REMOTE SENSING ANALYSIS OF THE STATUS OF THE BEIJING-HANGZHOU GRAND CANAL

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ABSTRACT:

Remote sensing began with the use of aerial photography and is acknowledged as a valuable tool for viewing, analyzing, characterizing, and making decisions about our environment. The Grand Canal of China is the longest ancient canal in the world and recently approved as the Key National Relics-preservation Unit. In our work multi-source and multi-temporal remote sensing data, including the aerial photographs taken half a century ago and the recently acquired SPOT5 multispectral images and the RADARSAT-1 images are collected. Through a comparative and complementary analysis of the data sets, some findings are given. The general characteristics of the canal course and the canal cities are also described, which provides important information for the making plans of the Grand Canal preservation.

1. INTRODUCTION

Remote sensing, in the broadest sense, is the short or large-scale acquisition of information of an object or phenomenon, by the use of either recording or real-time sensing device(s) that is not in physical or intimate contact with the object (such as by way of aircraft, spacecraft, satellite, buoy, or ship). In practice, remote sensing is the stand-off collection through the use of a variety of devices for gathering information on a given object or area.

Remote sensing has seen dramatic growth over the last few decades. In part, this can be attributed to the technical developments, but it is clear that remotely sensed data must also have some tangible advantages to justify the expense of acquiring and analyzing them. These advantages derive from a number of characteristics of remote sensing. Probably the most important of these is the fact that data can be gathered from a large area of the Earth's surface (or a large volume of the atmosphere) in a short space of time, allowing a virtually instantaneous 'snapshot' to be obtained. For example, the LANDSAT Thematic Mapper, a spaceborne instrument, can acquire data from an area 185 km square in about half a minute. When this aspect is combined with the fact that airborne and spaceborne systems can obtain information from locations that would be difficult (slow, expensive, dangerous, and politically awkward) to measure in situ, the potential power of remote sensing becomes apparent. The second advantage is that the wide range of spectrum that the sensor responds. Human eyes can only feel the visible electromagnetic spectrum which ranges from 0.38 to 0.76 micron in wavelength, only a slim portion of the whole electronic spectrum. However, with the technical developments, different types of advanced sensors are available, covering the ultraviolet, visible, infrared, and microwave portions of the electromagnetic spectrum which ranges from 0.3 micron to 1000 millimeters, far greater than that of human eyes feel. The third advantage is the high spatial resolutions available. Nowadays, QUICKBIRD can provide optical images at the spatial resolution of 0.61 meter, while the TERRASAR can provide radar images at the spatial resolution of 1 meter. The fourth advantage is the high spectral resolution. Now the hyperspectral sensor can acquire image at hundreds of channels simultaneously, which can grasp the small changes of reflectance and make possible the discrimination of some targets. Further advantages derive from the fact that most remote sensing systems now generate calibrated digital data which can be manipulated in a computer.

2. REMOTE SENSING IN ARCHAEOLOGY

The spectrum of sunlight reflected by the Earth's surface contains information about the composition of the surface, and it may reveal traces of past human activities, such as agriculture. Since sand, cultivated soil, vegetation, and all kinds of rocks each have distinctive temperatures and emit heat at different rates, sensors can "see" things beyond ordinary vision or cameras. Differences in soil texture are revealed by fractional temperature variations. So it is possible to identify loose soil that had been prehistoric agricultural fields, or was covering buried remains. More advanced versions of such multi-spectral scanners (Visible & IR) can detect irrigation ditches filled with sediment because they hold more moisture and thus have a temperature different from other soil. This is how optical remote sensing works in archaeology. As to the active microwave remote sensing, radar emit energy waves to the ground and records the energy reflected and can penetrate darkness, cloud cover, thick jungle canopies, and even the ground, so in some cases radar remote sensing are more advantageous for archaeological target detection.

