Assessment of Hydrologic Alterations Associated with Water Projects in Shaying River, China

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***Abstract* — Hydrologic regime is considered to be the major driving force of riverine ecosystems, and has become a fundamental part of running water ecosystems studies and management. Base on the daily flow records of two hydrological stations, taking the methodology of Indicators of Hydrologic Alteration (IHA) and Range of Variability Approach (RVA), the hydrologic alterations associated with the water projects was assessed in the Shaying River, China. Median of monthly flow throughout the post-impact period indicates a decreasing trend, and the dispersion coefficients are mostly higher than those for the pre-impact period. Minimum and maximum flows over different durations significant changes across these stations. The number of high pulses, the rate of rise and fall has increased significantly. Results show that the construction of the dams and sluices disturbed the hydrologic regime downstream and directly affected the streamflow variations.**

Keywords - Hydrologic regime; Indicators of Hydrologic Alteration; Range of Variability Approach; Shaying River

I. INTRODUCTION

Hydrologic regime is considered to be the major driving force of riverine ecosystems, and has become a fundamental part of running water ecosystems studies and management [1-4]. With the widespread construction of water projects to control water resources for economic and social development, the natural flow regime was altered significantly from the pre-impoundment, ultimately producing impacts on biological communities, energy flows, nutrient sediment dynamics and the interaction [5]. Hydrologic alterations has impaired riverine ecosystems on a global scale, and the pace and intensity of human development greatly exceeds the ability of scientists to assess the effects on a river-by-river basis [6]. To maximize the multiple functional utilities of water conservancy buildings, downstream flow release usually only considers the minimum flow approach for maintenance of aquatic ecosystems, in many instances, the reference natural flow may be the ultimate target or goal of management options [7, 8]. The growing demands for water have raised the need for further understanding of the impacts of hydraulic structures on hydrological processes, some measures should be carried out to ensure the sustainability of water resources utilization and healthy ecosystem of the rivers [9]. Characterizing the hydrologic alterations associated with water projects construction is very important for watershed management.

In order to combat the hydrological impacts on river ecosystems, the science of environmental flow assessment was established, and a variety of methods have been developed for setting environmental flows, each method has its strengths and weaknesses and requires varying levels of effort [10]. Maintaining the natural variability of a river's flow regime is one of the most critical strategies to sustaining the ecological integrity of aquatic ecosystems, because it is difficult for managers to achieve the strict standard of natural flow regime [11]. The Indicators of Hydrologic Alteration (IHA) method developed by The Nature Conservancy, USA, is a novel and increasingly used method [12]. Based on the IHA, Richter *et al.* (1997) developed the Range of Variability Approach (RVA) to establish flow based river management targets that incorporate the concepts of hydrologic variability and aquatic ecosystem integrity [13,14]. The RVA compare hydrologic data from a pre-impact period with those from a post-impact period, determine the degree of hydrologic alteration by analysis on the frequency of hydrologic parameters in two periods, has been proven to be a practical and effective method and widely applied in ecological water resources management [15].

China accounting about 50% of the total number of large dams in the world, only a few of rivers remain in a natural and unmodified condition. The Huai River is the seventh largest river in China, the basin is characterized by water projects of large dams and sluices along the mainstream and major tributaries, more than 5700 dams and 5000 sluices were constructed with the aim of flood control and water supply. The same situation exist in Shaying river, which is the major branch of Huai River, the dams are located in the headstream with large storage capacity and main function of water storage, water supply and flood control, while sluices are usually located in the middle and lower streams with small storage capacity and main function of water supply and flood control [16].

The spatial and temporal distribution of hydrological regimes could have been significantly changed by the presence of water projects, may further affect the distribution and availability of riverine habitat conditions. The previous research on the impact of water projects in Huai river was mainly focused on trend detection, periodicity analysis, water quantity and quality changed by water projects [17]. The analyze of full range of natural flow regime changes and the degree of hydrologic alteration remains unclear, which is crucial for environmental flow assessment and rivers management. Using the method of IHA/RVA and daily discharges at hydrological stations, this work aims to: (1) identify and evaluate the impacts of water project constructions on the hydrologic regimes in the Shaying River; (2) analysis the spatial differences in the degree of HA in the hydrological stations along the river; and (3) disuss the possible reasons cause flow regime changes and the possible management measures respond to these changes. The current study will be helpful for water resources management under the changing environment.

