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Critical discharge at Datong for controlling operation of South-to-North Water Transfer Project in dry seasons

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Abstract: Previous research shows that there is a strong correlation between saltwater intrusion in the Yangtze Estuary and discharge at Datong. In the near future, the discharge of the Yangtze River during dry seasons will decrease due to the construction and operation of large water diversion projects, including the South-to-North Water Transfer Project, which will further exacerbate saltwater intrusion in the estuary. In this paper, a nested 1D river network model and a 2D saltwater numerical model are used to associate saltwater intrusion in the Yangtze Estuary with different values of discharge at Datong. It is concluded that 13 000 m^3/s is the critical discharge at Datong for preventing saltwater intrusion and controlling the volume of water transferred by the South-to-North Water Transfer Project. Furthermore, based on the analysis of river discharge from Datong to Xuliujing and in consideration of the influence of all of the water diversion projects, operation schemes are proposed for the Eastern Route of the South-to-North Water Transfer Project for different hydrological years.

Key words: *saltwater intrusion*; *critical discharge at Datong*; *water diversion*; *the South-to-North Water Transfer Project*

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1 Introduction

Saltwater intrusion in estuaries is an issue of much concern for coastal cities around the world. Forecasting saltwater intrusion and understanding related mechanisms are essential in helping these cities to avoid disasters and establish protective measures. As the annual hydrological data show, the fresh water upstream of Shanghai, which is located in the Yangtze Estuary, is not sufficient to counterbalance the tidal force during the annual period from November to April. Thus, Shanghai has seen considerable saltwater intrusion in its estuary area. Hydrological data from 1978 to 2003 show that saltwater intrusion is very serious near the Chenhang Reservoir at the South Branch of the Yangtze Estuary when the average monthly discharge at the Datong hydrological station is lower than 11 800 m^3/s during the dry seasons. Such was the case during the dry seasons of 1987, 1999 and 2000, when the minimum average monthly discharges were 7 600 m^3/s (in January), 9 100 m^3/s (in February), and 10 300 m^3/s (in January), respectively, and the corresponding numbers of continuous days unsuitable for water diversion were 13, 25 and 9. Thus, although Datong is more than 600 km away, the discharge there is strongly correlated with saltwater intrusion in the Yangtze Estuary (Gu and Yue 2004). Recent years have seen the planning, construction and preliminary operation of many large

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hydraulic projects, including the South-to-North Water Transfer and Three Gorges projects. Meanwhile, with the development of the economy, water diversion for irrigation, domestic and industrial water use and other needs is rising rapidly, and the downstream runoff of the Yangtze River will continue to decrease substantially in the future. Furthermore, it has been planned to divert 1 000 m^3/s of water from the Yangtze River by the Eastern Route of the South-to-North Water Transfer Project. The annual mean volume of this water diversion will be about 3×10^{10} m^3, about 3.3% of the total annual runoff of the Yangtze River. According to the scheme, that amount will rise to 14% of total annual runoff during dry seasons, and 7.7% during the period stretching from wet to dry seasons. Statistical data of average monthly discharge of the Yangtze River over the last forty years has shown that the water diversion will cause the proportion of months with runoff to the sea lower than 9 000 m^3/s to increase from 15% to 32%, the proportion of months with runoff to the sea lower than 13 000 m^3/s to increase from 59% to 71%, and, conversely, the proportion of months with runoff to the sea over 15 000 m^3/s to decrease from 21% to 14% (Yang 2001). Furthermore, the number of additional small water diversion projects along the Yangtze River from Datong to Xuliujing has also increased in recent years. Previous work (Zhang and Chen 2003; Zhang et al. 2007) shows that there had been 64 water diversion projects of different kinds until 2000, with a total water diversion capacity of 4 626 m^3/s, and by the end of 2006 there were 176 sluices and 29 pump stations, with cumulative designed water diversion capacities of 16 611.8 m^3/s and 2 198.76 m^3/s, respectively. The total water diversion capacity of these projects significantly exceeds the designed water diversion volume of the Eastern Route of the South-to-North Water Transfer Project. Due to the location of the intake near the Yangtze Estuary as well as the large diversion volume at present and the low river discharge during dry seasons, future operation of the Eastern Route of the South-to-North Water Transfer Project may further aggravate saltwater intrusion in the estuary.

