A short history of ancient canals for agriculture and industry

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Summary. Large canals for agriculture were developed in the Eastern ancient civilizations also having to cope with the management of large rivers. The earliest development of large-scale canals took place in Mesopotamia and in central Asia, in the bronze age period (from 4000 BC to 1100 BC). Later, agricultural canals development continued up to a considerable extent in central Asia and China. Canals development continued throughout Antiquity and middle age, together with the development of water-power, which was at the origin of the industrial revolution.

1. Introduction

The history of canals starts as early as at the beginning of irrigated agriculture. As canal building and maintenance have to be the task of a community of men, the history of canals is also the history of the civilizations. The story starts with the civilizations which developed in the basins of the Tigris, Euphrates, Nile, Amu Darya and Yellow rivers. This paper is trying to give some insight in this history, starting with the early bronze age, and continuing with the development of water power through the middle age and modern times.

2. Irrigation canals in the early eastern civilizations.

Early canals used to be built for navigation, irrigation, drainage, or in order to divert rivers (see Viollet, 2000, 2006, for a review). Canals used to be derived from either permanent or non-permanent rivers.

Irrigation probably began to develop at a small scale as early as in the neolithic period, in the so-called “fertile crescent” – an arc constituted of the hills of Syria-Palestine and the feet of the Taurus and Zagros mountains, as well as south-east of the Caspian sea, when agriculture spread out from its initial Levantine birthland. But the conditions leading to large-scale hydraulic engineering and water management really appeared when early farmers settled in the low plain where the Tigris and Euphrates join. There, towns and cities appeared during the IVth millenium BC, with the Sumerian and Akkadian civilizations – when writing was also invented. Civilization development followed in Egypt, in Central Asia, where are the earliest known traces of irrigation after Mesopotamia, and also in the Indus valley with the Harappan civilization which developed during approximately 10 centuries from the beginning of the IIIrd millennium, and later in China. Those bronze age civilizations were highly centralized, at the scale of a city-state, a country, or an empire, the “palace” controlled the collection and distribution of the main products, and managed large public works, including control of the large rivers (Euphrates, Tigris, Yellow River). This came together with their capacity to develop large-scale water-management technique and works.
2.1. Irrigation methods in the earliest civilizations.

In Egypt, Mesopotamia and Central Asia, agriculture is impossible without irrigation. Available irrigation techniques at that time were:
- a- small scale lifting device, mainly the shaduf, (figure 1), only available for small-scale gardens close to a river or a canal; more efficient lifting devices, irrigation wheels and Archimedes’s screw, appeared after the IIIrd century BC (Oleson, 2000; Viollet, 2005).
- b- natural irrigation resulting from the submersion of land during the flood of a river, provided the annual flood calendar is compatible with the cycle of agriculture;
- c- gravity fed irrigation canals, derived from a large river, with a smaller slope than the river, allowing the canal to be, after some distance from the derivation point, above the land to be irrigated. This main canal used to feed secondary canals or furrows.

In the early civilizations, only the second and third of those techniques were suited to large-scale irrigation.

2.2. Egypt

In Egypt, the flood of the Nile lasts from July to October, and allowed the Egyptians just to use the flood to water the fields prior to ploughing and seeding. In Egypt, canals were used to increase the land surface which could be reached by the flood, and cultivated, and also for navigation purpose. For the management of water from the Nile, see Bonneau (1993).
2.3 Mesopotamia

The situation is quite different in Mesopotamia because the annual floods of the Tigris and Euphrates rivers come at their peak in April and May, when the grain may still be in the fields (harvesting is between February and May), and can be taken over by the flow if the flood is not kept under control. And in the summertime when irrigation is needed, water in the two rivers is at its lowest level. So agriculture in the Tigris and Euphrates valleys was just impossible without gravity-fed irrigation canals, and such canals were developed to a considerable extent. The extended use of such irrigation canals allowed those countries to be prosperous and renown for their rich agriculture. But in lower Mesopotamia intensive centuries of irrigation may have caused by 1000 BC soil salinization and as a consequence some decline in the prosperity of agriculture. It nevertheless remained a prosperous country throughout the Middle Age.

The texts from ancient Mesopotamia allow us to understand some of the features regarding the management of the canals. There were a variety of classes of canals, with different names. Considering land to be irrigated above the banks of a major river or canal (naru) flowing with some downward gentle slope, it is for that purpose necessary to derive a secondary canal (namkaru) from the larger river, (naru), and then to give to this namkaru a downstream slope smaller than the slope of the naru; after some distance downstream the valley, the secondary canal is no longer dug in the surrounding ground, but rather built over the ground, thanks to dikes.