Almost in every field of modern civilization there is the requirement of electrical energy which has resulted in a considerable increase of electrical power consumption. To meet the demand of large electrical energy, the size of the power generating stations has become large. In many cases a few generating stations are connected among themselves by interconnected networks (power grids), making the utility systems extremely large. Usually the consumption area of electrical power is very wide, the chances of any kind of unforeseen accident, fault or abnormal condition is very common. Somewhere in a power utility network, an unforeseen accident creates a short circuit. The long transmission lines are bare and nakedly exposed to atmosphere. Lightning may have struck a part of the system or the wind may have blown down an electric pole and grounded the wires. Alternatively, a fallen tree limb, flyaway metallic balloon or unwary squirrel may have been the cause of the failure. The blackout of Aug. 14, 2003 in USA was caused by a cascading failure – a succession of transmission and generation outages, one precipitating another – that spread through Northern Ohio, much of Michigan, Ontario, and New York, as well as parts of Pennsylvania. One suggestion which was put forward is to go for increased use of distributed generation (DG) which involves placing smaller generation sources closer to the loads. But even with DG based system possibility of occurring fault do exist.

II. Materials and Methods Study area and Data

The Shaying River, originating from Henan province and flow through Anhui province, is the largest tributary of the Huai River, which is a typical area in China with the highest density of water projects and serious water environmental and ecological problems. The Shaying River is 620 km long and has a watershed area of 39880 km2, accounting for about 18.1% of the Huai River basin. Annual mean temperature in the basin ranges from 14 to 16℃ and the average annual rainfall is 770 mm. The Shaying River mainly consisted of the Jialu River, Ying River and Sha River, which merge near the Zhoukou city, downstream and feeds into Huai River at Zhengyangguan in Anhui province.

Large number of dams and sluices were built in Shaying basin since 1950’s for the purpose of flood control and drought relief. Dams were mainly built in the upstream, many sluices were constructed in the tributaries and main channel, in which, Zhoukou, Huaidian, Fuyang and Yingshang sluices are four main sluices built in the main channel of Shaying river. The Zhoukou sluice located in the middle of Shaying River, and with a drainage area of 25800 km2, plays a vital role in flood control and irrigation. Huaidian sluices is about 60 km downstream of the Zhoukou, was built as one of the most important floodgates in the river in the 1970s. Fuyang sluice located about 130 km downstream of Huaidian, and with a drainage area of 35246 km2,was built up to control floods in the downstream part of the Shaying River, Yingshang sluice located about 69 km downstream of Fuyang, and with a drainage area of 36606 km2,was finished in 1970s for the benefit of irrigation and flood control.

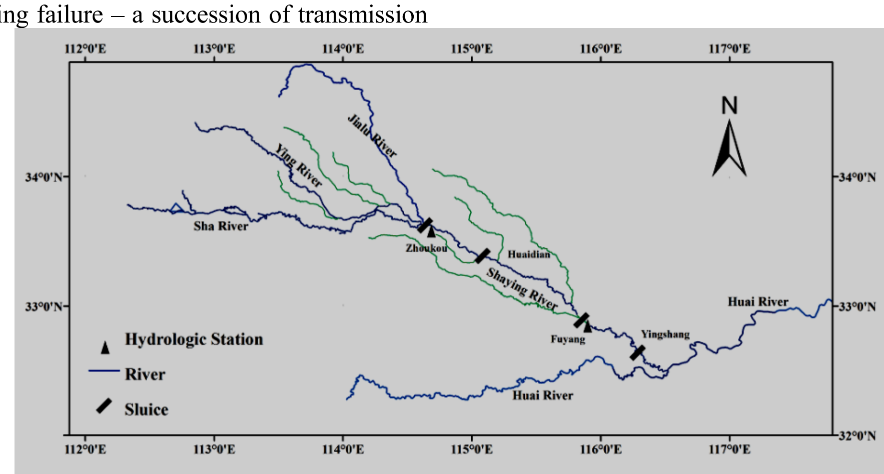

Figure 1. Map of the study area and sampling locations

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Daily streamflow data from two hydrological stations were analyzed in the current study. The selected hydrological stations located downstream of corresponding sluices, date on flows were obtained from the Hydrology Bureau of Huai River Conservancy Commission, China. The time series of these data were divided into pre- and post-alteration periods based on the timing of the water projects constructed. Detailed information about the sluices and hydrological stations are detailed in Figure 1.

