Key Role of the Lakes in Runoff Supplement in the Mid-lower Reaches of the Yangtze River During Typical Drought Years

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Key role of the lakes in runoff supplement in the mid-lower reaches of the Yangtze River during typical drought years

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***Abstract*—To examine the abnormal runoff characteristics and their influencing factors along the mid-lower reaches of the Yangtze River (MLRYR) during the different extreme drought hydrological years of 1978 and 2006, history records of water levels and discharges were collected at Yichang, Hankou, Datong, Chenglingji, and Hukou stations. The Dongting and Poyang Lakes in the middle part play important roles in supplement runoff of Yangtze River during extreme drought years. In these years, the widening gap of the water level at Chenglingji and Hukou stations, gathered the outflow speed of lakes and supplied more water to the Yangtze River. In 1978, before the building of the Three Gorges Dam (TGD), the water supplied by the two lakes was 1.946×1011 m3 and 8.95×1010 m3, accounting for 30% and 14% of the runoff at Datong station at the same time, respectively. The lowest discharge at Datong station reaches 7220 m3/s. After the Three Gorges Dam's building up, discharges in the whole year at Datong station were more than 10000 m3/s by the adjustment of lakes (reservoir) in 2006 and the annual average was 20975 m3/s. In the spring of 2007, TGD had a positive impact on the discharge at Yichang station, the discharge was more than 4000m3/s. The water supplied by Dongting and Poyang Lakes was 1.853×1011 m3 and 1.444×1011 m3 during 2006, accounting for 28% and 22% of the runoff at Datong station at the same time. This study results showed that the lakes had played important roles in supplement of water along MLRYR in the extreme drought years.**

Keywords-extreme drought; lake; the Three Gorges Dam (TGD); runoff supplement; the Yangtze River

I. INTRODUCTION

Water resources shortage is one of the most serious problems in the world [1-3]. In recent decades, deficiency of the water in most countries has been abrupt intensified due to the increased trends in the frequency of extreme drought events and demands of economic development [4-7]. In addition, global river systems in relation to lakes have been increasingly altered by dam constructions and water diversions for water and energy needs [8-9]. It's well known that lakes are important subcomponents to adjust the catchment-scale sediment and water balance, low flow, and flood changes [10-15]. However, when it had relation to the obvious tendency for extreme events, i.e. low runoff in drought years [16], little studies has been done on how the lakes play function in the river system during the extreme drought events. Moreover, the lakes along the mid-lower reaches of Yangtze River (MLRYR), such as Dongting Lake and Poyang Lake, are important sources of tributaries. Several studies have discussed volume variations in water sediment of these two lakes, as well as the interaction of tributaries and lakes before and after the construction of the Three Gorges Dam (TGD) [17-25]. However, only a few studies were done on the characteristics of low flow under drought condition, especially water exchange of river and lake combined with extreme dry event. Thus, the purpose of this paper focused on the function of lakes how to regulate main stream water in the typical drought years. This work would be helpful in improving the management and the allotment policy of water resources along MLRYR.

II. STUDY AREA AND DATA

Yangtze River is the longest river in China. The river is about 6.4×10^3 km long, and can be divided into three reaches (upper reach from riverhead to Yichang, middle reach from Yichang to Hukou and lower reach from Hukou to estuary), and receives its biggest tributary of Hanjing River at Hankou (Fig. 1). TGD is built on the upper reaches of The Yangtze River at a distance of 43 km from Yichang, which is one of the largest dams in the world. Yichang station has a drainage area of 1.0×10^6 km^2, taking up 56% of the Yangtze River basin, with annual mean runoff of 4.364×10^{11} m^3, representing the runoff of the Yangtze upstream. Hankou station is located in the midstream with mean annual runoff of 7.117×10^{11} m^3. Datong station controls a drainage area of 1.7×10^6 km^2, taking up 95% of the Yangtze basin, with annual mean runoff of 9.034×10^{11} m^3, representing the total river discharge. Obviously, the annual mean runoff at Yichang station is half of the runoff into the sea at the Datong station. The output of flows of Dongting and Poyang Lakes are controlled by Chenglingji and Hukou stations, respectively (Fig. 1).