Therefore, it is necessary to find a critical discharge at Datong that inhibits saltwater intrusion in the estuary and mitigates the effects of the South-to-North Water Transfer Project. The quantification of critical discharge will be an efficient method for analyzing and predicting saltwater intrusion in the Yangtze Estuary and enhancing cooperation between large projects such as the South-to-North Water Transfer Project, the Three Gorges Project and others during dry seasons.

2 Influence of discharge at Datong on saltwater intrusion in the Yangtze Estuary

2.1 Methodology

Statistical analysis of years of continuous and hourly telemetry data shows that salt water from the North Branch of the estuary flows backwards into the South Branch when Datong discharge is less than 25 000 m^3/s and the tidal range at Qinglong Harbor is larger than 2.5 m.

When Datong discharge is less than 11 000 m^3/s, a large quantity of salt water from the North Branch flows into the South Branch and causes the water quality in the water source areas to seriously deteriorate. In order to study the relationship between variation of salinity in the Yangtze Estuary and variation of Datong discharge, 1D and 2D numerical models were developed based on hydrological and salinity data collected in the estuary in March 2002, and used to predict the critical Datong discharge that provides sufficient fresh water to resist saltwater intrusion. This critical discharge can be used as a parameter in controlling the South-to-North Water Transfer Project during dry seasons.

2.2 Mathematical model set-up

2.2.1 One-dimensional river network model for the section from Datong to the Yangtze Estuary

A 1D numerical model based on Saint-Venant equations was established to calculate water levels throughout the river network. The upper boundary of this model is located at the Datong hydrological station in Anhui Province, the lower boundary is located at the Port of Lianxing in the North Branch and Liuxiao at the South Branch of the Yangtze Estuary, and the total distance of the simulated river is approximately 591 km (Huang 2006; Zhu et al. 2001). The calculation range of the model is shown in Figure 1. Numbers in the figure represent the sequence of the inlets.

