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STUDY ON TREND PREDICTION AND VARIATION ON THE FLOW INTO THE LONGYANGXIA RESERVOIR

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ABSTRACT: The Longyangxia Gorge Key Water Control System is the first of the stairstep power sations along the Longyangxia-Qingtongxia river section. It has been playing an very important role in providing power, protecting flood and ice run supplying and irrigation etc. in the northwestern China. Therefore, the study on trend prediction, variation on the flow into the Longyangxia Reservoir are of the great social and economic benefits. In the medium-and-long-range runoff forecast, all kinds of regression equation are often used for predicting future hydrologic regime. However, these regression models aren't appropriate to super long -range runoff forecast because of the restricting on weather data and so on. So a new super long-range runoff forecast model don't depend on Reai-time weather data and called " Period correcting for residual error series GM(1, 1) model" is presented based on analyzing for the relational hydrologic data and the variation on the flow into the Longyangxia Reservoir, and the forecast model was applied successfully to predict the recent and super long -term trends of the flow into the Longyangxia Reservoir. The results indicate that the annual flow into the Longyangxia Reservoir is in the ending minimum period of the runoff history. The runoff increasing is expected in for the coming years.

KAY WORDS: flow variation; trend prediction; residual error series; Longyangxia Reservoir

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1 INTRODUCTION

The second longest river in China is the Huanghe (Yellow) River on the north of Mt Bayankala on the Qinghai-Xizang (Tibet) Plateau. It winds its way through Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shanxi, Shaanxi, Henan, Shandong, and empties into the Bohai Sea at Kenli County of Shandong Province. It has a total length of 5464km with a drainage area of 752 443km^2. The rushing currents from Longyangxia Gorge to Qingtongxia Gorge in its upper reaches, running 918km with a fall head of 1324, provide rich hydroelectric resources of high technical and economic standard, located on the boundary of Gonghe and Guinan Counties of the Hainan Tibetan Autonomous Prefecture, Qinghai Province, 1688km down from the source of the Huanghe River. As the first of the stairstep power sations along the

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Longyangxia-Qingtongxia river section, it is called the "First Dam on the Huang he River". The high of the highest point measuring of the system's main dam is 178m. The Longyangxia Reservoir can hold 24.7 billion m³. The upper Huanghe River above Longyangxia Gorge is located in the northeastern Qinghai-Xizang Plateau, between 95°50′ - 102° 52′ E, 32°20′ - 36°30′N, with a catchment area of 13.14×10^4km². The Tangnag station, upstream about 110km from the reservoir, is the representative stations for runoff into the Longyangxia Reservoir. Since 1956 runoff is observed and documents more than forty years have been recorded at the station now. The inflow into the reservoir mainly comes from the upper secondary above Tangnag, so studying the variation characteristics and forecasting the future runoff trend at Tangnag can provide an important basic for controlling the inflow into the reservoir.

2 VARIATION CHARACTERISTICS ON RUNOFF INTO THE RESERVOIR

2.1 Seasonal Variation on Runoff

Seasonal runoff variations are decided by the supply conditions of river. In general, features of runoff variations in the upper Huanghe River are that the period from late winter to early spring (from November to March in next year) is low flow season and the period from early summer to late autumn (from mid June to late September) is flood flow season. After March, the runoff begin to increase noticeably corresponding to snowmelting and soil thawing with the air temperature rising. In summer and autumn, the runoff is most abundant because of the extensive and frequent rains fed by the summer monsoon, the supplies of glacier and snow melt water, and the groundwater. The floods also occur in autumn when the rainy season persists. At the Tangnag station the dayly maximum runoff into the Longyangxia Reservoir occur in July and September, and the dayly minimum runoff occurs in February (Table 1). Inflow volumes to the reservoir in flood season(period from May to October) account for 79.2% of annual inflow volume, and inflow volumes in the rest six months only account for 20.8% of annual inflow volume. Therefore, total inflow volumes into the reservoir basically decide the inflow volume in flood season. It can be observed clearly in Fig. 1 that both variation process are very similar.