Daily water levels and discharges data were collected from the key gauging stations (Yichang, Hankou and Datong) as shown in Fig.1. The data during 1950-1987 were provided by the books of *Hydrological Data of Changjiang River Basin, Annual Hydrological Report P. R. China*. And the data during 2000-2007 were provided by *Changjiang*

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Sediment Bulletin. And the data of tributaries hydrological stations of Chenglingji and Hukou's were provided by *Hydrological Data of Changjiang River Basin, Annual Hydrological Report P. R. China* since 1950s. The mean daily meteorological data were downloaded from the website of China Meteorological Administration (http://www.cma.gov.cn) since 1950s.

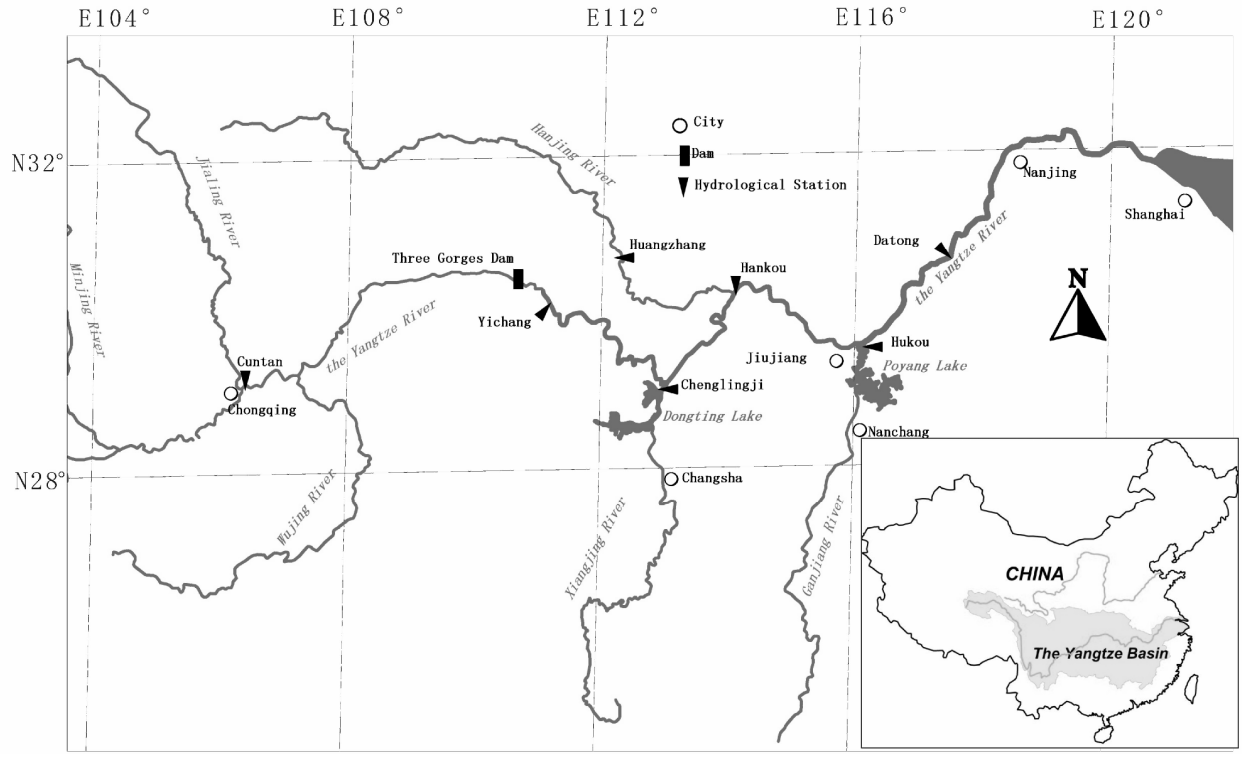

Figure 1. Hydrological stations and study area

The whole hydrological year was adopted in this paper, that is, form May in 1978 to April in 1979 (1978 for short) and form May in 2006 to April in 2007 (2006 for short).

III. RESULTS

A. Rainfall and temperature in 1978 and 2006

According to statistics, the rainfall in Chongqing, Yichang, Wuhan, Yueyang and Nanchang in 1978 and 2006 decreased respectively by 97.8 mm, 45 mm, 424.2 mm, 545.1 mm, 421.3 mm and 299.9mm, 115.4 mm, 124.5mm, 316.7mm, 108.3mm, compared with the average of accumulated years (Chongqing, Yichang and Wuhan weather stations are on the trunk river along MLRYR. Yueyang and Nanchang respectively are important weather stations in the Doting and Poyang Lakes drainage basin). It could be seen that the percentage departure value of annual precipitation at each station was negative (Fig.2); the mean monthly percentages departure value of precipitation were also negative in 1978 except several stations, yet the positive percentages departure in 2006 focued on the form next January to March of the dry season.