III. METHODS

To ascertain the hydrologic alterations associated with water projects construction, we utilized the Indicators of Hydrologic Alteration (IHA), developed by The Nature Conservancy. This model uses daily data on flows and calculates 33 parameters that describe the hydrologic regime. The 33 parameters generated by IHA consist of magnitude, magnitude and duration of annual extreme conditions, timing of annual extreme conditions, frequency and duration of high and low pulses, and rate and frequency of changes in conditions. Values are computed for each of the 33 parameters for each year of record, enabling users to assess the inter-annual variability and changes in each hydrologic parameter for selected time periods or for the entire period of record.

The RVA was expressly designed for application in situations in which very little or no ecological information is available to support environmental flow determination. When applying the RVA, targeted ranges of values for any or all of the 33 IHA parameters can be defined based on analysis of daily flow records from a time period representing the natural flow regime. The degree of hydrologic alteration is then determined by a range-of-variability analysis based on the frequency with which post-impact hydrologic parameters fall within a range of values selected from the distribution of pre-impact values. The measure of hydrologic alteration, expressed as a percentage, can be calculated as:

HA (%) = ((Observed frequency - Expected frequency) / Expected frequency) × 100

where “Observed” is the number of years wherein the observed value of the hydrologic parameter fell within the targeted range and “Expected” is the number of years wherein the value is expected to fall within the targeted range. A positive deviation indicates that annual parameter values fell inside the RVA target window more often than expected; negative values indicate that annual values fell within the RVA target window less often than expected. Hydrologic alteration is equal to zero when the observed frequency of post-development annual values falling within the RVA target range equals the expected frequency. In the absence of specific ecological information, the ranges of natural variability are usually based on selected percentile levels or a simple multiple of the parameter standard deviations for the natural or pre-impact hydrologic regime. The management objective is not to have the river attain the target range every year but rather, to attain the range at the same frequency as occurred in the natural or pre-development flow regime. Richter et al. proposed a simple three-class evaluation system for individual IHA, in which the degrees of HA are classified into minimal or no alteration (0% – 33% as indicated by L),moderate alteration (34% – 67% as indicated by M), and high alteration (68% – 100% as indicated by H)(Richter et al., 1998).

IV. RESULTS AND DISCUSSION

Considering the actual situation of the water projects construction and operation of the study area, daily flow data was divided at 1976 into pre- and post-impact data series. The medians, coefficients of dispersion, RVA targets and hydrologic alteration factors for two periods were calculated of Zhoukou and Fuyang hydrological stations. The 25th and 75th percentile values were calculated based on the available pre-impact records, which were considered the low and high boundaries of the RVA target range, the results of the RVA analysis are shown in Table 1.

TABLE I: ALTERATION OF THE 33 HYDROLOGIC PARAMETERS FOR ZHOUKOU HYDROLOGICAL STATION

Groups	Medians of Pre-impact period		Medians of Post-impact period		RVA Boundaries				Hydrologic Alteration	
					Low		High			
	Zhoukou	Fuyang	Zhoukou	Fuyang	Zhoukou	Fuyang	Zhoukou	Fuyang	Zhoukou	Fuyang
Parameter Group 1										
January	40.1	43.8	25.3	15.7	24.7	33.6	53.9	60.4	-0.02	-0.71
February	41.1	39.1	11.1	13.2	21.7	14.3	47.5	53.9	-0.40	-0.29
March	35.0	40.8	20.9	22.4	26.8	23.9	43.6	52.8	-0.70	-0.71
April	30.4	43.7	24.8	28.7	24.5	24.6	46.6	60.1	-0.10	-0.29
May	42.2	52.6	28.3	21.1	28.2	42.0	51.0	79.0	-0.17	-0.71
June	24.1	33.2	18.5	13.2	10.6	12.3	34.5	54.4	-0.62	-0.50
July	104.0	199.0	100.0	99.5	56.3	97.8	211.4	349.1	0.58	-0.07
August	148.0	161.0	81.9	133.0	89.7	88.7	276.8	328.0	-0.17	0.07
September	96.7	118.8	78.0	91.0	71.2	71.4	121.2	140.3	-0.40	-0.64
October	61.3	87.5	45.0	16.7	53.2	71.6	91.4	128.8	-0.70	-0.79
November	56.6	71.0	32.5	37.7	48.3	61.1	70.9	81.2	-0.70	-0.71

