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History of hydrology

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Preface

According to Comte, "no one can be really master of any science unless he studies its special history", but, unfortunately, the history of development of the science of hydrology has been a most neglected subject. Even in the closely related field of hydraulics, only one serious study is available: *History of Hydraulics* by Hunter Rouse and Simon Ince. Thus, it is not surprising that hydrologists have very little knowledge of their heritage, and historically erroneous statements can frequently be seen in hydrologic literatures. Early 1964, I started to read the works of early hydrologists primarily to satisfy my own curiosity. As time progressed, the subject became more and more fascinating, and I wrote a few papers on certain specific aspects of history of hydrology – notably in the journals of the Royal Society of London, American Society of Civil Engineers, International Association of Scientific Hydrology and the Society for the History of Technology. The papers, somewhat to my surprise, were enthusiastically received by both hydrologists and historians of science and technology. This enthusiastic response, coupled with the requests from fellow hydrologists from all the world, prompted me to put my work in a book form.

One of my major difficulties was a universally accepted definition of hydrology. Unfortunately, no such definition exists, and even if it did, considering the present-day tendency of multi-hydrology end, and two closely associated endeavours, hydraulics disciplinary approach to subjects, any such definition is bound to be over inclusive. For example, where does and meteorology, begin? In the present case, discharge measurement techniques, both equipment and formulas, have been considered as hydrologic events where as other aspects of open channel flow are assumed to be within the domain of hydraulics. It can be argued, with some justification that sedimentation, weather modification, soil physics and some aspects of oceanography, may be included within the field of hydrology, but to keep the book within manageable proportion, I have excluded them, and I do not propose to present a lengthy argument for or against such a step.

During the course of my research, I visited a number of museums and university libraries in Europe and North America. In the text, wherever possible, I have acknowledged their specific assistance. Many distinguished hydrologists and historians of science and technology, from all over the world, have freely given their advice and aid. It is impossible for me to express my grateful appreciation to them. But special mention should be made of continued interest and assistance from Professor Ray K. Linsley, Stanford University; Professor Ven T. Chow and Professor George White, University of Illinois; Professor J. C. I. Dooge, University College, Cork, Ireland; Professor A. Volker, Rijkswaterstaat, Den Haag, The Netherlands; Sir Harold Hartley, F.R.S., Central Electricity Generating Board, London; Professor Aurèle La Rocque, Ohio State University; Professor Gunther Garbrecht, Middle East Technical University, Ankara, Turkey; and late Professor William Fraser and Professor D. I. H. Barr, University of Strathclyde, Glasgow. My greatest debt, however, is to Arthur H. Frazier, former Chief, Division of Field Equipment, U.S. Geological Survey, without whose co-operation this book would never have been written. Finally, I would like to express my appreciation to the staff of the North-Holland Publishing Company, especially Mr. A. T. G. van der Leij, for their unfailing cooperation.

Ottawa, Canada,
March 6, 1970.

Asit K. Biswas

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G. Bell & Sons, London; Aristophanes, The clouds, translated by B. B. Rogers. 1952.

Basil Blackwell, Oxford; K. Freeman, Ancilla to pre-socratic Philosophers, 1948.

Clarendon Press, Oxford; Aristotle, Meteorologica, translated by E. W. Webster, 1952; Plato, Timaeus, translated by B. Jowett, 1953.

Hafner Publishing Co., New York; P. Perrault, On the origin of springs, translated by A. LaRocque, 1967.

Harvard University Press, Cambridge, Mass.; M. R. Cohen & I. E. Drabkin, Editors, A source book in Greek science, 1948.

Macmillan & Co., London; L. A. Seneca, Physical science in the time of Nero, translated by J. Clarke, 1910.

Miss G. M. A. Richter and Oxford University Press, London; Leonardo da Vici, The literary works of Leonardo da Vici, edited and translated by J. P. Richter, 1939.

Russell & Russell, New York; Lucretius, Roman poet of science: Lucretius, De Rerum Natura, translated by A. D. Winspear, 1955

University of Illinois Press, Urbana; B. Palissy, The admirable discourses of Bernard Palissy, translated by A. LaRocque, 1957.

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INTRODUCTION

When and where did the science of hydrology begin? It is difficult to answer, as the roots of modern hydrology lie deeply buried in antiquity. From the beginning, man realized that water is essential for survival, and hence it is not surprising that evidences of the earliest civilizations have been found along the banks of rivers: the Tigris and Euphrates in Mesopotamia, the Nile in Egypt, the Indus in India, and the Huang-Ho (Yellow River) in China. Gradually, they developed their water supply systems, constructed dams and levees, made channel improvements, and dug canals for drainage and irrigation. The presence of these structures proves that man had some knowledge of water, its powers and limitations – although it was admittedly not very scientific. The first hydrologic principles were extremely crude, but in the beginning, man was primarily interested in controlling nature; and only later, during the Hellenic Civilization[1] (around 600 B.C.), did he try to understand nature. It may be said that one cannot treat a branch of science as such until a certain degree of development has taken place, but who will define and measure that degree? To paraphrase the great historian of science, George Sarton, a 2-in. high *Sequoia gigantea* may not be very conspicuous, but it is still a *Sequoia*. After all, when the first primitive mathematician realized that there was something similar about three palm trees and three donkeys, how abstract was his thought?

ANCIENT ‘HYDROLOGIC’ WORKS

The three major civilizations that flourished some 4000 years age, were those of the Egyptians in the Nile Valley, the Sumerians in Mesopotamia, and the Harappans in the Indus Valley.[2] Much is known about the Egyptian and the Sumerian civilizations, but little about the Harappans; yet theirs embraced an area more extensive than either of the others. In contrast to the abundance of written records available of the Egyptians and the Sumerians, the history of the Harappans must be gleaned from the archaeological findings at Harappa and Mohenjo-daro, mainly because written records are scarce and are yet to be deciphered (the civilization was excavated only in the 1920’s). It has been argued recently that the Harappan civilization came to an end in a catastrophic flood of the River Indus due to tectonic disturbances.[3]

The Chinese civilization grew up on the banks of the Huang-Ho river, but their contribution to hydrology, especially prior to 600 B.C., is not as significant as that of the other three. All four civilizations had, in general, similar geographical conditions: they were based on major rivers, rainfalls were scanty, summer temperatures were high, and the phenomena of river fluctuations were comparable.

A brief review of the development of early hydrologic and hydraulic engineering around the world is presented in this chapter, and a chronology of hydrologic engineering is shown in the table.

‘KING SCORPION’ AND KING MENES

Probably one of the earliest evidences of hydrologic work having been accomplished can be found in the drawing of an imperial macehead held by the protodynastic ‘King Scorpion’,[5] a ruler who acquired his name from the scorpion appearing in front of him (fig. 1). In the drawing he wears the white crown of Upper Egypt and is probably ‘cutting the first sed’ of an irrigation ditch, a ceremony inaugurating the inundation which has continued to be practiced into the nineteenth century[6] at the festival of the ‘day of breaking the river’. In front of the king is a man holding a basket (probably filled with seeds), and beyond him is another man who is holding ears of corn. Below him are workmen who are adding the final touches to the canal. The king who has a hoe in his hand is about three times larger than the other men around him, which probably is an indication of his authority and power. The Pharaoh ruled sometime during the fourth millennium, probably around 3200 B.C. Little additional information is known about this mysterious king with his characteristic scorpion and his seven-petalled lotus insignia.

Figure 1. ‘King Scorpion’ cutting the first sod of an irrigation canal (by courtesy of Ashmolean Museum, Oxford).

King Menes ruled around 3000 B.C. He built his capital at Memphis, and was legendarily the first of the Pharaohs. According to the historian Herodotus[7] he dammed the Nile about 21½ miles south of Memphis at Kosheish, and diverted the course of the river to a newly dug channel between two hills. The gravity dam seems to have had a maximum height of about 50 ft and a crest length of some 1470 ft.8 The new capital of Memphis was then built on the old fertile river bed. Later, he excavated a lake to the north and west, of the new town, and dug a canal to connect the lake with the River Nile. The system of water courses, *viz*., the lake, the canal, and the river, served as a moat to protect King

Menes from his enemies. Consequently, the new dam had to be carefully guarded and maintained, because had there been a breach, the entire city of Memphis would have been flooded. When Herodotus visited Egypt some 2500 years later, the dam was still guarded with the greatest care by the Persians. The Egyptian priests showed the historian a list of some 330 monarchs who followed King Menes, but they were 'personages of no note or distinction', except the last who was named Moeris (better known as Amenemhet III), of whom further mention will be made later.

TABLE

A chronology of recorded hydrologic engineering prior to 600 B.C.