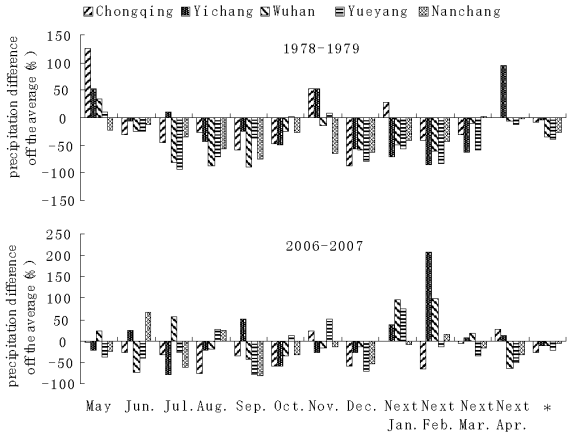

Figure 2. The percentages departures of precipitation at these main meteorological stations of the Yangtze River basin in 1978 and 2006. Ordinate represents the percentages departures of the precipitation. A positive value indicates that it's more than mean values of accumulated years and instead, it's less. * represents annual rainfall percentages departures.

The mean monthly temperature were positive at Chongqing, Yichang, Wuhan, Yueyang and Nanchang weather stations in 1978 and 2006, and temperature was high all year round (Fig.3). The curve of temperature departures had two peak areas: from June to September and from December to next April. However, departures of most months in 2006 were positive, which indicated that 1978 and 2006 were typical extreme drought years in the Yangtze River basin.

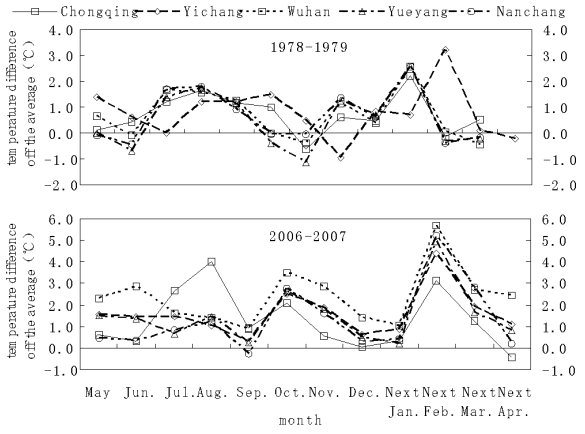

Figure 3. Mean monthly atmospheric temperature differences off the average at these main meteorological stations of the Yangtze River basin in 1978 and 2006. Ordinate represents the departures of mean monthly temperature. A positive value indicates that it's more than mean values of accumulated years and instead, it's less.

B. Runoff characteristics of MLRYR in extreme drought years

Compared with the annual mean runoff, percentages departure value in the flood season of drought years were negative and the percentages were greater (Fig.4). From the mean monthly flows, differences off the averages of most months were negative in 1978, except June. There were negative and positive percents of departures in the dry season of 2006, but the percentages of positive values were smaller.

Runoff changes of Trunk River had showed a significant difference between 1978 and 2006. The mean monthly flows were less than mean values of accumulated years except June at Hankou and Datong stations in 1978 (Tab.1). At the different seasons, the differences were more significant between dry season and flood season. The dry season runoff in 2006 accounted for larger in the mean values of accumulated years (Fig. 5[A]) and these percentages at Yichang, Hankou and Datong stations were 91%, 87% and 84%. The percentages in the flood season were 58%，66% and 69% respectively, less than that in the dry season. However, the percentages in 1978 were higher than the flood season and lower in the dry season (Fig. 6[B]). At three stations, the percentages in flood and dry season reach 91%, 82%, 75% and 82%, 71%, 67%, respectively.

