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Water discharge changes of the Changjiang River downstream Datong during dry season

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Based on hydrometric data and extensive investigations on water-extracting projects, this paper presents a preliminary study on water discharge changes between Datong and Xuliujing during dry season. The natural hydrological processes and human factors that influence the water discharge are analyzed with the help of GIS method. The investigations indicate that the water-extracting projects downstream from Datong to Xuliujing had amounted to 64 in number by the end of 2000, with a water-extracting capacity up to 4,626 m3/s averaged in a tidal cycle. The water extraction from the Changjiang River has become the most important factor influencing the water discharge downstream Datong during dry season. The potential magnitude in water discharge changes are estimated based on historical records of water extraction and a water balance model. The computational results were calibrated with the actual data. The future trend in changes of water discharge into the sea during dry season was discussed by taking into consideration of newly built hydro-engineering projects. The water extraction downstream Datong in dry season before 2000 had a great influence on discharges into the sea in the extremely dry year like 1978-1979. It produced a net decrease of more than 490 m3/s in monthly mean discharges from the Changjiang into the sea. It is expected that the water extraction will continually increase in the coming decades, especially in dry years, when the net decrease in monthly mean water discharge will increase to more than 1000 m3/s and will give a far-reaching effect on the changes of water discharge from the Changjiang into the sea.

Water discharge changes of the Changjiang River downstream Datong during dry season ZHANG Erfeng, CHEN Xiqing, WANG Xiaoli (State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai 200062, China) 1 Introduction Being the largest river in China, the Changjiang (Yangtze) River empties a large volume of freshwater into the sea. The annual discharge averages approximately 28,700 m3/s between 1950 and 2000, with large annual and seasonal variabilities. The monthly mean discharge varies from 84,200 m3/s in August 1954 to 6,730 m3/s in February 1963. The discharge during dry season (November to next April) only accounts for about 29.11% of the total each year, which may become a critical problem for the water resource in the delta area in the future (Chen and Chen, 2000). Historical records in the past 20 years show that saltwater intrusion is the major cause for seasonal water shortage in the vicinity of the Changjiang Estuary (Mao et al., 2000; 2001). The water resources in the Changjiang delta will face two challenges. The first challenge comes from the global climate change and human activities in the upper and middle reaches, which will influence the hydrological processes in headwater area and the upper basin. For instance, the climate warming in the upper basin has influenced the glacier and lakes, while deforestation in the Minjiang and the Jialing river basins has resulted in a striking decrease in dry-season discharges (Chen et al., 2001). Additionally, although the monthly mean discharge did not yet show a decreasing trend, the rapid increase of water consumption in the middle and lower reaches has been great enough to cause a large and episodic decrease in minimum discharge at Datong during dry season (Chen, 2002) (Figure 1). The second challenge comes from hydrological processes in the Changjiang Estuary (downstream the tidal limit). Large amount of water extraction between Datong and Xuliujing may greatly reduce the water discharge into the sea. In the past, Chinese scientists and engineers usually use the Datong records to represent water discharge from the Changjiang into the sea. Datong hydrometric station is located at the tidal limit of the Changjiang River. Upstream from Datong, there is a good relation between water level and water discharge. But from Datong downstream, the traditional hydrometric stations are unable to monitor the river discharge effectivel