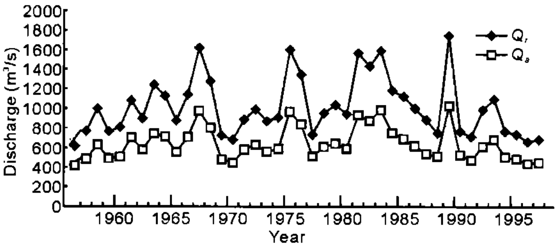

Fig. 1 Curve of the annual mean discharge(Q_a) and flood season mean discharge(Q_r)

Table 1 Monthly runoff distribution at the Tangnag Station

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec	Mean
Q_m(m³/s)	170	168	221	364	597	892	1327	1107	1257	1000	486	229	665
Proportion (%)	2.17	2.15	2.83	4.65	7.63	11.41	16.97	14.16	16.09	12.79	6.22	2.93	100

2.2 Yearly Variations on Runoff

Long-term average runoff at the Tangnag Station is 665m³/s. The low-flow year is 17 times, the normal-flow year is 15 times and the high-flow year 11 times during 1956 to 1997. Extremum radio of the high and the low-flow(Q_{max}/Q_{min}) is 2.46. Departurefrom the mean runoff in highest -flow year is 57% (1989), and departure of the mean runoff in lowest -flow year is −36% (956). The most fast transition on the departure of the mean runoff from the low-flow year to the high-flow year is −21.0% in 1988 to 57% in 1989, and the most fast transition from the high-flow year to the low-flow year occurred from 57%

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in 1989 to − 19.0% in 1990. The analyzing results for runoff observation at the Maduo, the Jimai, the Maqu and the Tangnaig. stations show that the runoff variation coefficients of upper Huanghe River, *C*v, are less than 0.3 except the region above Jimai due to the adjustment of lakes (LAN, 1989). It will be seen from this that although the runoff in the upper Huanghe River are affected significantly by the atmospheric circulation, yearly variations on runoff are gentle compared with other great rivers in China (LAN, 1998).

The high, the mean flow year and the low flow years in the upper secondary are demarcated according to the given repeat ratio (XI, 1996), that is,

$P \leqslant 12.5\%$, the extremely high flow year (PHFY) } the high flow year (HLY)
$12.5\% < P \leqslant 37.5\%$, the generally high flow year (GHFY) }
$37.5\% < P \leqslant 62.$ the normal flow year (NFY)
$62.5\% < P \leqslant 87.5\%$, the generally low flow year (GLFY) } the low flow year (LFY)
$87.5\% < P$, the extremely low flow year (ELFY) }

The high, the normal and the low flow period of annual runoff at the Tangnag can be analyzed according to the corresponding model-ratio of K_p (K_p = the annual runoff volume in some one-year/ long-term average annual runoff). K_p at Tangnag and its variation from 1956 to 1997 can be seen in Table 2 and Fig 2.

Table 2 Model-ratio of coefficient K_p of the annual runoff at Tangnag

HFY		NFY	LFY	
PHFY	GHFY		GLFY	PLFY
> 1.46	1.46 − 1.05	1.04 − 0.93	0.92 − 0.79	< 0.79

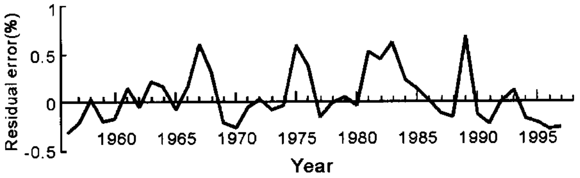

Fig. 2 Curve of the residual error series ($q^{(0)}(t)$) of the annual mean discharge into the Longyangxia Gorge Reservoir

Alternating and circulating among the high-flow period (HFP), the normal-flow period (NFP) and the low-flow period (LFP) of the inflow into the reservoir since 1956 can be seen in Table 2, which may roughly be divided into two integrated high-low flow cycling