Remote sensing techniques have proven to be very useful in the search for archaeological sites. In World War I, Lieutenant-Colonel G. A. Beazeley, a military officer, discovered the extensive outlines of ancient canals in Mesopotamia's Tigris-Euphrates plain (Dache, 1936). In 1981, the shuttle imaging radar (SIR-A) penetrated the extremely dry Selima Sand Sheet, dunes, and drift sand of the eastern Sahara, revealing previously unknown buried valleys, geologic structures, and possible Stone Age occupation sites(J. F. McCAULEY, 1982). In 1982, Payson Sheets and Tom Sever analyzed color and false-color infrared photographs and detected the oldest known footpaths in Arenal Region, Costa Rica (Tom Sever, 2000). In 1987, Scott Madry discovered Remains of a Gallo-Roman villa rustica in the town of Autun in the Burgundy region of France (Madry, 1987). In 1992, radar images from space revealed ancient caravan routes that lead to the discovery of the lost city of Ubar in the southern Empty Quarter of the Arabian Peninsula in the sultanate of Oman (Blom & Crippen, 1997). In 1994, SIR-C radar images of the Great Wall of China found an earlier piece of the Wall—long suspected to have existed, but never located—buried under dirt and sand(Lu et al., 1997) and targeted the ancient city of Angkor in Cambodia and pick up details of the topography hidden below(Freeman et al., 1999). In 1999, E. Ben-Dor et al. detected buried ancient walls in Leviah Enclosure, an Early Bronze Age settlement that is covered by a thin layer of soil, using airborne thermal video radiometry (E. Ben-Dor, et al., 2001). In 2004, Sarah Parcak identified new archaeological sites in Egypt using satellite remote sensing (Sarah Parcak, 2004). However, almost all the researches and projects only target a small area, such as a village, a complex of tombs, a segment of wall, a short segment of the Silk Road, and an ancient city. So for quite a few of them, high resolution images, such as QUICKBIRD or IKONOS, are warmly welcomed and can get good results. In the case of the long “belt” archaeological target like the Grand Canal of China, very few comprehensive researches have been done.

3. STUDY TARGET AND OBJECTIVE

The Grand Canal of China is the longest ancient canal or man-made river in the world. The oldest parts of the canal, known as known the Han Gou or 'Han-country Conduit', date back to the 5th century BC. The Grand Canal as we see it today was in great part a creation of the Sui dynasty (581-618), a result of the migration of China’s core economic and agricultural region away from the Yellow River valley and toward what is now Jiangsu and Zhejiang provinces. During Ming (1368-1644), and Qing (1644-1911) dynasties, the Grand Canal served as the main artery between northern and southern China and was essential for the transport of grain to Beijing. After that, due to the lack of water supply in the northern section and the emergence and surge of advancing transport system the railway system, the Grand Canal had not been attached as great importance as before. Since then, the northern section has undergone great changes and destruction due to the slack management, poor maintenance and the intervening of human activities. In May 2005, the Grand Canal of China was approved as “The Key National Relics-preservation Unit” by the State Council. In December 2006, the Grand Canal headed the new China world heritage candidates list. So how to effectively and objectively find the old canal course and assess the status of the course and its surroundings is our main purpose.

3.1 Data collection

The image dataset used in this study consists of scanned aerial photographs, Landsat-5 TM Landsat-7 ETM+ images, SPOT5 multispectral images, and RADARSAT images, ranging between 1930s and 2007. As to the optical satellite images, only images acquired in spring and summer months were considered. The available images were further screened based on the absence of cloud cover, however when multiple cloud free images were available for a given year, the image acquired closest to May was selected for inclusion in the time-series. All the satellite images were reprojected to the UTM coordinate system (zone 50) with a root mean square error of less than 0.5 pixels per image.

3.2 Data Preprocessing

The two most common types of error encountered in remotely sensed data are geometric and radiometric. Geometric correction is concerned with placing the reflected, emitted, or back-scattered measurements or derivative products in their proper planimetric location so they can be associated with other spatial information in a geographic information system or spatial decision support system (Jensen 2002). This is because Remote sensing images are subject to geometric distortions due to several factors, including: perspective of the sensor optics, motion of the scanning system, motion of the platform, curvature and rotation of the Earth. So in our work the image data sets were geometrically corrected to the UTM coordinate system involved the following steps: (1) Map to image and image-to-image methods have been used in rectification process; (2) Digitized of ground control point’s coordinates from standard topographic 1/25000-scaled maps and 1/5000-scaled orthophoto maps. Twenty-five ground control points used in this step; (3) Computation of least square methods solution for a first order polynomial equation required to register the image data sets; (4) For the resampling method of geometric correction using cubic convolution algorithm. The total root mean square (RMS) error falls below 1 pixel for the image sets.

