Stronger Than a Hundred Men: A History of the Vertical Water Wheel, Terry S. Reynolds, JHU Press, 2002, 0801872480, 9780801872488, 480 pages. Like many apparently simple devices, the vertical water wheel has been around for so long that it is taken for granted. Yet this "picturesque artifact" was for centuries man's primary mechanical source of power and was the foundation upon which mills and other industries developed. Stronger than a Hundred Men explores the development of the vertical water wheel from its invention in ancient times through its eventual demise as a source of power during the Industrial Revolution. Spanning more than 2000 years, Terry Reynolds's account follows the progression of this labor-saving device from Asia to the Middle East, Europe, and America-covering the evolution of the water wheel itself, the development of dams and reservoirs, and the applications of water power.

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Records of water-wheel tests made at Lowell, Mass., and other places, since May, 1869, James Emerson (of Williamansett, Mass.), 1872, Technology & Engineering, . . .

A Practical Treatise on the Construction of Horizontal and Vertical Water-wheels ... Specially Designed for the Use of Operative Mechanics, William Cullen, 1871, Hydraulic engineering, 63 pages. .


An experimental enquiry concerning the natural powers of water and wind to turn mills, John Smeaton, 1760, 77 pages. .

Studia archeologica, Issue 156, Adriana de Miranda, 2007, Science, 369 pages. This is a study of the water-raising wheels of western Syria from the aspects of sources, terminology, typology, origin, history, technology and architecture, and gives a ....


Cassel self-governing water wheels ... adapted for the conversion of water power for electrical generating, mines and collieries ..., Cassel Automatic Water Motor Co, 1902, Turbines, 76 pages. .

Wind & water in the Middle Ages fluid technologies from antiquity to the Renaissance, Steven A. Walton, 2006, 300 pages. .

Water for Gotham A History, Gerard T. Koeppel, 2001, History, 355 pages. This text examines New York City's struggle for that vital and basic element - clean water. Drawing on primary sources, personal narratives, and anecdotes, it shows how the ....


Notes on Water Wheels: Water power, Mortimer Elwyn Cooley, , Technology & Engineering, . .

Stronger than a Hundred Men explores the development of the vertical water wheel from its invention in ancient times through its eventual demise as a source of power during the Industrial Revolution. Spanning more than 2000 years, Terry Reynolds's account follows the progression of this labor-saving device from Asia to the Middle East, Europe, and America-covering the evolution of the water wheel itself, the development of dams and reservoirs, and the applications of water power.

This is the only book I've read on water wheels, but it's fascinating. It seems like a pretty thorough history going back as far as possible, and it discusses theories about how the ideas developed and
includes many drawings and a few photographs. Lot of material here. Seems pretty thorough and interesting and authoritative for a textbook on "any" subject.

Setting out to restore a dam and millpond on my farm, I felt the need to understand something about the history of waterpower. This book was very helpful. (I also consulted a book from 1939 titled LOW DAMS.) I found 100-Men very informative, especially regarding its more recent history of smaller waterpower over the past century, when this technology was, sadly, allowed to decay, and was lost and largely forgotten, due to cheap oil. Trying to recover this resource is doubly difficult today, due to scarcity of know-how and restrictive ordinances. I also bought a book titled MICROHYDRO, by Davis, which is very up to date.

"The most comprehensive and definitive history of the water wheel ever published... Reynolds's study is documented by a staggering number of notes and a vast bibliography, and the text is supplemented by numerous excellent illustrations... An attractive and highly useful source of information." -- Choice

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A water wheel is a machine for converting the energy of free-flowing or falling water into useful forms of power, often in a watermill. A water wheel consists of a large wooden or metal wheel, with a number of blades or buckets arranged on the outside rim forming the driving surface. Most commonly, the wheel is mounted vertically on a horizontal axle, but the tub or Norse wheel is mounted horizontally on a vertical shaft. Vertical wheels can transmit power either through the axle or via a ring gear and typically drive belts or gears; horizontal wheels usually directly drive their load.

Water wheels were still in commercial use well into the 20th century, but they are no longer in common use. Prior uses of water wheels include milling flour in gristmills and grinding wood into pulp for papermaking, but other uses include hammering wrought iron, machining, ore crushing and pounding fiber for use in the manufacture of cloth.

