WATER RESOURCES TECHNOLOGY TRANSFER AND CAPACITY BUILDING

Kodwo Andah
Water Resources Research and Documentation Centre, Villa la Colombella, Perugia, Italy

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Contents

Summary

Water resources technology is essential for the monitoring of the hydrological cycle, for water resources assessment, for the design and management of water projects. From ancient times up to now the level of water development is a strong indicator of the general socio-economic development of a given human society. As the demand on water increased, so water development perceptions attained different dimensions, passing from single-purpose through multi-purpose projects to water resources systems. The present day call for integrated water resources management (IWRM) is based on the realisation that water is both of economic and social good and its development and management must be carried out in harmony with the environment There is an imbalance of development between developed countries of the North and less developed countries of the South which calls for the transfer of technology from the north to the south.

This contribution gives some history of ancient practices and the historical phases of water resources development from antiquity to the present era. Further discussions centre on development and transfer of water resources technologies, concepts and problems in transfer mechanisms and also the role of capacity building in the adaptation and assimilation of new technologies into new environments. Different types of water resources technologies have been discussed with respect to availability of human and institutional capacities and the corresponding enabling environment.

The need for a concerted effort at the international scale to devise mechanisms for favourable and preferential terms for water technology transfer from developed to developing countries has been discussed with reference to the possibility of integrating intellectual property rights into public sector official development assistance and through collaborative research networks and programmes of cooperation and assistance. It is reiterated that the choice of technology is a human responsibility which can only be dispensed in an enabling environment with proper knowledge and skills, which in turn demands a complex set of continuing education actions towards capacity building for both institutional and human decision making capabilities, especially in the developing countries.

1. Introduction

Technology in its general sense is defined as the science of technical processes in a wide, though related, field of knowledge. Collins Cobuild English Language dictionary however defines technology "as the activity or study of using scientific knowledge for practical purposes in industry, farming, medicine, business etc." It further signifies technology as "an area of activity that requires scientific method and knowledge, as changes in agricultural technology, computer technology and so forth." Thus water resources technology would embrace the physical, chemical, biological and socio-economic processes involved in water resources development and management and also in the conservation of the natural ecosystem. Technology transfer therefore implies the transfer of technical knowledge generated and developed in one place to another with the intent of achieving some practical end.

Water bodies in all their many forms of occurrence (rivers, lakes, seas, etc.), from ancient times have exerted decisive influence on the development of human society. Water finds use in human activities in diverse forms:

- As an indispensable physical substance for drinking and for daily necessities of people, for agricultural production and animal husbandry, for the production of many industrial products and for the supply to technological processes of production.
- As a medium, necessary for fishery, water transport, recreational needs, etc.
- As a mass, used (by creating a fall in water level) for producing mechanical energy which in turn is usually transformed into electrical energy.

In its relationship with human societies, water in its excess also provokes destruction of life, domestic and industrial installations, and when in scarcity it can bring devastation to agricultural production and famine.

The technical processes that involve the utilisation of water from withdrawal to its conveyance and distribution to end users include the following basic structures:

- Intake structures (for surface and groundwater sources and also for springs) and diversion works (weirs);
- Reservoirs or storage facilities (for regulation purposes);
- Conveyance structures (canals, tunnels, pipelines);
- Treatment plants (water treatment, sewage treatment);
- Distribution systems (water supply networks for domestic and industrial uses, irrigation canal systems), and
- Runoff structures (drainage-sewer systems).