Date* (B.C.)	Event
3200	Reign of King Scorpion; first recorded evidence of water resources work.
3000	King Menes dammed the Nile and diverted its course.
3000	Nilometers were used to record the fluctuations of the Nile.
2850	Failure of the Sadd el-Kafara dam.
2750	Origin of the Indus Valley water supply and drainage systems.
2200	Various waterworks of 'The Great Yü' in China.
2200	Water from spring was conveyed to the Palace of Cnossos (Crete). Dams at Mahkai and Lakorian in Persia.
1950	Connection of the Nile River and the Red Sea by a navigational canal during the reign of Seostris I.
1900	Sinnōr constructed at Gezer (Palestine).
1850	Lake Moeris(?) and other works of Pharaoh Amenemhet III.
1800	Nilometers at Second Cataract in Semna.
1750	Water codes of King Hammurabi.
1700	Joseph's Well near Cairo, nearly 325 ft in depth.
1500	Two springs joined by a sinnōr in the city of Tell Ta'annek in Palestine.
?	Marduk Dam on the Tigris near Samarra, destroyed in 1256 A.D.
1300	Irrigation and drainage systems of Nippur.
	Quatinah Dam on the Orontes River in Syria constructed under the reign of Sethi I or Ramses II.
1050	Water meters used at Oasis Gadames in North Africa.
750	Marib and other dams on River Wadi Dhana in Yemen.
714	Destruction of qanāt systems of Ulhu (Armenia) by King Saragon II. Qanāt system gradually spread to Persia, Egypt, and India.
690	Construction of Sennacherib's Channel.
600	Dams in the Murghab River in Persia, destroyed in 1258 A.D.

* In the absence of accurate information, many of these dates are approximate.

SADD EL-KAFARA DAM

In 1855, Schweinfurthg[9] discovered the remains of what is sometimes called the oldest dam of the world, in the Wadi el-Garawi about 18 miles south of Cairo, Egypt. The abutments of the Sadd el-Kafara ('Dam of the Pagans') are still in existence, and it is now generally agreed that the dam (figures 2 and 3) was built during the third or the fourth dynasty, sometime between 2950 B.C. and 2750 B.C. Murray[10] made detailed measurements in 1935, and found that the structure was 348 ft long at the top and about 265 ft long at the base, with its crest some 37 ft from the lowest bed level.

It was made up of two separate rubble masonry dams, each 78 ft thick at the base, and they were separated by a space of 120 ft along the stream bed, which was later filled in with over 60,000 tons of shingle from the river bed and the adjacent hill. The upstream and the downstream dams contained about 30,000 cu. yd. of dry rubble masonry. The upstream portion of the dam had a carefully placed facing of roughly dressed limestone blocks weighing about 50 lb. each, in steps 11 in. high. Probably the engineer was pressed for time, as the downstream portion must have been hurriedly built; this would account for the shoddy workmanship of the downstream side compares to the upstream construction.

Figure 2. Sadd-el-Kafara Dam (2800 B.C.) looking downstream (by courtesy of Mrs. G. Murray).

Two notable features of the dam were that there was no provision for a spillway (was the dam supposed to be a temporary structure?), and that no mortar was used in its construction. Schweinfurth believed that the dam had been constructed to provide drinking water for the workmen and animals of an alabaster quarry located about two miles to the cast, and hence its failure due to overtopping probably did not have catastrophic consequences. The capacity of the reservoir was only 460 acre ft, and the drainage area was 72 sq. miles. Assuming that the climate of 5000 years ago was similar to that of today (in fact Murray[11] has shown it to be so), the first heavy rains would probably have been enough to fill the reservoir and overtop the dam.[12]

Complete absence of sediments upstream of the dam probably indicates the dam had failed during its first flood season. Murray stated that:

> 'it is hard not to feel sympathy with the unknown engineer who so boldy attempted the impossible – for that age. His was as notable a failure as that of Brunel with his 'Great Eastern' or that of Winstanley with the first Eddystone Lighthouse; but with a difference. The modern attempts were not absolute failures. They pointed the way for the successful designers of the next generation. But the Sadd el-Kafara is no landmark in the history of engineering. It was an outstanding solitary adventure which merely taught the ancient Egyptians never to attempt anything of the sort again. Its designer thought far ahead of this time. Had he made use of mortar, had he provided a spillway, had he chosen a wadi with a gentler slope, how different might have been the history of Egyptian irrigation!'[10]

The Egyptians did however build another dam during the reign of Sethi I (1319–1304 B.C.) on the Nahr el Asi (Orontes) near Homs in Syria. It was a 20 ft high and about 6560 ft long rockfill darn which is still in use.[13]

Figure 3. Facing the Sadd el-Kafara Dam (by courtesy of Mrs Murray).

YÜ, THE GREAT

According to Matschoss,[14] the legendary hero-emperor in China Yü, the Great, was asked in about 2280 B.C. by Emperor Yau to build great waterworks, dams and dikes. He studied the rivers, and showed genius in controlling them. He was instrumental in reclaiming much land and was said to have ‘mastered the waters’. So impressive was his work that after the death of Emperor Shun, he became the new Emperor of China. In later times he became the patron of all hydraulic, irrigation, and water resources engineers. Even in the early twentieth century prayers were offered for this great engineer-emperor in all of the river temples of China. Emperor Yü, as the eminent sinologist Joseph

Needham has pointed out,[15] is a legendary character, and no one knows exactly when he lived or indeed even whether he was an actual historical person at all. Nor can one point to any specific hydraulic or hydrologic undertaking that can be attributed to the times of Yü. But anything having to do with hydrologic engineering, in medieval China, was always considered to be under the aegis of this great legendary imperial engineer. For example, figure 4 shows a diagrammatic chart of the river systems of West China,[15] from a printed work of 1160 A.D. which carries the name of Yü because of that legend.

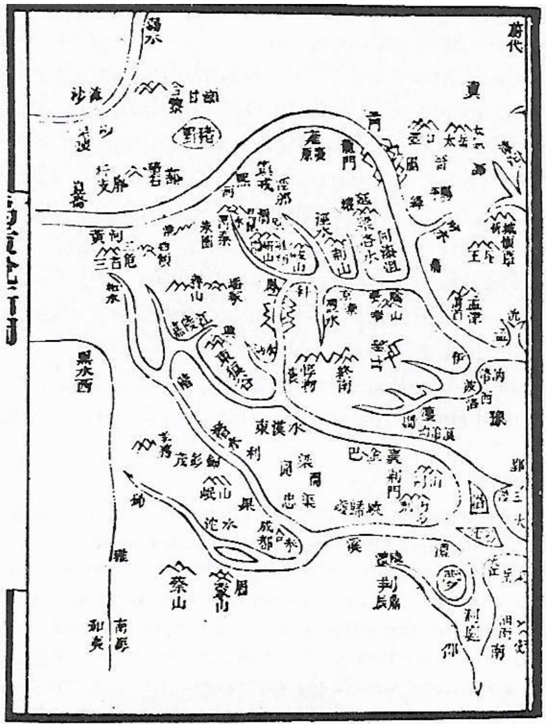

Figure 4. Diagrammatic chart of the river systems of West China from Fu Yin's *Yü kung shuo tuan* (by courtesy of Joseph Needham).

It may be pointed out that the Chinese classified their emperors as being 'good dynasty' or 'bad dynasty' depending on whether they maintained their waterworks carefully or allowed them to fall into disrepair.[16]

PHARAOH AMENEMHET III

It is sometimes reported,[17] on the authority of Herodotus, that during the Middle Kingdom (2160–1788 B.C.) artificial lakes were used to store and control the high flood flows of the Nile. The most famous Pharaoh of this period was Amenemhet III (described as King Moeris by Herodotus) who ruled for nearly 50 years (1850–1800 B.C.).

Herodotus was much impressed by the 'artificial' Lake Moeris (now called Birket Qārūn), and according to his description it had a circumference of 450 miles, which is equal to the entire Egyptian coast line. of elongated shape, the lake had an area of 656 sq. miles, a capacity of 40,000,000 acre ft,[18] and its maximum depth was 50 fathoms. There were two pyramids rising 300 ft above the water level at the middle of the lake, and Herodotus estimated the height of the structures to be about

600 ft.19 During floods on the Nile, water was diverted to Lake Moeris by means of a canal. When the inundation came to an end, the stored water of the lake was returned to the Nile, and thus the storage capacity of the lake was made available for the next flooding season. Two earthen dams controlled the flow,[20] and they were cut only in times of emergency. If the dams were cut during a year of normal or low flow, the level of the Nile dropped substantially in Lower Egypt, thus making famine inevitable. These breaches were later repaired at great expense, and the labor force necessary for such work was considered excessive, even by the pyramid builders.