December	42.4	53.4	29.8	41.0	29.4	39.3	58.0	63.3	-0.32	-0.71
Parameter Group 2										
1-day minimum	4.6	0.3	0.4	0.0	0.7	0.0	9.3	7.4	0.05	0.22
3-day minimum	5.3	1.8	0.5	0.0	0.8	0.0	10.3	7.6	0.05	0.22
7-day minimum	5.8	2.0	0.7	0.4	1.0	0.0	11.4	9.5	-0.10	0.35
30-day minimum	12.6	13.9	2.3	7.0	5.8	5.7	19.1	16.5	-0.40	-0.14
90-day minimum	25.3	27.5	9.9	14.6	17.7	17.1	34.0	38.5	-0.40	-0.36
1-day maximum	2020.0	1620.0	1070.0	1290.0	1322.0	1320.0	2331.0	2821.0	-0.32	0.14
3-day maximum	1560.0	1467.0	817.3	1121.0	910.8	1050.0	1927.0	2760.0	-0.25	0.29
7-day maximum	997.3	994.9	657.6	840.1	598.7	825.5	1623.0	2336.0	0.20	0.14
30-day maximum	450.7	572.6	321.9	390.1	279.3	428.3	827.8	901.3	0.20	-0.36
90-day maximum	255.2	325.8	173.6	250.9	162.5	226.0	446.9	505.8	-0.02	-0.36
Number of zero days	0.0	0.0	0.0	14.0	0.0	0.0	0.0	9.0	-0.22	-0.47
Parameter Group 3										
Date of minimum	171.0	158.5	170.0	22.0	128.8	65.0	179.0	172.3	-0.59	-0.29
Date of maximum	213.0	206.0	215.0	207.0	195.6	195.7	218.4	226.1	-0.17	0.14
Parameter Group 4										
Low pulse count	6.0	4.5	14.0	12.0	3.6	1.9	9.0	6.0	-0.39	-0.84
Low pulse duration	6.3	14.8	4.0	5.0	4.5	11.2	8.0	19.8	-0.20	-0.71
High pulse count	8.0	8.0	10.0	12.0	5.6	5.9	8.4	9.0	-0.70	-0.60
High pulse duration	5.0	5.8	3.0	3.0	3.3	4.0	6.5	9.6	-0.12	-0.49
Parameter Group 5										
Rise rate	4.1	3.8	5.2	15.7	3.5	2.0	5.3	5.6	-0.40	-0.64
Fall rate	-3.9	-2.8	-6.2	-12.6	-4.5	-4.5	-3.6	-2.2	-0.73	-0.79
Number of reversals	100.0	60.0	118.0	92.0	90.0	54.0	111.4	70.1	-0.39	-0.56

V MAGNITUDE OF MONTHLY WATER CONDITIONS

In the monthly mean flow data, at Zhoukou and Fuyang station, median of monthly flow throughout the post-impact period indicates a decreasing trend compared with that in the pre-impact period. The dispersion coefficients for the post-impact period are mostly higher than those for the pre-impact period at two station, for example , parameter ranging from 1.15 to 4.57 for the post-impact period and ranging from 0.62 to 1.96 for the pre-impact period, indicating the higher monthly flow fluctuations in the post-impact period due to the regulation of sluices operation.

As shown by the calculated results, monthly deviations in February, October, November and December were relatively high at two stations. The October deviation at Zhoukou station reached 79% while Fuyang reached 70%, which exceeded the pre-impact values (Fig. 2).