Throughout history water resources have been the decisive factor in the growth and development of human civilisations. All the ancient civilisations were distinctly and predominantly hydraulic in nature since they owed their origins to the availability of water resources to meet their needs in agriculture, inland transport and water supply. Consequently, water played a central role in the socio-economic lives of these people, and as such most of these civilisations are commonly referred to as river valley civilisations. Prime examples of ancient river valley civilisations which flourished between 3000 and 2000 B.C., are the Egyptian civilisation of the Nile valley, the Mesopotamian in the valley of the rivers Euphrates and Tigris, the Harappan in the Indus valley and the Chinese in the Huang-Ho river valley. There is historical evidence to show that certain engineering measures were adopted during those periods in order to enhance and sustain the beneficial aspects of water and also to protect against damaging phenomena of floods. Historically, the science of engineering hydraulics started to develop in order to provide explanations to the complex processes of the occurrence of water and the dynamics of its movement. Certainly, the success of any proposed design relied on many experiments, and much trial and error. It is also known that the transfer of such acquired knowledge was mainly through oral transmission and manuscripts even if the tendency of specialist to jealously conserve their secrets did not favour diffusion of knowledge. Although the concept of technology transfer in antiquity was essentially different from present day exigencies, the movements and migration of people to new environments, and conquests of new territories, created the necessity to satisfy water needs in agriculture and domestic use. In terms of ancient hydraulics, one can say that they had a perception of the relationship between pressure, flow area and outflow discharge and also that between the slope of a canal and the direction of flow. Although knowledge of hydraulics was simply an art without scientific basis and practised empirically, the ancient constructors must be admired for the remarkable results achieved, without which the gradual development of the sciences of hydraulics and hydrology could never have begun.

2. Historical development of irrigation canals and water supply technologies in antiquity

Water resources development in ancient times appeared intuitively in the search for water for domestic use and to cover deficits in agricultural water needs through the construction of diversion and irrigation canals. Hydraulic structures were constructed in remote ancient periods by the populations of Rome, Egypt, Mesopotamia, India, China and other countries. With regard to studies concerning the ancient history of hydraulics, the engineering aspect is somehow more privileged than others since the presence of canals and aqueducts is an element which mostly stands out among the remnants of ancient civilisations. Historians are yet to establish from the remnants of pre-historical irrigation systems, which of the two areas, Egypt and Mesopotamia, was the first to realise a system of control over their waters.

2.1. Egypt

The original Nile valley in Egypt consisted of an uninterrupted swamp subjected to seasonal floods and surrounded by deserts. There are indications that under Menes, the legendary founder of the first dynasty, the first stone filled dam was constructed in Menphi (the ancient capital of Egypt) as far back as 4000 years B.C. This made it possible to cultivate a large expanse of the surrounding arid area. Around about 2500 years B.C., a canal for potable water had already been constructed between Cairo and Suez. Successive attempts were also made to construct a navigation canal between the Mediterranean Sea and the Red Sea, following almost the same layout as the present Suez Canal. An extensive system of canals and impoundment basins was realised during the reign of Ramsey II in the fourteenth century B.C. In the years 1319-1304 B.C., Egyptians constructed a stone filled dam six meters high and 2000 metres long on the river Asi (now river Oront) which is still used today.

2.2. Mesopotamia

An analogous situation is found in Mesopotamia, an expanse of land between the rivers Tigris and Euphrates. Even though written documentation is not available until 3500 B.C. the first written testimonies indicate that boundaries of independent states were for some time delimited with stone lined canals. The concentration of large populations within the Babylonian plains was certainly made possible by virtue of the reclamation of vast swampy zones realised through the construction of skilfully designed and managed canals, the remnants of which testify to the level of development of a country then considered to be the most fertile in the world.

2.3 India and China

It is now well known that the civilisations which developed diffused irrigation systems in India and Pakistan in the Indus valley about 3000 years B.C. had achieved levels well above those of Egypt and Mesopotamia. The excavations of Harrapu and Moenjo-Daro have given evidence of the existence of baths in many houses with baked clay pipelines and drainage conduits. Due to variations in river beds there is no evidence of remnants of canals. The Rig-Veda, an ancient scripture dating back to 1100 B.C., describes the successive Aryan civilisation in the Ganges river valley, including references to damming of river flows, water wheels and canals for irrigation.

Ancient China, which is well known for many inventions and discoveries, has also a long history of water conservation works. These achievements are symbolised by the harnessing of rivers by the legendary emperor/engineer Yu, the Yellow river control works in successive dynasties, the Dujiangyan irrigation systems, the Lingqu canal connecting the Yangtse and the Pearl rivers, the Grand Canal crossing through the north and the south and many other ancient water works. Specifically, the great Yu, about 4000 years B.C., is purported to have invented perfectly functional dam systems for flood control in order to guarantee the territory thousands of years of protection. It is also known that around 3000 years B.C. a Chinese engineer by the name of Li devised a vast system of canalisations, erected monumental signals for indicating levels reached by water and established rules for their management which are still valid.