Herodotus also mentioned that he had heard a rumour that there was a subterranean passage from Lake Moeris to the Libyan Syrtis. This is confirmed by the Greek historian Diodorus Siculus, who visited Egypt during the first century B.C. He was much impressed by the water resources development works of the Egyptians, and according to him, ‘no one can adequately commend the King’s design, which brings such usefulness and advantage to all the inhabitants of Egypt’. His discussion reads:

‘For being that the Nile never kept to a certain and constant height in its inundation, and the fruitfulness of the country ever depended upon its just proportion, he dug this lake to receive such water as superfluous, that it might neither immoderately overflow the land, and so cause fens and standing ponds, nor by flowing too little, prejudice the fruits of the earth for want of water. To this end he cut a trench along from the river into the lake, fourscore furlongs in length, and three hundred feet broad; into this he let water of the river sometimes run, and at other times diverted it, and turned it over the fields of the husbandmen, at seasonable times, by means of sluices which he sometimes opened, and at other times shut, up not without great labour and cost; for these sluices could not be opened or shut at a less charge than 50 talents. This lake continues to the benefit of the Egyptians for these purposes to our very day, and is called lake of Myris or Meris to this day.’[21]

Herodotus was mistaken when he considered the Faiyūm oasis (about 50 miles southwest of Cairo) to be the artificial Lake Moeris. The Faiyūm is a natural depression which was once fed by a branch of the Nile, but was separated from the valley before the neolithic age. In the lower part of the depression there was always a natural lake surrounded by marshy areas (figure 5). The pyramid builders, during the third and the fourth dynasties (2600–2450 B.C.), first made an attempt to drain the marshlands and to cultivate those areas. The work continued for several hundred years, and was culminated by the effort of Amenemhet III who reactivated the old branch of the Nile that once led to the Faiyūm. The channel is known as Bahr Yusuf or ‘Joseph’s Arm’.

Herodotus’ statement about the circumference of the lake seems to have been much exaggerated as it was highly unlikely to have been more than 110 miles. But the historian’s gravest error was about the use of the lake as a flood control reservoir for the Nile – a statement frequently quoted in many books. While it is certain that flood water was used to irrigate the Faiyūm, it is equally certain that none of it could have flowed back to the Nile. The topographical conditions make it completely impossible. Recent investigations[22] have clearly indicated the non-existence of any high level lake in the area during historic times. During the time of Diodorus (30 B.C.) or Strabo (20 A.D.), however, there was some arrangement at Illahun, which was 92 ft above sea level, by which water could either be diverted to the depression or sent back to the Nile by a 50-mile long canal. The device is freely assumed to have been a sluice gate[21] but it is highly doubtful. Diodorus describes it as a ‘skilful and costly device’ and Strabo as an ‘artificial barrier’. Diodorus also mentions that it could not be ‘*opened or closed* at a less charge than 50 talents’ ($28,000). The only way these three descriptions can be reconciled is by some system of temporary dams, and that is probably what existed.

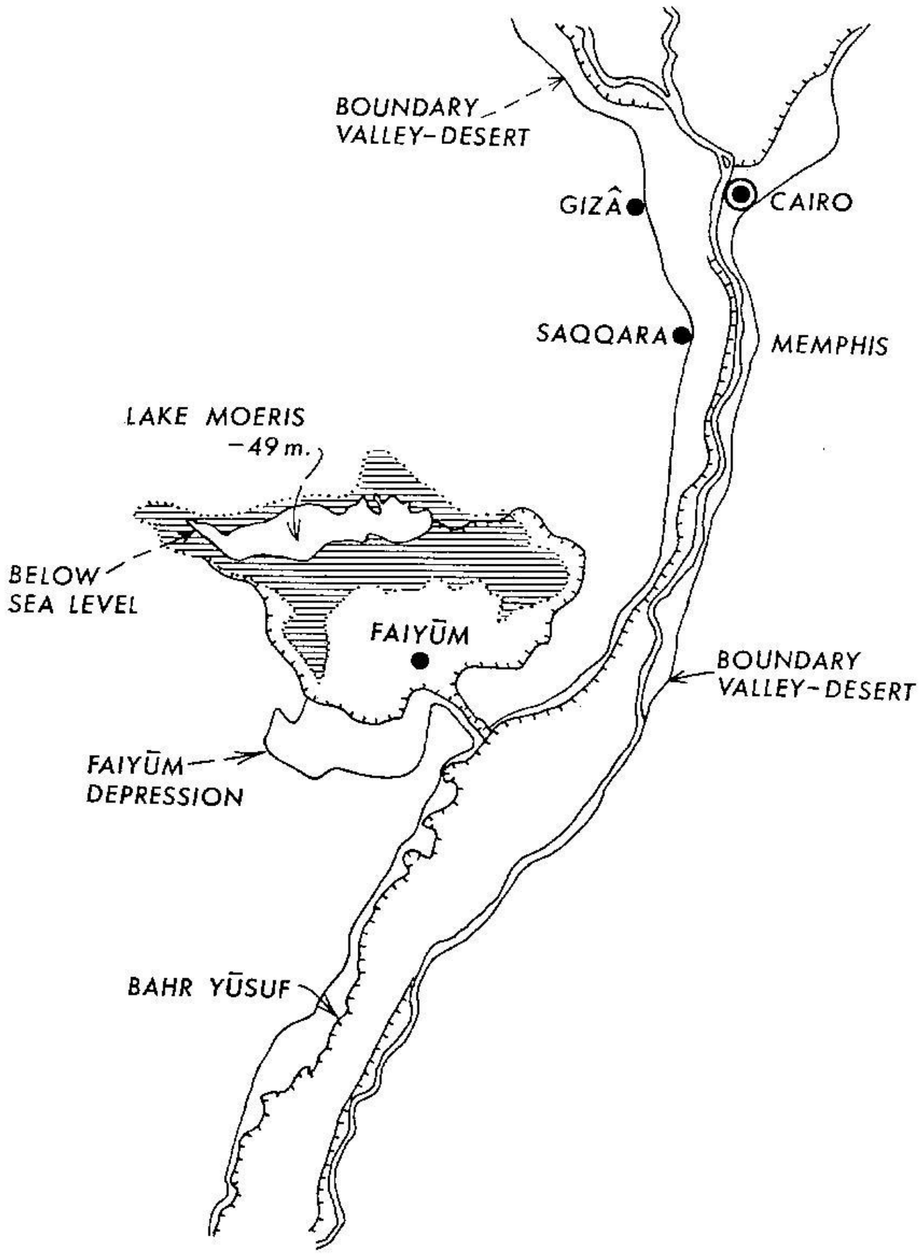

Figure 5. Faiyūm depression in the Nile Valley

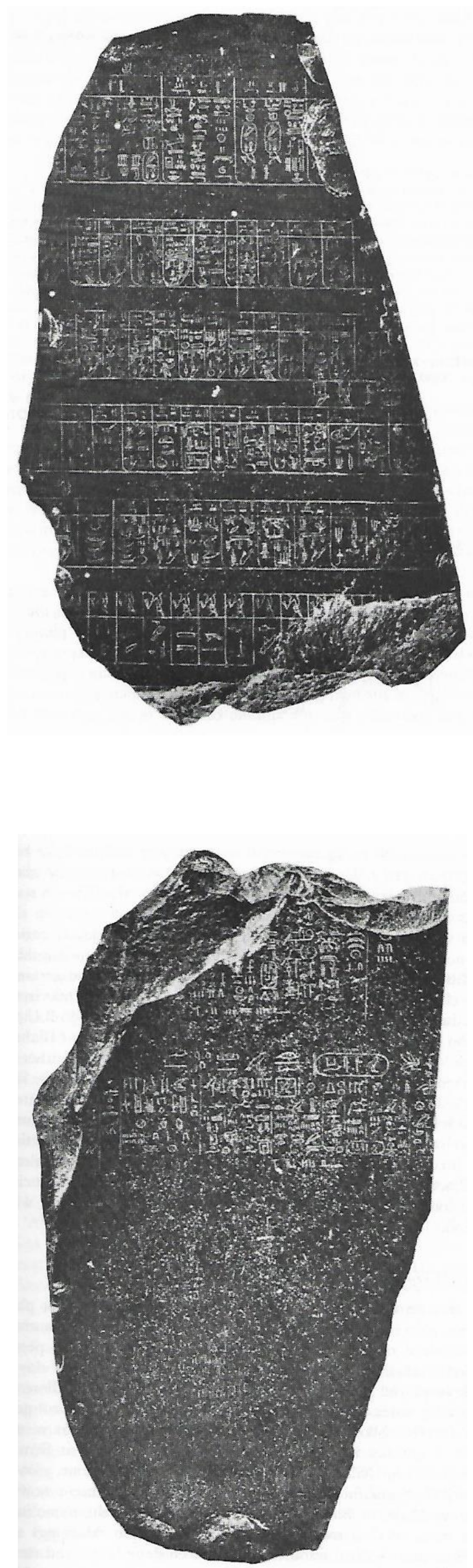

Figure 6. Records of Nile levels (3000–3500 B.C.) from fragments of an ancient monument (by courtesy of Palermo Museum, Sicily).