The annual runoff at Datong station was 6.6×10^{11} m^3 in 2006, and 6.5×10^{11} m^3 in 1978 as shown in Tab. 1. There was no significant difference between the two extreme drought years. In the flood season, the runoff at Datong station reduced 3.27×10^{10} m^3 in 2006, compared with 1978. And especially the runoff at Yichang station during

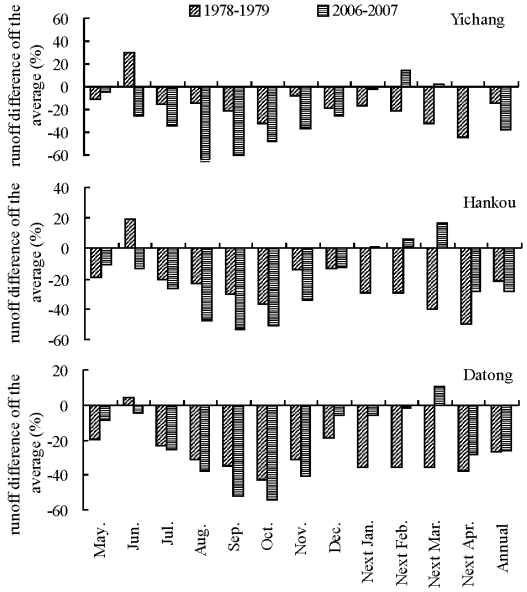

Figure 4. The percentages departures of the mean monthly runoff during extreme drought years 1978 and 2006. Ordinate represents the percentages departures of runoff. A positive value indicates that it's more than mean values of accumulated years and instead, it's less. Annual represents annual runoff percentages departures.

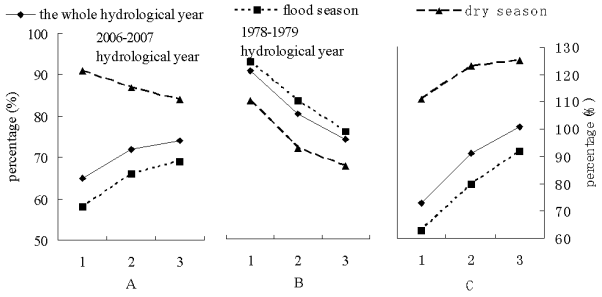

Figure 5. The percentages changes of runoff at Yichang, Hankou and Datong stations between drought years and annual mean values. 1-3 respectively mean Yichang, Hankou and Datong hydrological stations. A and B mean the percentages changes of runoff during 2006-2007 and 1978-1979 accounting for the averages of many years. C means the percentages runoff during 2006-2007 accounting for 1978-1979.

the flood season in 2006, accounts for only 63% of that in 1978 (Tab. 1 and Fig.5[C]). Furthermore, the runoff in the dry season in 2006 was 111% (Yichang), 123% (Hankou) and 125% (Datong) greater than that in 1978 (Tab. 1 and Fig. 5[C]). Thus, we can concluded that the runoff

characteristics along MLRYR during 1978~1979 and 2006~2007 were: ‘‘extreme drought all the year, more drought in the dry season’’ and ‘‘no flood in the flood season, no drought in the dry season’’.

C. *Outflow characteristics of Dongting and Poyang lakes in extreme drought years*

Dongting Lake is the second largest freshwater lake of China. The annual mean runoff of Dongting Lake in the recent 50 years is 2.91×10^{11} m^3, flowing into the Yangtze River at Chenglingji all at once. Dongting Lake is supplied by Four Tributaries-Xiangjiang, Zijiang, Yuanjiang, Lishui and Three Inlets (Four Inlets)-Songzi, Taiping, Ouchi, Tiaoxian (closed in 1958) (Fig.1). The Poyang Lake is the biggest freshwater lake in China and located on the south bank of the Yangtze River, where the middle reach and the lower reach meet. Poyang Lake is supplied by Five Rivers-Ganjiang, Fuhe, Xinjiang, Raohe and Xiuhe and flows into the Yangtze River at Hukou. The annual mean runoff at Hukou is 1.46×10^{11} m^3. Dongting and Poyang Lakes are the most important adjustment lakes for the Yangtze River.

In serious drought years, characteristics of discharges of Chenglingji and Hukou stations were as follows.

Firstly, the mean monthly discharges of not only Hukou but Chenglingji were lower than annual mean value in 1978 (Fig. 6(b)).