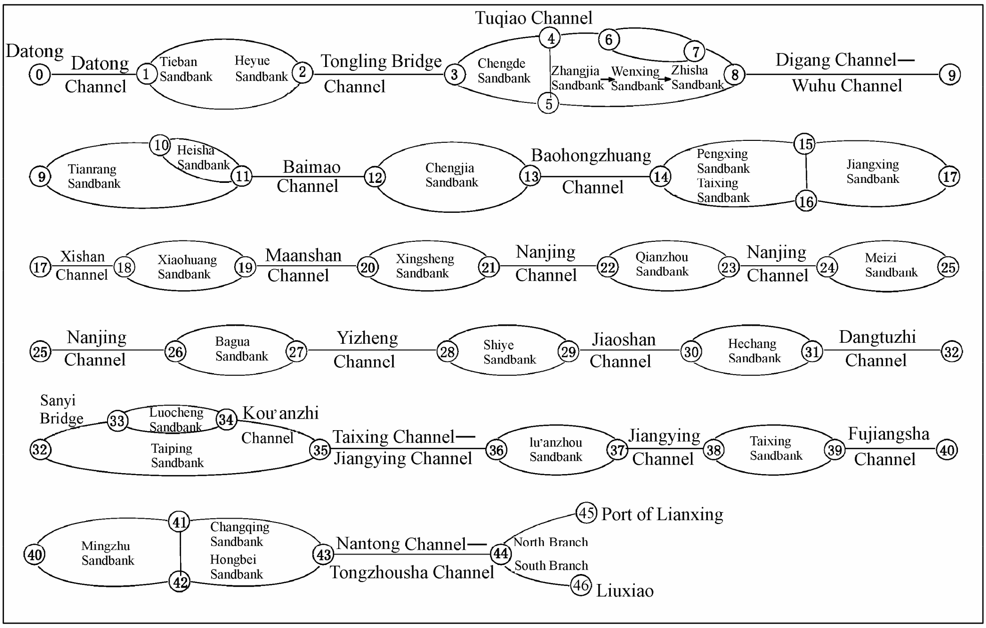

Figure 1 Calculation range of 1D Model

2.2.2 Two-dimensional flow and salinity numerical model of the Yangtze Estuary

Because the horizontal scale of the Yangtze Estuary is much larger than the vertical scale, a 2D depth-averaged numerical model was established to calculate flow and salinity in the estuary. The calculation domain of the 2D numerical model is shown in Figure 2. The western boundary is located at Jiangyin and Hangzhou Bay, the northern boundary at Lüsi, the southern boundary near the southern end of the Zhoushan Archipelago, and the eastern boundary at -50 m isobaths. The total area is 4.27×10^5 km^2 (Huang 2006).

Figure 2 Calculation domain of 2D model

2.3 Influence of Datong discharge on variation of water level at Jiangyin

2.3.1 Hydrological conditions

Taking into account constant tides, and integrating the variation in Datong discharge with the operation of the Three Gorges and South-to-North Water Transfer projects, the 1D river network model was used to simulate water levels at Jiangyin in response to different Datong discharge values.

Investigation shows that the minimum daily Datong discharge is 4 620 m^3/s. Therefore, a discharge of 5 000 m^3/s was set as the lower limit. Generally, when Datong discharge is comparatively low, saltwater intrusion in the Yangtze Estuary is serious. In order to investigate the salinity variation in the estuary for the duration of low Datong discharge, it is necessary to reduce the increment between Datong discharge values when discharge is less than 10 000 m^3/s. Therefore, the hydrological conditions used as inputs were as follows.

The spring range and neap range were, respectively, 4.72 m and 1.01 m at the Port of Qinglong in the Yangtze Estuary and 4.19 m and 0.7 m at Zhongjun. Simulated values of Datong discharge were 5 000 m^3/s, 7 666 m^3/s (when the influence of the South-to-North Water Transfer Project was considered), 8 926 m^3/s (when the influence of the combined operation of the South-to-North Water Transfer Project and the Three Gorges Project was considered), 9926 m^3/s (when the influence of the Three Gorges Project was considered), 10000 m^3/s, 15000 m^3/s, 20000 m^3/s, 30000 m^3/s, 40000 m^3/s and 50000 m^3/s.

2.3.2 Simulation results and primary analysis

As shown in Figure 3, water level variation at Jiangyin during the 200 hours after March 1, 2002 follows a similar trend under different conditions, but is strongly correlated with discharge at Datong. When Datong discharge is high through continuous spring, middle and neap tides, the water level at Jiangyin is usually correspondingly high. When Datong discharge increases from 5000 m^3/s to 50000 m^3/s, the mean water level at Jiangyin increases from 0.5 m to 1.69 m, an increment of 1.19 m. Maximum and minimum values of water level rise by increments of 1.33 m and 1.47 m, respectively, from 2.01 m and -0.51 m to 3.34 m and 0.96 m. Durations of flood and ebb tides at Jiangyin are influenced by Datong discharge as well. Variations in Datong discharge change the balance between runoff and the tidal current at Jiangyin, causing durations of flood and ebb tides to increase or decrease accordingly. Owing to the short distance from Jiangyin to the estuary, visible variations of flood and ebb tide durations mainly appear with comparatively high Datong discharge. It is concluded that when the mean water level at Jiangyin is comparatively high and Datong discharge is greater than or equal to 40000 m^3/s, the duration of the ebb tide is prolonged by one hour, compared with the ebb tide during lower Datong discharges, and the flood tide duration is reduced by one hour. Moreover, when the mean water level at Jiangyin is comparatively low, distinct variations in flood and ebb tide durations appear with Datong discharge greater than or equal to 30000 m^3/s.