2.4. Ancient Rome

The more than 200 aqueducts, constructed by the ancient Romans in Rome and other parts of the then known world in the years between 312 B.C. and 455 A.D., are well known. These were the first structures created with some sort of perfection and some of them are still in use. Remnants of such aqueducts which are of immense technological curiosity and tourist attraction can be found in Rome and throughout Italy and also in Spain, Portugal, France, Germany and in North Africa. These structures served both as water supply canals and also bridges across valleys. Most of the knowledge acquired about the technology and construction of the Roman aqueducts is attributed to Sesto Giulio Frontino through his historical work, “De aquaeductibus urbis Romae”, produced at the beginning of his career as curator aquarium (water commissioner) in 97 A.D. The first aqueduct Aqua Appia was already in operation from 269 B.C. followed by ten others up to 266 A.D. as the city of Rome expanded and became more urbanised. The main features of the Roman aqueducts were that they extended from distant spring-fed sources or the river Anio in the form of tunnels through the hills and over bridges across depressions and valleys bringing water into reservoirs for onward distribution to the city. It is on record that a water commissioner was nominated directly by the emperor, for the purposes of organisation and administration of water, charged with the duties of construction, maintenance and management of the aqueducts. At the time of Frontino, the daily water supply from nine aqueducts amounted to about 1 million cubic metres. The famous eleven aqueducts of Rome were long distance water supply conveyance systems spanning a total distance of about 500 km with a total flow capacity of about 13.5 m^3/sec. under gravity. The conduits were of rectangular cross-section with widths ranging from 0.6 m to 1.75 m and heights from 1.1 m to 2.75 m.

The eleven aqueducts of Rome, shown in Figure 1, are briefly introduced below:

Aqua Appia, was the first aqueduct constructed in 312 B.C. and named after its constructor by name Appius Claudio Crasus with the title of Censor, who was subsequently nominated as Caecus and Caius Plautius for his discovery of springs situated about 11.5 km from the ancient Prenestina Street. In spite of the low level of the conduits the daily discharge of this aqueduct system was about 73 000 m^3; it was supplied to seven regions of Rome through 20 water towers. Technologically the Aqua Appia was similar to the construction of the Etruscan drains

Anio Vetus, the construction works started 40 years after Aqua Appia in 272 B.C. to directly capture water from the river Aniene, (from which the name Anio was derived—it became Anio Vetus after the construction of Anio Novus). The water intake was at an elevation of about 850 m upstream of St. Cosimano Gorge on the left bank of the river, reaching Rome with an almost underground conduit, about 64 km. long, compared with the part constructed on an aqueduct bridge of only 327 metres long. The capacity was about 176 000 cubic metres per day, much higher than that of Aqua Appia.
Aqua Marcia, was considered the 'pride of ancient Rome' As a result of the growing population, Quintius Marcio Rex, the praetor of the Republic, started construction works for a new aqueduct in 144 B.C, in addition to his innovation works on Aqua Appia and Anio Vetus. The Aqua Marcia was the first of the aqueducts to be built on high arches across the open *campagna* (countryside). The same arches later carried the channels of the Aqua Tepula and Aqua Julia, superimposed upon the Marcia. Water from the Aqua Marcia was distributed widely from the area of Porta Viminalis. This was realised in 125 B.C by Censors Servillus Caepio and Cassius Longinus Ravilla, utilising different sources of water and uniting them into one conduit which transported the water to Rome. The daily water supply of this aqueduct was however limited and did not exceed 16 000 cubic metres. The Aqua Tepula canal was carried on top of the Aqua Marcia for much of its journey

Aqua Julia is known from the manuscripts of Frontino to have been constructed by Agrippa in 33 B.C. and renovated by Augustus in the period between 11 and 4 B.C. With a daily supply of 64 000 cubic metres, the Aqua Julia passed through seventeen castles and distributed water to seven regions of Rome. The Aqua Julia was carried atop the canals of the Aqua Tepula and Aqua Marcia for much of its journey into the city

Aqua Virgo: The Aqua Virgo was built by Agrippa at his own expense and completed in 19 BC as part of an urban water infrastructure improvement program that he had initiated in 33 BC. He built the Virgo principally to provide water to the Terme Agrippae (Baths of Agrippa). The water was also used for other purposes, including public drinking supply. According to Ovid the aqueduct terminated near the Juturna Templum, but according to Frontinus it terminated at the north end of the Saepta. Lanciani proposed the existence of a castellum (holding tank) in front of the area now occupied by the church of St. Ignazio, where extensive ruins were uncovered in the seventeenth century. The Virgo was the only aqueduct to deliver water from the north and it ran entirely underground until reaching the Pincian hill inside the city walls. For this reason it was restored intermittently throughout the medieval and renaissance periods and still functions today as the Acqua Vergine.

