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Evaluation of Economic and Hydrologic Impacts of Unified Water Flow Regulation in the Yellow River Basin

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Abstract Unified water flow regulation has been implemented in the Yellow River, Hei River and Tarim River in China since 1999 as a result of institutional reforms. It has been one of the most important water resources management practices in China during recent years and has generated significant impacts. Based on the data of such an experiment in the Yellow River during 1999 to 2004, a "with-without" scenario analysis method is employed in the paper to evaluate the economic and hydrological impacts of regulation through a holistic model coupling economic water use and hydrologic cycle applied to the study basin. The results show that about 2.5% of GDP was increased every year and the Flow Cutoff Events were avoided as a result of the unified water flow regulation.

Keywords Water resources management · Water regulation · Impacts evaluation model · Institutional reform

1 Introduction

The Yellow River is the second largest river of China (shown in Fig. 1).The lower reach of the Yellow River had been dry every year from 1972 to 1998. It has caught

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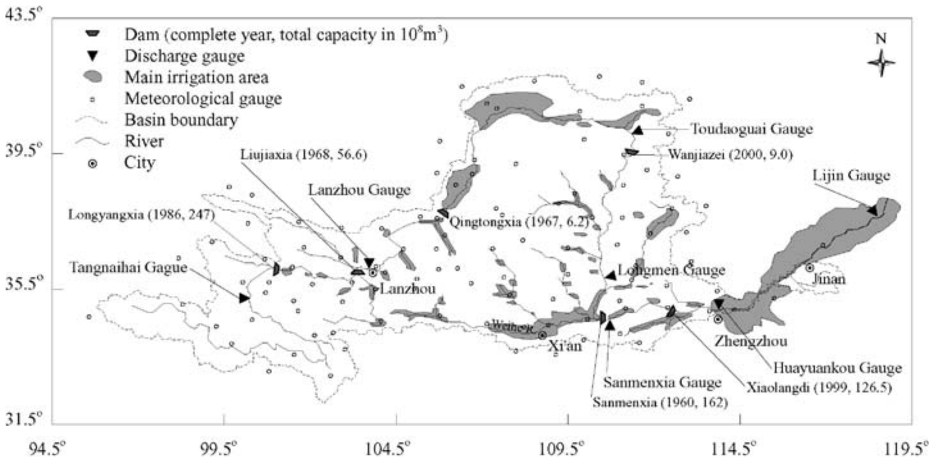

Fig. 1 The map of Yellow River Basin

wide attention in both China and the world. In December 1998, the Yellow River Conservancy Commission (YRCC) was authorized by the State Council of China to implement a plan of Unified Water Flow Regulation (UWFR) in the Yellow River Basin (YRB). The plan, which was first issued in 1987 as a water allocation agreement among the nine provinces specifies a water use permit for each province in the basin. To process the implementation, YRCC established the Bureau of Water Resources Management and Regulation in the beginning of 1999, which monitors water diversions and manage the operation of large reservoirs on the Yellow River.

In the next two years, UWFR was implemented in the other two river basins in north China – Hei River Basin and Tarim River Basin. As a result of water resources management reforms, the Flow Cutoff Events disappeared in these basins after unified regulation, which meant the increasing of ecologic water use. At the same time, together with the water-saving projects financed by the State Council, the efficiency of water utilization was also improved. Thus, UWFR reduced the conflicts between economic water use and ecology water use, which was one of the most important reasons of the Flow Cutoff Events. But how to evaluate economic impacts and ecological impacts quantificationally are still interesting problems, which are important for the managers to summarize the regulation experiences and improve regulation methods.

Many researches have been done to valuate the impacts of water use in different level. Classifying from the objects of researches, the researches mainly include the valuation of water for agricultural uses, valuation of water for nonagricultural uses, and valuation of comprehensive benefit of water use in rive basin level.

Valuation of water for agricultural uses includes crop production functions with water and mathematical programming models. Four broad approaches to production functions can be identified: evapotranspiration and transpiration models, simulation models, estimated models, and hybrid models that combine aspects of the first three types. The production function method proposed by Dinar and Letey (1996) is one of the representative research results, which issued a polynomial function to describe the relationship among crop yield, water application to potential evapotranspiration, salinity of the irrigation water, and irrigation uniformity. Based on describing the relation between water use and crop production, mathematical programming models for optimal water use can determine the farmer's joint choice of a cropping pattern, water application levels, and irrigation technologies, conditioned on input costs and output prices. One represent is the optimal model proposed by Mukherjee (1996).

Nonagricultural uses of water include domestic demand for household activities; demand for commercial, industrial, and mining uses, including hydropower, cooling, condensation, and factory and mining production; recreational demand; and demand for environmental purposes such as maintenance of in-stream river flows and flushing of pollutants. There are two general approaches that have been used in inferring the value of nonagricultural water uses: market-based valuation techniques, and nonmarket-based valuation techniques.

