WATER STORAGE, TRANSPORTATION AND DISTRIBUTION

Yutaka Takahasi
Professor Emeritus, the University of Tokyo, Japan
United Nation University, Tokyo, Japan

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Summary

The collection, storage, transportation, and distribution of water are essential components in making water resources accessible for human use.

Dams and reservoirs are key structures for intercepting and storing water. They play an important role in adjusting water supply, power generation, transportation, etc. Building dams and reservoirs requires serious planning, geologic and hydrologic studies, design, and construction. Feasibility studies are helpful in decision-making and geological investigation is an essential prerequisite of site selection.

Water transportation and distribution are important aspects in providing adequate water supply. Water intake and wastewater discharge are carried by transport and distribution systems. Different systems may be necessary for different uses.

The aim of this theme paper is to guide the reader through the history of dams and reservoirs, and sewerage systems. After that, the text describes the present situation regarding dams and reservoirs, which is now entering a turning point as regards environmental and social issues.

There are many important and difficult issues concerning the environment and resettlement those affected by dam building. Also it must be recognized that the situation is different between developed and developing countries. The present situation regarding sewerage systems shows the same tendency－how to develop and overcome new difficulties depending on the different conditions of each country.

In this Theme, emphasis is placed on dams and reservoirs, aqueducts, municipal and rural wastewater systems, pumping stations, and other structures for water transport. The Theme contains 23 writings separated into four Topics.

1. Introduction

A dam is the most important hydraulic structure for storing water. A dam is a barrier built across a river, stream, or lake to control the flow of water. The International Commission on Large Dams (ICOLD), established in 1928, defined a large dam as a dam with a height of 15m or more from the foundation. If dams are between 5~15m high and have a reservoir volume of more than 3 million m^3, they are classifies as large dams. Using this definition, there were over 45,000 large dams around the world in 2000.

The two main categories of large dams are reservoir－type storage projects and run-of-river dams that often have no storage water and may have limited daily reserve. By this general classification there is considerable diversity in scale, design, operation, maintenance, and undesirable impacts to environment and society. Reservoir type dams hold water for seasonal, annual and in some cases, multi-annual storage and regulation of the river for the purposes of water resources development and hydroelectric generations, flood control etc. Run-of-river type power stations consist of weirs and intake canals to hydropower station.

A growing human population and a rising level of economic activity and standard of life-style increase demand for water and water-related services. At the end of the twentieth century, around 3,800km^3 of fresh water was withdrawn annually from the world's rivers, lakes and aquifers. This was twice the volume extracted in the middle of the century. The economic growth period after the Second World War triggered a phenomenal rise in the rate of dam construction around the world, lasting well into the 1970s and 1980s. The increase in water supply and sewage treatment continued into the twenty-first century. This increase in water-related infrastructures has stimulated economic development and raised human living standards. Dam constructions reached a peak between 1970 and 1975, with nearly 5,000 dams being built worldwide within those years, but the decline in the pace of dam building after 1980 was dramatic, especially in North America and Europe where most technically suitable sites have already been developed. Furthermore, the environmental impacts of large dams was recognized as an important and serious problem worldwide, especially after 1980. This will be discussed in this article.

2. General View on Engineering Water Works

So many kinds of engineering works were constructed throughout history for water transportation. Nearly 6,000 years ago, the Nile in Egypt was life-preserving the water source. The civil engineers of the Persian Gulf constructed extensive hydraulic works in 2350 B.C.

Among several huge works, the aqueducts of the Romans were historical monuments. Many Roman writers make several references to water supply and related works. At the beginning stage, the people of Rome were supplied with water from private wells or the river. Roma's first aqueduct was built by Appius Claudius in 313 B.C, which brought water to the city from a spring. The length of the channel was about 17km including underground channel about 100m, and almost on a masonry arched structure above ground. The aqueduct was followed in 273 B.C. by Curius and Fulvius of the Anio Vetus.