NILOMETERS AND FLOOD CONTROL

The day on which the annual inundation of the Nile took place was the most important one in the Egyptian calendar. As the summer season wore on, and the Nile stage gradually increased, people waited anxiously for the *wafa* to come –for *wafa* is the day of celebration and feasting,[23] when the dikes can be cut to allow the life-giving water to flood the land, and thus raise hopes for a good crop for the following year. The levels were marked at several places –notably in a section of the second cataract at Semna. Records of the Nile levels can be traced back to about 3000 to 3500 B.C., from the fragments of an ancient monument now in Palermo Museum, Sicily (figure 6). Nilometers, as the name indicates, were used to measure the levels of the Nile. Markings and inscriptions at several nilometers have been deciphered and correlated. 'At Karnak in 1895, M. LeGrain found a series of 40 high Nile levels marked on the quay walls of the great temple. They date from about 800 B.C., and the mean altitude given by them for a high Nile is 74.25 meters (243.6 ft) above sea-level, while that of today [1906] is 74-93 [probably a misprint 74.25 + 2.68 = 76.93 m], showing a rise of the river bed of 2.68 meters (8.8 ft) in 2800 years, or at the rate of 0.096 meters (3.8 in.) per century.'[24] Jarvis calculated 25, the rate of aggradation of the Nile Delta to be 5.2 in. per 100 years over the period 200 to 1800 A.D.

Three types of nilometers were used. The first type consisted simply of marking the water levels on cliffs on the banks of the river. The second utilized flights of steps which led down to the river. The third and most accurate one used conduits to bring water of the Nile to a well or cistern. The levels were marked either on the walls of the well or on a central column.

The longest continuous record of the Nile is available from the nilometers near Cairo –the most notable one being the Roda (or Rauda) nilometer. When the Arabs conquered Egypt in 641 A.D., they found several *Miqyas an-Nil* (measure of the Nile) in use. The first known Arab nilometer was built on the southern end of the Roda island in 715 A.D., under the Omayyad caliphs Walid ibn 'Abd al-Malik (705–715 A.D.) and Sulaiman (715–717 A.D.).

It was rebuilt in 861 A.D. Practically nothing is known about the several other nilometers around Cairo prior to 715 A.D., nor do we know at which particular nilometers the river levels were read.[26] Most of the nilometers now extant, however, originated in the Persian, Ptolemic, and Roman periods.[27]

The Roda nilometer was first investigated by Le Pere and Marcel (1798–1800 A.D.) during the Napoleonic expedition into Egypt. It consisted of a square well connected to the Nile by means of three conduits. At the centre of the well is a graded octagonal column of white marble, and there are steps leading down to the bottom of the well (figure 7). The records of maximum and minimum levels of the Nile are available for the Roda site from 64I A.D. to 1890 A.D. With the completion of Aswan Dam in 1890 A.D., the readings of before and after the date cannot be compared satisfactorily.

The Egyptians depended on the regular inundation of the Nile for their livelihood, but the river in a high flood was entirely another question. It then turned from creation to destruction, and one such flood recorded in 638 B.C. turned the whole valley into 'a primordial ocean, and inert expanse'. Since the Egyptians repeatedly had to face the problem of serious flooding, they gradually developed a system of flood warning encompassing the various temples and their nilometers. At present, little evidence is available of any actual technical cooperation having taken place between the temples[28] but according to Diodorus[29] flood warnings were sounded to the population from the nilometer at Memphis in case of emergency. With the approach of the flood season, the levels of the Nile were carefully watched and compared with the markings of the previous year. Swift rowers were sent from the furthest upstream of the gauging stations, one after another, to report the latest level at the capital. These extremely good rowers, rowing with the current, were able to outpace the approaching peak flood and give sufficient advance warning to the to people of the forthcoming catastrophe.

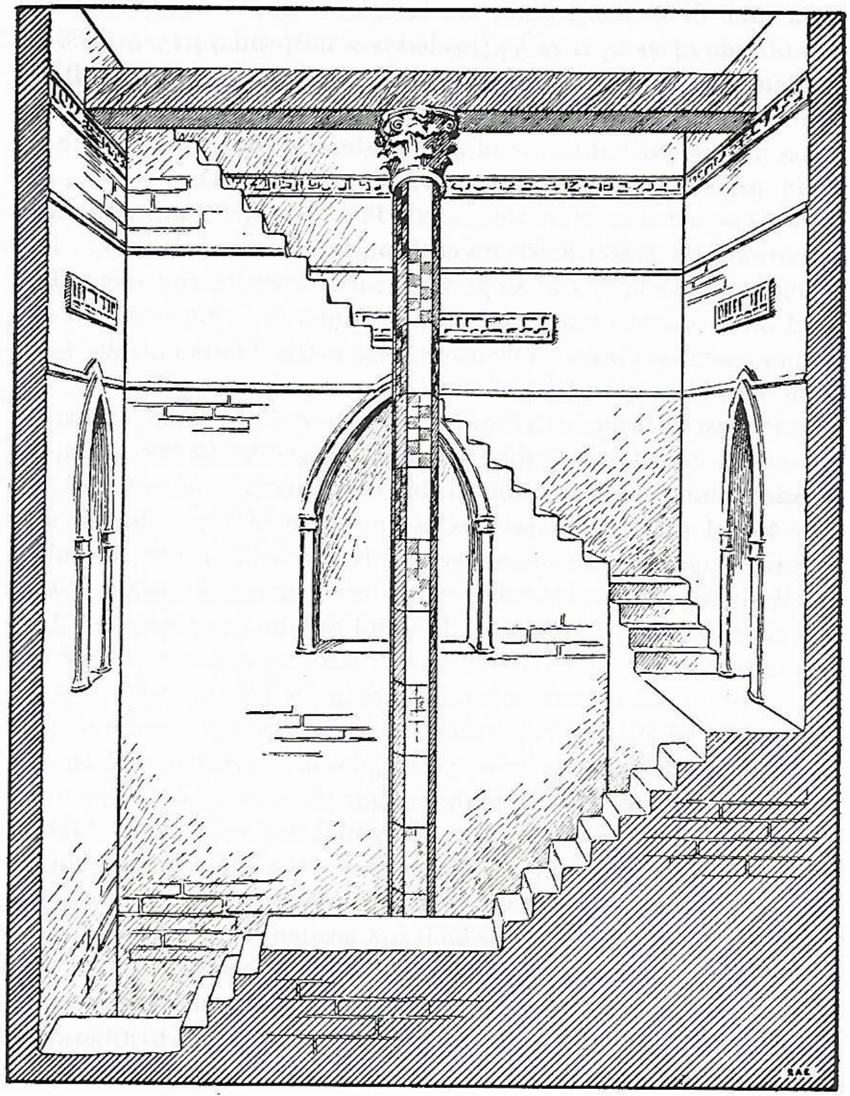

Figure 7. The Roda nilometer in 1798 A.D., a reconstruction from descriptions (by courtesy of University of California Press).

Diodorus reports that 'out of the fear of inundation, a watch-tower is built in Memphis, by the Kings of Egypt, where those who are employed to take care of this concern, observing to what height the river rises, send letters from one city to another, acquainting them how many cubits and fingers the river rises, and when it begins to decrease; and so the people, coming to understand the fall of the waters, are freed from their fears, …, and this observation has been registered from time to time by the Egyptians for many generations'.[28, 29]

The flood observations continued without a break even during major religious or political upheavals. Engreen believes[30] that an interrelation developed between the observations of the Nile flood and the cult of the god Serapis. He quotes Rufinus' statement on the nilometer in the Serapeum at Alexandria in support of his theory: 'But as it was common use in Egypt, that the measuring of the river Nile during its rise was reported to the temple of Serapis, reported, as it were, to the originator of the increased waters and inundations ...' [29, 30]

Various concepts of the origin and rise of the river Nile will be discussed in detail in chapter 6.

UR BABYLONIAN TABLET

The Old Babylonian cuneiform tablet shown in figure 8, presently in the British Museum, presents, on both sides thereof, many problems with their solutions. On the side shown in this figure,[16] problems appear concerning dams, walls, wells, water-clocks, and excavations.