Table 3 High-low flow variations on runoff at the Tangnag Station

NFP			LFP			HFP		
Years	Length	K_p(mean)	Years	Length	K_p(mean)	Years	Length	K_p(mean)
1956 − 1968	13	1.04	1956 − 1960	5	0.90	1961 − 1968	8	1.18
1969 − 1986	18	1.06	1969 − 1974	6	0.87	1975 − 1986	12	1.24
1987 −			1987 − 1997	11	0.93*			

* Mean value of K_p in the low flow period staring from 1987 is close to the multiyearly average of K_p because there is a extremely high flow year, 1989 ($K_p = 1.68$), in this low flow period.

Table 4 Decennial variations on runoff at the Tangnag since 1956

Years	Discharge (m^3/s)	Departure (%)	Mean K_p	High-low flow degree
1956 − 1959	512.5	−21.8	0.77	Extra low flow
1960 − 1969	685.7	+4.53	1.03	Normal flow
1970 − 1979	646.1	−0.0	0.97	Normal flow
1980 − 1989	763.0	+16.3	1.15	General high flow
1990 − 1997	529.4	−19.3	0.80	General low flow

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periods and an alone low-flow period. Lengths of the each period are different, but their K_p values are close to multi-year average. Now it is just at the third low-flow period starting from 1987. The high-low flow cycling periods (HLCP) at Tangnag Station are shown in Table 3.

Considering as a representative period taking every decade from the 1950s to the 1990s, the 1950s is the low flow period, the 1960s and the 1970s are the normal flow periods, the 1980s are the general high flow period and the 1990s is again the low flow period for the inflow into the reservoir (as shown in Table 4). It also will be seen from Table 4 that the probability for appearing the low flow period is very high in the upper Huanghe River.

3 ANALYZING ON PERIODIC CHANGING OF THE INFLOW TO THE RESERVOIR

There are periodic fluctuations in the long-term changes on hydrologic variables and meteorological variables, and atmospheric circulation (HUANG, 1996). Spectral analysis on a basis of Fourier analysis is just a method used for researching these fluctuations. Spectrum analysis is correspond with a nonlinear autoregression model in time series analysis, it can be used for extracting periodic components and forecasting periodic components 's changes based on the periodical extrapolation. Annual runoff in upper Huanghe River above Tangnag are analyzed and tested by means of power spectrum, harmonic analysis and variance analysis methods, and the prominent changing cycles about 2 – 3 years, 6 – 7 years, 16 – 17 years and 22 years on runoff are obtained. It is considered to possess of some physical meaning for existing cycles above.

First, the about 3 year and the 6 – 7 year cycles on runoff are accordant to the 3-year quasi-cycles on Pacific subtropical belt high ridge's positions (XU *et al.*, 1982), and the 7 year cycles on the amplitude variations of the geomagnetic pole movement, which are the important weather systems for affecting regional precipitation in western China, and cycles changes above will even influence other hydrologic variables at bringing the variations on the earth ecstaltic forces system and the variations on atmospheric circulation, air mass, and moistureshus transportation. Pacific subtropical zone of high presure is one of the major weather systems for affecting the precipitation in the whole Huanghe River. Therefore, presence of the 2 – 3 year cycles on runoff in upper Huanghe River may reflect the mutual action between sea and atmosphere. The presence of the 2 year or 3 year cycles has been verified well in the upper Huanghe River basin above Tangnag by many hydrologists and meteorologists (HUN *et al.*, 1996). The 16 – 17 year and the 22 year cycles may be related to mid-term and long-term periodical variations of sunspot activities and the movements of celestial bodies (CHENG, 1994). For example, KANG(1992) analyzed the 11-gear and 12-year cycles on climatic in the northeastern areas of the Qinghai-Xizang Plateau to the mid-term fluctuations on sunspots. Large-scale droughts and floods are closely related to the fluctuations on sunspots and the variations of other climatic variables in China sometimes. So the runoff in the upper Huanghe River also be influenced frequently by the fluctuations on sunspots. Sunspots increasing generally correspond to longitudinal strengthening circulation (E-type) and to latitudinal circulation (W-type) weakening. The former can favor the latitudinal air mass movements and precipitation formation. The latter generally strengthens the hot lows over the Qinghai-Xizang Plateau (QTP), resulting in increasing precipitation and runoff in river head of the Huanghe River situated in northeastern QTP. Conversely, runoff in the upper Huanghe River will be reduced while the radial winds abate and the zonal develop. Sunspot activity reached a maximum in 1990 (HUO *et al.*, 1996). As a result, the precipitation and stream flow in northeastern Qinghai-Xizang Plateau has been decreasing ever since due to the gradual decline of the radial winds and the gradual buildup of the zonal.