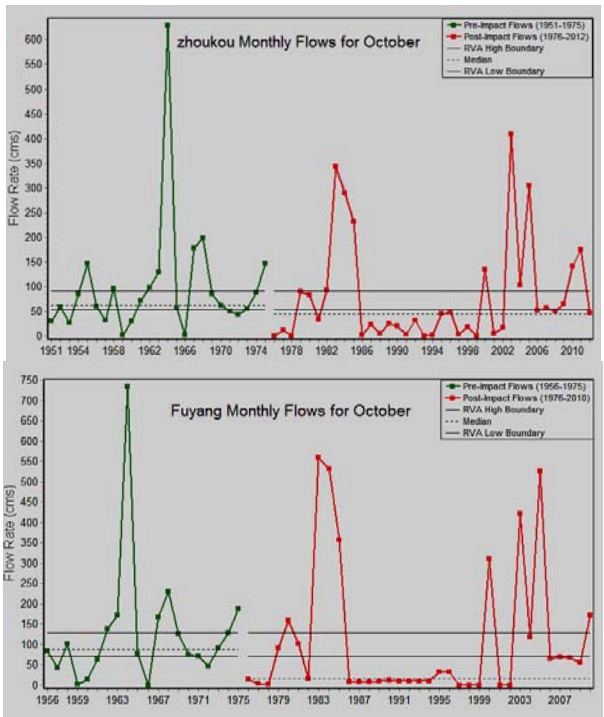


Figure 2. Monthly flows for October

VI MAGNITUDE AND DURATION OF ANNUAL EXTREME WATER CONDITIONS

Both Zhoukou and Fuyang stations, the medians of annual 1-, 3-, 7-, 30-, 90-day minimum and 1-, 3-, 7-, 30- and 90-day maximum for the post-impact period decrease significantly. Results indicate that the daily, weekly, monthly and quarterly maximum/minimum flow cycles are negatively influenced by the regulation of water projects(Fig. 3).

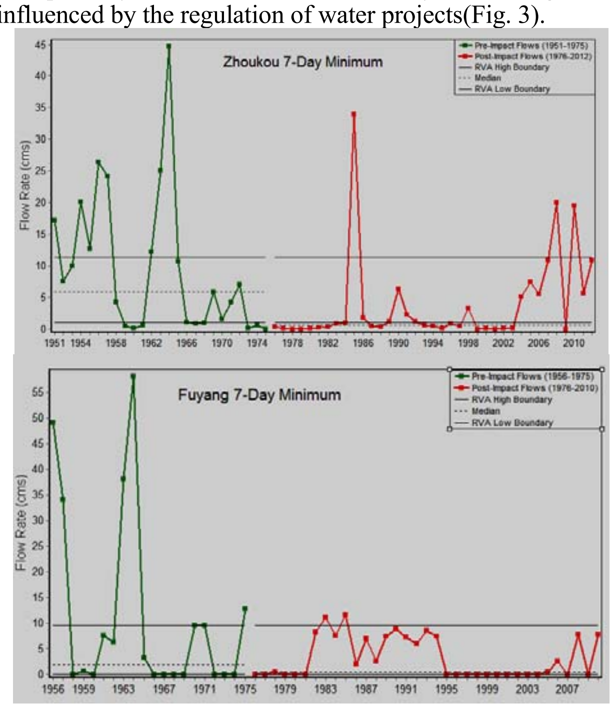
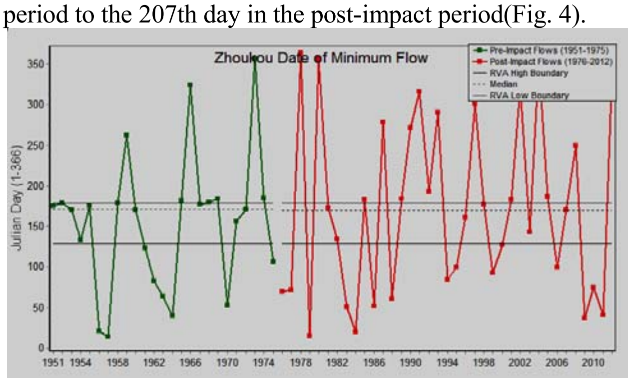


Figure 3. 7-Day Minimun flows of two stations

VII TIMING OF ANNUAL EXTREME WATER CONDITIONS

At both hydrological stations, the median Julian dates of each annual 1-day minimum move backward in the post-impact period to the pre-impact period. The median Julian dates of each annual 1-day maximum at Zhoukou station move backward from the 213th day in the pre-impact period to the 215th day in the post-impact period, while at Fuyang station move backward from the 206th day in the pre-impact period to the 207th day in the post-impact period(Fig. 4).