2.4. Example: the middle Euphrates valley

During the time period between 2900 and 1700 BC, in the area of the ancient city of Mari in the middle Euphrates valley, in today’s Syria, there was on the right bank of the river, two successive and independent irrigation systems, each one depending upon such a canal as long as 20 to 30 km. The map of this area is shown on figure 2. In the ancient texts from Mari, such canals are called rakibum, a name which means “the one which rides” (over the land); figure 3 shows a typical cross-section of present remains, showing how massive the dikes used to be. These rakibum were not in use all the year long, but only during the irrigation season, and there were no villages along their course. Considerable maintenance work was necessary every year prior to the opening and use of these canals. On the left bank of the Euphrates, There was another canal, 120 km-long; this navigation canal may have been dug when the city of Mari was founded (by 2900 BC). It is known from the texts that in later times it was also used for irrigation. Mari was destroyed in 1761 BC by Hammurabi, king of Babylon.

Much later, between the VIIIth and the XIth centuries AC, in the islamic period, there was, in the same area as canal 5 of figure 2, a 35 km long irrigation canal called the Nahr Saïd, along which there were permanent human settlements; this has been interpreted as resulting from the differences in irrigation techniques, the irrigation in the islamic period using more lifting machines like chain-pot wheels (Berthier & d’Ont, 1994).
Ancient canals by 1800 BC on the middle Euphrates valley, in the area of the ancient Mari, together with the known settlements of the same time. Two canals used to be directly associated with the city of Mari: a water-supply canal (1) and an irrigation canal (2). Both canals are contemporary to the foundation of Mari, by 2900 BC. The long navigation canal Nahr Dawrin (4) was also probably built at the same period. North, a city called Dur Yahdun Lim, associated to a water-supply and irrigation canal (one single or two different canals?), may have been founded by king Yahdun-Lim of Mari by 1850 BC. From the texts dated 1800-1760 BC, it is known that the Isim Yahdun Lim irrigation canal extended as far as towards Terqa, and that the Nahr Dawrin was at that time also used for irrigation of the left bank of the Euphrates - drawn by the author using the results of the field surveys (see Geyer & Monchambert, 2003, Margueron, 2004) and other sources (see Viollet, 2000).
Figure 3. A typical cross-section of the present remains of the Mari irrigation canal (rakibum) – the canal n° 2 on figure 2; present state of conservation (after Geyer and Monchambert, 2003). Horizontal and vertical scales are different.

2.5. Central Asia

Central Asia was the second historical area of water management techniques following Mesopotamia and Syria (Masson, 1992, Sarianidi, 1992). Unfortunately, no written sources are available and the civilizations which early developed east of the southern shores of the Caspian Sea are poorly known. In the Oasis of Geoksyur, the Tedzhen river ends in the Kara Kum desert, and artificial irrigation is known as early as in the IVth millenium BC, with small canals (3 to 5 m wide, a few km long) derived from the Tedzhen and extending the area where its water could be used. Later in the bronze age, the same water management techniques extended towards the Murgab river in the Merw oasis, east of Geoksyur, as well as towards the riverine areas of the Amu Darya, and towards the Zeravchan river (in the area of the present Samarkand), with extended networks of canals.

In Shortughāi, in eastern Bactria (north of modern Afghanistan), a canal 35 km long was built by the middle of the IIIrd millennium BC in order to irrigate a large terrace which dominates the valley of the Amu Darya river (the ancient Oxus), where an ancient city pertaining to the Indus civilization had been founded. This canal was not derived from the Amu Darya itself, but rather from the Kokcha, which is another river joining the Amu Darya (figure 4).

Figure 4. The irrigation canal of the ancient Harapean settlement of Shortughāi in eastern Bactria (north of modern Afghanistan), by 2500 BC. The canal is derived from the Kokcha Darya, an affluent of the Amu Darya, and allowed to irrigate a surface of 6000 ha. Note that the course of the Amu Darya is 20 m lower than the area to be cultivated, so that its water could not be used. Drawn by the author using data from Gentelle (1989) and Gardin (1998).
In the following centuries, irrigation canals continued to develop in central Asia, up to a considerable extent. Figure 5 shows, as an example, the map of canals in eastern Bactria by 400 BC, on the eve of the arrival of Alexander the Great. Those canals were derived from the Amu Darya and its tributaries, with diversion points far upstream in order to allow the canals to “climb” upon the terraces according to the principle already described in Mesopotamia. One of those canals, called Rudi-i-Sharawan, 50 km long between the Taluqan river and the Amu Darya may be the earliest known experience of trans-basin water transfer.

