Ancient Hydraulic Systems - Part VII (conclusion)

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When most of us think of water-related technology, we tend not to think of such ancient inventions as the shaduf, the pot-wheel, rota, tympanum or bucket-chain described in an earlier article of this series, but instead of a device which is still in use today and would not cause the majority of us to sit back and ponder its origin: the water-wheel. This water-wheel is often partially submerged in water and attached to a mill of some kind, but despite its continued modern use and its appearance in landscapes of many modern artists, the origin of both the water-wheel and the water-mill goes back some 2000 years.

Although such ancient devices as the shaduf, pot-wheel and bucket-chain were in common use for hoisting water for many decades and even centuries before the invention of the water-wheel, it was not until well into the time of the Roman Republic that people actually made use of the water-wheel as a labour-saving device to mill grain. We are told by Marcus Vitruvius Pollio, who wrote in the late first century B.C., that water-wheels accomplished "the necessary work through being turned by the mere impulse of the river, without any treading on the part of workmen." (Ten Books on Architecture, X.5.1). Although this concept may seem quite simple and obvious to most of us in our mechanized world, the invention of a water-wheel as a power source to do work for us was a long time in coming and revolutionized ancient engineering. In this case, the stream was not lifted for use in irrigation or for consumption, but instead the power of the water itself was used to turn the wheel. While there is literary evidence of the water-wheel being used as a source of power as early as the first century B.C., there is no real archaeological evidence for its use as such until the second century A.D., with large-scale application of the system not being found until the third or fourth century A.D.

One reason for the slow uptake of this new technology in Greece and Italy, as suggested by many modern scholars, may have been the lack of rivers in those areas which maintain a steady and adequate flow of water year-round. While the late first century B.C. author Strabo, in his work on Geography (XII.3.40), mentions that Mithridates, in what is now north central Turkey, built a water-mill in the first century B.C., his installation was constructed close to a large and substantial river system providing his mill with water virtually year-round. This kind of adequate, fast-flowing water supply is rarely found in Greece or Italy, but the problem was, nevertheless, addressed in ancient times by actually building a fast-flowing supply of water to feed the ancient water-wheels in the form of aqueducts and conduits.

While one factor limiting the widespread use of water-mills in some areas may have been a lack of adequate rivers feeding the mills, another very real obstacle to the spread of ancient water-driven mills was the cheap and abundant availability of draught-animal power to drive mills at the time. Animal mills were not only less expensive to build but had also been around for many generations and were, therefore, well established in the lifestyles of the ancient people.

The three basic water-wheel types are commonly called the vertical-shaft, the undershot and the overshot, with the latter two most prevalent in ancient Greece and Rome. The vertical-shaft water-wheel consisted of a hub with blades attached to it at about 30 degrees at the bottom of a vertical shaft (see Figure 1a). This turbine-type of system depended on a very fast stream which could be channelled through a trough or aqueduct onto the wheel of blades, thereby turning a vertical axle which in turn rotated a millstone directly and did not depend on complex gearing of any kind. This type of water-wheel system continues to be used in such areas as Norway where fast-running rivers can be directed onto the turbine blades.

The second type of water-wheel device is generally referred to as the undershot wheel or "Vitruvian" water-wheel since it is the one described in great detail in that author's comprehensive work on architecture and building techniques (Ten Books on Architecture, X.5). The undershot wheel operated with moderate efficiency where a substantial, although perhaps sluggish, river flowed beneath the blades of a wheel set vertically into the water (see Figure 1b). As the force of the water turned the wheel, a simple but efficient gearing mechanism transformed this vertical movement into a horizontal one and made possible the rotation of a millstone used in grinding grain for meal (see Figure 2). The key to the efficiency of this type of arrangement is its gearing, yet the Vitruvian water-mill did not immediately take over from the earlier draught-animal driven mills, since animals such as donkeys were still an inexpensive form of "manual" labour. Once established, however, this water-mill proved to be far more efficient with an output many times greater than the animal-driven mill.

For all its apparent sophistication over the earlier types of mills, the undershot wheel was still less effective than the main component of the next "generation" of water-mill mechanisms: the overshot wheel. While perhaps twice as powerful and efficient as its predecessors, the overshot wheel did, however, require a great force of water from a mill-race or aqueduct to be directed onto the paddles of the vertical wheel, which was now no longer in the water itself (see Figure 1c).

Due to the sometimes enormous costs of transporting the construction materials and building the overshot installation and its accompanying mill-race, the undershot arrangement, as described by Vitruvius, was still the one preferred in many cases, despite being slower and less efficient. Because the undershot wheel required no mill-race or aqueduct to raise water to the necessary height of the wheel for the water to fall from the top, or a pit for the wheel itself as did the overshot, virtually any location with a moving stream was adequate for the construction of an undershot mill.

In regards to the overshot mill, what may have been one of the largest and most efficient overshot installations in the ancient world was located at Barbegal, near Arles in southern France. Here, the Romans of the third or fourth century A.D. built a series of eight pairs of overshot water-mills, complete with mill-races, wheel pits and mill-houses supplying a great quantity of grain products for the entire region. Evidence for this massive installation can still be seen at this site today. Portions of mill-races, aqueducts, overshot wheels, millstones, mill-houses, wooden mill-wheels and iron spindles from the second to the fourth centuries A.D. can also be found in other parts of France, as well as in Italy, Greece and Great Britain.

One of the main factors in favour of the overshot mill was, as mentioned earlier, the fact that throughout much of the Mediterranean region there is no dependable and continuous supply of running water necessary for the undershot wheel to be functional. Due to seasonal fluctuations in many areas, therefore, and despite the much higher cost of building an overshot mill and aqueduct or the overall inefficiency of animal-driven mills, both of these latter systems had their advantages over the undershot wheel in many cases. It was not until several centuries later, in medieval times, that the Vitruvian undershot mills gained popularity and increased efficiency.

Although the investigation into early water-mills could be a very in-depth and complex proposition of gear-ratios, flow rates and mechanics, the overview given here has, I hope, provided some insight into this revolutionary ancient technology. As with most of the concepts presented in these last seven articles on ancient hydraulic systems, they have merely been an attempt to introduce the fascinating world of early engineering techniques and technology. Ancient hydraulic systems covered every aspect of water collection, storage and subsequent distribution, and in this series of articles we have looked at the various ways in which early civilizations raised water, collected it, transported it and made use of it. Many ancient and modern sources could be tapped to investigate further this extraordinary aspect of our early history.

The advances which took place in hydraulic engineering in the ancient Near East, Greece and Rome were, without a doubt, among the most significant technological achievements ever accomplished by mankind in the history of the world. If this seems like a broad, sweeping statement consider the fact that these advances made possible habitation of regions which would otherwise have been entirely inhospitable to civilization; and consider the fact that these advances made day-to-day living far more enjoyable and manageable for our ancestors.

It should be encouraging to all of us today to realize that our ancestors rose to the challenge of finding ways to ease their toil and hardships through some of the ancient hydraulic systems described in this series of articles, and thereby passed on to us a legacy of technology which may well outlive us all.