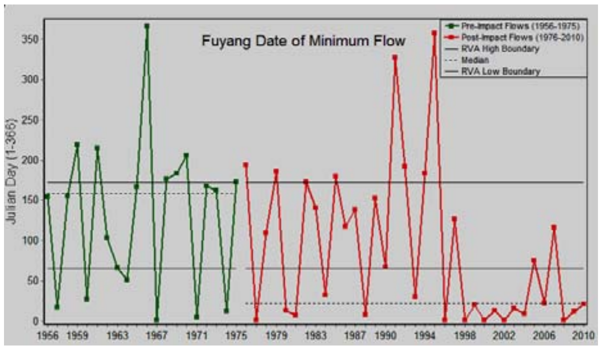


Figure 4. Date of minium flows of two stations

VIII FREQUENCY AND DURATION OF HIGH AND LOW PULSES

The medians of low and high pulse counts in the post impact period are higher than those in the pre-impact period, which may be a result of inadequate records in the pre-impact period. The medians of low and high pulse durations in the post-impact period are lower than the pre-impact period, especially in Fuyang station, which indicates the sluices have remarkable influence only on hydrologic alteration of low and high pulse durations(Fig. 5).

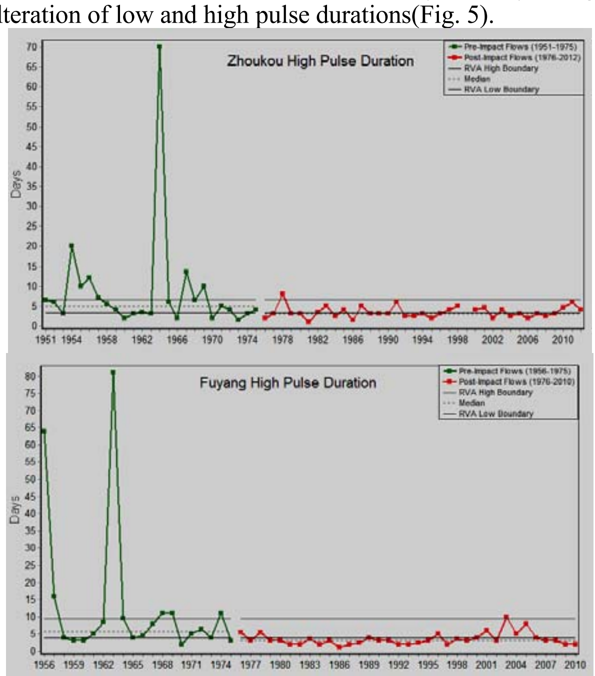


Figure 5. High pluse duratin of two stations

IX RATE AND FREQUENCY OF WATER CONDITION CHANGES

The medians of rise rate, fall rate and the number of reversals increased, and the coefficients of dispersion of rise rate are higher than in the earlier period at two hydrological stations (Fig. 6).

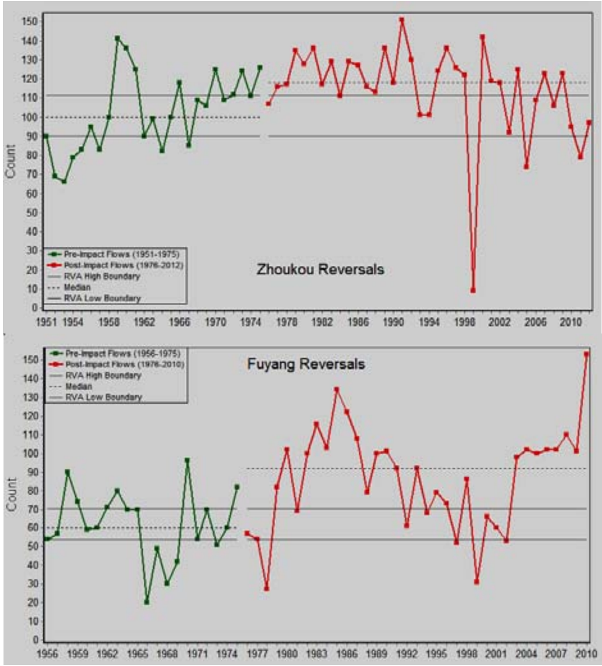


Figure 6. Number of eversals of two stations

X NON-PARAMETRIC ANALYSIS OF HYDROLOGIC ALTERATION

The 33 hydrologic alteration values for the two hydrological stations in Shaying River were analyzed to investigate the order of indicators of hydrologic alteration caused by the reservoirs using a non-parametric statistical method. The degree of indicators of hydrologic alteration at Zhoukou and Fuyang station is accepted as a paradigm to demonstrate the changes of each hydrological indicator at lower Shaying river, which suffers the greatest hydrological alteration among the water projects in the study region.