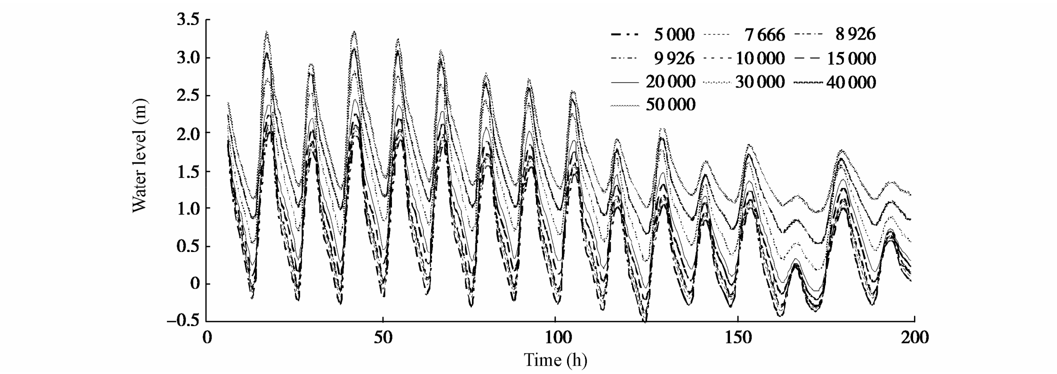

Figure 3 Water level at Jiangyin with varying Datong discharge

If tidal conditions were held constant, the mean water level at Jiangyin would increase along with Datong discharge. The water level at Jiangyin is not influenced only by Datong discharge, but also by the variation of the tide level in the estuary. The variation of the water level at Jiangyin remains steady throughout the continuous process of spring tide, middle tide and neap tide, but the flood and ebb tide durations, tidal phase and mean tide level all show some change.

2.4 Influence of Datong discharge on variation of saltwater intrusion in the Yangtze Estuary

2.4.1 Hydrological conditions

Considering the calculated water level at Jiangyin under different hydrological conditions the upper boundary of the 2D numerical model, saltwater intrusion in the Yangtze Estuary was simulated under various combinations of hydrological conditions.

2.4.2 Salinity distribution in the Yangtze Estuary corresponding to different Datong discharge values

In order to characterize salinity distribution in the estuary, this study identified 12 salinity stations at important locations (Figure 4).

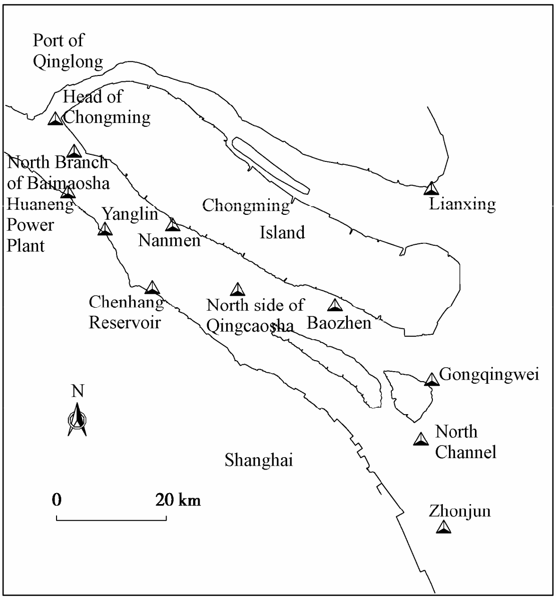

Figure 4 Salinity stations

Table 1 provides the variation of the mean and maximum salinity values during continuous spring, middle and neap tides with different Datong discharge values. The table also shows that there is a strong correlation between Datong discharge and the salinity values at each station in the estuary: increasing discharge causes the mean and maximum salinity values to decrease; correspondingly, decreasing discharge causes salinity to increase.

In the South Branch, salinity is higher at Chongming Island and Baozhen, which is near the island, and lower in the middle of the branch. The salinity distribution shows a distinct concavity. However, values of salinity always remain high at the Port of Lianxing in the North Branch. This demonstrates that salt water flowing from the North Branch to the South Branch is the main cause of higher salinity near the water source areas in the South Branch.