Some water wheels are fed by water from a mill pond, which is formed when a flowing stream is dammed. A channel for the water flowing to or from a water wheel is called a mill race (also spelled millrace) or simply a "race", and is customarily divided into sections. The race bringing water from the mill pond to the water wheel is a headrace; the one carrying water after it has left the wheel is commonly referred to as a tailrace.[1]

The two main functions of water wheels were historically water-lifting for irrigation purposes and as a power source. In terms of power source, water wheels can be turned either by human or animal force or by the water current itself. Water wheels come in two basic designs, either equipped with a vertical or a horizontal axle. The latter type can be subdivided, depending on where the water hits...
the wheel paddles, into overshot, breastshot and undershot wheels.

The Romans used water wheels extensively in mining projects. They were reverse overshot water-wheels designed for dewatering deep underground mines.[citation needed] Several such devices were described by Vitruvius. The one found during modern mining at the copper mines at Rio Tinto in Spain involved 16 such wheels stacked above one another so as to lift water about 80 feet (24 m) from the mine sump. Part of a similar wheel dated to about 90 AD, was found in the 1930s, at Dolaucothi, a Roman gold mine in south Wales.

Taking indirect evidence into account from the work of the Greek technician Apollonius of Perge, the British historian of technology M.J.T. Lewis dates the appearance of the vertical-axle watermill to the early 3rd century BC, and the horizontal-axle watermill to around 240 BC, with Byzantium and Alexandria as the assigned places of invention.[6] A watermill is reported by the Greek geographer Strabon (ca. 64 BC–AD 24) to have existed sometime before 71 BC in the palace of the Pontian king Mithradates VI Eupator, but its exact construction cannot be gleaned from the text (XII, 3, 30 C 556).[7]

The first clear description of a geared watermill offers the late 1st century BC Roman architect Vitruvius who tells of the sakia gearing system as being applied to a watermill.[8] Vitruvius's account is particularly valuable in that it shows how the watermill came about, namely by the combination of the separate Greek inventions of the toothed gear and the water wheel into one effective mechanical system for harnessing water power.[9] Vitruvius's water wheel is described as being immersed with its lower end in the watercourse so that its paddles could be driven by the velocity of the running water (X, 5.2).[10]

About the same time, the overshot wheel appears for the first time in a poem by Antipater of Thessalonica, which praises it as a labour-saving device (IX, 418.4â€“6).[11] The motif is also taken up by Lucretius (ca. 99-55 BC) who likens the rotation of the water wheel to the motion of the stars on the firmament (V 516).[12] The third horizontal-axed type, the breastshot water wheel, comes into archaeological evidence by the late 2nd century AD context in central Gaul.[13] Most excavated Roman watermills were equipped with one of these wheels which, although more complex to construct, were much more efficient than the vertical-axle water wheel.[14] In the 2nd century AD Barbegal watermill complex a series of sixteen overshot wheels was fed by an artificial aqueduct, a proto-industrial grain factory which has been referred to as "the greatest known concentration of mechanical power in the ancient world".[15]

In Roman North Africa, several installations from around 300 AD were found where vertical-axle water wheels fitted with angled blades were installed at the bottom of a water-filled, circular shaft. The water from the mill-race which entered the pit tangentially created a swirling water column that made the fully submerged wheel act like true water turbines, the earliest known to date.[16]

Apart from its use in milling and water-raising, ancient engineers applied the paddled water wheel for automats and in navigation. Vitruvius (X 9.5-7) describes multi-gearde paddle wheels working as a ship odometer, the earliest of its kind. The first mention of paddle wheels as a means of propulsion comes from the 4thâ€“5th century military treatise De Rebus Bellicis (chapter XVII), where the anonymous Roman author describes an ox-driven paddle-wheel warship.[17]

The earliest vertical-wheel in a tide mill is from 6th century Kiltofban near Waterford, Ireland,[19] while the first known horizontal-wheel in such a type of mill is from the Irish Little Island (c. 630).[20] As for the use in a common Norse or Greek mill, the oldest known horizontal-wheels were excavated in the Irish Ballykilleen, dating to c. 636.[20]