The use of irrigation canals in Central Asia continued during the Middle Ages, until the Mongol invasions at the beginning of the XIIIrd century AC. These invasions destroyed most of the irrigation infrastructures or made impossible maintenance of the canals. A number of prosperous areas then returned to desert.

Figure 5. Irrigation canals in eastern Bactria (today’s Afghanistan) by 400 BC, in relation with known settlements for the same period. The irrigated fields used to lay between the canals and the rivers. Drawn by the author using data from Gardin (1998).
2.6 Other Middle-eastern areas

Early irrigation canals were also known in Syria (with the Damascus oasis, which has been irrigated from derivations of the Barada river since 1500 BC, and still active today), in south Yemen (Arabia felix), in the Nabatean area of present Jordan, etc.

2.7 China.

Civilization in China started in the Yellow River basin. Water engineering in China was primarily developed in order to handle with the terrible floods of this large river, possibly as early as during the first Xia dynasty, by 1600 BC. Its is during the so-called feudal period (VIth to Vth century BC) that canals, both used for irrigation and transport, began to be developed. This story is known from the books written by the ancient historians of the Han dynasty (ie Sima Qian, by 100 BC). See also reviews from Needham & al (1963) and Riuju, Zhaojin, Jialin (1985).

By 410 BC, a Confucianist called Ximen Bao derived a canal from the Jiang river, a tributary of the Yellow River, running towards the north-east in a course parallel to the Yellow River, allowing secondary canals to irrigate all the land between the canal and the Yellow River. Another early example is the canal built by Zheng Guo in the area of the ancient capital Changan (today's Xian, Shaannxi province) : this canal, probably built by 250 BC, was more than 150 km long, derived from the Jing river (a tributary of the Yellow River) in the upper Yellow River valley, allowing to irrigate again all the land situated between the canal and the Yellow River. Another very important irrigation program was developed by 310 BC by an engineer called Li Bing, in the Sechuan province, with a derivation hydraulic structure in Dujiangyan, origin of a system of canals irrigating all the area around Chengdu. This hydraulic structure is still in operation today.

In the following periods, especially in the early Han dynasty, this development continued. The major hydraulic achievements which were developed between the Vth century BC and the XIIIrd century AC, leading to the present Grand Canal, were for navigation purpose.

3. Canals for irrigation, transport and water-power.

Irrigation techniques which developed very early in the eastern world were later transferred to northern Africa and Southern Europe during the Arab invasions in the VIIIth century AC. Considerable development of irrigated agriculture through canals took place in El-Andalous. In the south of France (Roussillon), similar techniques were developed by the XIth century AC. See Lagardere (1991) for a review.

An important change in the history of canals is the development of water-power (see Viollet, 2005, for a review).
3.1 The origin of water-power and its development in the Roman Empire and in China.

The earliest proof of the existence of the water mill is from Greek texts and dated from the 1st century BC, in Anatolia (today’s Turquay). Water mills then developed quickly, in parallel in the Roman and in the Chinese worlds. In the Roman Empire (see Wilson, 2002), vertical wheel watermills developed to a large extent for grinding cereals. They were mostly installed upon aqueducts. There are many examples of aqueduct systems initially developed for water supply of cities, which have been later used or extended to power watermills, i.e. in Rome on the Janiculus hill and in the Caracalla Baths (IIIrd century AC), in Athens on the slopes of the Acropolis hill (Vth century AC), but also in many countryside villas. Figure 6 shows the keynote example of the Roman mills in Barbegal, which were built by the beginning of the IIInd century AC, from a deviation of the aqueduct supplying the city of Arles, in the south of France. This was powering the 16 vertical waterwheels of the mill (Leveau, 1995). By the IVrd century AC, waterpower was also used in the Roman world for sawing marble.

![Diagram of the location of the Roman mills in Barbegal](image)

**Figure 6.** The location of the Roman mills in Barbegal, on an aqueduct derived from the aqueduct system which used to supply Arles with drinking water. The Barbegal mills may have been in use between the first half of the IIInd century AC and the end of the IIIrd century.

In China, there is evidence from ancient texts that waterpower was used for industrial applications (powering mortars and hammers, as well as bellows for metallurgy…) as early as from the 1st century AC (Needham & Ling, 1965).

3.2. Canals for water-power and industrial applications in the western middle age.

In the middle age in the West, aqueducts declined with the fall of the Roman Empire, and cities centres moved from hills (which used to be supplied with aqueducts) to the vicinity of rivers, with canals for industrial activities, including watermills (Guillerme, 1983). Within and without the cities watermills development continued on small rivers or on canals derived from rivers. In 1086, after the Norman conquest of England, the *Domesday book* identifies no less than 5624 water mills in this country.
Monks (especially Benedictines and Cistercians) were among the most active communities in the development of watermills, having skillness, and manpower. It is known for example than 84 waterwheels were owned by the abbey of Saint Germain des Prés in France, one of the major abbeys owning lands between the Loire and the Rheine rivers, by the IXth century. Figure 7 shows the example of the canals and watermills in the smaller area surrounding the Pontigny abbey in France, in the XIIIrd century.