y. The distance from Datong to the river mouth is more than 600 km. Within this area, there are no large tributaries flowing into the mainstream of Changjiang. On the other hand, the water consumption in this area has increased rapidly in recent decades. The East Route South-to-North Water Diversion Project will take source water from this area. It will remarkably decrease the freshwater into the sea. Therefore, the discharge at Datong during dry season can no longer represent the discharge into the sea (Chen and Chen, 2000). For example, the saltwater intrusion in the estuary is getting stronger under the same Datong discharge. Thus, study on the local hydrological processes is necessary for understanding the important phenomena and processes in the Changjiang Estuary. It can also provide the scientific basis for the future operations of the South-to-North Water Diversion Project and the Three Gorges Project. 2 Geographical setting The study area extends over 500 km in length from Datong to Xuliujing, with an area of about 103×103 km2 (Figure 2). This area has favourable natural conditions, fertile land resources and well-developed industry and agriculture. There are 13 cities along the riverbanks, i.e., Tongling, Wuhu, Maanshan, Chaohu in Anhui province, Nanjing, Zhenjiang, Changzhou, Wuxi, Suzhou, Yangzhou, Taizhou, Nantong in Jiangsu province and Shanghai. The study area has a subtropical monsoon climate with rich rainwater. Dense river networks and numerous lakes are distributed in this area. The major tributaries include the Yuxi, the Qingyijiang, the Shuiyangjiang, the Zhanghe, the Qinhuaihe and the Chuhe rivers as well as the Huaihe Canal (Figure 2). The subtropical monsoon brings about plenty of precipitation from May to October each year. The yearly precipitation averages about 1,000 mm. But floods and droughts also took place frequently in this area. In recent decades the rapid increase in demand for water resource and water pollution has greatly aggravated the local water environment. 3 Database The water discharge records at Datong are continuous from 1950 to 2000. The data recording water extraction along the riverbanks are gathered during field investigation and from documented material by the local government departments. These data have been up-dated to the year 2000. The water-extracting engineering projects amounted to 64 in number including sluices and pumping stations, with the water-extracting capacity up to 4,626 m3/s (average discharge in a tidal cycle). Water is extracted from the main Changjiang by sluices and pumping stations. According to their water-extracting capacity, the projects are divided into 5 grades (Figure 2). Additionally, the hydrological data such as precipitation, evaporation and discharges from tributaries between 1960 and 1985 in the study area are collected from the officially published materials. 4 Mechanism of discharge change during dry season A number of factors may influence the discharge change downstream Datong, such as precipitation, evaporation, water input from tributaries, water exchange between surface and ground water. Notable is the effect of human activity, such as water extraction and drainage, which has become the most important aspect in recent decades for change of discharge during dry season. The water balance equation between Datong and Xuliujing may be expressed as: RDatong + Rtributary + Rdrainage + P + R1 = Rsea + Rextraction + E + R2 where RDatong is discharge recorded at Datong, Rtributary is input from tributaries, Rdrainage is local water drainage, P is precipitation input, R1 is input from ground water, Rsea is water discharge into the sea, Rextraction is water extraction from the main Changjiang, E is evaporation from river surface, and R2 is output from the Changjiang into ground water. The precipitation (P), the evaporation (E) and the exchange between river water and ground water (R1, R2) are related to many other factors. No evidence indicate that these components play a significant role on local changes of discharge. So they are not taken into account in this paper. We only consider the input from tributaries, drainage and output by water extraction. Thus, the water balance equation can be simplified as: RDatong + Rtributary + Rdrainage = Rsea + Rextraction Sluices are constructed usually at mouth of tributaries to the Changjiang. Our study selects six major tributaries, i.e., the Yuxi, the Qingyijiang, the Shuiyangjiang, the Qinhuaihe and the Chuhe rivers as well as the Huaihe Canal. The yearly discharge into the Changjiang from these tributaries averages 405.12 m3/s during dry season. It may exceed 700 m3/s in flood year and drop greatly in extremely dry year like 1978 when there was only 65.14 m3/s of water discharge into the main Changjiang. It is therefore clear that the discharge into the Changjiang from tribu-taries is very limited during dry season. Downstream Datong the water level of the Changjiang changes with the tidal fluctuation. It provides favourable conditions for natural water transfer through sluices. In order to cope with the water shortage problem in north Jiangsu and Anhui provinces, many water-extracting pro-jects have been built along the Changjiang since the 1950s, including sluices and pumping sta-tions. Pumping stations are divided into two types, i.e., "Pump I" and "Pump