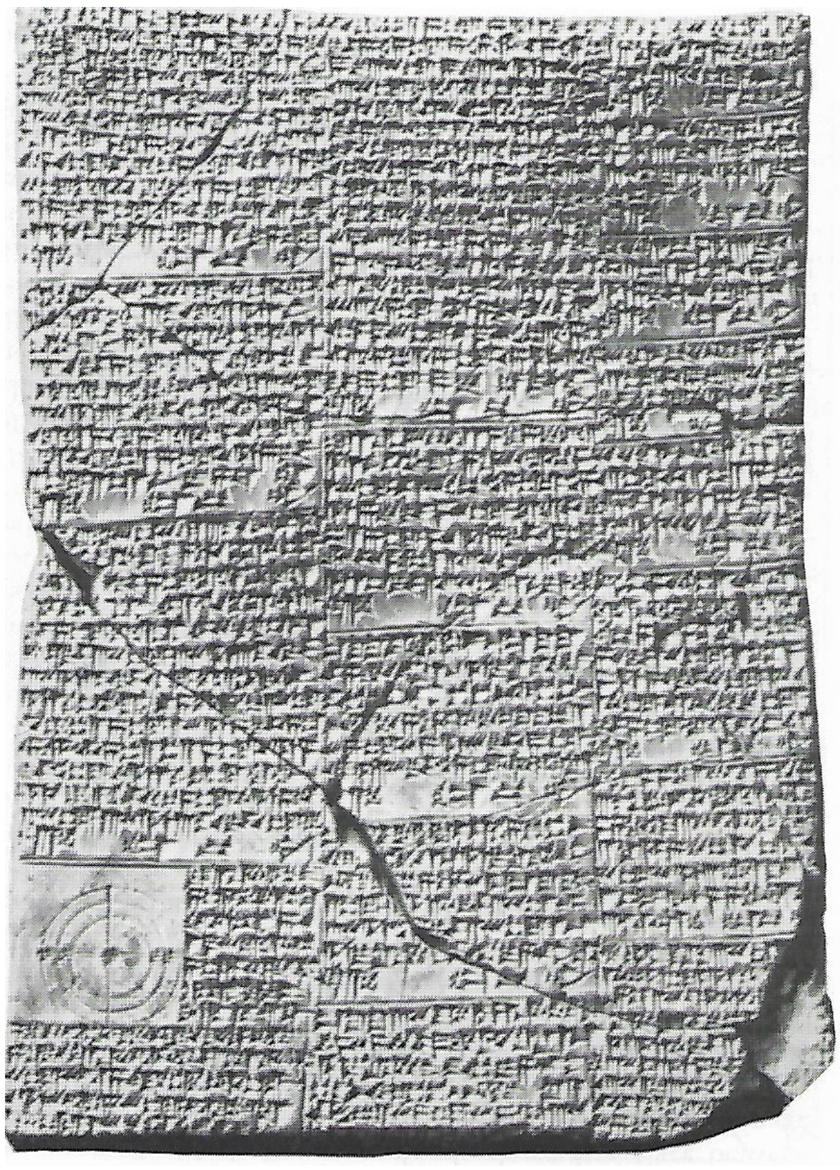

Figure 8. Part of Ur Babylonian tablet, 1800 B.C. (by courtesy of Trustees of the British Museum).

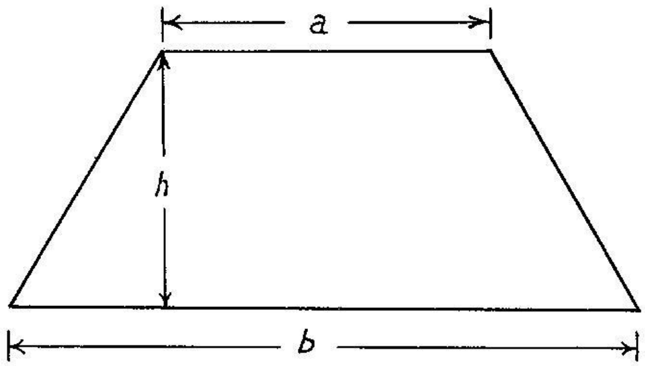

Figure 9. Construction of a dike profile, 1800 B.C.

There is no information on the precise provenance of this Ur Babylonian tablet (BM 85194), but its date can be said to be roughly in the eighteenth century B.C.

Part of the fourth problem, illustrated by a drawing, requires a dike profile to be constructed in the form of an isosceles trapezoid.[31, 32] The base *b*, inclination *a*, and the area A, are given (figure 9), and the top width *a* is to be calculated. It actually calculates a^2 from

$$a^2 = b^2 — \quad 4^{aA}$$

and

$$A = \left(\frac{b + a}{2} \right) h$$

Hence,

$$4^{aA} \quad = \quad b^2 — a^2$$

In another problem in the same text, a is known, and b is calculated from the first equation.

CODE OF HAMMURABI

King Hammurabi, the self-styled 'obedient and god-fearing prince', conquered Mesopotamia around 1760 B.C. He was the sixth and the greatest King of the first (Amorite) dynasty of Babylon, and was aware of the necessity of having a good network of canals for irrigation as well as for communication and transportation. Unlike the Egyptians with the Nile, the Sumerians had two extremely unpredictable rivers in the Tigris and Euphrates. Flooding was a constant danger, and if it occurred simultaneously in both rivers, it brought untold misery. The story of Noah comes from the legendary greatest flood of the Sumerians,[33] and hence it is no surprise to find the art of building flood protection works, like earthen walls or levees, was quite will developed during this period.

Rulers of this period were as much interested in their hydraulic works as in their conquests, and justifiably so. According to Sarton,[34] traces of their early canals can still be distinguished from the air. The available documentary evidence indicates that King Hammurabi often directed his provincial governors to dig canals as well as to dredge them regularly. In a memorandum to one Sid-idinnam, the King complained about a canal having been so imperfectly dug that boats could not enter Erech, and also about the canal needing repair near the banks of the Druru. He ordered an official to rectify those defects within three days of receipt of his communication, using men who were then at his disposal. Thus, with the gradual political integration of the country, there was a strong centralized control of water.

The famous Code of Hammurabi is the most complete codification of Sumerian and Babylonian law. It was discovered in Susa in 1901 by the French Assyriologist Jean Vincent Scheil, and is at present in the Louvre Museum in Paris. Figure 10 shows the upper part of the Code of Hammurabi, depicting the King as either offering it to the Sun God Shamash or being charged by the God to write his code. The laws concerning irrigation were carefully contrived, and it seems that they were primarily aimed at preventing carelessness which might result in flood damages, as emphasized in the following excerpts:

‘Sec. 53. If any one be too lazy to keep his dam in proper condition, and does not keep it so; if then the dam breaks and all the fields are flooded, then shall he in whose dam the break occurred be sold for money and the money shall replace the corn which he has caused to be ruined.’

Figure 10. Part of the code of Hammurabi in the Louvre Museum.

‘Sec. 55. If any one open his ditches to water his crop, but is careless, and the water flood the field of his neighbor, then he shall repay his neighbor with corn for his loss.’

‘Sec. 56. If a man let out the water, and the water overflow the land of his neighbor, he shall pay 10 *gur* of corn for every 10 *gan* of land flooded.’[35]

In the absence of further records, it can safely be assumed that hydrologic engineering was quite advanced nearly 4000 years ago, and that even today one can detect the influence of the Code of Hammurabi on modern water laws.

SINNŌRS OF PALESTINE

Sinnōrs, or water tunnels, were used in Palestine prior to 1200 B.C. The cities in Palestine and Syria were usually built on the tops of hills at the bottoms of which were streams providing the municipal water supplies. Thus, during times of war, cities were rather vulnerable because invaders could easily cut off the supply of water from the city. To protect the city, first a tunnel was dug, one end of which provided a secret approach to the stream. Its other end was located within the city’s boundary. Entrance to the sinnōr was gained by a shaft provided with a flight of stairs. In later versions thereof, a conduit on the floor of the tunnel brought water from the stream to the base of the shaft.[36]

Figure 11 shows the Siloam sinnōr which King Hezekiah constructed around 700 B.C. According to the Second Book of Chronicles, the King also ‘stopped the upper watercourse of Gihon, and brought it straight down to the cast side of the city of David’. The 1750 ft long tunnel, cut through limestone, conducted the water of the Gihon well under the city wall into the city proper. The tunnel is still in use today.

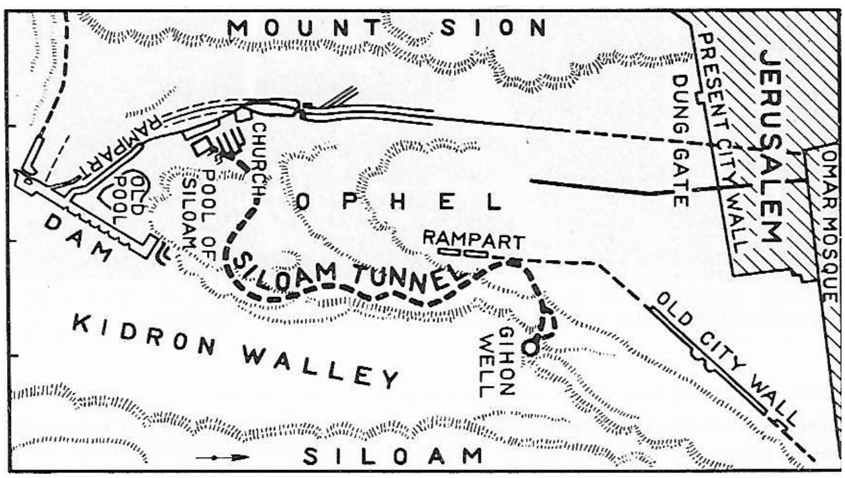

Figure 11. Plan of Siloam tunnel (by courtesy of Nils Borg).