Aqua Alsietina: The Aqua Alsietina was built specifically to deliver water to the Naumachia Augusti which was an outdoor ampitheather built for mock naval battles. It was located in the area of the Transtiberim known as the "Codeta" which stood at an approximate elevation of 16 meters above sea level. As Frontinus notes, the water was of inferior quality, but he adds that it supplemented the public water supply during emergencies. After the demise of the Naumachia (circa 80 - 100 AD) the Alsietina was used for irrigation purposes both inside and outside the Aurelian walls, and it was also used to power the grain mills on the Gianicolo.

Aqua Claudia: Physically the Aqua Claudia was the most impressive of the aqueducts. It was carried on high arches over long stretches of the campagna. The specus (channel) of the Aqua Anio Novus was carried atop the Claudia. The waters were mixed once the aqueducts entered inside the city walls, and they were delivered throughout the city, including the Transtiberium.

Aqua Anio Novus: Pliny stated that: "all previous aqueducts have been surpassed by the most recent and very costly work inaugurated by Emperor Gaius and completed by Claudius, inasmuch as the Curtian and Caerulean Springs, as well as the Anio Novus, were made to flow into Rome from the 40th milestone at such a high level as to supply water to all the seven hills of the city. The canal is carried atop that of the Aqua Claudia, and within the city their waters were mixed together, even though that of the Anio Novus was often muddy.

Aqua Traiana: The Aqua Traiana delivered water to every area of the intramural city. It was considered to be inferior in terms of taste, clarity, and temperature, and was used extensively for industrial and agricultural purposes, including powering water mills until the Gothic invasion of 537. It was restored several times during the mediaval period, in particular to power the water mills located on top of the Janiculum. The Aqua Traiana was superseded by the Acqua Paola, constructed from 1607-1612 by Paulo V. This tapped the same water sources, followed the original route to some extent and reused some small portion of the original structure, some of which can still be seen along the Via Aurelia. Lanciani gives the length of the aqueduct course at 57.70 meters and the volume of water at 118 126 cubic meters per day. A branch line that led to the Vatican was also restored during the medieval period.

Aqua Alexandriana, the last of the ancient roman aqueducts was constructed in 226 A.D. by the emperor Alessandro Severo. The daily water supply was about 21 600 cubic metres and traversed a distance of 22 km. Although the Aqua Alexandriana entered Rome through the Porta Maggiore, no trace of the channel of the Aqua Alexandrina has been discovered within the city walls. The aqueduct is generally thought to have terminated at the Baths of Nero, now called Baths of Alexander after their restoration by Severus Alexander Severus.