II". "Pump II" is combined with sluice at the outlet of tributaries. These projects are artificially controlled. Dur-ing water shortage period, sluices and "Pumps I" are opened firstly to extract water as much as possible. When water level of the Changjiang is not high enough, sluices are closed to prevent from back flows, and "Pumps II" are put into operation. In the flood period, pumps and sluices are also used to drain off floodwater. Based on the data from typical projects, our study shows that the water drainage is only equivalent to 1% of the water extraction by pumps and sluices during the driest month (January or February) in the extremely dry year like 1978-1979. In ordinary year t his proportion may increase to 17%. Obviously, water drainage into the main Changjiang by sluices and pumps is small in quantity during dry season. In summary, the local runoff from land into the Changjiang is small, especially in dry year. Therefore, the variability of water discharge is mostly influenced by the water extraction along riverbanks. The rapid socioeconomic growth in the future will further increase the demand for water resources in areas along the Changjiang. In addition, the East Route South-to-North Water Diversion Project is as high as 800-1000 m3/s in capacity. They will remarkably influence the discharge from the Changjiang into the sea. 5 Investigation about water-extracting capacity between Datong and Xuliujing As a result of rapid socioeconomic development, human activities have strongly influenced the discharge downstream Datong during dry season. Before the 1970s, when the discharge at Datong was about 10,000 m3/s, there was usually no strong saltwater intrusion at estuary. However by the end of the 1970s, when the monthly mean discharge at Datong was 10,400 m3/s, strong saltwater intrusion took place in estuary. The chlorinity of Wusong waterworks of Shanghai reached 1,360 mg/l (the national standard of drinking water is less than 250 mg/l) (Chen and Chen, 2000). Saltwater controlled the entire estuarine reach, with its impacts extending to the hinterland of deltaic plain. It seriously influenced the industry, agriculture and people´s daily life in Jiangsu province and Shanghai. In March and April of 2001, serious saltwater intrusions occurred despite the discharge was more than 15,000 m3/s at Datong. In addition to an intensified saltwater intrusion from the North Branch to the South Branch, the water extraction from the lower Changjiang is one of the major causes for this phenomenon. Our investigation shows that the water-extracting capacity downstream from Datong to Xuliujing had amounted to 3,000 m3/s by the year 1978. Due to severe drought, the water extraction was as high as 33.1×109 m3 in 1978 (Wang et al., 1994). Chen et al. (2001) carried out systematic survey and found that the total water transfer was 32-33×109 m3, close to the previous estimate by Wang et al. (1994). According to the actual data from typical water-extracting projects, the water transfer from November of 1978 to April of 1979 may account for about 30.98% of the annual total in 1978. Based on this ratio, the total water extraction between Datong and Xuliujing from November of 1978 to April of 1979 is estimated to be 10.25×109 m3. By the end of 2000, the water-extracting engineering projects in the study area had reached 64 in number (Figure 2), with a total capacity up to 4,626 m3/s (Figure 3). If the extreme drought like the one from the autumn of 1978 to the spring of 1979 take place again, the total water extraction during dry season will increase from 10.25×109 m3 in 1978 to 15.81×109 m3 in 1979. 6 Estimation about discharge change during dry season The discharge variability downstream Datong is strongly influenced by the water extraction along riverbanks during dry season. Although the total water extraction during flood season is much more than that during dry season, it has less effect on the discharge of the Changjiang. The focus of this study is the water extraction during dry season. All statistical parameters based on the data are from dry season. The typical hydrological years were determined according to the discharge from tributaries and the relative departure of local precipitation and evaporation. They were classified into four grades, i.e., the extremely dry year 1978-1979, the dry year 1976-1977, the ordinary year 1977-1978 and the flood year 1975-1976. Due to yearly climate change and seasonal variation in water demand, there is a large fluctuation in amount of water extraction and tributary inflow. Based on the actual water-extraction data from typical projects and discharge from tributaries, we propose the following four statistical parameters in different hydrological years: (1) operation frequency (P), (2) time of water