Water supply of the cities in ancient China

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Abstract Water-supply facilities have a long history in China. Historical records show that the level of
development of a city depended highly on sufficiency of water. Past research has shown that highly
developed water-supply facilities existed in ancient China, and the prosperous periods in Chinese history
all had comprehensive water-supply planning and reasonable choice of water source. This paper introduces
and analyzes the highly comprehensive water system planning, water-supply facilities and the evolution of
water-supply technology of cities in ancient China. The discussion includes water-supply system consisted
of pipeline system and cleaning measures in City of Yangcheng (of Eastern Zhou Dynasty), and the choice
of water source and history of water-supply development of ancient Cities of Chang‘an (modern Xi’an) and
Beijing. The paper also sums up the main methods and achievements in water-supply of cities in ancient
China, and the experience that are applicable in modern city planning and water-supply technology.

Keywords Ancient city; city planning; water supply facilities

Introduction
Water supplies of the cities in ancient times were mainly for satisfying lives, production,
navigation, irrigation, landscape, fire control, etc. It was required that water used in daily
life and production to have good quality and stable amount. Water for these purposes
usually came from wells and springs, or sometimes rivers and lakes. Water used for
navigation, irrigation and fire-control purposes had a relatively lower standard. It usually
came from developed city water system. City water systems in ancient times were very
important facilities that ensured the use of water within the city. They generally consisted
of natural rivers, lakes, artificial trenches, channels, pools. Also, pipe systems used for
water supply were discovered in archaeological excavations.

Water is the bloodline of a city. Development of a city cannot be without water supply
for even the tiniest moment. Water shortage is severely problematic for modern city
development. As of today, out of about 600 cities in China, the number of cities that
have water shortage problems already passed 400. The questions of how to ensure water
for development and how to supply water in a sustainable fashion have become global
focuses. In a situation like this, looking back to the history of water-supply in ancient
times and summarizing the experience of opening water sources in ancient cities would
be very meaningful.

Background on water supplies of cities in ancient times
Water supply facilities of the city of Yangcheng in eastern Zhou dynasty
City of Yangcheng of Eastern Zhou Dynasty was located in the town of Gaocheng in
Dengfeng Prefecture, Henan Province. It was an important western military base of the
States of Zheng (in Spring-Autumn Period) and Han (in Warring-States Period). The
underground water-supply pipelines were important discoveries in recent archeological
excavations. They serve as realistic (opposed to recorded) proofs, which are uncommon,
to the research of underground water-supply facilities in ancient China. Since Yangcheng

doi: 10.2166/ws.2007.020
city was built on a slope with relatively higher elevation, for water-supply purposes within the city, jointed clay pipes were installed underground, transferring water into the city from outside. The pipelines were equipped with cleaning pools and valve trenches. This is a relatively complete water-supply system of Eastern Zhou Dynasty discovered so far (An, 1992).

The clay pipelines were installed from north to south, into well-dug sockets in the stone layer. About 500 m of pipelines had already been discovered, in which a T-shape joint was found every 30 ~ 50 m. The south end was connected to a storing pool, which stores the water transferred from the north side (in higher elevation). The storing pool was also dug in the stone layer. The shape was an east-to-west rectangle with large top (opening), small bottom, narrow east side and a broad west side. The four walls were installed neatly in order. The opening of the pool was 14.6 m long, the west end was 4.52 m wide, and the east end was 4.2 m wide. The bottom of the pool was 13.25 m long, the west end was 3.75 m wide, and the east end was 3.25 m wide. The west end of the pool was 2.2 m deep, and the east end was 1.5 m deep. The bottom of the pool was covered by pebbles with diameters of 0.4 ~ 0.5 m. The pebbles might be used for sediments in the water to precipitate.

In the bottom of the center of the eastern wall of the storing pool, there was a small culvert on the slope, with a length of 3.8 m. The west mouth of the culvert was 0.4 m higher than the east mouth. The height of the culvert was 0.21 ~ 0.98 m, the width of the bottom of the culvert was 0.2 ~ 0.7 m. At the bottom of the culvert, 11 joints of clay pipelines were installed from the storing pool towards the east, each joint was broad on one end and narrow on the other end, 0.6 m long. The broad end had a diameter of 0.17 ~ 0.18 m, and the narrow end had a diameter of 0.13 ~ 0.14 m. The thickness of the pipeline was about 2 ~ 3 cm. At the joints, narrow ends are installed into broad to about 4 ~ 6 cm. Since the purpose of the pipelines in the culvert was transferring water to the east, all the joints were set in the same direction: broad end heading west, narrow end heading east (Yang, 1985).