Table 1 Salinity at stations in the Yangtze Estuary corresponding to different Datong discharge values

Datong discharge (m^3/s)	(1)		(2)		(3)		(4)		(5)		(6)	
	Ave (%)	Max (%)	Ave (%)	Max (%)	Ave (%)	Max (%)	Ave (%)	Max (%)	Ave (%)	Max (%)	Ave (%)	Max (%)
5 000	0.92	1.91	0.65	0.87	0.71	0.75	0.73	0.75	0.73	0.76	0.84	0.98
7 666	0.77	1.78	0.49	0.72	0.53	0.56	0.54	0.56	0.55	0.57	0.63	0.76
8 926	0.71	1.72	0.43	0.66	0.46	0.49	0.47	0.49	0.47	0.50	0.55	0.67
9 926	0.67	1.69	0.39	0.63	0.41	0.44	0.42	0.45	0.43	0.45	0.50	0.61
10 000	0.49	1.48	0.24	0.40	0.26	0.28	0.27	0.29	0.27	0.29	0.35	0.48
15 000	0.35	1.33	0.14	0.29	0.14	0.16	0.14	0.16	0.15	0.16	0.19	0.29
20 000	0.25	1.21	0.09	0.24	0.08	0.11	0.09	0.10	0.09	0.10	0.11	0.18
30 000	0.14	1.03	0.04	0.19	0.03	0.06	0.04	0.05	0.04	0.05	0.05	0.09
40 000	0.08	0.87	0.02	0.15	0.02	0.04	0.02	0.03	0.02	0.03	0.02	0.05
50 000	0.05	0.73	0.01	0.13	0.01	0.03	0.01	0.02	0.01	0.02	0.01	0.04
Datong discharge (m^3/s)	(7)		(8)		(9)		(10)		(11)		(12)	
	Ave (%)	Max (%)	Ave (%)	Max (%)	Ave (%)	Max (%)	Ave (%)	Max (%)	Ave (%)	Max (%)	Ave (%)	Max (%)
5 000	1.24	1.62	1.31	1.71	2.01	2.43	0.63	0.72	0.73	0.75	2.80	2.91
7 666	0.98	1.39	1.04	1.41	1.76	2.22	0.46	0.54	0.54	0.56	2.69	2.83
8 926	0.88	1.29	0.92	1.28	1.65	2.12	0.39	0.47	0.47	0.49	2.65	2.80
9 926	0.80	1.22	0.84	1.20	1.56	2.04	0.35	0.43	0.42	0.45	2.61	2.78
10 000	0.68	1.11	0.72	1.08	1.48	1.99	0.21	0.26	0.27	0.29	2.64	2.77
15 000	0.42	0.84	0.43	0.76	1.10	1.60	0.11	0.15	0.14	0.16	2.49	2.65
20 000	0.27	0.65	0.26	0.55	0.81	1.28	0.06	0.10	0.08	0.10	2.36	2.55
30 000	0.12	0.43	0.11	0.30	0.44	0.89	0.02	0.05	0.04	0.05	2.12	2.36
40 000	0.07	0.30	0.05	0.19	0.26	0.65	0.01	0.04	0.02	0.03	1.91	2.20
50 000	0.04	0.23	0.03	0.13	0.16	0.49	0.01	0.03	0.01	0.02	1.72	2.05

Station numbers: (1) Head of Chongming, (2) North branch of Baimaosha, (3) Yanglin, (4) Chenhang Reservoir, (5) North side of Qingcaosha, (6) Baozhen, (7) Gongqingwei, (8) North Channel, (9) Zhongjun, (10) Huaneng Power Plant, (11) Nanmen, (12) Port of Lianxing; Ave: average salinity values; Max: maximum salinity values