4 GREY PREDICTING ON INFLOW TO THE RESERVOIR

4. 1 Calculation Principle

Based on Grey System Theory, the systems in which

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the partial information is specific and another partial information not specific are called Grey system (DENG, 1986). Natural runoff is affected by various factors, such as air temperature, precipitation etc, the influences of some factors are obvious in physics, another not obvious and even not clear. Therefore, the variation of runoff can be treated as typical problem in Grey systems. To both avoid analyzing the complicated factors affected runoff variation and to open out objectively the variation laws on runoff, Grey forecast method in Grey System Theory is used for researching future trend on the inflow into the Longyangxia Reservoir.

4. 2 Calculation Model

GM(1, 1) model is the basic of Grey forecast, whose basal mathematics form is

$$dx^{(1)}/d(t) + ax^{(1)} = u \qquad (1)$$

where a, u are the determinative parameters; above formula is a degree differential equation expressing variable x, control variable u, and variation rate $dx^{(1)}/d(t)$ linear combination, whose time function is

$$X^{(1)}(t+1) = (X^{(0)}(1) - u/a)e^{-at} + u/a \qquad (2)$$

GM(1, 1) model is a exponential curve equation whose shape is simpler and monotonously increasing or decreasing by degree. It is difficult for GM(1, 1) model to reflect the fluctuant varietying status. Because curve of annual runoff series presents, fluctuant status, GM (1, 1) model can't be used simply for simulating the variation. So a new Grey model called the period correcting for residual error model is present. (LAN *et al.*, 1997; FU, 1992). New model differing from above simple GM(1, 1) model, the residual error correcting value in each period can calculated respectively by the new model and be overlapped with the initial calculated values in the same period through analyzing the residual error series of initial calculated results fluctuating with periodical variation on climate, which may make forecasting values in a gray extent. Thereby, the practicability and scientifically on forecast can be improved(YUAN, 1991). If the established GM(1, 1) model corresponding time responding function according to the initial annual mean runoff into the reservoir, $X^{(0)}$ series,

$$X^{(0)}(t+1) = (-a(X^{(0)}(1) - u/ae^{-at} \qquad (3)$$

The calculating progression by the model

$$X^{(0)*}(t) = \{X^{(0)*}(1),\ X^{(0)*}(2\cdots,\ X^{(0)}n)\} \qquad (4)$$

Known the initial annual mean runoff into the reservoir, $X^{(0)}$ series is

$$X^{(0)}(i) = \{X^{(0)}(1),\ X^{(0)}(2)\cdots,\ X^{(0)}(n)\} \qquad (5)$$

the residual errors q are defined as

$$q^{(0)}(t) = X^{(0)}(i) - X^{(0)*}(t), i, t = 1, 2, \cdots, n \qquad (6)$$

Therewith there will be the residual error progression as follows

$$q^{(0)}(t) = \{q^{(0)}(1),\ q^{(0)}(2)\cdots,\ q^{(0)}(n)\}$$

The obvious periodicity on the residual errors series can be observed by plotting curve (Fig . 2). So the residual errors series are fitted by mean of sinusoid or cosine curve based on period analyzing and orderly sectioning according to the different period and variation extent, Then the residual corrected values are respectively calculated and are residual error correcting value in each period can calculated respectively and be overlapped with the initial values calculated by GM(1, 1) model in the same period (LAN, 1997). GM(1, 1) model is also established for $q^{(0)}(t)$ and the calculating formula for period correcting is