Next to the east end of the culvert there was a “valve trench.” (Figure 1) This was made by digging a lateral square trench and a lateral circular trench in the stone layer. The square trench was at the west side. Its each side was 1.35 m, and it was 1.7 m deep. The circular trench was at the east side. Its diameter was 1.1 m, and it was 1.85 m deep. The pipelines from the culvert extended to where the two trenches connect. There were obvious marks

Figure 1 The “valve trench” (Henan Province Artifacts Research Institute, 1982)
left from grinding and colliding, meaning this opening might be used to release water and block water with something (which created the marks). This explains that the two trenches might be used when blocking and releasing water, similar to modern tap water valves. Under the southeastern side of the valve trench, there was a 0.7 m long, 1.03 m high, 0.3 ~ 0.54 m wide arch-shaped culvert dug towards southeast. Connecting to the culvert, continue going southeast, there was an exposed trench that was 0.25 ~ 0.6 m wide at top, 0.25 ~ 0.35 m wide at bottom, 0.14 ~ 1.76 m deep. The bottom parts of the culvert and the trench were both installed with jointed pipelines. After the pipelines were installed, the trench was covered by soil and the pipelines became underground pipelines. 61 joints of this section of pipelines have been discovered, with 32.6 m remaining underground (Henan Province Artifacts Research Institute, 1982). The entire water-supply system of Yangcheng was reasonably planned and designed. It is important realistic information for the research of water-supply of cities in ancient China.

Rise and fall of the water source in Chang’an
In 206 B.C., Liu Bang established the Han Dynasty and named Chang’an the capital city. Chang’an of Han was located at the northwestern side of modern city of Xi’an. The city was in Guanzhong Plain with Weihe River crossing the north side. With the tributaries of Weihe River covers most of the city, at the time it was said that “Chang’an was surrounded by eight waters (rivers)”. At the south of Chang’an, there was the prosperous Ba and Shu (modern Sichuan Province); at the north of Chang’an, there were the profits from foreign tribes. The defense of the surroundings had always been strong (Wu, 1995). Therefore many dynasties named Chang’an the capital. From Western Zhou Dynasty to Tang Dynasty, a total of 10 dynasties named Chang’an the capital in a 1062-year span (Dong, 1988). City of Chang’an in Han Dynasty was established on the base of the palaces of Qin Dynasty. The old palace-wide water-supply system was put in use. In the beginning years of Han Dynasty, water-supply in Chang’an was adequate. Wu Emperor (7th emperor of Han) rapidly expand the size of the capital. Water-supply then became insufficient. Therefore the Kunming Reservoir was dug. For a long time, the purpose of Kunming Reservoir was said to be for military training for upcoming battles against the Kunming State in Yunnan. In fact, the main purpose of the reservoir was to serve as a source of water in Chang’an (Liu, 1988).

Huang (1958) made a map of water-transfer channels of Chang’an in Han Dynasty (Figure 2) after a series of research. He also deeply investigated the city water system. The water in Kunming reservoir originated from Jiaoshui River. The Book of Water (Annotation) recorded that there was a stone tablet built at the point where Jiaoshui River enters Kunming Reservoir. The purpose of the tablet was for blocking/transferring water into the reservoir. In flood season, extra water from Jiaoshui River could flow over the tablet into Fengshui River, thus protecting Kunming Reservoir from the flood. Kunming Reservoir supplied water to downstream through channels in the east side and the north side. The one in the east was called Old Kunming Channel, built specifically for supplying water to canals. The one in the north was called Kunming Reservoir Water, built specifically for supplying water within the city. There was another adjusting reservoir connected to Kunming Reservoir Water before it enters the city. The water was divided into two distributaries after this: one to the north into the palace heading for Weihe River, one to the northeast into the city (Xiong and Guo, 1989).