The market-based techniques include the direct estimation of water demand functions (when observable prices are available), the sales comparison method, the land-value differential approach, and the least-cost alternative approach. These approaches apply mainly in evaluating the demand of family and industrial water uses, whose most valuable research results can be referred to those from Dandy et al. (1997).

Nonmarket approaches include inferential valuation or revealed preference, which involves the imputation of implicit prices, in terms of expenditures incurred by individuals in using the resource; and stated preference or contingent valuation, which elicits direct responses of potential users to structured survey questions regarding the amount they are willing to pay for water services. Scholars like Lee and Moffitt (1993) and Whittington (1998) have conducted fruitful researches.

From the perspective of the whole river basins, the effect of the holistic utilization of water resources dose not equal simple adding of the partial ones. On the contrary, how to manifest complex responses of water using benefit in a specific macro economy system becomes the key in evaluating economic impacts of water resources.

Computational general equilibrium (CGE) model are one kind of general methods to evaluate the impacts of water use in basin level. Roe and Diao (2000) issued a general equilibrium model framework to analyses the scenarios in different Institutional and technological boundaries between two countries with shared water aquifers. The CGE model is very efficient for economic impacts analysis but not good at hydrology and water flow analysis.

Holistic models which include hydrologic components and economic components are suitable methods to evaluate the impacts of water use in basin level. Under the holistic approach, there is one single unit with both components tightly connected to a consistent model, and an integrated analytical framework is provided. There are many researches on holistic model. As a representative study, Ximing (2002) issued a hydrology-agriculture-economy coupling model at the basin level. It is used to analyze the long-term and short-term efficiency of using water in drainage area, and it brought forward new methods in the solutions of nonlinear problems. It has also been applied in Syr Darya drainage area for analyzing the scenes of the sustainable development in the river basin. Jianshi et al. (2004) issued a model framework, regarding water resources as an important restraint factor of economic activities. The model included the equations of economic development itself and the equations of hydrologic recycle. For valuation of comprehensive benefit of water use in river basin level, this method is comparatively complete.

Based on the data of UWFR practice in Yellow River during 1999 to 2004, a "with-without" scenario analysis method is used in the paper to evaluate the economic and hydrologic impacts of regulation, and a holistic model framework coupling economic water use and hydrologic cycle is issued to analysis the different scenarios. Thus, the economic impacts can be evaluated quantificationally, including impacts on economic sectors, hydropower, water quantity transferring to the Hai River Basin and the flow process in the river course.

2 Assessment Model

To evaluate the economic impacts of UWFR in YRB, a model framework is issued in the paper. The model framework presented is used for evaluation of institutional and technological changes in river basin management,but not for decision analysis.

The core of the model framework lies in the holistic coupling of a dynamic input-output balance and the water balance among different water-use units. The basic components of the model are the module of input-output analysis, the module of water demands analysis, the module of water regulation, and the module of the water use evaluation. All these components are coupled in the model framework with dynamic connections, through which the economic and hydrologic components can be solved in an interactive way. The structure of the model framework is showed in Fig. 2.

Figure 3 shows the relationship of unit water utilization and water balance in the model framework.

With a time period of one month, unit water balance equation can be written as:

- ♦ Reservoirs

$$VE(M+1, N) = VE(M, N) + I(M, N) - O(M, N) - SP(M, N) - LK(M, N) \quad (1)$$

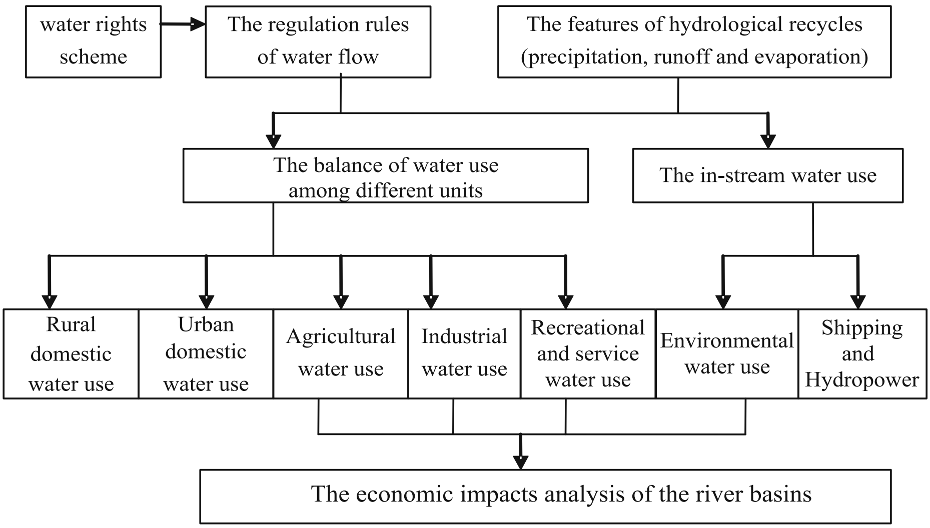

Fig. 2 Evaluation model framework of economic impacts of river Basins

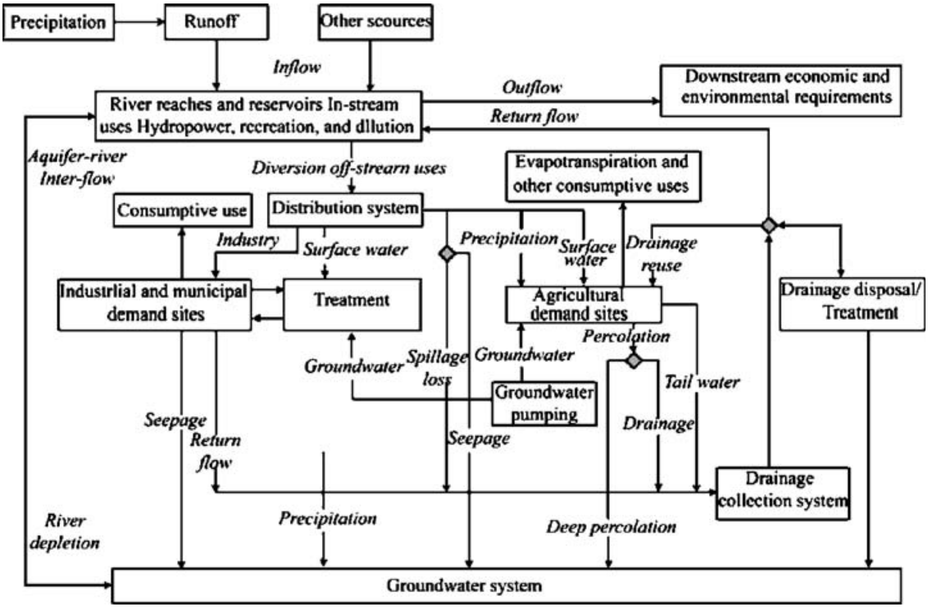

Fig. 3 Relationship between unit water balance and water utilization in the model framework (McKinney et al. 1999)

Where VE(M, N) is the water storage of the reservoir node N in the month M, I(M, N) is the inflow of the reservoir, O(M, N) is the outflow of the reservoir, SP(M, N) is the water supply of the reservoir, and LK(M, N) is the leakage of the reservoir.

- Groundwater aquifers

$$\begin{aligned} GVE(M+1,N) = {} & GVE(M, N) + GSA(M, N) + GSP(M, N) \\ & + GSR(M, N) - EG(M, N) - GSP(M, N) \end{aligned} \quad (2)$$

where GVE(M, N) is the water storage of the Groundwater aquifers node N in the month M, GSA(M, N),GSP(M, N), GSR(M, N) are the replenishment of the irrigation, replenishment of the rainfall and the replenishment of the river, EG(M, N) is the evaporation of the groundwater, and GSP(M, N) is the amount of groundwater for exploitation.

- Diversion nodes

$$O(M, N) = I(M, N) + R(M, N) - SP(M, N) \quad (3)$$

Where O(M, N) is the outflow of the node, I(M, N) is the inflow of the node, R(M, N) is the return flow of the node, and SP(M, N) is the diversion flow of the node.

- Conflux nodes

$$O(M, N) = \sum_J I(M, N, J) \quad (4)$$

Where O(M, N) is the output flow of the node, and I(M, N, J) is the input flow of the node.

The relationship of unit water resource utilization includes descriptions water uses of rural and urban human living, agriculture, industries and service industries, adopting respectively the method of ration to calculate the individual relationship between its water consuming and production. The out-put of planting industry of agriculture, for example, needs to be calculated in accordance with crop types, hydro-production function, the process of water consuming and the sown area. The overall relation of resource utilization of the unit satisfies the following relations:

$$\begin{aligned} \mathrm{WT(M,N)} = {} & \mathrm{WVP(M,N)} + \mathrm{WCP(M,N)} + \mathrm{WAR(M,N)} \\ & + \mathrm{WIN(M,N)} + \mathrm{WSE(M,N)} \end{aligned} \tag{5}$$

$$\mathrm{WT(M,N)} \leq \mathrm{SP(M,N)} \cdot \mathrm{PS(M,N)} + \mathrm{GSP(M,N)} \cdot \mathrm{PG(M,N)} + \mathrm{WTR(M,N)} \tag{6}$$

Where WT is the total water consumption of the unit; WVP(M, N), WCP(M, N), WAR(M, N), WIN(M, N), WSE(M, N) are respectively the water consumption of rural human living, urban human living, agricultures, industries and service industries; PS(M, N) is the utilization factor of unit surface water resource; PG (M, N) is the utilization factor of unit underground water resource; WTR(M, N) is the volume of unit sewage recycles.

