Ancient Hydraulic Systems - Part V

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In previous articles of this series we looked at the ways and means by which ancient civilizations captured and contained the precious resource of water, conducted it over deserts, hills and through mountains, and used it in public and private ways. In this and the next two articles - which will conclude our look at ancient hydraulic systems - we will see how ancient engineers and farmers put water to good use by lessening their labour, increasing their yield and "automating" their world.

There seems to be little doubt that most, if not all, mechanical water-lifting devices used by the Greeks and Romans were originally developed in Egypt. This may have been due to the simple fact that the climate and landscape along the Nile Valley - where most of Egypt's agricultural productivity took place - necessitated mechanical or artificial irrigation techniques of various kinds. Without some way of lifting the Nile's water into their fields, the Egyptian farmers were at the mercy of the harsh desert climate, with only the Nile's annual flooding to supply them with an over-abundance of water. If the farmers were to produce perennial crops, their fields would have to be supplied with water the year round. While it was possible to irrigate the fields using only bucket and scoop, this must, at the very least, have been back-breaking work. Even with simple mechanization, such as the shaduf (which will be explained shortly), farmers still spent up to half their productive working day irrigating their parched fields. Mechanization would help yield more crops year round and take much of the backache out of lifting water into the fields.

In its simplest form, the shaduf is merely a post and pivoted beam arrangement. The post, which has a fork at the top, is planted into the ground and a beam is supported in the cradle of the fork. One end of the beam has a bucket suspended from it over the water source, while the other end is counterweighted with a stone or mud to counteract the weight of the water as it is drawn up from the water source by hand. Once the bucket is lifted clear of the water by the counterweight, it is emptied into a conduit or reservoir to be used from there or lifted higher still by another shaduf. This arrangement, illustrated in Figure 1(a), must have greatly eased the toil endured by the early farmers, but it was still a slow and laborious task. It did, however, significantly increase the amount of water that a farmer could raise into his fields and therefore increased his potential crop yield. It even made possible the use of land which was beyond the direct annual flooding of the Nile and so greatly increased the agricultural resources of the Egyptians.

This shaduf water-lifting device came into use some time around 3000 BC in Mesopotamia and Egypt, and continued in use well into Classical times. Possibly the earliest evidence of the already well-established shaduf is shown on Mesopotamian seals dating from around 2000 BC. Egyptian tomb paintings, such as the line drawing in Figure 1(a), dating from about 1500 to 1200 BC, also show the shaduf in action. Illustrations of it are also depicted on sixth century BC Greek vases, but it seems to have been such a common sight to the Greeks and Romans that little mention of it is made in early classical literature. Herodotus (*Histories*, I.193) mentions it, almost in passing, in a chapter on Mesopotamian history, but other than that we have only the Greek name of *keloneion* for the shaduf, and the Latin names *ciconia* and *tolleno*. Despite the lack of an abundance of early literary evidence for the shaduf - even though it may have been one of the earliest major agricultural breakthroughs in history - it is still in use today in Egypt, virtually unchanged after 5000 years!

While there seems to be no archaeological evidence outside of Egypt for any water-lifting devices, other than the shaduf, before the third century BC, another mechanical apparatus does make its appearance at this time in history. Most sources, in particular Diodorus in his *History* 1.34.2, seem to agree that Archimedes of Syracuse invented a "contrivance" in the third century BC by which the inhabitants of the Nile area could "easily irrigate the whole region by means of a certain device ... called the 'screw' on account of its design." (Agatharchides of Cnidus, 180-116 BC).

Besides various ancient allusions to the use of the water-screw in antiquity, the only real description of its construction that we have comes from the first century BC engineer Marcus Vitruvius Pollio in his *Ten Books on Architecture* (X.6.1-4), making his account unique and invaluable. Simply put, based on Vitruvius' description, the water-screw is merely a beam with spiral channels running its length "which naturally look just like those of a snail shell" (X.6.2), hence the Greek name of *cochlias* and Latin name of *cochlea* (see Figure 1(b)). Vitruvius went on to describe how the water-screw was to be set up according to the Pythagorean principle of right-angle triangles (X.6.4), which meant that it would have to be operated at an angle of less than 45 degrees to be most effective. Consequently, this meant that the water-screw could only be used to lift water at a small height, but could raise the water over small river banks into adjacent irrigation canals or cisterns - which was probably why Archimedes invented the device in the first place. The main features of the water-screw were the large quantities of water it could move, its simple and efficient operation, its portability and its dependable operation no matter how much silt it dredged up - unlike some of the other water-lifting devices we will be looking at in the next two articles of this series.

The operation of the water-screw is one for which we have several descriptions from ancient sources. Vitruvius quite simply tells us that "the screw is turned by the treading of men." (X.6.3). By this he meant that a man, supporting himself on a crossbar, turned the screw by "walking" on treads mounted to the middle of the outside of the drum. This description is supported by an account in *De Confusione Linguarum* (38) by Philo of Alexandria, in which he writes that "there are some treads around the middle on which the husbandman steps whenever he wants to irrigate his field" and, in order "to keep from continually falling, he grasps something sturdy nearby with his hands and clings to it, suspending his whole body from it." There is physical evidence for this as well as in the form of a fresco preserved in the Casa di P. Cornelius Teges in Pompeii, which shows a workman in action treading a water-screw. After the Classical period, a crank was added to the upper end to facilitate turning the screw rather than workmen treading its case. As is indicated by the actual water-screw remains found in Egypt, frescoes, pottery and Vitruvius' own description, cranks were never applied to these devices in classical times.

There is also an ancient literary reference for the application of the Archimedean water-screw in the *Geography* of Strabo (63 BC-21 AD), in which he tells us that water-screws were used to irrigate the Hanging Gardens of Babylon (XVI.1.5). Later in the same work, Strabo describes how a series of "wheels and screws bring water up from the [Nile] river" keeping "one hundred and fifty prisoners busy at the work" of treading to supply water to the Legionary camp of Babylon, near Memphis (modern Cairo) in Egypt (XVII.1.30). The water-screw remained in use as one of the most practical and efficient water-lifting devices throughout the Mediterranean world until at least the time of the late Empire. It was put to many uses during the Roman Empire, remaining an important device for irrigation, mine drainage (which we will investigate in a subsequent *Labyrinth* article), public, private and military water supply systems and harbour construction.

In the next article of this series, we will continue our investigation into ancient hydraulic systems by looking at other mechanical water-lifting devices which were in use throughout the classical world and which helped lift hydraulic technology to new heights.