Radiometric correction is concerned with improving the accuracy of surface spectral reflectance, emittance, or back-scattered measurements obtained using a remote sensing system. Two types of radiometric corrections, absolute correction and relative correction, are commonly employed to normalize remotely sensed images for time-series inter-comparison (Coppin et al., 2004). Absolute radiometric correction is aimed towards extracting the absolute reflectance of scene targets at the surface of the earth. This method requires the input of simultaneous atmospheric properties and sensor calibration, which are difficult to acquire in many cases, especially in historic data (Du et al., 2002; Song et al., 2001). Relative radiometric correction is aimed towards reducing atmospheric and other unexpected variation among multiple images by adjusting the radiometric properties of target images to match a base image (Hall et al., 1991), thus it is also called relative radiometric normalization. Relative radiometric normalization is an image based correction method achieved by setting the multi-temporal images into a common scale without extra parameters from other measurements. Taking into account the effectiveness that will fulfill our research objective and the time cost of the two methods, the relative radiometric correction was employed in our work.

4. GENERAL CHARACTERISTICS OF THE GRAND CANAL COURSE

LANDSAT TM/ETM+ images give us the direct and visible information of the targets, so it helps for us to get to know the general characteristics of the Grand Canal. We collected 18 scenes of ETM+ imagery, acquired around the year 2000. All of them were geo-corrected and then combined together according to the geo-coordinates. From the mosaic image, the general characteristics of the Grand Canal are very clear. Of them the most noticeable one is the multiple curves of the Grand Canal northern section. Here the Grand Canal northern section refers to the canal above the Yellow River.

The multiple curves happen in the Grand Canal northern section means the ground undulation. In order to balance the ground undulation and make the water flow smoothly, the canal course was intentionally built curvedly. To quantitatively describe the curve, based on the mosaic image we measured a segment which starts from Tianjin to Linqing, and found the length of the course is about 394km, and the direct distance of that segment, by linking all the cities and towns together, is about 290km, that is to say the length of the canal course about 1.5 times of the direct distance. However, this is not the case with the Grand Canal in southern section, referring the one below the Yellow River. And actually the northern section and the southern section are presently two separate sections, because of the cut of the Yellow River since the year 1855. As to the course features, the striking difference between the southern and the northern section is that the straightness, as shown by Fig 1. Of course the width of the course is much wider than the northern section because the southern section still undergoes heavy cargo transportation, while the northern section fell into disuse, except for irrigation.

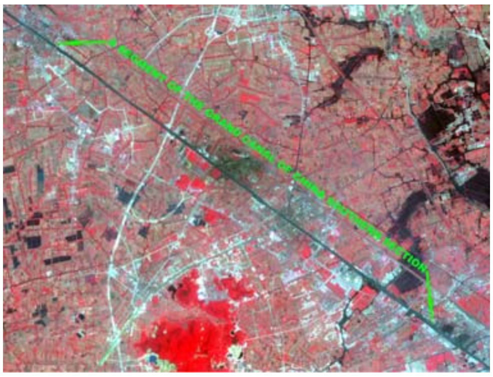

Fig 1: straight course of the Grand Canal southern section

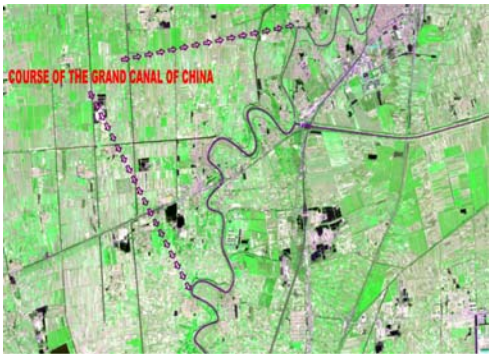

Fig 2: the Grand Canal course curves revealed by SPOT5 multispectral image.

However, the Grand Canal northern section was not as straight as Fig. 2 showed. From Fig. 2 we find that the Grand Canal north section has undergone some changes over the past half century. On the one hand, the course was straightened. On the other hand, the course was widened to some extent. From Fig. 2 we can explain the cause of the striking difference. Maybe at the beginning the northern and southern sections were more or less as curve as Fig. 2 showed. However, since 1855 when the Yellow River cut the Grand Canal into two separate sections, the northern section fell into disuse and most parts of the course kept the original state. While the southern section was not severely influenced by the Yellow River and still undergoes heavy cargo transportation, so the need for straightening and widening emerged. Under this background the Grand Canal southern section has evolved to the present state.