3 Critical Datong discharge for regulating the South-to-North Water Transfer Project

3.1 Critical Datong discharge

In order to determine critical Datong discharge that will provide a basis for controlling the amount of water diverted by the South-to-North Water Transfer Project during dry seasons, this study compared the mean and maximum salinity values in the estuary corresponding to different Datong discharge values and found a link between the variations of mean salinity and Datong discharge. Because the Chenhang Reservoir, the only Yangtze River water source reservoir, supplies Shanghai with about one third of its tap water, a curve was fit to describe the relationship between Datong discharge and the mean salinity of the Chenhang Reservoir. The best-fit equation, shown in Figure 5, is

$$S = 1.8223\times 10^{7} Q^{-1.946} \qquad (Q \geqslant 5\,000 \ \ m^3/s)$$
$$R^2 = 0.98$$
where Q is Datong discharge in m^3/s, S the mean salinity (%) during spring, middle and neap tidal processes and R the correlation coefficient.

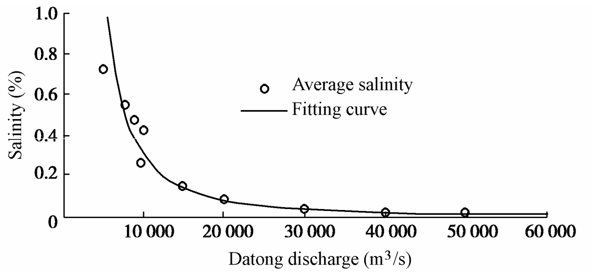

Figure 5 The best-fit curve of Datong discharge versus average salinity during spring, middle and neap tides

According to international public water supply standards, chlorinity should not exceed 250 mg/L in drinking water (the adopted international standard for the empirical relationship between ocean salinity and chlorinity is that S (%) equals the product of chlorinity (mg/L) and $1.806\,55\times10^{-4}$), 660 mg/L in irrigation water for rice seeding and 1 100 mg/L in other irrigation water. There are requirements for industrial water as well. For example, the Baoshan Steel Factory requires that the monthly mean chlorinity be less than 50 mg/L and the maximum value not exceed 200 mg/L (Shen et al. 1980; Song and Mao 2002).

A Datong discharge of 12 295 m^3/s corresponds to a 0.2% salinity value (equal to a chlorinity of 1 100 mg/L) in the Chenhang Reservoir. For practical applications and security assurance, we determine 13 000 m^3/s to be the critical Datong discharge. This critical discharge is higher than that of Gu and Yue (2004), who suggested a monthly mean Datong discharge of 11 000 m^3/s to ensure resistance to saltwater intrusion. It also exceeds the original index proposed in the planning of the Eastern Route of the South-to-North Water Transfer Project, which stated that Datong discharge should not be less than 8 000 to 10 000 m^3/s.

3.2 Influence of water diversion along the Yangtze River on operation of the South-to-North Water Transfer Project

3.2.1 Water diversion volume in different hydrological years

Investigations and studies indicate that, with the rapid development of the economy, the volume of water diverted from the Yangtze River has continuously increased from the 1950s onward, and this trend has been more and more pronounced in recent years. Nowadays, the water diversion capacity along the river greatly exceeds the monthly minimum Datong discharge of 6 800 m^3/s, and it has become an important factor affecting runoff from the Yangtze River to the sea during dry seasons. A minimum discharge at Datong of only 12 295 m^3/s will not be enough to counteract the enhancing effect of the diversion of water along more than 500 km of river on saltwater intrusion in the estuary. In order for the critical Datong discharge to be of use in controlling the South-to-North Water Transfer Project and diminishing saltwater intrusion in the estuary, the capacity of other potential water diversion projects in different hydrological years must be considered.

Based on recent observations (Zhang et al. 2007), the water diversion capacities of sluices and pump stations along the Datong to Xuliujing section of the Yangtze River approached 16 611.8 m^3/s and 2 198.76 m^3/s, respectively, in 2006, and the total capacity approached 20 000 m^3/s. Due to limitations of the running time of the projects, the operation percentages of pumps and sluices, the duration of the flood and ebb tides near sluices and pump stations, the water level in the main stream, the climate, the industrial, agricultural and domestic water use, actual discharge of the Yangtze River during dry seasons and other conditions, the actual water diversion volume falls far below the maximum capacity.

