly wheels, partly due to the geographic proximity of these mines to the Knight and Sutter Creek Foundries and partly due to the earlier development of the Knight wheel. Further north in Placer, Nevada, Yuba and Sierra Counties, the Pelton might have been chosen at this early moment in the tangential wheel evolution. This year, 1888, was the same year that Pelton took his manufacturing capabilities from Nevada City to San Francisco. It can be noted that the overshot wheel, of great historic importance, still prevailed in regions of low water head such as Jamestown in Tuolumne County and Angels in Calaveras County. It can also be noted that despite the efficiency differences of the various wheels, the most primitive wheels such as hurdy-gurdys were able to drive major machinery if provided with adequate water head and volume. From this 1888 snapshot data, the importance of water head is clearly established. A five feet tangential water wheel with over 400 feet of head can produce more work than a 40 feet overshot using comparable volumes of water. At 100% efficiency, one miner's inch, with a head of 415 feet, will produce one horsepower. This horsepower produced will rise or fall linearly with greater or lesser head. Horsepower also has a linear relationship to water flow in miner's inches. In general, the higher the water head, the smaller the volume of water needed to meet workload requirements. Roughly calculated, a five feet Pelton with a head of 500 feet, would be expected to produce in excess of 500 horsepower.

In the same year, 1888, in the same four gold-mine-rich counties of California, the following tabulates water wheels used in those counties:

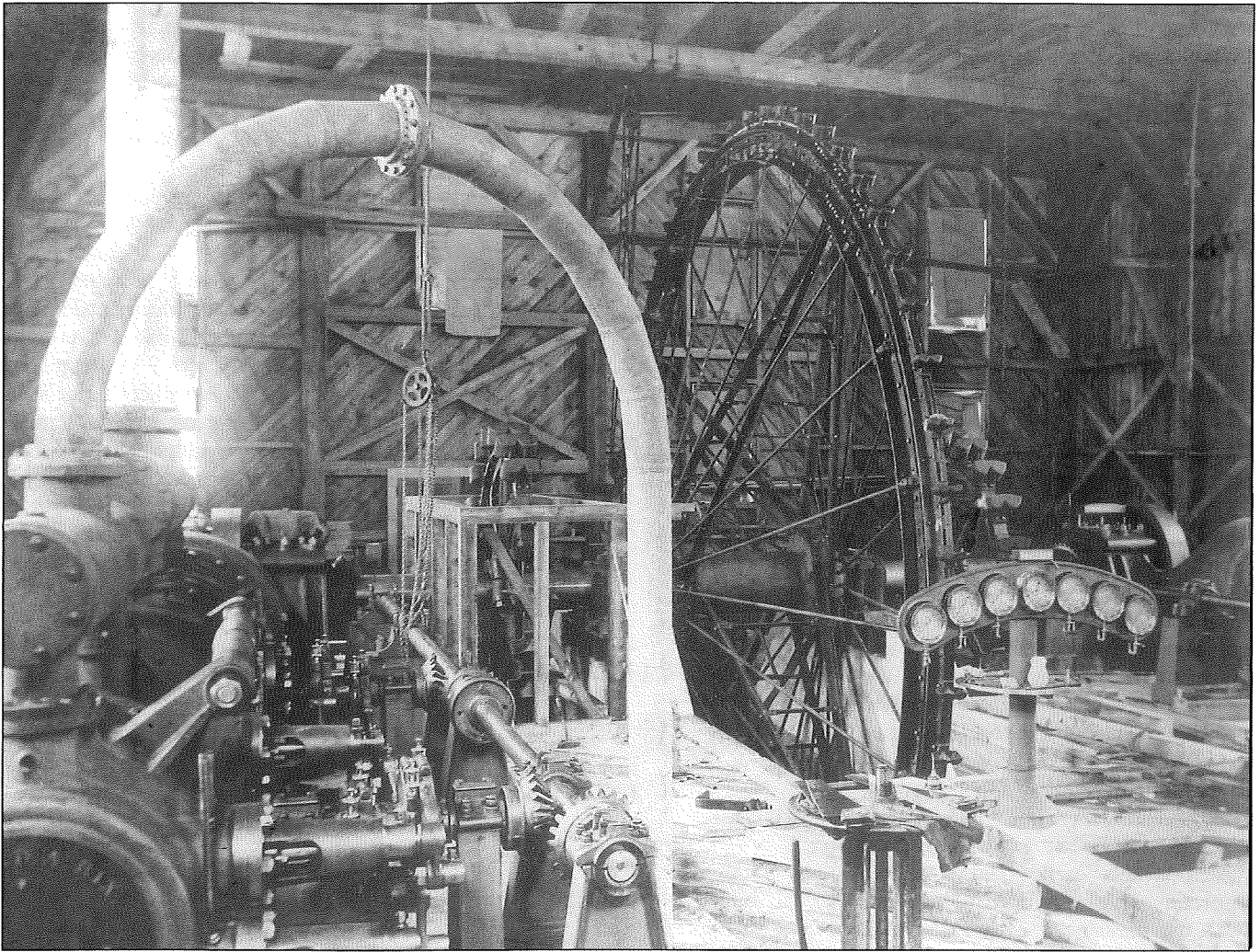
10 Overshot	46 Knight Tangentials
4 Hurdy-gurdys	39 Pelton Tangentials
3 Leffel Turbines	28 Donnelly Tangentials
2 Knight Turbines	1 Lepley Tangential