5. GENERAL CHARACTERISTICS OF THE CANAL CITIES

Canal cities here refer to the city alongside the Grand Canal. They are, from north to south, Beijing, Tianjin, Cangzhou, Dezhou, Linqing, Liaocheng, Jining, Xuzhou, Suqian, Huai'an, Yangzhou, Zhenjiang, Changzhou, Wuxi, Suzhou, Jiaxing, and Hangzhou. The Grand Canal assumed an important role in making the urbanization of the areas along its route in North China. According to historical document, in the Mid-to-late Ming, the commercial tax levied on the canal occupied 90% of the total amount of the empire, which we can see the prosperity of the Grand Canal. All these cities have much to do with the Grand Canal, and some of them were emerged just because of the Grand Canal, such as Yangzhou. Hundreds of years ago when the canal functioned very well, the canal was the core of the cities, because all the commercial activities were conducted alongside the Grand Canal for convenience. Hundreds years later, with the emergence of the advancing transportation tool such as the railway and the expressway, the canal could not enjoy as high status as before, as we can see from Yangzhou, as Fig. 3 shows.

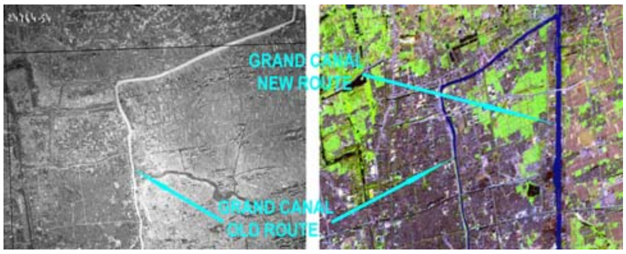

Fig 3: Grand Canal in aerial photograph taken in around 1954 and that in SPOT5 multispectral images acquired in 2002.

From the image pair we can find that the old canal no longer supports the heavy transportation and another straight new canal was built. According to our investigation this May, that old section has been used for scenery only. This phenomenon, the separation of the scenery canal and the transportation canal, is not alone, as we can see from the case of Huai'an. This separation reflects on the pressure of the crowding of urban land use and the heavy transportation, the old canal stepped out of the functional use and become the scenery canal only.

6. SAR IMAGE DETECTION OF THE DISAPPEARED LAKES

While reflectance measurements in the visible and infrared regions are primarily related to molecular resonances of surface materials, the backscatter of a radar wave is largely determined by the physical properties of surface objects such as surface roughness and dielectric constant (Floyd, 1997). Moisture in the landscape influences the backscattering coefficient through changes in the dielectric constant of landscape materials. (the dielectric constant is a measure of the ability of a substance to conduct electrical energy—an important variable determining the response of a substance that is illuminated with microwave energy.) Roughness refers to minute irregularities that relate either to textures of the surfaces or of objects on them (such as, closely-spaced vegetation that may have a variety of shapes). Examples include the surface character of pitted materials, granular soils, gravel, grass blades, and other covering objects whose surfaces have dimensional variability on the order of millimeters to centimeters. The height of an irregularity, together with radar wavelength and grazing angle at the point of contact, determines the behavior of a surface as smooth (specular reflector), intermediate, or rough (diffuse reflector). The backscatter of a radar wave can also be influenced by the geometric configuration of targets. Objects that have complex geometric shapes, such as those encountered in an urban landscape, can create radar returns that are much brighter than would be expected based upon size alone. This behavior is caused by objects classified as corner reflectors, which often are in fact corner-shaped features (such as the corner of buildings and the alleyways between them in a dense urban landscape), but are also formed by other objects of complex shape. Corner reflectors are common in urban areas due to the abundance of concrete, masonry, and metal surfaces constructed in complex angular shapes.

This work begins with the RADARSAT-1 mosaic imagery. It was created by some 15 RADARSAT-1 images taken around 1997 with ScanSAR mode. The mosaic imagery was created with UTM projection (zone 50) and WGS-84 datum. The spatial resolution of the mosaic imagery is 50 meters, much greater than most segment of the Grand Canal. So directly retrieve the canal course form this mosaic imagery is quite difficult. However, as mentioned above, the radar signal are very sensitive to the corner-shaped features, so radar detection of the canal related settlements and the town alongside the canal are possible.

As can be seen from the subset of the mosaic imagery, shown in Fig. 4, a vast "dark zone" lies in the middle of the image. As analyzed above, the dark zone in the radar image indicates low backscatter. That is to say, this area has high soil moisture content or very small roughness. However, the small roughness occurs in place such as the aircraft runway. And because usually the runway is surrounded by the low vegetated area and the boundary between them is very clear, which reflected in the radar image is that the sharp difference between the runway and its surroundings. So the assumption that the area appears in dark because of the small roughness can be excluded. That is to say the high soil moisture content attributes to the darkness in the radar image. But why there is a so large area with high soil moisture? Compared to the surroundings of the dark area, the human settlements distributed uniformly and densely. So this is even more strange that why such a vast area with very sparse human settlements. This is the first puzzle.