Water supplies were extremely important to the communities to continue the prosperity the Roman Empire. The historical monumental relics can be found in Southern Europe, the Middle East and Northern Africa. It is estimated that about 200 examples of Roman aqueducts are still existing.

The construction of canals have been carried out for water supply to cities, irrigation and navigation since the olden times, such as the Grand Canal between the Nile and the Red Sea, a length 60km, eight canals in Egypt in about 1300 B.C. The Babylonians used canals for irrigation and trade, by the river improvement works. The Grand Canal in China from north to south was constructed in 1289, over about 1700km length for transporting goods and passengers from many parts of China, Japan, even European passengers. The canal has been a glorious symbol of Chinese Civilization.

The accomplishments of canal system in Western Europe, especially in Britain, France etc were also remarkable in so called "the Age of Canal" the sixteenth and seventeenth centuries. Some examples are the Brussels canal, connecting Brussels to Scheldt completed in 1560, the Burgundy and Picardy canals in the first half of the seventeenth century, and the great Languedoc Canal by Riquet, connecting the Atlantic with the Mediterranean, completed in 1681 of nearly 290km in length.

In the seventeenth century, canal building became active in Britain with the river improvement on the Severn, Thames, Tyne, Yorkshire Ouse, and other many rivers. It must be mentioned that an Act was passed in 1755 for the improvement of the Sankey Brook, from the Mersey to St. Helens, through the efforts of the commercial groups of Liverpool. After the Act, the planners cut a canal with locks. Then Sankey Brook was called the first canalized river in Britain.

On the other hand, in the dry countries from North Africa to northwestern China through the Middle East, qanats systems have been developed since about 700 B.C. The qanat is a mining installation or technique using galleries or crosscuts to extract water from the depths of the earth, by A.K.S Lambton's definition. It is said, that the ground water development are mainly initiated by Persian's contribution, it is said. Qanats are developed in alluvial fans or valleys and Persian platean, where geological characteristics are favorable to the enrichment of underground water. By means of a gently sloping underground tunnel, water is transported by gravity flow from the upper end to a ground surface outlet where people can take the water for domestic and irrigation purposes.

In eastern and southeastern Persia, Afghanistan, Baluchistan, these systems are called Kariz; in Algeria they are called foggara, in Turfan in China, called Kangting. They are also found in the Damascus, Palmyra, and other many oases in Syria, southeast of

Riyadh at al-Kharg, north of Dhahran at Qatif in Saudi Arabia, and in Cyprus, Oman, and Marrakech in Maroc, Spain introduced by the Umayyad, the Canary Islands, Mexico and Chile etc.

The gradient of a qanat varies from 1:1,000 or 1:1,500 in a short qanat, whereas a long qanat is nearly horizontal. The length of qanat that varies from 8 to 15km are common, and some are 30km or more in length. The depth of the original well varies from less than 8m to 100m or more. The discharge of the flow varies the nature of the soil and the season. If a qanat does not constitute of a stable groundwater or in porous soil, the flow will be reduced to nothing in summer or in a dry year.

The flow of some qanats reach 1m^3/s or less.

Because of the technological development of modern pumps since the end of twentieth century qanat systems are declining in several oasis, as the pumping up the groundwater is much easier than the traditional use of qanat. But the use of this modern technology is likely to lead to excessive pumping towards the lowering the groundwater level and even exhausting the water. These are also the environmental crisis of groundwater.

3. History of Water Resources Development and Sewerage System

3.1 History of Dams

The story of dam construction goes back to the Egyptian civilizations.

The remains of water storage dams found in Jordan, Egypt and other countries of the Middle East date back to 3,000 B.C. or before. Historical records indicate that the use of dams for irrigation and water supply became more widespread about a thousand years later in the Mediterranean region, China and Central America.