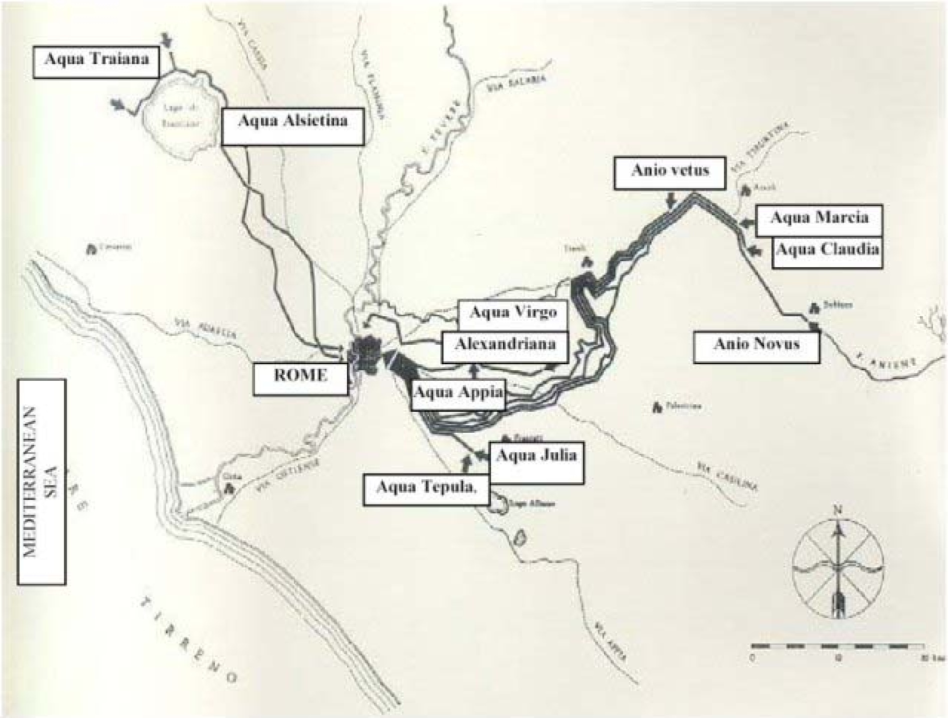

Figure 1. The layout of the water supply system of ancient Rome

2.5. Water Raising Technologies and Groundwater Exploitation

The withdrawal of groundwater from wells, a practice not as ancient as canalisation, required a different engineering skill. A vivid example is Joseph's Well in Cairo, dated around the seventeenth century B.C., which was excavated to about 100 metres through rocks. The ancient Chinese are believed to have constructed a well with a depth of more than 300 metres. Water raising technology was needed not only for withdrawing water from wells but also for irrigation canals.

Egyptian paintings dating back to about 4000 years ago provide evidence for a technique of passing water from rivers to canals. A more involved system that can be defined as semi-mechanical is represented by the introduction of sacks and counterweight attached to the extremities of a rod mounted in equilibrium.

This technique dates as far back as 1000 years B.C. and can still be found in use in India and Egypt. Another example is the use of sacks attached to a circular chain system which was used to raise water from Joseph's Well. An analogous system was also adopted for irrigation, initially with human labour and subsequently draft animals.

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Biographical Sketch

Dr. Kodwo Andah was born in 1947 in Ghana. He is the Scientific Co-ordinator of the Water Resources Research and Documentation Centre, WARREDOC, of the University for Foreigners of Perugia, Italy. Dr. Andah obtained his M.Sc. in Civil Engineering with specialisation in Hydraulic Structures at the Patrice Lumumba Friendship University in Moscow in 1978. He later obtained his PhD in 1983 at the Hydrology and Water Resources Department of the same University. He was invited by the Hydraulic Institute of the University of Genoa to carry out a research programme in Quantitative Geomorphological Approaches to River Basin Analysis and Response in 1984. He moved to Perugia 1986 to coordinate the activities of the then newly founded Centre. WARREDOC’s main activities are centred on organising an International Advanced Course on Water Resources Management for developing countries. He lectures on *Hydroemeteorological Data Collection Techniques and Network Design*, and also on *Quantitative*

Geomorphology of River Drainage Networks. He also supervises case studies on real world hydrological and water resources problems brought in by participants from Africa and Asia in particular.

His research interests cover Geomorphological Characterisation of River Networks and Hydrological Response, Analysis of Extreme Hydrological Events, Analysis of Water Resources Systems, Modelling of Agricultural Droughts, Capacity Building in Water Resources Management.

Dr. Andah has participated and continues to participate in various capacity building initiatives sponsored by the European Commission, specifically in EUWATERMAN, European Union SOCRATES/ERASMUS Project co-ordinated by Budapest University of Technology and Economics on the development of water management policies in Europe. He is also a member of the Management Committee of the TEMPUS Joint European Project on *Decision Making for Flood Protection* within a process of continuing education and institutional capacity building for Public Administrators in the Czech Republic. He has had a number of special service agreement consultancy projects with WMO. He has extensive experience in organising and coordinating international scientific meetings and summer schools not only on water resources but also on hydrogeological disaster prevention. He is presently engaged in the organisation of a 6-month postgraduate training course on Integrated Water Resources Management for water professionals from sub Sahara African countries. Dr. Andah has been nominated as a member of the Peer Review Committee for the publication of the African Water Development Report (AWDR). He is an author and co-author of more than 60 scientific and technical papers and has edited a number of proceedings.