extraction (T), (3) drainage coefficient (K) and (4) discharges into the main Changjiang from tributaries (Vtributary). The operation frequency (P) of water-extracting projects in different hydrological years is based on data between 1973 and 1985. The statistical result shows that, it may be as high as 97.5% during dry month of extremely dry year like 1978-1979, and varied from 86% to 92% in dry year like 1976-1977 and 1979-1980, from 83.3% to 76% in ordinary year like 1977-1978 and 1980-1981, and 72% in flood year like 1975-1976. According to the above statistics, the presumption was made that the operation frequency is 100% in extremely dry year, 90% in dry year, 80% in ordinary year and 70% in flood year. The time of water extraction (T) includes sluices (Tsluice) and pumping stations. According to the difference of operation, pumping stations are divided into Pumps I (except for Jiangdu Pivot), Pumps II and Jiangdu Pivot station. The time of water extraction for them (Tpump I, Tpump II and TJiangdu Pivot) was computed separately. Based on the actual data from typical projects, water extraction in different months of various hydrological years was computed. It was then divided by the actual water-extracting capacity of typical projects. The time of water extraction by Jiangdu Pivot was computed based on the actual measured discharge. On the grounds of the above parameters, the equations for calculating water extraction by different projects can be expressed as follows: Msluice＝Qsluice×Psluice×Tsluice Mpump I = Qpump I×P pump Ⅰ×Tpump I Mpump II＝Qpump II×Ppump Ⅱ×T pump II MJiangdu Pivot ＝QJiangdu Pivot×PJiangdu Pivot×TJiangdu Pivot where Q is the water-extracting capacity of projects between Datong and Xuliujing. The total water extraction between Datong and Xuliujing (Rextraction) is the sum of the above four portions (Msluice＋Mpump I＋Mpump II＋MJiangdu Pivot). The water discharge for this s tudy is the monthly mean discharge. From the above calculation, the total water extraction in different months of various hydrological years can be transformed into monthly mean discharge (Vextraction). The water drainage by pumps is neglected in this paper because it is very small in quantity. We only consider water drainage through sluices. Due to the complexity in computation and lack of field data, the drainage coefficient (K) was determined according to the ratio of monthly water extraction to monthly water drainage as: K = Mextraction/Mdrainage. Thus the total water drainage between Datong and Xuliujing (Rdrainage) was calculated based on the total water extraction (Rextraction) multiplied by the drainage coefficient (K). The monthly mean drainage discharge (Vdrainage) was transformed by the total water drainage. Tributaries selected in this paper have complete discharge data, so it is easy to calculate its monthly mean discharges into the Changjiang (Vtributary) in different hydrological years. Based on the above parameters and a special geographical information system for these engineering projects, a mathematical model for discharge change during dry season was expressed as: C ＝Vextraction－Vdrainage－Vtributary where C is the net decrease in monthly mean discharge of the Changjiang. The statistical parameters for extremely dry year and dry year were calibrated with the actual data. The total water extraction from November 1978 to April 1979 was estimated to be about 9.94×109 m3. The annual total water extraction in 1978 was 32.09×109 m3. Wang Chaojun (1994) estimated that the total water extraction in 1978 was as high as 33.1×109 m3, very close to our estimation. In the same way, the calculated total water extraction of Jiangsu province in 1995 was 20.36×109 m3, close to the documented figure 20.09×109 m3 (Editorial Board of China Water Resources Almanac, 1997). In ordinary year and flood year, calibration was difficult because of lack of actual data. The monthly mean water discharge changes during three typical months (November, January and March) for four typical hydrological years and the dry year 1994-1995 were calculated respectively (Table 1). 