The analysis of the macro economy development in this paper is based on the model of the Dynamic Input-Output Model which is used to illustrate the inter-relationships among different national economic sectors by treating the total economy of a region as a whole. The core equation of the model can be written as follows:

$$\mathbf{A}\boldsymbol{X}(t) + \mathbf{B}[\boldsymbol{X}(t+1) - \boldsymbol{X}(t)] + \boldsymbol{V}(t) = \boldsymbol{X}(t) \tag{7}$$

Where **A** is the matrix of direct consumption; **B** is the matrix of capital; $\boldsymbol{X}$ is the total output vector; $\boldsymbol{V}$ is the net products vector.

3 Methods

To analyze the impacts of UWFR of YRB, a "with–without" scenario analysis method is a suitable tool, by which the differences between real scenario with regulation and a virtual scenario without regulation can be compared. Therefore, it is necessary to give a definition to "without UWFR" at first. In facts, the differences between the two scenarios reflect the Institutional and technological changes from non-unified to unified regulations. According to the objectives, water saving investment implemented, key tools, and the external impacts of the regulation, we defined the significant differences between with and without regulation in four aspects.

1. Objectives. The water resources allocation scheme of YRB issued by the State Council in 1987 is the target scheme for UWFR. At the same time, maintaining a basic in-stream water flow above 50 m^3/s is the other important object. The scheme issued by the State Council in the 1987 is shown in Table 1.

Table 1 Water Consumption Indexes issued by the State Council in the 1987 (unit, 10^8 m^3)

Province	Qinghai	Sichuan	Gansu	Ningxia	Inner-Mongolia	Shaanxi	Shanxi	Henan	Shandong	Tianjin	Total
Water consumption	14.1	0.4	30.4	40.0	58.6	38.0	43.1	55.4	70.0	20.0	370.0

Shaanxi and Shanxi are different provinces in China with the same pronunciation

So, the first connotation of the “without UWFR” is that every province would be free from the index control of water consumption of Yellow River issued by the State Council and the basic in-stream flow would not be considered anymore. In another word, units of the upstream would use water at first, and downstream units could use only the rest water resources. Such a hypothesis will be one of the boundary conditions of “without UWFR” scenario.

2. Water saving investment. Together with the regulation, about 10 billion Yuan was invested by the State Council of China for water saving in YRB. So, the efficiency of water use is remarkably raised. The water use efficiency of YRB, measured by GDP output of unit water, increased form 20.81 Yuan/m^3 to 33.49 Yuan/m^3 form 1999 to 2004. It means that the water use efficiency increased 10% every year. Comparing with 4.25%, the water use efficiency increasing ratio from 1980 to 1997, it was a big difference.

According to the above analysis, the second connotation of the “without UWFR” is that the water use efficiency of YRB would keep its previous changing tendency. That is to say, the water use efficiency from 1999 to 2004 would keep the increasing ratio of 4.25% every year if without UWFR.

3. Key regulation tools. Changing the regulation rules of key Reservoirs is a chief tool to realize the water resources regulation of Yellow River. With UWFR, the regulation rules of key reservoirs will guarantee the water use of every provinces and the basic in-stream flow of Yellow River at first. In certain degree, such changes influence the hydropower of these reservoirs.

So, the third connotation of the “without UWFR” is that instead of aiming at guaranteeing the water use of every provinces and the basic in-stream flow of Yellow River, the key reservoirs would focus on optimizing hydropower production while giving dual attention to water supplies just as usual.

4. External impacts. From 1999 to 2004 since the implementation of UWFR, the Yellow River has provide Tianjin Municipality out-transferring water about totaling 3.656 billion m^3 which has strongly backup the development of local economies. Without regulation, this kind of water transferring had never been safeguarded.

So, the fourth connotation of the “without UWFR” is that water transferring to Tianjin Municipality would not be guaranteed to supply.

In summary, we can identify the connotations of “without UWFR” from these four significant impacts. The boundary of “without UWFR” scenario can be defined as the one with following features: the upstream units would use water first; water use efficiency would keep the previous changing tendency; reservoirs would optimize hydropower production while giving dual attention to water supply; and water transferring to Tianjin Municipality would not be guaranteed.

Based on the analysis above, the assessment model framework is applied in YRB for evaluation of the economic impacts of UWFR.

The temporal scale of the economic evaluation model of UWFR in YRB is from January 1997 to December 2004. The minimum calculation interval is one month. The period from 1997 to 1998 during which UWFR of YRB has not been implemented, is used to validating the model framework. The period from 1999 to 2004, which comes after the regulation implementation, is the main focus period to analyses.