EVIDENCE AT NIPPUR

Around 1300 B.C., Nippur in Mesopotamia was one of the most famous centres of Sumerian religion, and recently American archaeologists have excavated thousands of tablets at the site. Most of these tablets were unbaked, and hence they are not well preserved, and are very difficult to decipher, but some of the maps excavated at Nippur were so faithfully made that they even helped the archacologists to continue their excavations.

Figure 12 is a map of fields and canals at Nippur. A translation of the cuneiform captions is shown in figure 13. Unmarked fields were either common lands for grazing or in the process of changing hands. Probably the ‘Canal of Hamri’ was the main canal, and water entered it during periods of the river's high flow. It is likely that channels marked ‘irrigation’ or ‘canal’ were intended for irrigation purposes, whereas those marked ‘stream’ could have been drainage ditches. The drainage ditches were perhaps used to remove the water out of cultivated areas during low-river stages. It is interesting to note the designation ‘Marshland of the town of Hamri’, where in all probability cane-reed was cultivated. Since the country was almost treeless, reeds were used for almost everything – building, basketry, furniture, and firewood. Reed-matting was used for strengthening the dikes which protected the alluvial soil.

Figure 12. Map of irrigation system near Nippur in Mesopotamia, around 1300 B.C. (by courtesy of Pennsylvania Museum).

WATER METERS

A primitive type of water meter was used at the Gadames oasis of North Africa more than 3000 years ago,[31–39] and it is still being used without modification. The oasis has a small spring called Ain el Fras (‘Spring of the Mare’) which according to legend, was discovered by the horse of an Arabian conqueror. The spring discharges around 180 cu. m per hr, which is collected in a basin and distributed through a main canal and two side canals. The process was developed for the equitable distribution of irrigation water from the spring to the various agricultural fields.

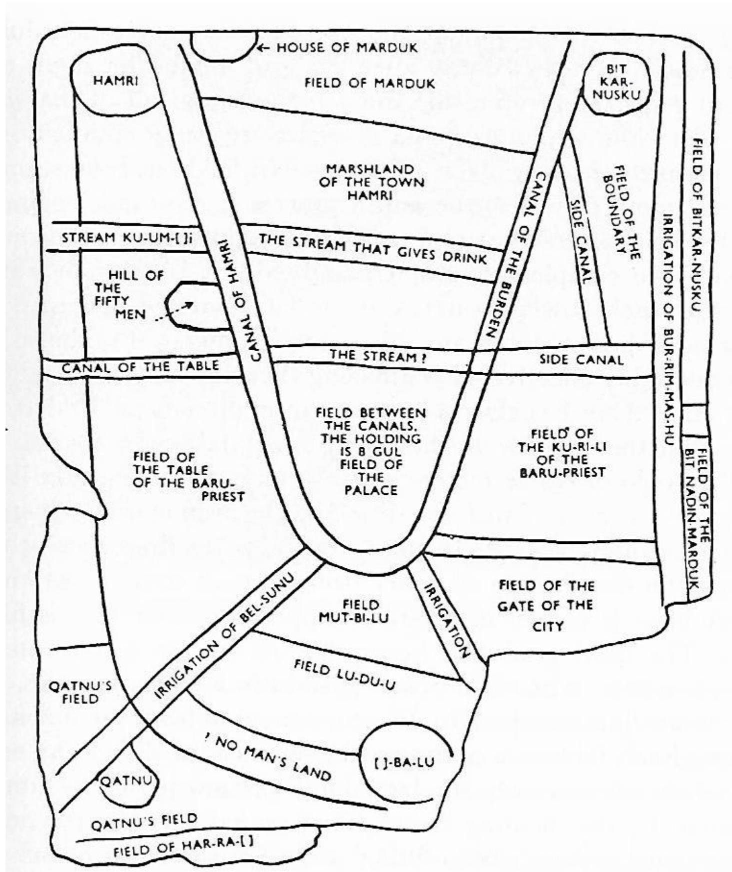

Figure 13. Translation of the cuneiform text of figure 12.

A container, consisting of a pot with a hole in its bottom, is lowered by means of a rope into the water of a well at the market place. When filled it is pulled up, the water is allowed to drain back into the well through the hole in the pot, and the cycle is repeated over and over again. It requires a period of about three minutes for each cycle to be completed. This arrangement forms the basis of the water-distribution system. A water commissioner decides the amount of time, as measured continuously by the filling and emptying of the pot, that a given land owner may divert the entire flow of the nearest irrigation ditch onto his land. Upon the arrival of the last cycle to which a given participant is entitled, a small bundle of straw is dropped into a nearby reach of the irrigation ditch, and allowed to float down to that man's field. When it arrives there, he must clear the channel so as to allow the water to flow down to the dam of the next participant, and he must also seal off his own diversion sluices. That process is repeated day after day and night after night until the last participant along the ditch has received all of the water released to him while his quota of cycles are being counted off at the well in the market place. After that last field has been supplied with its quota of water, the entire process is repeated, beginning with the field nearest the supply reservoir. About 12 days are required to make the complete round. Undoubtedly it is a crude way to distribute such flowing water, but the fact that the process is still being carried out without any appreciable changes, is evidence that it is reasonably effective. It is amazing that day and night for over 3000 years there has always been a man in attendance at that well to see that the water from the spring is equitably distributed.

Another type of water meter, whose principle of operation is just the reverse of the one just describes, has been in continuous use in Yemen for many years.[40] In this instance, a 'floating clock' is used to time the distribution of water from a small stream. An empty copper bowl is placed in a larger copper container that is full of water. The bowl gradually becomes filled by the water entering through a hole in its bottom, and it sinks in about 5 minutes. It is then immediately raised to the surface to repeat the unending process. Each farmer is permitted in his turn, to divert the entire flow of the stream onto his land for a certain period of' time as measured by the ‘floating clock’. That period is computed on the basis of one cycle of ‘bowl-filling’ time for each 100 *lubnah* (approximately 2/3, acre) of land in the field. Because of the importance water in the desert, the job of *Muqassim addayri* (the water-divider) is important and prestigious.

GROUND WATER UTILIZATION

Undoubtedly the greatest achievement in the utilization of ground water of ancient times was the building of qanāts (or kanāts). A qanāt is an artificial underground channel which carries water over long distances either from a spring or from water-bearing strata, and it solved several problems in water resources engineering. First, evaporation was undoubtedly a major problem in hot and arid climates, and hence, with the limited water supply, surface transport was a distinct hazard. Secondly, it was difficult to maintain a uniform slope in a hilly country; and finally, qanāts kept water cool and free of surface pollutants. Figure 14 is an aerial photograph of qanāt systems originating in the talus deposits at the foot of the mountain near Kashan in Persia.

Figure 14. Aerial photographs of qanāt systems in Persia.

Contrary to present belief, qanāt building probably started in Armenia[36, 41] and not in Persia. In his invasion of Urartu (present Armenia), King Saragon II (791–705 B.C.) of Assyria destroyed the irrigation network of the town of Ulhu. He describes the irrigation system of the vanquished King of Ulhu in these terms: ‘Following his ingenious inspiration Ursa, their King and Lord ... revealed the water outlets. He dug a main duct which carried flowing waters ... waters of abundance he caused to flow like the Euphrates. Countless ditches he led out from its interior ... and he irrigated the fields’.[42]

The construction of this remarkable system, which according Tolman[43] was 'the greatest waterworks of the ancients', was directed by an engineer called *Muqannī*. He first located the water bearing strata by digging a number of test wells, and when a good stratum was hit, a mother well was dug. Another well was dug some distance away, usually about equal to the depth of the well, and the two wells were connected by a tunnel. By this procedure the construction continued. The direction and depth of the tunnel was determined by means of a crude but adequate system of plumb bobs. Figure 15 shows a typical water supply system by qanāts; the cross-section was somewhat egg-shaped. Since the Persians rarely dug through rock, the routes of the qanāts had numerous twists and turns, and large deviations were also made around hills. Only one man could dig at one time, and the excavated material was removed in a goat-skin bag through vertical air shafts. If necessary (depending on the soil conditions), lining materials were carried in the same bag on the return journey. As reflected light was used for digging, and working conditions were rather grim, one would expect that accidents would be rather common and loss of lives frequent. Details of qanāt construction have been discussed in detail by Wulff.[44]