7 Changes in discharge during dry season in recent two decades and future Table 1 shows that the water extraction downstream Datong was very great in the extremely dry year 1978-979, while the drainage and tributary discharges into the Changjiang was small. In typical months (November, January and March), the net decrease in monthly mean discharge amounted to 674 m3/s, 494 m3/s and 539 m3/s respectively, equivalent to 4.26%, 6.85% and 5.19% of monthly mean discharge recorded at Datong. In other hydrological years, due to large discharge into the Changjiang, the net decrease in water discharge is small, and even increases in ordinary year and flood year. Since the 1990s, an increasing demand for water resources has resulted in a great increase in water extraction. In the dry year 1994-1995, the net decrease in monthly mean discharge of dry season was about two times that in the typical dry year 1976-1977. According to this proportion, the net decrease in monthly mean discharge into the sea will exceed 1,000 m3/s if the extremely dry year recurs in the coming years. In addition, our results indicate that the water extraction in November or April reaches its maximum in discharge. While water extraction in January or February was not very great in discharge, but has a greatest proportion at Datong. The study area is one of the economic centers in China. The water-extracting capacity will increase greatly in the future. The projects being planned and built will be all finished before 2030, when the total water-extracting capacity will amount to 5,416 m3/s. The water discharge diverted by the East Route South-to-North Water Diversion Project has exceeded 500 m3/s during dry season now. It will amount to 800-1000 m3/s when the second-phase project is completed (Water Information Web, 2001). This great project will become one of the most important factors for changes in discharge into the sea during dry season. The East Route South-to-North Water Diversion Project will be constructed based on the Jiangdu Pivot. It replaces the Jiangdu Pivot in calculating future water discharge change. The estimated results (Table 1) show that, in extremely dry year for the coming decades, the net decrease in monthly mean discharge of three typical months will amount to 1,578-1,778 m3/s, 1,279-1,479 m3/s and 1,369-1,569 m3/s, accounting for 9.99-11.25%, 17.72-20.49% and 13.16-15.09% of monthly mean discharge recorded at Datong, respectively. In dry year, the net decrease will be more than 1,000 m3/s in all typical months, and more than 10% of monthly mean discharge at Datong. In ordinary year the net decrease will amount to 800-1,000 m3/s. Because there is little water extracted from and much water flowing into the main Changjiang in flood year, the net decrease in monthly mean discharge will not be great. Obviously, the net decrease in monthly mean discharge downstream from Datong to Xuliujing will increase greatly during dry season in the coming decades, which will definitely influence the discharge into the sea. 8 Conclusions and suggestions The total capacity of water-extracting engineering projects from Datong to Xuliujing was less than 400 m3/s in the late 1950s. It increased to more than 2,000 m3/s in the 1970s and reached 3,000 m3/s in 1978. The amount of water extracted from the Changjiang downstream Datong had little impact on the discharge into the sea during dry season before the end of the 1970s. Afterwards, the impact became more and more remarkable. In the extremely dry year like 1978-1979, water extraction produced a net decrease of more than 490 m3/s in monthly mean discharge from the Changjiang into the sea, equivalent to more than 5% of monthly mean discharge recorded at Datong. Due to a rapid increase in water demand, the discharge from the Changjiang into the sea decreased rapidly since the 1990s, espec

ially in the extremely dry months. By the year 2000, the projects had totaled 64 in number, with a water-extracting capacity up to 4,626 m3/s. Although the monthly mean discharge recorded at Datong was relatively large during dry season, the influence of water extraction on water discharge into the sea was remarkable. It is estimated that, if the extremely dry year recurs now, the net decrease in monthly mean discharge into the sea will exceed 1,000 m3/s. In the coming decades, when the projects under construction and to be built are all completed, the total water-extracting capacity will amount to 5,416 m3/s. The great increase of water consumption will further decrease the discharge into the sea during dry months. In the extremely dry year and dry year, the net decrease in monthly mean discharge between December and March will account for more than 10% of monthly mean discharge recorded at Datong, even reach 20% in January of extremely dry year. From January to March in ordinary water year and from January to February in flood year, the net decrease in monthly mean discharge will be more than 6% of monthly mean discharge at Datong. Due to the complexity in processes of the discharge change, there are still several factors not considered in this paper. For example, the water extraction along the Changjiang is influenced by both natural processes and socioeconomic activities. Further studies are necessary for a more accurate estimate. In addition, some small tributaries into the Changjiang should be taken into consideration in future studies.

关键词： the Changjiang River; dry season; water discharge into the sea; human impacts