The spatial scale setting of the model is the water supplying areas of the Yellow River. They include the whole of the Yellow River Basin, parts of the He Nan Province and Shan Dong Provinces, which divert water from Yellow River, and the other water-diversion districts of Tianjin Municipality. According to superposition between grade III sub-basins and provinces, the basic units of the model are divided into all together 56 units. The spatial structure of units of river basin is shown in Fig. 4.

The input data of the model is mainly form national comprehensive planning of water resources, water resources communiques of Yellow River, and the statistical yearbook of the related provinces. The input data includes the social and economic indexes of each unit, the population from 1997 to 2004, the development of three industries, and the irrigation area and grain production. A 40 sectors input-output matrix of each year is necessary input data for the Dynamic Input–Output Model, which is made from the input -output matrix of each province in 1997 using a RAS revising method.

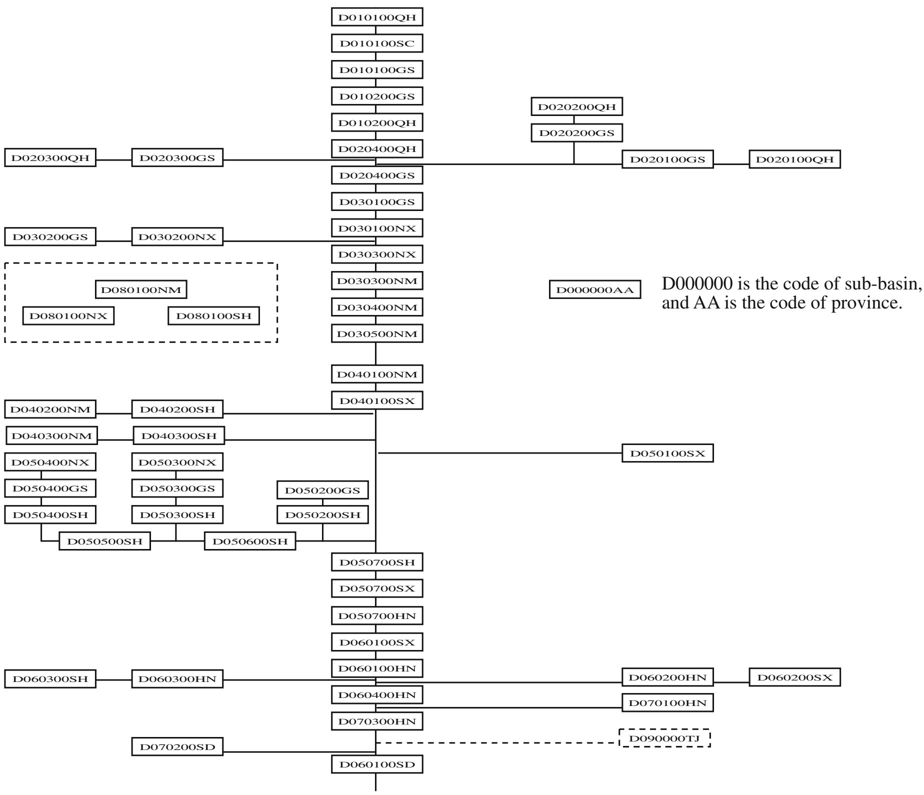

Fig. 4 The spatial structure of model framework

Table 2 GDP difference – scenario with UWFR minus scenario without UWFR (unit, 10^8 Yuan)

Year	Qinghai	Sichuan	Gansu	Ningxia	Inner Mongolia	Shaanxi	Shanxi	Henan	Shandong	Total
1999	−0.22	−0.02	−1.16	0.00	−0.57	5.43	−1.23	6.86	108.27	117.36
2000	−0.42	−0.02	−1.73	−0.43	−0.44	5.58	−4.03	2.46	269.90	270.87
2001	−0.65	−0.06	−2.59	−0.53	0.55	5.26	−4.50	19.67	476.66	493.81
2002	−0.90	−0.07	−3.92	−0.69	−3.50	1.37	−7.63	2.43	303.51	290.60
2003	−1.26	−0.09	−4.44	−1.03	−1.20	−1.83	−9.47	−1.99	228.75	207.44
2004	−1.24	−0.09	−4.87	−0.95	−2.82	−0.28	−9.78	0.26	309.26	289.49
Total	−4.69	−0.35	−18.71	−3.63	−7.98	15.53	−36.64	29.69	1,696.35	1,669.57
Average	−0.78	−0.06	−3.12	−0.61	−1.33	2.59	−6.11	4.95	282.73	278.26

4 Results

A "with–without" scenarios analysis method is used to evaluate the economic impacts of UWFR in yellow river. The data of real scenario with UWFR has been collected form the data source in the front parts of the paper. That is to say, the data of real scenario are not form model simulation but form investigation. Using the model issued in the paper, the scenario without UWFR can be simulated. By simulating the scenario without regulation and comparing with the scenario with regulation, economic impacts of UWFR are quantitatively calculated by the holistic model (shown in Table 2).