Wu (1995) gave an approximate figure of the capacity of Kunming Reservoir at 35.497 Mm³, which is equivalent to a medium-size modern reservoir. Kunming Reservoir and it channels ensures water-supply in Chang’an for the rest of the Han Dynasty. At the end of Han Dynasty, Chang’an was severely damaged due to numerous civil wars. The channels
were also destroyed. Water in the city was not suitable for drinking due to salinization. This was one of the key reasons that Sui and Tang Dynasties went seeking new locations for the capital. The north and east sides of the new capital were surrounded by rivers. The selection of location was closely related to water source. Water source of the new capital and the city development was planned simultaneously. City of Daxing was built in 583 AD, and at the about same time, three channels-Longshou, Yong’an, Qingming-were built and put in use. These channels solved the problem of city water-supply.

At the end of Tang Dynasty, a powerful warlord named Zhu Quanzhong forced the emperor to move the capital to Luoyang (in Henan Province). Chang’an was again ravaged in a series of civil wars. Although the following dynasties all had put effort to restore the city, the size of Chang’an never reach even 1/6 of the original size during Tang Dynasty. The water-transfer systems from Sui and Tang Dynasties were all ruined, and the channels were mostly abandoned. Wells became the only source of drinking water within the city. In 1014 AD, Longshou channel was restored to transfer due to severe salinization of well water. The channel was in use until the end of Jin Dynasty, when it was again abandoned. During 1264 ~ 1294 AD, Longshou channel was repaired twice to supply water for the entire city. It was abandoned again in mid-Yuan Dynasty. At the beginning of Ming Dynasty, Longshou channel was again restored due to salinization of well water. Yong’an and Qingming channels were never used after Tang Dynasty, and were replaced by Tongji channel, built in 1465 AD. Most of the channels outside of the city were the old channels from Tang Dynasties. From then on, east side of the city relied on Longshou channel, and west side relied on Tongji channel. The two channels supplied water for the entire city.
Chang’an. Hundreds of years later, Qianlong emperor built the modern Xi’an City, and the two channels were abandoned since then (Huang, 1958).

The water source of Chang’an is summarized as above. Building channels to transfer water into the city and establishing fluent city water system not only supplied water to the city, but also satisfied the needs of navigation, fire-control, landscape, defense, drainage, etc. This is important experience from water-supply of cities in ancient times.

History of water supply in Beijing

The City of Beijing has a long history. In the Warring-States Period, it was then called Ji, which was the capital of Yan State. From Qin Dynasty to Tang Dynasty, Ji had always been an important military base and capital of feudal states and prefectures. In 936 AD, Taizong Emperor of Liao Dynasty(The Kitan Empire) named Ji the second-capital of the empire and then rename it Nanjing (Southern Capital) or Yanjing. In 1153 AD, Jin Dynasty (The Jurchen Empire) moved its capital to Yanjing and renamed it Zhongdu (Central Capital). Since then, Beijing became center of power of Imperial China for more than 700 years (Chen, 1991).

According to The Book of Water, the first effort put into solving water source problem was made in the Three-Kingdom Period. A general of Wei Kingdom named Liu Jing transferred water from Yongding River into City of Ji for irrigation purposes (Cai, 1987). Although this was a simple agricultural project for food supply of military, it had great impact on upcoming water source problems in Beijing.

Before Yuan Dynasty (The Mongol Empire), the city of Beijing was close to Lianhua (Lotus) Reservoir watershed. Sources of water in the city were wells and transferring surface water from Lianhua Reservoir. Lianhua Reservoir was originally an underground spring and was called Xi Hu (the West Lake) (Duan, 1989). According to The Book of Water (Annotation), the flow from the east side of the reservoir was Xima channel and enters Ji city from the south gate (of City of Ji in Northern Wei Dynasty). After Jin Dynasty moved its capital here, Xima channel was planned as part of the city, crossing the imperial palace. It became an important water source in the palace (Figure 3) (Hou, 1979). City of Zhongdu expanded rapidly and the population reached one million. Need of water increased rapidly with population, and Lianhua Reservoir quickly became insufficient. Xishan Spring extraction was started to solve the problem. Cai (1987)

Figure 3 Channels into the palace of Zhongdu (Hou, 1979)
analyzed that during Jin Dynasty, there might be channels located upstream of Lianhua Reservoir that transferred water from Xishan.

The capital of Yuan Dynasty, Dadu (Great Capital), was located northeast to Zhongdu, moving from Lianhua Reservoir watershed to Gaoliang River watershed. One reason for moving was that Zhongdu was severely damaged in times of war, and the palaces were in ruins. Another, and a more important reason was for abundant water resource (Chen, 1991). Since then, under the clever design of Liu Bingzhong and his pupil, Guo Shoujing, the construction of Dadu was completed in 1285 AD, having taken 18 years.