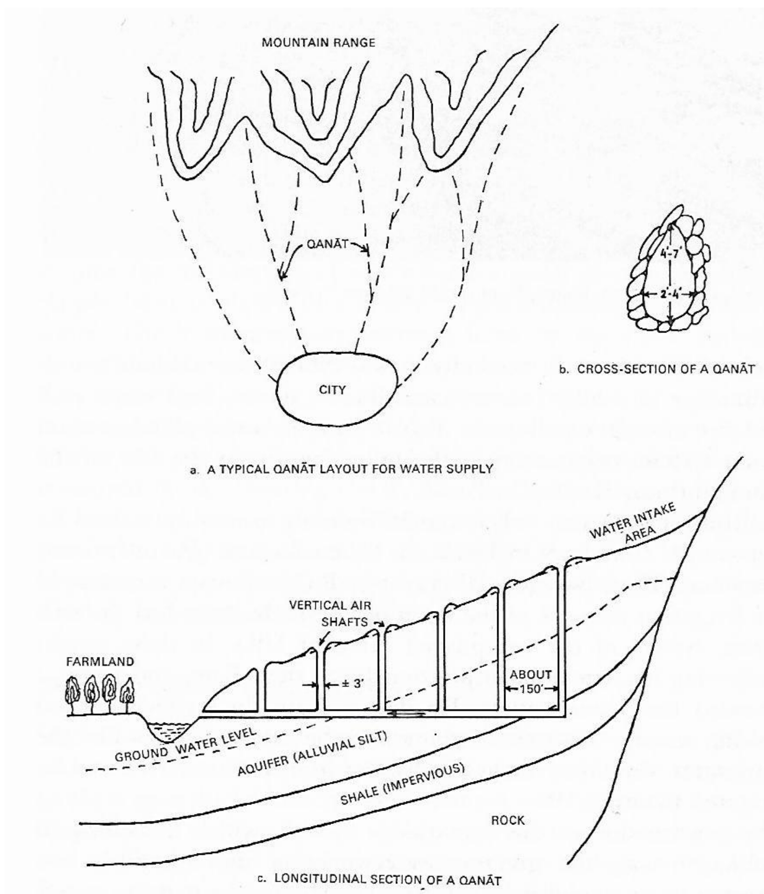

Figure 15. Details of qanāt system (not to scale).

South of Dizful in Persia is one of the old qanāt systems. It consists of three pairs of tunnels taking water from the gravel bars near the River Ab-i-diz, about seven miles north of Dizful. Two pairs of qanāts supply water to the neighbouring land for agriculture, and the remaining pair supplies the city.

These qanāts are at such a depth that some houses in the city extend six stories below the ground level to tap the water.

During the time of Darius I (521–485 B.C.), his Caryandan Admiral Scylox went to the oasis of El-Khargeh[45] in Egypt, and there introduced the qanāt system of irrigation. Butler believed[35] that they must have extended far enough eastward – in fact under more than a hundred miles of rolling desert to intercept seepage from the Nile. Recent investigations, however, have clearly indicated[46] that the trace of the qanāts can be found from discharge point back toward the intersection of the water table in the talus slope of the escarpment of the plateau, a distance of about 2 miles. Traces of it can be followed very easily by the vertical air shafts connected with the main ditch.

Use of these long infiltration galleries to tap ground water from soft sedimentary rocks or alluvial fan deposits quickly spread from Armenia to as far as Northern India.

The qanāt used the principle of gravity flow. Its average length in desert regions was 25 to 28 miles. It had a gentle slope of 1 to 3 on 100. In some places it had a depth of nearly 400 ft.47 Considering the state of hydraulic science during the period in question, it was n mean achievement.

MARIB DAM

The Marib dam, which was probably constructed somewhere between 1000 and 700 B.C., was considered to be one of the wonders of the ancient world.[48] It was located on the Wadi Dhana, nearly 40 miles from the ancient city of Marib (now in Yemen), and was known to the Moslems as Sudd-el-Arim. According to the Encyclopedia of Islam,[49] a series of dams controlled the River Denne, a fair-sized river on the eastern side of the high mountain range in Yemen.[18] Of all the dams on the river, Marib was the largest and was an earthfill structure. The dam was some 33 ft high and 1900 ft long. It was flanked on either side by large outlet works of excellent masonry.[50] No mortar was used in the construction of the dam (just as in the ill-fated dam at Sadd el-Kafara), except for a covering on the top, which was probably added for the prevention of damage from rain.

The dam first breached in the fifth century A.D., and was finally destroyed during the latter half of the next century. But unlike Sadd el-Kafara, its failure had terrible consequences. ‘There is hardly any historic event of pre-lslamic history that has become embellished with so much that is fanciful, and related in so many versions, as the history of the bursting of the Marib Dam.’[49] According to the Koran (Sura 34, verse 14) ‘the people of Seba had beautiful gardens with good fruit. Then the people turned away from God, and to punish them, He burst the dam, turning the good gardens into gardens bearing bitter fruit’.

WORKS OF SENNACHERIB

No work on ancient hydrologic engineering can be complete without reference to Sennacherib (705–681 B.C.). Out of shear barbarism, the Assyrian King dammed the Euphrates in 689 B.C., only to let loose the resulting flood on the vanquished and burnt city of Babylon. But Sennacherib was an excellent strategist, a good architect, and among other things he invented water-lifting machines and introduced cotton to Assyria. His main contribution to hydrology, however, was his successful attempt to develop the water resources of the region.[50]

The capital of Assyria was Nineveh, on the banks of the River Tigris, but the muddy water of the river was not good enough for an emperor, and hence he sought clear water for Nineveh and his palace at Khorsabad. It was accomplished in three stages. The first stage involved placing a weir across the River Khosr near Kisiri (703 B.C.), and constructing a 10-miles-long canal to irrigate the orchards of some 18 settlements in the plain west of Nineveh (figure 16). In the second stage (694 B.C.) 18 water courses were diverted and canalized to bring water from the mountainous Jebel Bashiqah region to the city. Two dams, constructed of square stone blocks, were used in series to divert this water from the Khosr River to the capital. The diversion of water from the Atrush-Gomel River system (690 B.C.) was accomplished during the final stage. To do so, a diversion dam was built obliquely across the Atrush River near the gorge of Bavian to create a reservoir. Then he constructed a magnificent canal[51–55] (Sennacherib's Channel), for conducting the water from the reservoir. The canal followed the natural course through the foothills with a slope of about 1 on 80. It took 15 months to complete this 35-mile long canal with its extensive limestone- block pavements and its arched aqueducts over several brooks and valleys. The aqueduct of Jerwan was nearly 1000 ft long, 39 ft wide, with two side walls 5 ft high and 8 ft thick. Fourteen piers were used to carry the aqueduct, the bed of which consisted of three layers of limestone blocks. The inscription on the structure stated, 'Over deep-cut ravines I spanned (lit., caused to step) a bridge of white stone blocks. These water I caused to pass over upon it.[44] A rock carving near the headwork of the structure records, 'To the great gods the King prayed and they heard his prayer; they directed the work of his hands. By gates and a tunnel the sluices opened of themselves and permitted the rich water to flow down According to the wishes of the Gods' heart, he had dug the water, carried from the stream, and directed its force'.

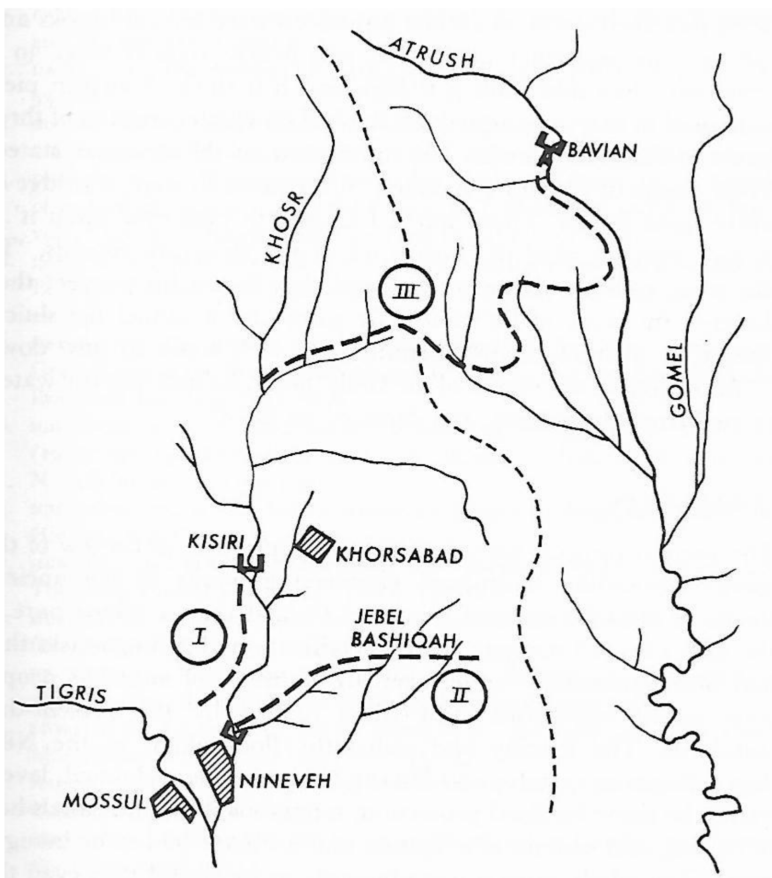

Figure 16. Water resources development of King Sennacherib.