In addition, because of the implementation of UWFR, the emergency water transfer to Tianjin was strongly ensured, which had not been done for many years before 1998 due to the flow cutoff. The benefit of water is regarded as 7.123 Yuan/m^3, which was the efficiency of water use in non-agriculture sectors of Tianjin in year 2000. The volume of transferred water and its benefits are shown in Table 3.

The regulation rules of key reservoirs require that electricity production of hydropower should subject to water supply schemes during the dry seasons, which means the decrease of electricity production. The electricity production differences between "without UWFR" and "with UWFR" are shown in Table 4.

The comparisons of the main hydrologic gauging stations between the two scenarios were also done. Toudaoguai gauging station is the boundary mark of upper reaches and middle reaches of Yellow river. Huayuankou gauging station is the boundary mark of middle reaches and lower reaches, and Lijin gauging station is near the sea. Comparisons of the flow process for the three gauging stations are as shown in Figs. 5, 6, 7.

The precipitation values in the years from 1999 to 2004 are 398.40, 381.80, 404.00, 404.20, 555.60, and 421.80 mm. Comparing with 447.00 mm, the average value of

Table 3 Volume of transferred water to Tianjin Municipality and its estimated benefits since the implementation of UWFR

Year	1999	2000	2001	2002	2003	2004	Total
Volume of transferred water (10^8 m^3)	2.41	7.7	2.17	4.02	11.261	9.01	36.57
Estimated benefits from transferred water (10^8 Yuan)	17.14	54.83	15.42	28.64	80.21	64.19	260.43

Table 4 Hydropower generation difference of key reservoirs – scenario with UWFR minus scenario without UWFR (unit, 10^8 kW/h)

Reservoirs	1999	2000	2001	2002	2003	2004	Total
Longyang Gorge	−3.225	−6.959	−8.435	−10.364	−10.822	−6.731	−46.536
Liujia Gorge	−1.04	−1.586	−1.826	−1.476	−1.577	−0.974	−8.479
Wanjia Village	−1.168	−1.279	−0.559	−0.426	−0.018	−0.155	−3.605
Sanmen Gorge	−0.027	0	0	−0.023	0	0	−0.05
Xiao Langdi	−3.395	−8.408	−6.261	−2.938	−0.453	−1.139	−22.594
Total	−8.855	−18.232	−17.081	−15.227	−12.87	−8.999	−81.264

"–" means that UWFR reduced the hydropower generating

1956–2004 series, it was obviously that YRB was in a dry period except year 2003. The precipitation series of YRB from 1956 to 2004 are shown in Fig. 8.

As a general result, if UWFR had not been implemented, the Flow Cutoff Events would be more serious than usual. So comparison of monthly values between the non-impact and impact periods could further provide more insights into the impacts. The Lijin gauging station, which is the last gauging station of the downstream of YRB, is suitable for this comparison, because both the amount of water into the sea and the condition of flow cutoff can be implied by flow process of it. The monthly flow data of Lijin gauging station is shown in Table 5.

Obviously, the most important difference between the non-impact and impact periods was happened in June. Before 1999, the flow cutoff events often happed in June, because it is still in dry seasons and the economic water use was very huge in a disordered way. But since 1999, with UWFR, the flow cutoff events have never happened. The statistics of flow cutoff in every year from 1972 to 2004, which is shown in Fig. 9, also supported this conclusion.