Remains of earth embankment dams built to transport water to large communities can still be found in Sri Lanka, Israel etc. Dams and large scale aqueducts built by the Romans to supply drinking water and sewerage systems for cities and towns, still exist today throughout Southern Europe. According to Herodotus' "History"(around 485 to 425 B.C.), in about 2900 B.C. In order to built Memphis, Mena diverted the course of the Nile by constructing a dam of ashlars masonry, 15m in height at Kosheish. In 1885, Schwein－felt, a German archeologist, discovered the remains of a dam built in about 2750 B.C. at Helwan, 32km south of Cairo. The dam, which was called Sadd-el-Kafera, was to supply drinking water for the workers constructing the Pyramids. The height was 11m, and the crest length 106m. But the dam was washed away by a big flood, because there was no spillway.

Around 750 B.C, great technological progress was achieved with the first spillway. This was in the Marib dam (Sadd-el-Arim Dam, Muclem) in Yemen, which supplied drinking water to the capital, Marib. The original height was 4m, and the crest length 650m. The height was raised 7m in 500 B.C, and again to 14m in about A.D. 325. Before the Marib Dam, failures of dams had been caused repeatedly by severe floods. Table 1: shows the main events in the history of dams.*Based on Smith, N. and Schmitter, N. J. (see*

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about 2900 B.C.	Kosheish Dam on the Nile (15m high, 450m long).
about 2500 B.C.	Sadd-el-Kafara Dam (11m high, 107m long) on the Nile.
694 B.C.	Two Dams on the Khosr of the Tigris River system to capital Nineveh in Assyria (1.4m, 2.9m high respectively).
750 B.C.	Marib Dam in Yemen (4m high, 600m long).
460	Long earth embankments in Sri Lanka (34m high), the world's highest for more than a millennium.
1100's	King Parakram Babu in Sri Lanka (15m high, 13.6km long) for irrigation.
1300's	Kebar Dam in Persia (26m high) the first Arch Dam masonry with mortar joint.
1384	Almansa Dam in Spain (14.6m high), the gravity arch dam.
1586	"Dle Beghinselen des Wasserwichts" by Simon Steven, was published, the first theoretical study on dam design.
1594	Alicante Dam in Spain (40m high) the highest in the world, masonry gravity dam with mortar joint.
1671	St-Ferreol Dam in France (36m high), the first fill-type dam.
1730's	Osiyan Dam in Spain (3m high), multi-arch dam.
1747	Almendralejo Dam in Spain (19.5m high), buttress, the first hydroelectric generation (waterwheel).
1766	Caromb Dam in France (21m high).
1791	Puentes Dam in Spain (50m high), the highest masonry gravity dam, but in 1802 pile foundation was destroyed.
1852	South Fork Dam in U.S.A. (21.6m high, 284m long) Rock-fill Dam with core-wall.
1854	Zola Dam in France (42m high) Rock-fill Arch Dam, the first dam designed theoretically.
1858	Gouffere d'Enfer Dam in France (60m high) masonry.
1884	Bear Valley Dam in U.S.A. (28m high) Thin arch dam, joint grouted.
1888	San Mateo Dam in U.S.A. (47m high) the first concrete gravity dam.
1895	After the failure of Bouzey Dam in France owing to uplift pressure, Maurice Lévy presented the uplift pressure theory.
1912	Bear Valley Dam in U.S.A. (28m high) Thin arch dam, joint grouted. (original construction 1884)
1936	Hoover Dam in U.S.A. (221m high) the highest gravity 379m in length, it is said the historical achievement in dam history.
1959	The failure of Malpassét Dam in France, 66 high, thin concrete arch dam, owing to weak rock foundation.
1961	Grand Dixence Dam in Switzerland, the highest gravity dam (285m high).
1963	The failure of Vaiont Dam in Italy, 262m high the highest arch dam, owing to landslide on the surrounding of the reservoir.
1970	Aswan High Dam in Egypt, the huge rock-fill dam 111m high, 168,900 million m^3 in the reservoir capacity.
1976	The failure of Teton Dam in U.S.A. 124m high, earth-fill dam, owing to the piping.