The selection of location for Dadu was closely related to water-supply and transportation purposes. Gaoliang River watershed could provide much greater amount of water than Lianhua Reservoir watershed. Also, water from Baifu and Xishan Springs was transferred into Gaoliang River few years later. Water-supply and water-transport needs were met.

Jinshui River outside of Dadu was dug in Yuan Dynasty. It collects spring water from Yuquan Mountain and entered the city through Heyimen Gate (now Xizhimen). This water specifically served the imperial palace. For controlling the quality, no mixing with other water source was allowed. Independent troughs were bridged where Jinshui River must cross other channels. According to legal documents from Yuan Dynasty, bathing, washing, dumping and livestock drinking were all prohibited. Navigation canal was also constructed in Zhongdu in Jin Dynasty. But because water source could not be guaranteed, the canal was not effective. In Yuan Dynasty, Baifu Spring water was transferred to fill the canal. The entire project was completed in 1292 AD. Cargo ships and boats can directly enter the city through the canal. The canal was named Tonghui River, and is still in use. Baifu Spring water transfer project was one of the most innovative solutions to water source problems in the history of Beijing (Hou, 1979).

In Ming Dynasty, the canal stopped flowing due to lack or repair. In Early Ming, reconstruction of Beijing damaged the old canal system. The old canals were planned as part of the imperial palace (Forbidden City), therefore cargo ships were never be able to enter the city (Figure 4). The palace-only channel, Jinshui River, was also abandoned. There were efforts made to restore Tonghui River channel in Ming Dynasty, but none of them were effective due to lack of water source (Zheng, 1985). Water-supply in the city could only rely on spring water from Yuquan Mountain. Spring water was collected at Wengshan Lake (now Kunming Lake) and transferred into Jishuitan Reservoir within the city. Then the water was divided into two distributaries: one into Forbidden City, and one

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Figure 4 A comparison of Dadu (left) and Ming-Dynasty Beijing (right) (Hou, 1979)
into Tonghui River (canal). Therefore, the water supplied within Ming imperial palace was no different from water used in the canal. This was very different from the scenario in Jin and Yuan Dynasties. But the situation remained unchanged since then (Hou, 1979).

Water channels in Beijing in Qing Dynasty were mainly old channels left from Ming Dynasty. During Kangxi Reign (1662 – 1722), Tonghui River was used for transportation purposes. A channel at the east side of Beijing was opened for small cargo ships to enter the city. But lack of water source was still the main problem for transportation. In Qianlong Reign (1736 – 1795), the government finally decided to manage the water channels at the west of Beijing for landscape and transportation purposes. The first step was to utilize Wengshan Mountain as a site for landscape garden. Second, deepening Wengshan Lake, construct a levee at the east side to block streamflow from Yuquan Mountain, thus creating a much larger lake-modern Kunming Lake. Wengshan Mountain then was renamed Wanshoushan Mountain. The east levee significantly raises the water level and the capacity of Kunming Lake, making Kunming Lake the first artificial reservoir of Beijing. Situation regarding water source was much improved since then (Zheng, 1985).

Within City of Beijing, citizens had been using wells to draw groundwater for daily life uses for generations. The alleys in Beijing are called “hutong,” meaning “well” in Mongolian. In Dadu of Yuan Dynasty, the wells were dug in the alleys, and the alleys were named after the wells. Therefore “hutong” has the meaning of “alley.” City of Beijing was reconstructed in Ming and Qing Dynasty. Many hutongs were left without a well. According to contemporary records from Yuan, Ming and Qing Dynasties, water quality in the wells had been low due to salinization. Low water quality led to two results: water was supplied in three levels of quality (washing, cooking, drinking), and selling water became a profession in Beijing (Duan, 1989).

Main methods of water supply of cities in ancient China

From the rise and fall of water source of Xi’an (Chang’an) and Beijing in history, it can be concluded that rise and fall of a city is closely related to water supply. The movements of two ancient capitals were both related to lack of water source and to seek new water source. From water-supply of cities in ancient China, one can gain precious experience and information for modern city planning and development. Main methods of water-supply of cities in ancient China can be summarized as follows.