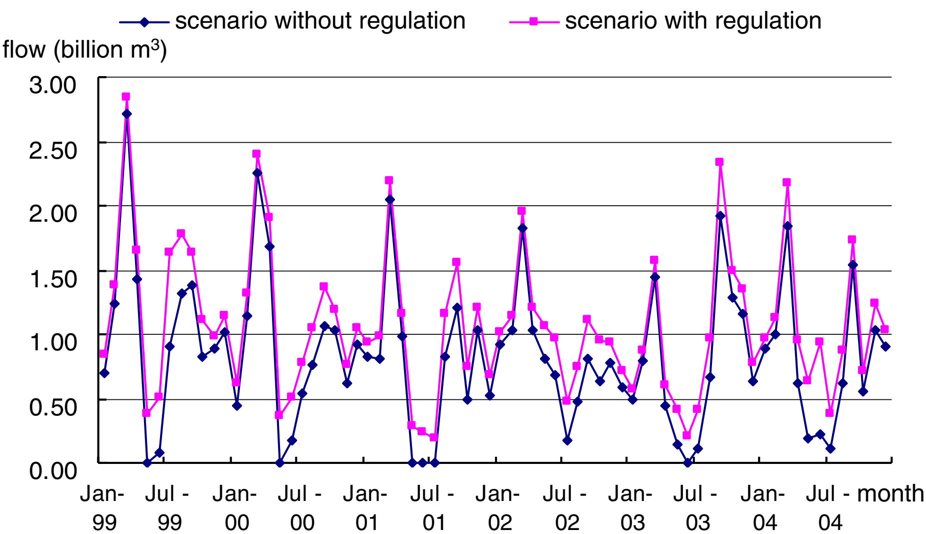

Fig. 5 Comparison of Toudaoguai station

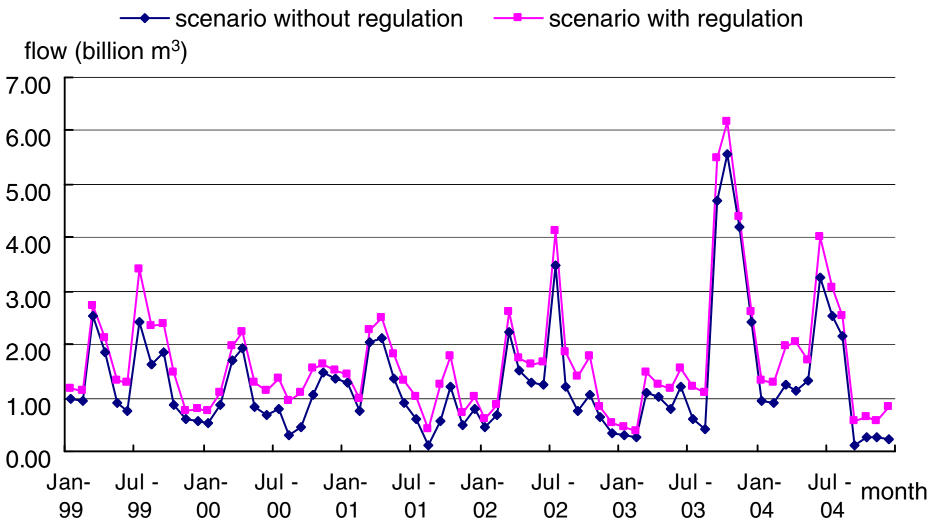

Fig. 6 Flow comparison of Huayuankou station

From all the analytic results mentioned above, we can get the following primary conclusions:

1. Under the comprehensive effects of setting boundaries, as shown the comparison analysis between scenarios comparison between "without UWFR" and "with UWFR" (which is the real scenario and the data comes form investigation), 166.96 billion RMB GDP loss was avoided because of the implementation of UWFR during 1999 to 2004.