$$Q(t_i) = A_i\sin(2\pi t_i / T_i) \qquad (7)$$

where $Q(t_i)$ is the correcting values in the t time of the i period; Ai is the maximal variation extents in the t time of the i period; Ti is the size of the i period. Finally the period correcting for residual error GM(1, 1) model of annual mean runoff into the Longyangxia Reservoir as follows

$$X^{(0)}(t+1) = (-a)(X^{(0)}(1) - u/a)e^{-at} + A_i\sin(2\pi t_i / T_i) = 9.69e^{0..103t} - 7.56 + A_i\sin(2\pi t_i / T_i) \qquad (8)$$

Evaluating the calculating precision of GM(1, 1) model with period correcting for residual error and calculating result for the annual runoff into the reservoir during the period from 1991 to 2010 can be seen in Table5.

$$X^{(0)}(t+1) = (-a)(X^{(0)}(1) - u/a)e^{-at} + A_i\sin(2\pi t_i / T_i) \qquad (9)$$

The calculated results of the annual runoff into the reservoir from 1986 to 1997 by the model are validated, which can be seen in Table 5. It will be seen from Table 5 that the calculating precision of the GM(1, 1) model with period correcting for residual error have

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Table 5 Verifying for Period correcting for Residual error series GM(1,1) model

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Mean
Calculating (m^3/s)	594	861	600	571	602	607	612	520	410	520	589. 7
Measuring (m^3/s)	520	1040	535	480	622	692	512	492	447	455	580
Precision(%)	85. 8	82. 8	89. 1	81. 0	96. 7	87. 7	80. 5	94. 3	91. 7	85. 7	87. 6

Table 6 Predicting values of the annual runoff into the Longyangxia Reservoir

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean
Calculating values(m^3/s)	638	655	587	656	786	634	584	633	500	520	620

been over 80 % , so the results accord with needs for the accuracy of a long-term hydrological forecast. The runoff of each year in future decade into the Longyangxia Reservoir is forecasted by the GM(1, 1) model with period correcting for residual error (Table 6). The forecasting results show that a concussive and rising trend on variation of runoff into the reservoir will present in some years from now on to early next century and the mean runoff in this period will be close or attain to long - term average runoff. The process of the calculated and the measured the mean annual runoff intothe reservoir will be compared in Fig. 3.

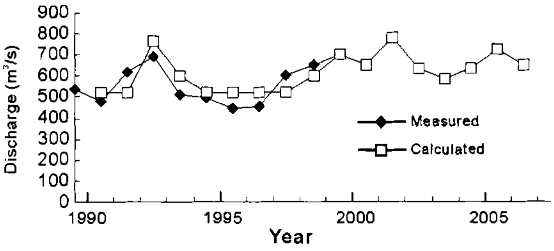

Fig. 3 The processes of the calculated and the measured the an nual runoff into the Longyangxia Gorge Reservoir

5 CONCLUSIONS

According to above analysis and calculation, an elementary conclusion could be obtained as follows

1) Runoff in the upper Huanghe River are affected significantly by the atmospheric circulation, however the yearly variations on runoff are gentle compared with other great rivers in China.

2) Inflow into the Longyangxia reservoir displayed significant periodical variations of 2 – 3 year, 6 – 7 year, 16 – 17 year, and 22 year cycles.

3) The high-low flow variation on the inflow into the Longyangxia Reservoir can be divided into two complete periods of high-low flow periods and one incomplete low flow and an incomplete low flow period hitherto. The averages K_p of each period are close to long-term average. The present situation is located going to the minimum of the third low flow period. The possibility occurring for low flow periods is very high in the upper Huanghe River.

4) It is expected that inflow into the Longyangxia Reservoir will increase in the forthcoming decade, and it will reach or slightly close to long-term average of the runoff.

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