The research of Zhang et al. (2007) shows that the operation percentage of pumps and sluices was 97.5% in the extreme dry year from 1978 to 1979, 86% and 92% in the dry years from 1976 to 1977 and from 1979 to 1980, respectively, 83.3% and 76% in the normal years from 1977 to 1978 and from 1980 to 1981, respectively, and 72% in the wet year from 1975 to 1976. Therefore, we assume that the operation percentage of pumps and sluices is 100% in extreme dry years, 90% in dry years, 80% in normal years and 70% in wet years.

Because the actual operating time of sluices and pump stations in different years is influenced by the durations of the flood and ebb tides, the water level in the main stream, the climate, rainfall, industrial and domestic water use and other factors, it is difficult to determine the exact operating time of the projects. We therefore base the operating time of projects on their actual operating mechanisms.

Generally speaking, sluices only run when the water level in the Yangtze River is higher than that in the branches, but the water level in the main stream is always rather low in dry seasons. Meanwhile, the period with a continuous high water level is limited by the period of tidal fluctuation. Generally, the durations of flood and ebb tides each occupy half of a regular semidiurnal tidal process, but the tide in the Yangtze River is a non-regular semidiurnal tide. The duration of the high water level is limited by the duration of the flood tide and it does not usually reach 50% of an entire tide, so we assume that, during a tidal period, the percentage of operating time of sluices is 50% in wet years, 40% in normal years, 30% in dry years and 20% in extreme dry years.

The operating mechanism of pump stations is different from that of sluices. During dry seasons, pump stations can generally draw fresh water for the whole day without consideration of the Yangtze River water level, but their operating time is still limited by the requirement of the water acceptance area. Under a condition of constant water requirements, the water level in the Yangtze River in a wet year is comparatively high, the operating time of sluices is longer and the water diversion volume is much higher. The operating time of pump stations is therefore shorter. In dry or extreme dry years, because of the low water level, the operating time of sluices is not long enough to divert enough water to satisfy the requirements of the water acceptance area, and it is necessary to increase the operating time of pump stations. For these reasons, we assume that, for an entire tide period, the percentage of operating time of pump stations can be 100% in extreme dry years, 90% in dry years, 80% in normal years and 70% in wet years.

The formulas for the monthly mean water diversion discharge during dry seasons are

$$Q_{\mathrm{y}} = Q_{\mathrm{y}}^{*} \times P_{\mathrm{y}} \times P_{\mathrm{yt}}$$

$$Q_{\mathrm{c}} = Q_{\mathrm{c}}^{*} \times P_{\mathrm{c}} \times P_{\mathrm{ct}}$$

$$Q = Q_{\mathrm{y}} + Q_{\mathrm{c}}$$

where Q_{y} and Q_{y}^{*} are potential diversion discharge and designed diversion capacity of sluices, respectively; Q_{c} and Q_{c}^{*} are potential drawing discharge and designed drawing capacity of pump stations, respectively; Q is the total potential diversion discharge; P_{y} and P_{c} are the operation percentages of pumps and sluices, respectively; and P_{yt} and P_{ct} are the percentages of running time of sluices and pump stations, respectively, during a tide period.

The water diversion discharge based on the formulas is 6 892 $\mathrm{m^3/s}$ in wet years, 6 723 $\mathrm{m^3/s}$ in normal years, 6 266 $\mathrm{m^3/s}$ dry years and 5 521 $\mathrm{m^3/s}$ in extreme dry years. This indicates that the water diversion discharge in dry seasons changes substantially in different hydrological years, and has approached and exceeded the known minimum monthly mean Datong discharge from the 1950s. The results also show that it is necessary to pay more attention to the influence of other water diversion projects along the Yangtze River on the South-to-North Water Transfer Project.