CONCLUSION

The various projects discussed in this chapter are just a few of the more outstanding hydrologic engineering works of the ancient times. It must be realized that they formed only a minor part in the man's overall struggle towards civilization. The huge tasks that had been successfully undertaken by countless of nameless people were major operations even when judged by the present-day standards. The marshy and unhealthy flood-plains of the Nile, Tigris-Euphrates, Indus and Huang Ho had to be reclaimed, levees had to be made for flood protection, numerous wells and canals had to be dug, and systems of irrigation and drainage had to be inaugurated. The whole process was obviously so successful that even the Garden of Eden was claimed to have been located between the Tigris and the Euphrates rivers. Hydrologists and hydraulic engineers played a significant part in the successful planning, design, construction, operation and maintenance of these works. Their works were instrumental in the development of these civilizations – so much so that we can justifiably call them 'hydraulic civilizations'.

REFERENCES

1. BISWAS, ASIT K., Hydrology during the Hellenic Civilization. Bulletin, International Association of Scientific Hydrology 12 (1967) 5–14.
2. EASTON, S. C., The heritage of the past, revised ed. New York, Holt, Rinehart and Winston Inc. (1965) p. 35.
3. DALES, G. F., The decline of the Harappans. Scientific American 214 (1966) 92–100.
4. BISWAS, ASIT K., A short history of hydrology. Proceedings of the International Seminar for Hydrology Professors, University of Illinois, Urbana (1969).
5. DROWER, M. S., Water-supply, irrigation, and agriculture. In: A history of technology, edited by Charles Singer, E. J. Holmyard and A. R. Hall, vol. I. London, Oxford University Press (1954) pp. 520–557.
6. LANE, E. W., Manners and customs of the modern Egyptians, edited by E. Rhys. London, Everyman's Library, J. M. Dent and Sons Ltd. (1908) ch. 14.
7. HERODOTUS, The history of Herodotus, translated by George Rawlinson. Great Books of the Western World, vol. 6, book 2. Chicago, Encyclopaedia Brittanica Inc. (1952) pp. 68–69.
8. SCHNITTER, N. J., A short history of dam engineering. Water Power 19 (1967) 142-148. Discussions by Asit K. Biswas, 19 (1967) 258. Reply by N.J. Schnitter, 19 (1967) 345.
9. SCHWEINFURTH, G. A., Auf unbetretenen Wegen in Aegypten. Hamburg, Hoffman und Campe (1922) pp. 213–231.
10. MURRAY, G. W., Water from the desert: some ancient Egyptian achievements. The Geographical journal 121 (1955) 171–181.
11. MURRAY, G. W., Desiccation in Egypt. Bulletin de la Société, Royale de Géographie d'Egypte 23 (1949).
12. HELSTRÖM, B., The oldest dam in the world. Bulletin no. 28, Institution of Hydraulies, Royal Institute of Technology, Stockholm (1951).
13. DUSSAUD, R., La digue du lac de Homs et le 'mur Egyptien' de Strabon. Monuments et Mémoires (1921–22) 133–141.
14. MATSCHOSS, C., Great engineers, translated by H. S. Hatfield. London, G. Bell and Sons Ltd. (1939) p. 5.
15. NEEDHAM, J., Science and civilisation in China, vol. 3. Cambridge, University Press (1959) p. 515.
16. BRITTAIN, R. F., Rivers, man and myths, from fish spears to water mills. New York, Doubleday and Co. Inc. (1958) p. 59.
17. PAYNE, R., The canal builders. New York, The Macmillan Co. (1959) pp. 13–16.

18. HATHAWAY, G. A., Dams – their effect on some ancient civilizations. Civil Engineering, ASCE 28 (1958) 58–63.
19. HERODOTUS, *op. cit*., p. 81.
20. WILLCOCKS, w., From the garden of Eden to the crossing of the Jordan, 2nd ed. London, E. and F.N. Spon Ltd. (1926).
21. DIODORUS SICULUS, The historical library of Diodorus, the Sicilian, translated by G. Booth, vol. 1. London, J. Davis (1814) p. 57.
22. BISWAS, ASIT K., Hydrologic engineering prior to 600 B.C. Journal of Hydraulics Division, ASCE 93 (1967) 115-135. Discussions by G. Garbrecht, G. J. Requardt and N. J. Schnitter, 94 (1968) 612–618, by B. F. Snow, 94 (1968) 805–807, and by F. L. Hotes, 94 (1968) 1356–1357.
23. THOMSON, M. T., The historic role of the rivers of Georgia: measurements from Mena to Mead. Privately circulated.
24. LYONS, H. G., Physiography of the River Nile and its basin. Cairo, Ministry of Finance, Survey Department (1906).
25. JARVIS, C.S., Flood-stage records of the River Nile. Proceedings, ASCE 62 (1936) 1012–1071.
26. POPPER, W., The Cairo nilometer. Publications in Semitic Philology, vol. 12. Berkeley, University of California Press (1951).
27. BORCHARDT, L., Nilmesser und Nilstandsmarken. Berlin, Preussische Akademie der Wissenschaften, Philosophisch-historische Abhandlungen nicht zur Akademie gehöbriger Gelchrter, no. 1 (1906).
28. OTTO, W. G. A., Priester und Tempel im hellenistischen Aegypten. Leipzig, B. G. Teubner, vol. 1 (1905) pp. 22, 43–44, Vol 2. (1908) pp. 311–313.
29. DIODORUS SICULUS, *op. cit*., pp. 42.
30. ENGREEN, F. E., The nilometer in the Serapeum at Alexandria. Medievalia et Humanistica I (1943) 3–13.
31. WAERDEN, B. L. V. D., Science awakening, translated by A. Dresden. Groningen, P. Noordhoff Ltd. (1954) p. 68.
32. NEUGEBAUER, o. and A. SACHS, JR., Mathematical cuneiform texts. New Haven, Conn., American Oriental Society and American Schools of Oriental Research (1945) pp. 96–97.
33. KAZMANN, R. G., Modern hydrology. New York, Harper and Row Inc. (1965) pp. 1–20.
34. SARTON, G. A., History of science: ancient science through the Golden Age of Greece. Cambridge, Mass., Harvard University Press (1959) p. 79.
35. BUTLER, M. A., Irrigation in Persia by kanats. Civil Engineering, ASCE 3 (1933) 69–73.
36. FORBES, R. J., Studies in ancient technology, vol. I. Leiden, E. J. Brill (1955) p. 151.
37. RICHARDSON, C. G., The measurement of flowing water. Water and Sewage Works 102 (1955) 379–385.
38. SCHAAK, M., Hundert Jahre Wassermessung. Neue Deliwa Zeitschrift zur Förderung des Gas-, Wasser- und Elektrizitatsfaches Hanover I (1953) 132–135.
39. COMMITTEE 86ID, Water meters – Selection, installation, testing, and maintenance. Chapter I, Early history of Water measurement and the development of meters. Journal, American Water Works Association 51 (1959) 791–799.
40. ABERCROMBIE, T. J., Behind the veil of troubled Yemen. National Geographic Magazine 125 (1964) 423.
41. LEHMANN-HAUPT, C. F., Armenien einst und jetzt, vol. II Berlin, B. Behr (1910) p. 111.
42. LASSØE, J., The irrigation system at Ulhu. Journal of Cuneiform Studies 5 (1951) pp. 21–32.
43. TOLMAN, C. F., Ground water. New York, McGraw-Hill Book Co. Inc., (1937) pp. 1-25.
44. WULFF, H. E., The qanāts of Iran. Scientific American 218 (1968) 94–105.
45. CATON-THOMPSON, G. and E. W. GARDNER, The prehistoric geography of Kharga Oasis. Geographical Journal 80 (1932) 369–409.
46. LAMOREAUX, P. E., Personal communication (1968).

47. FEILBERG, C. G., Qanaterne, Irans underjordiske vandingskanlen. Copen-agen, Øst og Vest (1945) pp. 105–113.
48. PHILLIPS, W., Qataban and Sheba: exploring the ancient kingdoms on the biblical spice routes of Arabia. London, Victor Gollanc Ltd. (1955) pp. 200–201.
49. ENCYCLOPEDIA OF ISLAM, vol. 3, Leiden, E. J. Brill (1911–38) pp. 263–293.
50. GLASER, E., Reise nach Marib. Vienna, Ed. A. Hölder (1913).
51. BROMEHEAD, C. E. N., The early history of water supply, part II. Geographical Journal 99 (1942) 183–193.
52. FINCH, J. K., Master builders of Mesopotamia. Civil Engineering, ASCE 27 (1957) 50–53.
53. MANER, A. W., Public works in ancient Mesopotamia. Civil Engineering, ASCE 36 (1966) 50–51.
54. JACOBSEN, T. and S. LLOYD, Sennacherib's aqueduct at Jerwan. Oriental Institute Publications, vol. 24. Chicago, University of Chicago Press (1935).
55. SCHMÖKEL, H., Ur, Assur und Babylon. Stuttgart, Killper Verlag (1955).