The results show that fall rate ranks first in all hydrologic alteration values followed by October, March, November, High and Low pulse count, June, September, December and number of reversals et,al, they are assumed to be strongly affected by construction and operation of the dams and sluices located upstream(Figure 7). In addition, the negative deviation values of most parameters indicate that the annual values of these parameters fell within the RVA target range less often than expected.

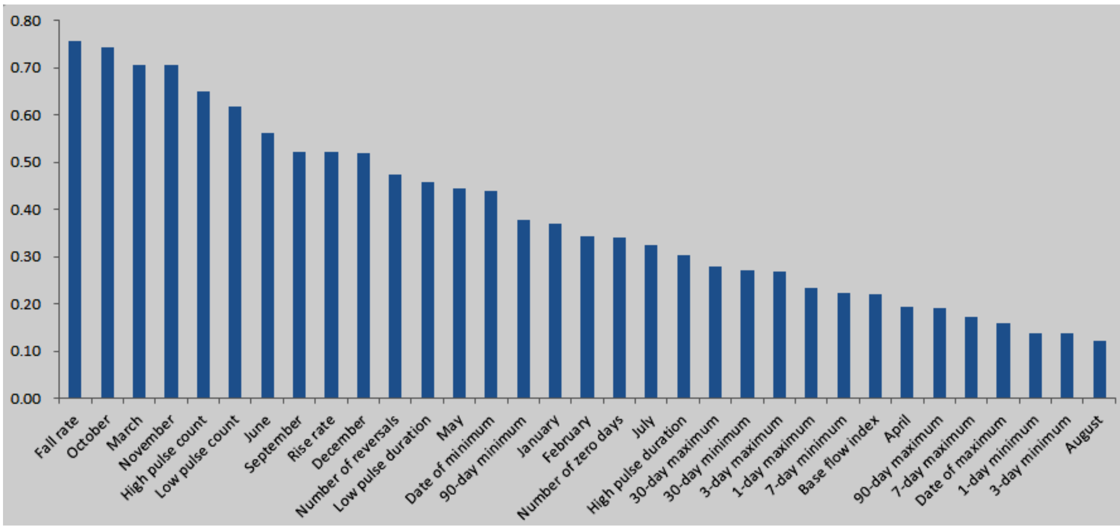


Figure 7. Ranked median absolute degrees and percentile value of 33 indicators of hydrologic alteration for 2 hydrological stations in the Shaying River

XI. CONCLUSION

The water projects construction and operation aiming to flood control, irrigation, and shipping have obviously affected the hydrological regime, result in undesirable ecological effects. Based on the IHA/RVA method, the influences of sluices on hydrological regimes in the Shaying River were systematically studied.

The impact of sluices on the hydrological regime is profoundly, the major changes was decreased the magnitude of flows, indicating that the river flow became more lower in the post-impact period, and they reduced annual peak discharges, decreased the range of daily discharges, increase the number of reversals in discharge, alter the timing of high and low flows, but have little change on the timing of the yearly maximum and minimum flows of Shaying River. The alterations in flow regime were closely related to the operation of the water projects, especially in the dry season, the regulation of dams and sluices intensified the decrease of runoff, because most dams and sluices were controlled in order to meet water demand for agricultural irrigation and water supply. In terms of spatial patterns, the impacts of the Fuyang on downstream flow regime increased than the Zhoukou of upstream, which was attributed to the increased confluent inflows in some tributaries along the river.

Construction and operation of the dams and sluices, aiming to reduce flood disaster and support the economic development, has inevitable result in high hydrologic alteration and further changed the natural situation of the riverine ecosystem. The natural flow paradigm emphasizes the need to maintain or restore the range of natural intra- and inter-annual variation of hydrologic regimes in order to protect native biodiversity. At present, the economy is far underdeveloped and water pollution is still serious in many basin, ecological river restoration on a large scale is not realistic. Under the current situation, make the hydrologic alterations parameters as part of the most important goals in the dams and sluices operation, is expected as technical support for the environment restoration and integrated management in the basins. As the the complicated impact of dams or sluices regulation on hydrologic regime, reseach and practice will be considered further.

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