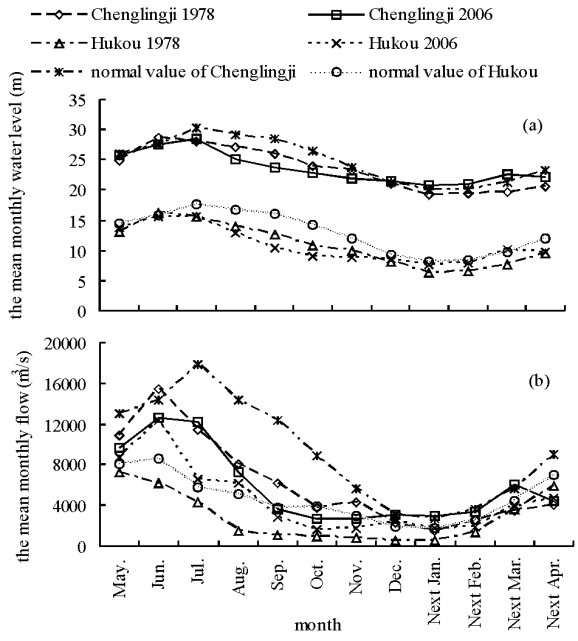

Figure 6. Variations in the mean monthly water levels and flows in different years at Chenglingji and Hukou gauging stations

Secondly, the mean monthly discharges of Chenglingji were lower than annual mean value almost all the year round, whereas the mean monthly discharges of Hukou from May to August were higher than annual mean value in 2006 (Fig. 6(b)). This situation at Hukou had to do with the rainfall of Poyang Lake drainage basin in 2006. And the rainfall was 92.7mm more than annual mean value of the corresponding period at Nanchang weather station (Fig.2). Thus, the outflow of Hukou was not lower.

Thirdly, it’s more interesting from May to September in Hukou. The water level was lower than the average for many years (Fig. 6(a)), while the outflow is more than the average for many years (Fig. 6(b)). It related to the low discharge of the trunk river in 2006, which compelled the outflow to keep larger.

Fourthly, there was significant difference that the water level and flow curve at Chenglingji and Hukou stations between drought years form other years. The daily water level and flow curve of Chenglingji and Hukou stations in November were typical of noose in 2005 (the year 2005 nearly normal year) (Fig.7). However, during the same period in 2006 and 1978, they were just simple linearity. The reason was that the water level of Trunk River kept less than the lakes and widens the water lever gap, which forced water of lakes flowing out.

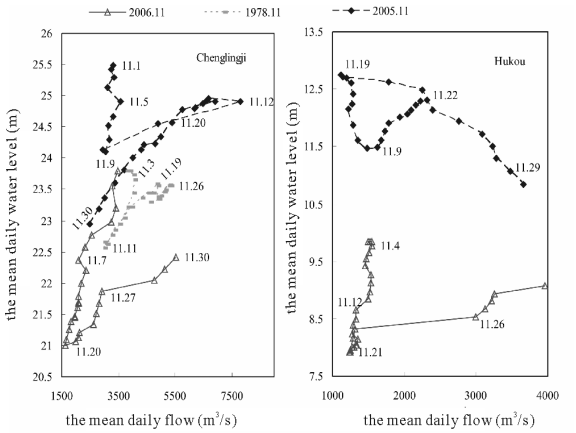

Figure 7. Variations in daily water levels and flows in November in different years at Chenglingji and Hukou gauging stations. The numbers besides curve represent the date of the water level occuring.

IV. DISCUSSION

A. *The function of runoff supplement by Dongting and Poyang Lakes on the middle reaches in extreme drought years*

1) *Analysis of supplement of Dongting and Poyang Lakes*

On the average for many years, the flows at Yichang and Datong stations decreased rapidly when the mainstream of Yangtze River entered the dry season. But the decline rate of the flows at Datong was less than that at Yichang station (Fig.8, Tab. 2), which was related to the adjustment of the outflows of the two lakes. Took the flow in the last month of the flood season (October) as a reference, the decline rate of the flows at Dongting and Poyang Lakes were both less than that at Yichang station, especially the

damping (22%) of the flow at Hukou station was only half of that at Yichang station (Fig.8, Tab. 2). This indicated that the flows out of lakes decreased slowly and supplied MLRYR in the dry season. The runoff in the lower reaches didn't reduce significantly, while the runoff at Yichang station in upper reaches reduces substantially, and the runoff at Datong station was not lower than 10000m^3/s all the year round in 2006. Obviously, it was closely related to the supply by lakes on the midstream (Fig.8, Tab. 2). On the average for many years, In the dry season, the runoff kept decreasing and then gradually increasing by mean range 59% after next January. But a contrary tendency that the runoff increased rather than decreased was observed after the dry season in these two extreme drought years. In next spring, the runoff increased quickly. And especially from January to April in 1979, the average increasing reached 128%, double than the average for many years.