3.2.2 Operation mechanisms of the South-to-North Water Transfer Project during dry seasons

The Eastern Route of the South-to-North Water Transfer Project is located in the lower reaches of the Yangtze River, and the Middle Route and Western Route are both located upstream of the Datong hydrological station. The long waterways, lakes, branches, and reservoirs between Datong and both the Middle Route and the Western Route have a regulating function, so the discharge into the estuary has a closer relationship with the Eastern Route than with the other two. The South-to-North Water Transfer Project will need to use the actual Datong discharge, the critical Datong discharge and the water diversion volume along the Yangtze River to guide the operation of the Eastern Route during dry seasons.

Usually, it takes three or four days for runoff from Datong to arrive at the intake of the Eastern Route. During the dry seasons of different hydrological years, when Datong discharge approaches 20 000 $\mathrm{m^3/s}$, it is necessary to take timed measurements of Datong discharge and water diversion volume along the Yangtze River and establish an index for withdrawal volume and operating time based on climate, precipitation, evaporation, industrial and agricultural water use and water diversion.

During the dry seasons of wet years, the water diversion volume along the river is generally large. While the project is in operation, the daily mean Datong discharge needs to remain around 7 000 m^3/s above the sum of the critical discharge and the volume of water diverted by the South-to-North Water Transfer Project to ensure that, after abstraction of water along more than 500 km of river, the discharge into the estuary will not be less than the critical discharge. This will decrease the harm done by saltwater intrusion, stop salt water in the North Branch from flowing into the South Branch and prevent the number of days unsuitable for water diversion from the water source areas from significantly exceeding the number necessary for agricultural and industrial water use. The daily mean Datong discharge should be 6 000 m^3/s to 7 000 m^3/s above the sum of the critical discharge and the volume diverted by the South-to-North Water Transfer Project during the dry seasons of normal, dry and extreme dry years. Water transfer should be stopped completely when Datong discharge approaches or falls below the critical discharge during the dry seasons of any hydrological year, because, in this case, water transfer will greatly reduce runoff, worsen the water quality of water sources in the South Branch and prolong the period unsuitable for water diversion. Climate is another factor that appears to enhance saltwater intrusion (an easterly fresh breeze can be considered the critical condition for saltwater intrusion near the Chenhang Reservoir): when the wind direction is the same as the flood tidal currents, wind strengthens the surge in the North Branch, the chloride content at the Port of Qinglong increases rapidly and, consequently, saltwater intrusion increases in intensity and duration. Under these conditions, the number of days unsuitable for water diversion from water source areas in the South Branch might greatly exceed the design standard and cause great harm to industrial production and denizens' quality of life.

4 Conclusions

This study simulated saltwater intrusion in the Yangtze Estuary with different values of discharge at Datong using large-scale 1D and 2D numerical models, and consequently identified 13 000 m^3/s as the critical Datong discharge that must be maintained to prevent saltwater intrusion. Based on the volume of water diverted along the Yangtze River, this paper also proposes guidelines for operating the Eastern Route of the South-to-North Water Transfer Project during the dry seasons of wet, normal, dry and extreme dry years. When Datong discharge approaches 20 000 m^3/s, it is necessary to carry out timed measurements of Datong discharge and the volume diverted by the South-to-North Water Transfer Project. In order to preserve good water quality during the operation of the South-to-North Water Transfer Project during dry seasons, the daily mean discharge at Datong, after subtracting the volume diverted by the South-to-North Water Transfer Project, should maintain a 7 000 m^3/s to 6 000 m^3/s margin over the critical Datong discharge, and when the Datong discharge approaches or falls below the critical discharge, the South-to-North Water Transfer should either stop diverting water or coordinate with the Three Gorges Project based on precipitation, evaporation, industrial and domestic water use and other conditions. Because of the complexity of saltwater intrusion in the Yangtze Estuary, future studies should examine links between Datong discharge and factors such as runoff, tides, winds, waves, salinity outside the estuary, temperature, stress, the self-purification capacity of the water, the water intake standard of Shanghai's water source areas, vertical distribution of salinity and the operating scheme of the Three Gorges Project.

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