According to the present maps of Shandong Province, the river depicted in Fig. 5 is a segment of Grand Canal. However, according to the historical documentation, the Grand Canal Shandong segment was built totally by manpower in the year around the year 1283. So the canal should not be so straight like that, due to conquering the terrain undulation. One the other hand, the canal is the pivot for the cargo transportation China since the formation of the Grand Canal hundreds years ago. So alongside the canal course there should be many human settlements, for the convenience of cargo transportation or commercial communication, just like nowadays, when an express way or rail way is built, it will attract the human settlements for commercial communication. So this is another puzzle that the manmade canal course was so straight and alongside the canal course there are very sparse human settlements.

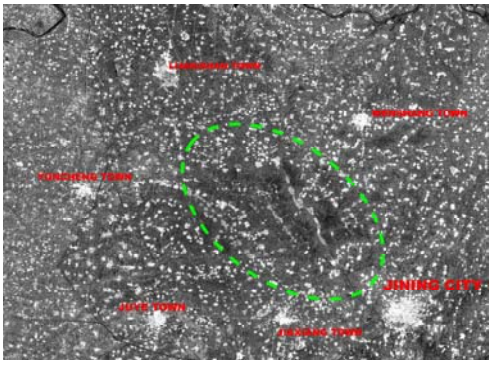

Fig 4: subset from the mosaic imagery, the dark area enclosed indicates the disappeared old reservoirs of the Grand Canal.

Bearing the two puzzles in mind, we checked some literature and found that just in the place Fig. 4 depicted there is the "throat" of the Grand Canal, the highest point of the whole Grand Canal. And since the building of that segment of the Grand Canal, it has been the great concern of the government of all levels. And very luckily we found a historical map that depicted all the immediate information about the Grand Canal, such as the water supply, the length between the two adjacent segments, and all the important water facilities, such as the lock and bridge and also the human settlements alongside the Grand Canal. So it is the most detailed and visual map of the Grand Canal and can give us quite lots of information about the situation that time. The map was drawn by an official in charge of the Grand Canal, according to the field investigation and mapping rules which are different from today. From Fig. 6, it can be found that except for the canal course, there are also four lakes: Machang Lake, Shushan Lake, Mata Lake, and Nanwang Lake respectively. For more information about the four lakes we checked the historical literatures and found that these four lakes called water reservoirs played a very important role in the function of the Grand Canal. The four water reservoirs were used to store the sufficient water and guaranteed the safety of the course in rainy seasons, and to supply the canal with the water stored in dry seasons. In one word, the four reservoirs were used to balance the water volume to make the canal function all the year around.

By comparison of the map of over one hundred years ago and the present satellite image, we can basically conclude that all the four lakes disappeared some time. To make sure when that happened, we referenced the old aerial photographs, which taken around the year 1954. The aerial photograph shows in Fig. 7A.

By comparison the aerial photograph mosaic and the Google Earth image of the same area, we can find that great changes have taken place over the past half century. On the aerial photograph mosaic, two reservoirs, the bigger one called Nanwang Lake and the smaller one called the Machang Lake, still existed. However, from the Google Earth image we can find that both lakes disappeared and just inside the Nanwang Lake, a new river which is just the straight river showed in Fig.

7B emerged. That is to say, during the past half century, both the Nanwang Lake and the Machang Lake died and a new river was built. To fix the time when this happened, we checked the local documents of that area and found that just in 1959, a new canal connecting Jining and Lianshan was built. And in the year 1973, when China was conducting the massive campaign of convert reservoirs into cultivated land, the three reservoirs were intentionally damaged and the large volume of water stored was flowed into the new canal. Since then, the dried reservoirs became the fertile fields and many crops were planted there, as we can see from Fig. 7B that the field patches lie inside the ever reservoirs.

Because of the strange topography—the bottom of reservoirs half a century ago, it is quite understandable that the soil moisture content is much higher than its surroundings. What's more, due to the same reason, there could be not many human settlements in that on the one hand, the change of land use is quite late compared to its surroundings, and on the other hand low topography are more subject to floods. High soil moisture content plus very sparse human settlements attributes to the low backscatter of the radar signal, and the low backscatter directly attributes to the appearance of the dark zone in the radar image. Now all the puzzles regarding the dark zone are resolved. However, the archaeologists are more concerned about the boundary of the reservoirs because almost all the archaeological things including the strobes were located in the boundary of the reservoirs. So our next task is trying to identify the boundaries of the disappeared reservoirs. However, according to Fig. 7A and Fig. 7B, we find that only the boundary of the Nanwang reservoir can be partially identified, because of the incomplete coverage of the aerial photographs, as shown by Fig. 7A. The boundary of Machang Reservoir can not be fixed because it shrunk too much and the actual boundary should be far outside that. So our future work is trying to collect more aerial photographs that would be helpful to fix the boundaries.