The ultimate beneficiary of this revolution in water wheel engineering was the hydroelectric industry which began in the 1890s. Although most mines in California had converted to electric motors to run their machinery by 1900, there were certain major exceptions such as the 30 feet wheel at the North Star Mine in Grass Valley which compressed air for major machinery for decades into the 20th Century. The tangential impulse water wheels were put to work generating electricity to supply increasing demands for electric power in mines, industry and cities. Although reaction turbines ultimately took over the major electricity generating tasks, hundreds of Peltons and other tangentials are still busy today generating electric power.

*Fig. 20. 30 feet diameter wheel with Risdon cups, North Star power house, Grass Valley, California, 1895.*







*Fig. 21. 33 feet diameter Pelton with two 11 feet Peltons, Morning Star Mine, Mullan, Idaho. 1900.*

Although this window of water powered mining engineering was brief, the consequences of this revolution have been wide spread and long lasting. A few isolated mines in California and throughout the world may still use water power. The Knight Foundry in Sutter Creek, though now a museum, still powers its machinery by Knight wheels as it has for over 125 years.

The evolution of cup and wheel design for tangential impulse water wheels began with flat paddles on a wooden wheel changing to shallow cups and later deeper sheet metal cups. Knight and Donnelly reshaped the cup to more efficiently receive and expel the high velocity jet stream of water. Pelton is credited with the scientific insight that the water stream must be reversed by the cup to deliver optimum kinetic energy. Doble, Risdon, Joshua Hendy, Dodd, Tutthill, Hug and others experimented with cup shapes, some improving the efficiency of the 1880 classic Pelton design. The jet stream velocity was found to be basically a function of water head. Although the cup velocity of a turning wheel could approximate this same jet speed if unloaded and allowed to reach a runaway state, it was found to be approximately one half of the jet stream velocity in a properly loaded system. The diameter of a wheel chosen for an installation was therefore more a function of the angular velocity desired than it was of horsepower of the system required. For best efficiency, the wheel diameter should be 15-20 times the jet diameter. The cup size chosen was a function of water volume per unit time flowing past each cup, ideally 3-4 times the diameter of the jet. The nozzle diameter selection would be

based on water head available and horsepower needed with the provision that water volume was available to match the diameter chosen. The horsepower of a wheel installation could be calculated from the jet stream velocity and jet stream diameter assuming that the efficiency of the wheel is known. The efficiency of a wheel was basically a ratio of the brake horsepower divided by the theoretic hydraulic horsepower, approaching 90% in a well designed wheel. In such a wheel the water jet is deflected approximately 165 degrees; greater than this would add efficiency until interference with the following bucket occurs. Abundant water at lower heads might call for a design where multiple jets would strike the same runner. Some efficiency would be sacrificed because of interfering water scatter. More than one runner on the same shaft was preferred over multiple jets striking the same runner. This technique was also used with reversible systems, such as hoists, where two comparable wheels on the same shaft with cups facing opposite directions could allow the shaft to rotate in either direction. When two water sources with different heads were used to drive the same shaft, two wheels of different diameters would be mounted on this shaft; the larger wheel would receive the higher pressure source and consequently the faster water jet. This would allow the cups of each wheel to reach their optimum linear velocity, one half that of the jet striking them.