Drawing water from wells

Drawing water from wells was an important method of water-supply in ancient China. Under the sanitation conditions in ancient China, even if there are multiple sources of water in a city, well water was always the top choice for drinking water for its stable quality. The first well found in archeological research in China was located in Hemudu Ruins (in Zhejiang Province), built approximately 5,700 years ago, which a comprehensive wooden well structure. History of wells in Central Plains of China began about 4,000 years ago. Although it began later than the south, but in terms of technology, the north was ahead. The ancient wells in Central Plains have larger diameter and a deeper bottom. For example, two wells found in Handan, Hebei Province were 2.1 m wide (in diameter) and 7.7 m deep; a well found in Xiangfen, Shanxi Province was more than 3 m wide and about 13 ~ 15 m deep (Fang, 1986).

In Xia, Shang and Zhou Dynasties, the use of wells was very common. The wells were mainly made of soil, such as Shang-Dynasty wells found in Yanshi and Zhengzhou of Henan Province. By Eastern Zhou Dynasty, use of wells grew even more. At some places the wells were densely distributed. For example, in Jinan Ruins in Hubei Province,
in a 1,000 × 60 m² area, 256 wells were present; in Ji City Ruins (southwest of modern Beijing), concentration of wells was as high as 4 wells in 6 m². During Eastern Zhou Dynasty, wells were mostly made of clay. Well technology had also much improved. Since Qin and Han Dynasties, wells and city development had been more closely related. Besides soil and clay, bricks and rocks were used to build wells.

Transferring water through canals
Ancient cities usually follows the rule “stay away from dry lands at high elevation; stay away from water at low elevation.” Considering the geographical and flooding conditions, the cities could not be built too close to water. Therefore canals must be built to transfer water into the cities. For example, Longshou channel of Chang’an, Jinshui River of Dadu, etc. Another well known example was Jinshui River Project in Chengdu (Capital of Sichuan Province) in Tang Dynasty. The project transferred water from Minjiang River. Water entered the city from the west, crossed the entire city, and made water-use convenient for the citizens. Jinshui River in Chengdu was repaired and harnessed in every dynasty after Tang, and was still effective after 1949 (Xiong and Guo, 1989).

Storing water by building dams
Building dams and levees to block and store water in rivers and form large capacity reservoirs was an important method for solving problems regarding city water source. Kunming Reservoir of Chang’an of Han Dynasty, West Lake of Hangzhou of Tang and Song Dynasties, and Kunming Lake of Beijing of Qing Dynasty were all well known examples. Other than these, some cities artificially dug large pools to store water from springs or rivers and used it as a supplemental source of water, such as Daming Lake in Jinan, Shandong Province. Reservoirs could not only serve as sources of water, but also manage floods and be effective in flood defence.

Delivering water by wagons
No matter how developed the city water systems were in ancient China, modern tap water pipeline networks were impossible to achieve back then. A well in each household was also an impossible scenario. Therefore selling and delivering water became a profession. This is an important supplemental method of water-supply in cities, especially when canals were abandoned in certain times in history. In Ming and Qing Dynasties, although Jinshui River was abandoned, the imperial palace still used spring water from Yuquan Mountain. Spring water was carried by royal water wagons and delivered to Forbidden City. This showed how important that water wagons were in water-supply of cities in Ancient China.

Methods that guaranteed water quality
Quality of drinking water can directly influence the users’ health. For this reason, people in every dynasty have paid attention to maintain water quality. Independent troughs bridged in Jinshui River canal of Dadu mentioned before was an example of maintaining water quality. This method was widely used in ancient China. Generally, water was used without any treatment because water sources were usually protected from pollution. In some cities that water at the sources was muddy in the first place, “purifying troughs” (similar to modern deposition pools) were built to purify the water. For example, In Northern Song Dynasty, Jinshui River of Chengdu was equipped with purifying troughs for sediments to deposit before the water entered the city. Also, large amount of sediments were present in water in some areas. Residents of these areas knew that stirring
after putting alum in water can quickly purify the water. This is the same mechanism as modern coagulation process.

Conclusion

The main experience from water-supply in ancient cities is to discover and open new water sources according to geography of the place. From examples of Xi’an and Beijing, it can be concluded that as long as the problem regarding water source was solved, city development would be rapid and smooth. On the other hand, if the problem could not be solved, then development would be limited. Methods and facilities of water-supply and controlling water quality in the cities of ancient China were significant achievements, which are worthwhile for us to learn and use as reference in modern city planning.

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