![Figure 7](image_url)  
*Figure 7. A map showing the watermills in the surrounding of the Pontigny Abbey (France), by the XIIIrd century AC. 9 mills have been identified in this area, either on the river Serein, or on a canal derived from this river (drawn by the author using data from Kinder, 1996).*

Medieval mills after the Xth century were used for many purposes: grinding cereals, moving hammers for industrial applications (paper, forges...), bellows, saws (Reynolds, 1983, Gies and Gies, 1994; for Spain, see also Gonzalez Tascon & Vazquez de la Cueva, 1993). The competition between water mills, or between water power and agriculture or navigation, was sometimes the occasion of disputes and trials.

3.3. Waterpower, canals and the development of industry.

During the period between the XVIIth and the XIXth century there was a progressive development or larger and larger industrial sites using water-power as the source of energy (for a review, see Viollet, 2005). Water-power was at the origin of the early industrial revolution, the use of coal as a source of energy developed only as a second phase.
Forges using water-powered hammers and bellows were installed on multiple canals derived from rivers, with many water wheels powering the different workshops of the chain between raw materials to terminated steel products. For instance, in 1772 in France, we know from a survey ordered by a minister of king Louis XV, that about 140 such integrated forges were known around that date. Figure 8 shows the example of one of those integrated forges, which was built by 1770 by Buffon, the naturalist and scientist.

![Diagram of Buffon forge](image)

**Figure 8.** The Buffon forge in 1828, installed on a canal derived from the river Armançon, with 8 water-wheels.

Water-power was also very important for the mining industry. In Germany, a large number of dams and canals were built between the XVIth and the XVIIIth century, in order to supply power to mines in the area of the Metal and Harz mountains. In the Harz mountains, situated between Hanover and Leipzig, more than 100 earthen dams were built in the above mentioned period, with more than 400 km total length of canals. Those technologies were then transferred to eastern and northern Europe. There were used also in the new worlds (for instance in the silver mines of Potosi in Bolivia). Very interesting illustrations of the use of the waterwheels in the mining industry of that time may be found in the book written in 1565 by a German scholar (Agricola, 1565), and translated into English in 1950 by US President Hoover and his wife.

The mechanical machine for cotton clothing manufacturing, the *spinning jenny* was invented in England in 1767. It was water-powered after 1769, and after that time water-powered mills quickly developed in England, in France and slightly later in USA. While in England the use of coal replaced hydropower after 1830 for cotton manufactures, water-power remained the main source of energy for cotton spinning mills in France and USA. In this country, in New England and Massachusetts, very large mills were built upon canals, which were powered by a large number of water-wheels, further replaced by hydraulic turbines. In 1823, a group of persons called the *Boston Associates* decided to concentrate upon the site of Lowell, where an existing navigation canal, called the Pawtucket canal and by-passing the falls of the Merrimack river already existed. From 1823 to 1847, 10 textile mills were built on this site, as shown on figure 9. J. B. Francis, inventor of the Francis turbine, spent his career as chief-engineer in Lowell. Many other similar sites were built in the country. Labour was hard and dangerous for the girls who were working in these textile mills (Corsaro & Roe, 2000).
Conclusion.

The history of canals is a very long continuous story starting with the earliest civilizations until today. Canals building and maintenance could not have been possible without civilization, and those early civilizations might not have developed without the need to organize works on canals. This happened as early as in the early bronze age period, in areas where agriculture is impossible without irrigation: Mesopotamia, Central Asia, China, and later in North Africa, Spain and southern Europe with the Arab expansion of the VIIth century AC. With the development of watermills, after the 1st century BC, another use of the canals appeared. Watermills developed in the Roman and Chinese Empires and, during the middle age, allowed the development of many industrial activities. As a continuation, water-power was at the origin of the industrial revolution of the XIXth century. Electricity generation from hydropower, from the beginning of the XXth century, was a progress in a sense that the industrial applications could be more distant from the falls, and electricity from hydropower brought new applications, as light in cities, electrochemistry and electrometallurgy. Later with the development of electrical interconnexions, it came possible to share hydropower at a larger scale. Today, hydropower for electricity generation still makes it necessary to use canals and galleries, and must be developed in a sustainable way; it provides 16% of the electricity generated worldwide, and, as a renewable source of energy, will be needed to cope with the increasing worldwide demand of energy with limited fossil resources.
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