The earliest excavated water wheel driven by tidal power was the Nendrum Monastery mill in Northern Ireland which has been dated at 787A.D. although a possible earlier mill dates to 619A.D. Tide mills became common in estuaries with a good tidal range in both Europe and America generally using undershot wheels.
Cistercian monasteries, in particular, made extensive use of water wheels to power watermills of many kinds. An early example of a very large water wheel is the still extant wheel at the early 13th century Real Monasterio de Nuestra Senora de Rueda, a Cistercian monastery in the Aragon region of Spain. Grist mills (for corn) were undoubtedly the most common, but there were also sawmills, fulling mills and mills to fulfil many other labour-intensive tasks. The water wheel remained competitive with the steam engine well into the Industrial Revolution. At around the eighth to 10th century, a number of irrigation technologies were brought into Spain and thus introduced to Europe. One of those technologies is the Noria, which is basically a wheel fitted with buckets on the peripherals for lifting water. It is similar to the undershot water wheel mentioned later in this article. It allowed peasants to power watermills more efficiently. According to Thomas Glick's book, Irrigation and Society in Medieval Valencia, the Noria probably originated from somewhere in Persia. It has been used for centuries before the technology was brought into Spain by Arabs who had adopted it from the Romans. Thus the distribution of the Noria in the Iberian peninsula "conforms to the area of stabilized Islamic settlement". This technology has a profound effect on the life of peasants. The Noria is relatively cheap to build. Thus it allowed peasants to cultivate land more efficiently in Europe. Together with the Spaniards, the technology then spread to North Africa and later to the New World in Mexico and South America following Spanish expansion.

The type of water wheel selected was dependent upon the location. Generally if only small volumes of water and high waterfalls were available a millwright would choose to use an overshot wheel. The decision was influenced by the fact that the buckets could catch and use even a small volume of water.[24] For large volumes of water with small waterfalls the undershot wheel would have been used, since it was more adapted to such conditions and cheaper to construct. So long as these water supplies were abundant the question of efficiency remained irrelevant. By the 18th century with increased demand for power coupled with limited water locales, an emphasis was made on efficiency scheme.[24]

By the eleventh century there were parts of Europe where the exploitation of water was commonplace.[22] The water wheel is understood to have actively shaped and forever changed the outlook of Westerners. Europe began to transition from muscle labour, human and animal labor, towards mechanical labour with the advent of the Water Wheel. Medievalist Lynn White Jr. contended that the spread of inanimate power sources was eloquent testimony to the emergence of the West of a new attitude toward, power, work, nature, and above all else technology.[22] Even the most conservative commentators regarding the extent to which the water wheel influenced Medieval western technology and science recognize the basic elements of a power-based economy responsible for distinguishing the Europeans above all others, had begun with the framework instilled by the water wheel. Furthermore Europeans, for the first time had begun to show their own capabilities for mechanized innovations, by not limited themselves to merely water, but by beginning to experiment with wind and tidal mills.[25] Waterwheels influenced the construction of cities, more specifically canals. The techniques that developed during this early period such as stream jamming and the building of canals, put Europe on a hydraulically focused path, for instance water supply and irrigation technology was combined to modify supply power of the wheel.[26] Illustrating the extent to which there was a great degree of technological innovation that met the growing needs of the feudal state.

The water mill was used for grinding grain, producing flour for bread, malt for beer, or coarse meal for porridge.[27] Hammermills used the wheel to operate hammers. One type was fulling mill, which was used for cloth making. The trip hammer was also used for making wrought iron and for working iron into useful shapes, an activity that was otherwise labour intensive. One application attributed from hammer milling was â€“ ironingâ€œ. The water wheel was also used in papermaking, beating material to a pulp.

Millwrights distinguished between the two forces, impulse and weight, at work in water wheels long before 18th-century Europe. Fitzherbert, a 16th-century agricultural writer, wrote â€œdruith the wheel as well as with the weight of the water as with strengthe [impulse].â€[28] Leonardo da Vinci also discussed water power, noting â€œthe blow [of the water] is not weight, but excites a power of weight, almost equal to its own power.â€[29] However, even realisation of the two forces, weight
and impulse, confusion remained over the advantages and disadvantages of the two, and there was no clear understanding of the superior efficiency of weight.[30] Prior to 1750 it was unsure as to which force was dominant and was widely understood that both forces were operating with equal inspiration amongst one another.[31] The waterwheel, sparked questions of the laws of nature, specifically the laws of force. Evangelica Torricella’s work on water wheels used an analysis of Galileo’s work on falling bodies, that the velocity of a water sprouting from an orifice under its head was exactly equivalent to the velocity a drop of water acquired in falling freely from the same height.[31]

Development of water turbines during the Industrial revolution led to decreased popularity of water wheels. The main advantage of turbines is that ability to harness head much greater than the diameter of the turbine, whereas a water wheel cannot effectively harness head greater than its diameter. The migration from water wheels to modern turbines took about one hundred years.

Chinese water wheels almost certainly have a separate origin, as early ones there were invariably horizontal water wheels. By at least the 1st century AD, the Chinese of the Eastern Han Dynasty were using water wheels to crush grain in mills and to power the piston-bellows in forging iron ore into cast iron.

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