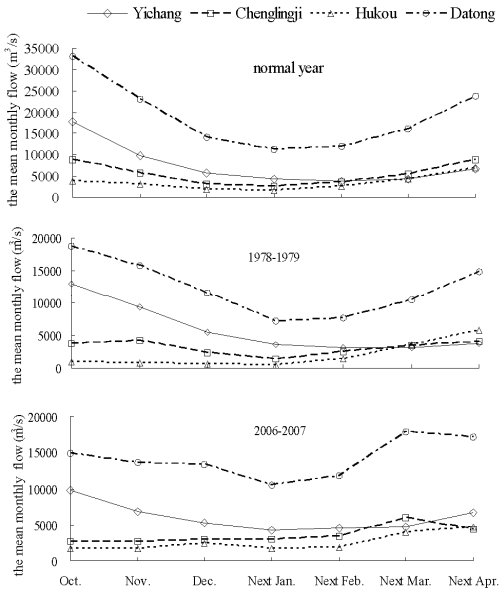

Figure 8. Variations in the mean monthly flow in different years at the four hydrological stations along MLRYR

2) Comparison of supplement by the lakes in different extreme drought years

During the whole hydrologic year in 1978, at Dongting Lake drainage area, compared to the average for many years, the runoff of Four Tributaries decreased 28%, the runoff of Three Inlets decreased 32%, and the outflow of Chenglingji decreased 33%. In Poyang Lake drainage area, the outflow of Hukou decreases 38% (Tab. 3). In 2006, at Dongting Lake drainage area, the runoff of Four Tributaries approached the average for many years, and the outflow of Three Inlets decreased 81% (Tab.3), compared to the average for many years. The proportion of the runoff of Four Tributaries occupies a dominant position in the outflow of Chenglingji. In Poyang Lake drainage area, the outflow of Hukou approaches the average for many years (Tab.3).

In general, the function of regulation by two lakes along MLRYR in 2006 was greater than that in1978. Especially, outflow of Poyang Lake reached the level of the average for many years in 2006 (Tab. 3), which played an important role in the runoff at Datong station keeping in a high level (Tab. 2, Fig. 10). According to the composition of the outflow of Chenglingji (Tab.3), the runoff of Four Tributaries accounted for only 62% of outflow of Chenglingji in 1978, whereas the proportion of the runoff of Four Tributaries occupied a dominant position (84%) in the outflow of Chenglingji in 2006. Therefore, while the low flow occurred in Trunk River, the water exchange between river and lake was intense. The function of water supply was obvious in Dongting lake drainage area.

In 1978, about 1.946×10^{11} m^3 and 8.95×10^{10} m^3 water was supplied to the Yangtze River from Dongting and Poyang Lakes by calculation and accounted for 30% and 14% of the runoff at Datong station. During 2006, the water into the Yangtze River was 1.853×10^{11} $m^3$and 1.444×10^{11} m^3 and the ratios reached 28% and 22%.

B. The adjustment of Three Gorges Reservoir

In 2006, the Yangtze River had suffered a serious drought [26], coinciding with the impounding of the Three Gorges Reservoir (TGR). The water level in TGR increased from 135m to 156m and total capacity reached 1.10×10^{10} m^3. TGR stored water from September 22 to October 27 in 2006, when the Yangtze River suffered a worst drought (Fig.2-3) and reached its lowest level in the flood season (Fig.4-5). According to statistics, the runoff into the sea at Datong station decreased about $6.00\times10^{10}m^3$ during the impounding of TGR in 2006, compared with the corresponding period in 2005. This loss should result from the impounding of TGR and the natural drought of the whole basin in 2006 which contribute 18% and 82%, respectively [27].