Table 1: Historical Events on Dams

As the historical records on the highest dams reveal in Table 2, civil engineers made great progress in dam technology, after several bitter experiences of failures.

1) Masonry and concrete dam

	name of dam	country	height (m)	type
B.C. 2900	Kosheish	Egypt	15	G
A.D. 13 century	Almonacid	Spain	29	G
1594	Tibi	Spain	46	G
1866	Gouffre d' Enfer	France	52	G
1904	Cheeseman	U.S.A.	72	A
1906	New Croton	U.S.A.	65	G
1910	Buffalo Bill	U.S.A.	99	A
1915	Arrowrock	U.S.A.	107	A
1924	Schrah	Switzerland	111	G
1929	Diablo	U.S.A.	118	A
1932	Owyhee	U.S.A.	127	A
1934	Chambon	France	136	G
1936	Hoover	U.S.A.	221	G/A
1957	Mauvoisn	Switzerland	237	A
1961	Vajont	Italy	262	A
1961	Grand Dixence	Switzerland	285	G

G; gravity dam
A; arch dam

2) Earth and rockfill dam

	name of dam	country	height (m)	type
B.C. about 240	Gukow	China	30	E
A.D. 1128	Daimon-ike	Japan	32	E
about 1500	Mudduck Masur	India	33	E
1675	St. Ferréol	France	36	E
1837	Entwhistle	G.B.	38	E
1867	Madag	India	44	E
1892	San Leandro Lower	U.S.A.	47	R
1909	Necaxa	Mexico	50	E
1911	Bull Corral	U.S.A.	73	R
1925	Dix	U.S.A.	87	R
1931	Salt Springs	U.S.A.	96	R
1939	San Gabriel No.1	U.S.A.	123	R
1948	Mud Mountain	U.S.A.	130	R
1950	Anderson Ranch	U.S.A.	139	E
1958	Swift	U.S.A.	186	E
1968	Oroville	U.S.A.	230	E
1972	Mica	Canada	242	E
1980	Nurek	Russia	300	E
Under construction	Rougun	Russia	335	E/R

E; earthfill dam
R; rockfill dam

Table 2: Historical records on the world's highest dams

About 2600 years passed before the height of the highest dam was increased from 15m to 30m, and another 2100 years were required for the height to reach 60m. But after 63 years in 1929, Diablo Dam in United States of America was constructed at a height of 119m, and the Hoover Dam, completed in 1935 on the Colorado River, which is regarded as a landmark in American engineering reached a height of 221m, only 6 years after completion of the Diablo Dam. The Grand Dixence Dam in Switzerland, constructed in 1962, attained 284m in height. In 1980, the Nurek Dam and the Rogan Dam in Russia attained heights of 300m, and 335m respectively. Not only have records on dam height been successively broken, but also a very large number of dams were constructed around the world after the Second World War.

Among several glorious records, the Hoover Dam completed in 1935, was an epoch-making landmark. The dam ranked not only as the world's highest (at 221m) and largest arch gravity dam up to 1959, but it produced 1.35 million KW of hydroelectric power, and it provided irrigation water to Imperial Valley and Yuma Plain, which were consequently converted from a semi-arid state to rich agricultural land.

Aswan High Dam on the Nile, completed in 1970, was a most important project and it contributed significantly to raising Egyptian living standards and the economy, although the environmental impact has been severely attacked by American and European environmentalists. The body of the High Dam is a huge rock-fill dam with a length of 3,830m, a height of 111m, and a maximum storage capacity of 137 billion m^3. Lake Nasser is a large artificial lake 500km long with an average width of 10km. The total electrical generating capacity is 2.1 million KW.

After the 1970's, dam engineering had to face new problem environmental impacts, and resettlement of people who lost their homes as a result of dam construction. These new difficult issues will be discussed later.