Varying workloads was a special problem in hoists, compressors and sawmills because an unloaded wheel could suddenly double its angular velocity. The solution to this, the rapid control of the jet stream, could also produce an even more



serious problem, water hammer with damage to pipeline. A battery of solutions to this included nozzle deflection to redirect the water stream, jet deflectors to quickly obstruct the water hitting the wheel, automatic governor controlled needle nozzles and even double needle nozzles where the water flow could be automatically switched from the working nozzle to a diverting nozzle in a rapid but smooth transition when the workload changed. After 1900, the Joshua Hendy Company produced a needle nozzle coupled with a jet deflector with the deflector acting quickly and the nozzle more slowly. This could prevent both a runaway wheel and water hammer when the wheel suddenly became unloaded.

In summary, it could be stated that with the availability of high pressure water at locations where large machines needed energy sources to function, the 19<sup>th</sup> Century gold mines of California, the tangential impulse water wheel was born and developed. Within a time frame lasting less than 30 years, this evolution produced a water wheel still used today and still the choice for hydroelectric generation where high water pressure is available. These water wheels were born and perfected as an offshoot of historic mining engineering. From the perspective of work performed for weight and physical size of these machines, the tangential impulse water wheels represented a quantum leap in water wheel engineering.

**References:**

Abner Doble Company 1904 *Tangential Water Wheels*, Bulletin No. 5.

American Impulse Wheel Company 1897 *The Perfect American Hurdy-Gurdy*.

Doland, James J., D. Sc. 1954 *Hydro Power Engineering*. (The Ronald Press).

Dougherty, R. L. 1930 *Water Turbines*. (International Text Book Co.).

Durand, W. F. 1939 *The Pelton Water Wheel. Mechanical Engineering*.

Glynn, Joseph, F.R.S. 1869 *Power of Water*. (Third Edition).

The Hug Water Wheel Company 1906 *Catalog No. 3*.

Irelan, William, Jr. 1888 *Seventh Annual Report of the State Mineralogist*. (Sacramento, California)

Joshua Hendy Iron Works 1906 *Tangential Water Wheels and Water Motors*. Bulletin No. 114.

Kilroy, Elza J. 1961, *The Pelton Water Wheel*. Nevada County Historical Society, 15, 2.

Knight Water Wheels 1912 *Catalog No. 6*.

Kraft, R. A., Christman, E. 1992 *The Pelton Water Wheel, Eureka*, 4.

Kraft, R. A., Samay, R. H., Christman, E. 1997 *The Pelton Water Wheel and its Historic Mining Role. Collectors' Mining Review*, 5.

James Leffel and Co. 1893 *New Samson Water Wheel*, Pocket Pamphlet.

Leshcoheir, Roger P. 1992 *Pelton and the Pelton Water Wheel*.

McQuiston, F. W., Jr. 1986 *Gold: The Saga of the Empire Mine*.

Mead, D. W. 1920 *Water Power Engineering*.

Merriman, Mansfield 1916 *Treatise on Hydraulics*. (Tenth Edition).

*National Cyclopedia of American Biography*. 1906

Oakland Iron Works 1899 *Tutthill Patent Water Wheels*.

Pelton Water Wheel Company 1890 *Catalog*, (Third Edition).

Pelton Water Wheel Company 1898 *Catalog*. (Seventh Edition).

Pelton Water Wheel Company 1909 *Catalog*. (Eleventh Edition).

Pelton Water Wheels 1915 *Bulletin*, 8.

Risdon Patent Tangential Water Wheels 1900 *Catalogue No. 4*.

Shortridge, R. W., Ph.D. 1989, Lester Pelton and his Water Wheel. *Hydro Review*, (Oct. 1989).

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