The regulation of TGR on the runoff of Yangtze River main stream was illuminated by the transformation of water level and discharged hydrograph between Cuntan (located at upper TGR) and Yichang (located at lower TGR) (Fig.1). The water level of Cuntan reached its trough in August in 2006, whereas the water level of Yichang decreased obviously from June to October after the regulation of TGR [26]. Compared to Yichang, the discharge of Cuntan almost remained the same, during flood season, from December 2006 to April 2007, the flow remained stable over 4000m^3/s (Tab.2), slightly lower than the averages for normal years, which indicated that TGR had a positive effect on regulating MLRYR runoff in 2006-2007 hydrological year.

Furthermore, Dongting Lake, Poyang Lake play important roles in supplying the lower reached of the Yangtze River in extreme drought years.

V. CONCLUSIONS

(1) The runoff characteristics of MLRYR during 1978~1979 and 2006~2007 were: ‘‘extreme drought all the

year, more drought in the dry season'' and ''no flood in the flood season, no drought in the dry season''.

(2) In extreme drought years, the widening gap of the water level at Chenglingji and Hukou stations, gathered the outflow speed of lakes and supplied more water to the Yangtze River.

(3) The lakes on the midstream were important water supply to the Yangtze River, especially in flood season. During 1978, about $1.946\times10^{11}m^3$ and $8.95\times10^{10}m^3$ water supplied from Dongting and Poyang Lakes to the Yangtze River by calculation and accounted for 30% and 14% of the runoff at Datong station. During 2006, the water into the Yangtze River was $1.853\times10^{11}m^3$and $1.444\times10^{11}m^3$ and the ratios reaches 28% and 22%.

ACKNOWLEDGEMENTS

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TABLE I. THE RUNOFF OF THE MAIN STATIONS ALONG THE YANGTZE RIVER IN EXTREME DROUGHT YEARS(FROM MAY TO NEXT APRIL)(UNIT:10^8M^3)

	Whole Hydrological Year			Flood Season			Dry Season		
Stations	***Yichang***	***Hankou***	***Datong***	***Yichang***	***Hankou***	***Datong***	***Yichang***	***Hankou***	***Datong***
annual mean value	4296	7089	8997	3410	5198	6414	907	1917	2614
1978-1979	3833	5585	6541	3108	4255	4809	744	1352	1757
2006-2007	2786	5072	6615	1970	3418	4437	826	1669	2196

TABLE II. THE MULTI-MONTHLY AVERAGE OF DISCHARGE AT THE FOUR STATIONS ALONG MLRYR (UNIT: M^3/S)

Gauging Stations	**Year**	**Oct.**	**Nov.**	**Dec.**	**Next Jan.**	**Next Feb.**	**Next Mar.**	**Next Apr.**	**Mean Value in Dry Season**
Yichang	annual mean value	17670	9852	5765	4283	3896	4396	6605	5800
	1978-1979	13000	9450	5540	3630	3160	3060	3720	4760
	2006-2007	9795	6784	5222	4260	4559	4612	6725	5360
Chenglingji	annual mean value	8829	5695	3138	2660	3581	5575	8957	4934
	1978-1979	3760	4230	2320	1480	2570	3470	4060	3022
	2006-2007	2630	2628	3038	2996	3412	6024	4372	3745
Hukou	annual mean value	3830	3000	1905	1750	2539	4406	6916	3420
	1978-1979	994	748	593	536	1336	3662	5851	2121
	2006-2007	1639	1741	2378	1737	1913	3966	4740	2746
Datong	annual mean value	33182	22999	14170	11150	11962	16154	23840	16713
	1978-1979	18700	15800	11500	7220	7670	10400	14800	11232
	2006-2007	14958	13654	13336	10512	11777	17872	17096	14041

TABLE III. THE RUNOFF OF DONGTING AND POYANG LAKES BASIN BY CONTRASTING IN DIFFERENT HYDROLOGICAL YEARS

Year	**Four Tributaries**			**Three Inlets**			**Chenglingji**		**Hukou**	
	Runoff (10^8m^3)	***Compared with Annual Mean Value (%)***	***Account for the Outflow of Lake (%)***	***Runoff (10^8m^3)***	***Compared with Annual Mean Value (%)***	***Account for the Outflow of Lake (%)***	***Runoff (10^8m^3)***	***Compared with Annual Mean Value (%)***	***Runoff (10^8m^3)***	***Compared with Annual Mean Value (%)***
annual mean value	1691		58	945		32	2910		1461	
1978-1979	1208	-28	62	620	-32	27	1946	-33	895	-38
2006-2007	1554	-8	84	179	-81	10	1853	-36	1444	-1

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