3.2 History of Sewerage System

Excavations at the site of Mohenjo Daro located about 300km north-northwest of Karachi in Pakistan, revealed cities dating back to a period between 3000 and 2500 B.C. The ruins show excellent well-planned sewage systems where the drains from each house were built into the walls and led into covered sewers running down the center of the grand streets. They also had several cesspools on the way to the streets and manholes along the main sewerage line. The system also contained wells, baths and toilets.

A similar sewerage system constructed around 1500 B.C. can be found in Knossos, on the islands of Cret. This was one of the most advanced sewerage systems in ancient times. Around 600 B.C, in Babylonia, Assyria, they had underground drainage canals with arched cross-section, and also at the same period, in Rome there were open drainage channels, the so called Cloca Maxima. Between 500 and 300 B.C. these channels were covered. In ancient Rome, although there were great underground drains, there were no direct connections from the houses to the drains.

By the time of the decline of the Roman Empire around 400 B.C., however the sewerage systems had not advanced much further. Almost all cities in Europe in the Middle Ages used human waste as fertilizer for cultivated land, but it was often dumped on the streets creating very unsanitary conditions.

In 1842, the Poor Law Commissioners of England decreed that outfalls should be constructed to dispose of the sewage from cities to landfills. We could say that modernization of the sewage system began in Great Britain, based on the administrative and legislative arrangements. About the middle of the nineteenth century with the increased use of the water closet, the deterioration of the rivers in cities accelerated. To help find a solution, the first Commission on Sewage Disposal was established, and in their first report in 1858, which has become a historical document, the Commissioners made the following points, which are quoted below with only minor modification.

1) That the increasing pollution of the rivers and streams of the country is a crisis of national importance, which urgently demands remedial measures: that the discharge of sewage and the noxious emissions of factories into them is a source of nuisance and danger to health; that it acts injuriously not only in the locality where it is dumped, but also on the population of the districts through which the polluted waters flow.
2) That this problem has greatly increased with the growing cleanliness and internal improvements of towns as regards water supply and drainage; that its increase will continue to be in direct proportion to such improvements; and that as these improvements are yet very partial, the nuisance of sewage, already felt very significantly, is extremely slight as compared to what it will become when sewage and drainage works have been carried into full effect.
3) That in many towns measures for water supply and drainage improvement cannot progress due to the difficulties of disposing of increased sewage which results from them; that the law which regulates the rights of outfall is in an anomalous and ill-defined condition; that judicial decisions of a conflicting nature have been arrived at in different instances, and that consequently before them the fear of harnessing litigation.
4) That the methods adopted for dealing with sewage are of two kinds: one being the application of the whole sewage to land; and the other that of treating it by chemical processes, to separate its most offensive portions; that the direct application of sewage to land favorably situated, if judiciously carried out, and confined to a suitable area exclusively grass, is profitable to persons so employing it; that where the conditions are favorable, a small payment on the part of the local authority will restore the balance.
5) That this method of sewage disposal, conducted with moderate care, does not pose a health hazard.
6) That when circumstances prevent the disposal of sewage by direct application to land, precipitation will greatly ameliorate, and practically obviate the crisis of sewage outfalls, especially where there are large rivers for the discharge of the sludge; that such methods of treating sewage do not retain more than a comparatively small portion of the fertilizing matter, and that although in some cases the sale of the manure may repay the cost of production, they are not likely to be successful as private speculations.
7) That considered merely as a means of mitigating a nuisance, these precipitating

processes are satisfactory; that the cost of them in any case is such as town populations may reasonably be called upon to meat; and that, by modifications of the existing methods, even the slightest risk of water quality deterioration may be completely eliminated.

8) That the employment of one or the other method of disposing of sewage, or of both conjoined, must be decided based on locality, levels, markets and a variety of other circumstances, and that the procedure of each town must be decided according to its own characteristics.
9) That there is good ground for believing that the methods proposed for dealing with sewage are not the best that can be devised, and further investigation will probably result in the discovery of processes more efficient in treating the waste, removing the annoyance, and at the same time expected to give more useful, acceptable final products.
10) That the extent of a town presents no real difficulty to the effective treatment of the sewage, as it can be considered as a collection of small towns.