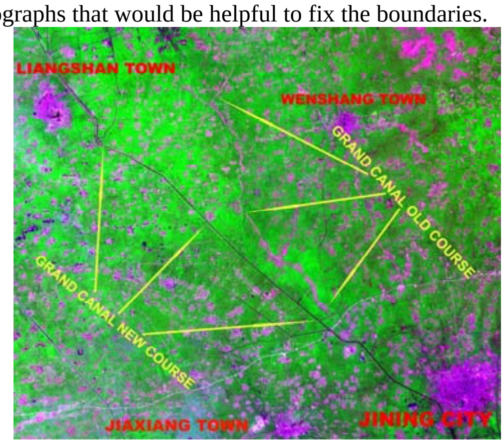

Fig 5: LANDSAT ETM+ band 7 4 3 combined false color image.

Fig 6: old map depicts the Grand Canal over one hundred years ago.

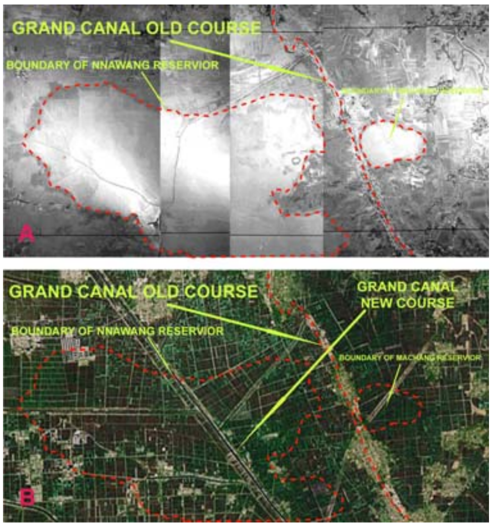

Fig. 7: aerial photographs taken in 1954 reveal the existence of reservoirs (A) and Google Earth image of the same area (B)

7. CONCLUSIONS AND FUTURE WORK

The present study has reflected objectively the present condition of the Grand Canal and the Grand Canal changes from satellite image data and the perspective of historical documents. The satellite images offer a means for demonstrating and for analyzing long-term scales and rates of the Grand Canal changes as a whole. By remote sensing analysis of the multi-source multi-temporal image sets, we found the Grand Canal has undergone great changes over the past half century. These changes can be classified into two types. One is pessimistic, which is the ever shrinking of the Grand Canal northern section. In some segments there is no water at all and the course uncovered is subject to the human interventions. As to this section, there is a long way to go to preserve the Grand Canal and the cultural relics related. The other one is optimistic, which is the strengthening of the Grand Canal by widening and straightening the canal course and separate the operational canal with the scenery canal. This is the best way to balance the contradiction of the urban development and the protection of the Grand Canal itself and its surroundings close to the canal cultures. Also this measures can effectively enlarge the potential of the Grand Canal as the its original function—cargo transportation.

However, one of the most important parameter the length of the Grand Canal is not given. According to the historical records, the length of the Grand Canal is about 1794km. This is the most common figure available now. But the Grand Canal is still alive, as we can see from the southern section the canal straightening and the emergence of new one. Also, this work has not incorporated the Grand Canal water supply changes and the interaction between the Grand Canal and the natural rivers such as the Yellow River, the Yangtze River and the Huai River. These are as important as the present condition for better preservation the Grand Canal and cultural relics related in the surrounding. Also it is very meaningful for us to retrieve the changes of the water volume of the Grand Canal and the lakes or reservoirs in its vicinity. That is because that the changes of the water volume will not only reflect the changes of the Grand Canal directly, but also reflects, from one aspect, the regional changes alongside the Grand Canal under the frame of the

Global Warming. So in the future we will, based on this work, conduct: measurement of the Grand Canal course; change analysis of the Grand Canal water supply and the interaction between the Grand Canal and the natural rivers such us the Yellow River, the Yangtze River and the Huai River; change analysis of the water volume of the Grand Canal and the the lakes or reservoirs in its vicinity.

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