However, as the conditions under which the effluent may be best removed will differ greatly in different localities, we think it would be desirable, before any legislation takes place on this subject, that investigation should be made into the states of the outfalls of different classes of towns, and of the condition of rivers in densely populated districts, with the view to advice as to the general legislatives measures that might safely be adopted.

A second report by the Commission on Sewage Disposal in 1861, recommended land treatment and “the establishment of conservancies throughout the country, armed with adequate power for preventing damage and for effecting improvements” .

The third and final report in 1865 recommended that “the right way to dispose of town sewage is to apply it continually to land, and it is only by such application that the pollution of rivers can be avoided”, and also “that wherever rivers are polluted by discharge of town sewage into them, the towns may be required to desist from causing that public nuisance”.

After ascertaining how the sewage of London and other towns might be utilized, the Sewage Utilization Acts of 1866 and 1867 were passed, which enabled local authorities to purchase land for sewage treatment and combine together to protect water courses from pollution.

In 1871, as the Local Government Board Act was passed, several recommendations were made on sanitary legislation. In 1875, the new Public Health Act was passed replacing all the previous Acts concerning disposal of sewage, pollution of rivers and sanitation. Furthermore, the local Government Act of 1888 authorized country councils to enforce the River Pollution Act of 1876. Thus, the legislative system was gradually established on disposal of sewage with the technological advances made in Great Britain.

In Paris, construction of underground drainage began about 1370, and a large-scale circular underground drainage system was completed about 1740. The system was for rainwater drainage, and as human waste was retained in cesspools, sanitary condition worsened. An epidemic of cholera in 1832 brought about the advancement of the sewage system in Paris. In 1865, sewage disposal by soil infiltration began, in 1880 sewage discharge of human waste started. In 1964, the first complete legislation on sewage system was formulated with a comprehensive and decentralized focus.

In Germany, an extensive fire in Hamburg in 1842 gave impetus to the development of a modern sewage system under the direction of an English engineer, W. Lindy. The system was enlarged in 1853 and further remarkable developments were achieved between 1871 and 1875. The sewage system in Berlin was originally a combined sewage system that discharged to agricultural land after settling treatment. However later the system changed gradually so that there was a separate sewer system, independent of rainwater drainage. In Germany and other countries there are even now some parts of area that has no storm water drainage system, but recommended rainwater infiltration method. On the other hand, all sewage treatment plants have the facility to remove nitrogen and phosphorus.

A legislative framework on sewerage system was established all over West Germany in 1957, when the Federal Water Management Act became law. The Act was subsequently modified several times to cope with socio-economic developments, and to allow the private sector to participate in the sewerage works under stipulated conditions.

In the United States, the first modern sewerage system s were planned in Chicago in 1855, and in New York in 1857. A basic act for the purpose to prevent water pollution, the Water Pollution Control Act was enacted in 1948, and after many revisions the Federal Water Pollution Control Act (1972) and the Clean Water Act (1977) were enacted as the fundamental legislative base. The Water Quality Act in 1987 was intended primarily to regulate non-point sources, to protect estuaries, to control overflow from sewage treatment works, to control poisoned toxic materials and sludge. These new items included in the Act were designed to meet new difficult social demands.

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Biographical Sketch

Yutaka Takahasi was a Professor of Civil Engineering at the University of Tokyo from 1978 to 1987 (now Professor Emeritus) and a Professor of Civil Engineering at Shibaura Institute of Technology in Tokyo from 1987 to 1998. He is now a Senior Programme Advisor (Environment and Sustainable Development) United Nations University. His research and teaching interests are focused in fluvial hydrology, water resources planning and history of Civil Engineering. He is a member, Board of Governors, World Water Council since 1996, and Vice-President, International Water Resources

Association from 2000 to 2003.