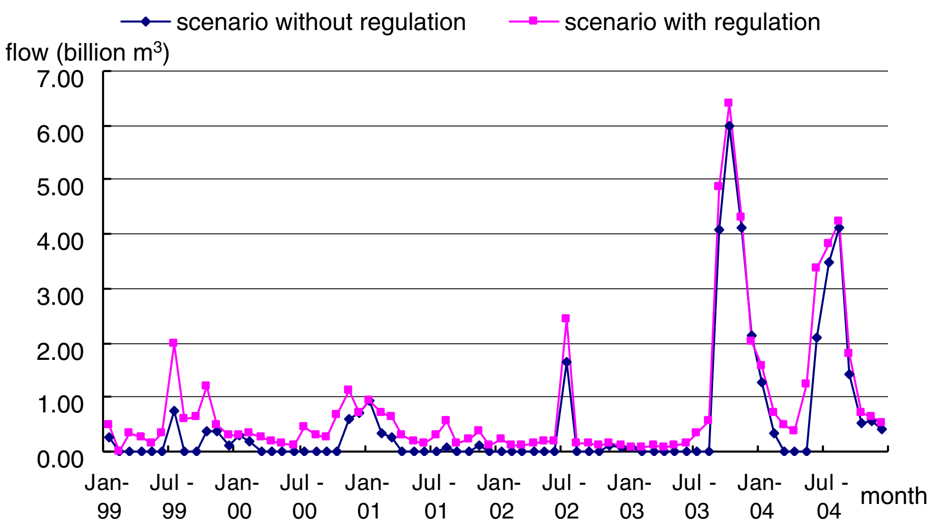

Fig. 7 Flow comparison of Lijin station

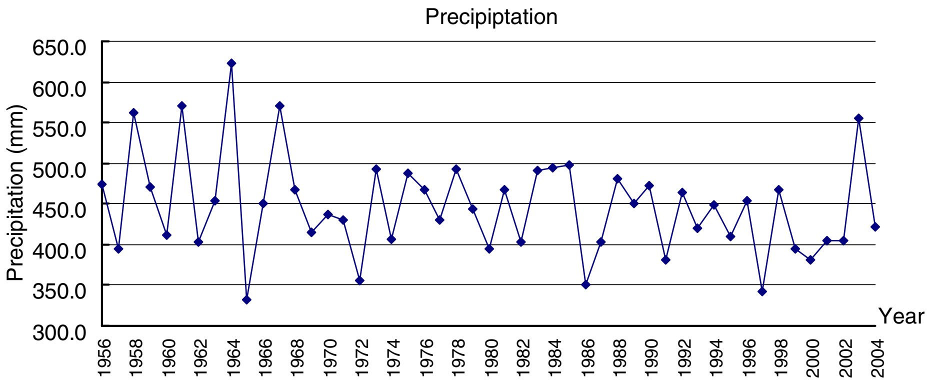

Fig. 8 The precipitation series of YRB from 1956 to 2004

2. During the 5 years implementation of UWFR, the transferred water volume from the Yellow River to Tianjin Municipality has amounted to 3.657 billion m^3, which was evaluated for about 26.04 billion RMB. Without UWFR, the water transfer could not be safeguarded.
3. According to the calculation and analysis, UWFR has some negative impacts on the electricity products of hydropower. A preliminary estimation shows that the total decrement of Hydropower during the five years is 8.126 billion kilowatts hours, equal to 3.576 billion RMB in electricity benefits. However, compared with the GDP increment of 166.96 billion RMB of the whole river basins, the negative impact is quite small.
4. Take all the evaluation results in to a comprehensive consideration, the GDP of the areas enjoying water supplies of the Yellow River would have decreased by 189.42 billion RMB (accounting for 2.5% of the total GDP of the same period) during the years from 1999 to 2004 if there were no UWFR.

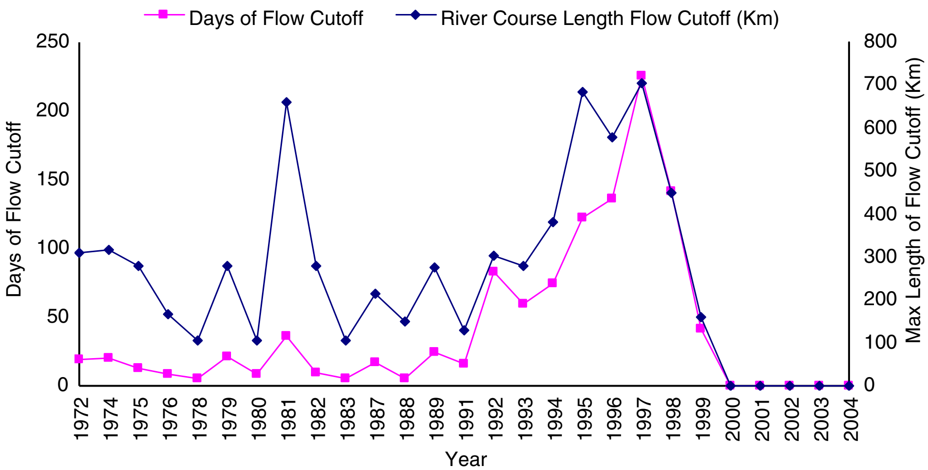

Fig. 9 Flow cutoffs days and max flow cutoff length in every year from 1972 to 2004

Table 5 Monthly flow comparison Lijin gauging station between the non-impact and impact periods

	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Set	Oct	Nov	Dec	Total
Non-impact period	1986	16.93	15.94	10.77	7.54	2.51	1.73	38.57	25.31	17.81	5.41	7.67	7.23	157.43
	1987	10.77	5.42	1.54	1.93	0.95	14.28	18.13	7.74	20.58	4.50	7.83	14.76	108.43
	1988	13.23	5.96	1.48	1.60	2.49	1.04	30.27	82.49	27.22	12.56	11.04	4.50	193.69
	1989	15.32	8.88	12.43	2.55	12.24	7.08	23.03	37.77	54.17	29.46	21.70	17.20	241.82
	1990	12.86	14.20	21.32	13.50	21.32	19.80	37.23	41.52	36.29	15.32	15.86	15.13	264.35
	1991	12.43	13.11	8.73	9.62	5.49	28.77	5.41	17.01	13.32	3.29	2.51	2.84	122.50
	1992	4.96	1.54	1.05	1.78	0.49	0.00	0.87	36.96	33.96	22.87	17.34	11.92	133.70
	1993	9.62	5.23	2.61	5.03	5.22	0.40	23.09	53.84	30.33	14.84	17.52	17.03	185.00
	1994	14.65	12.63	16.04	10.34	7.39	0.00	35.35	50.35	26.96	5.36	15.76	22.15	217.00
	1995	12.35	5.64	0.05	1.50	0.06	0.00	8.62	36.69	40.69	13.45	11.20	6.48	136.70
	1996	3.67	0.41	0.04	0.34	0.24	0.00	13.07	68.57	34.47	12.32	17.44	4.63	155.20
	1997	3.43	0.19	1.91	6.64	2.18	0.00	0.00	2.08	0.24	0.12	0.52	1.30	18.61
	1998	0.53	0.09	0.77	2.15	0.42	10.86	23.28	40.98	17.13	1.76	3.34	4.85	106.10
Impact period	1999	5.06	0.05	3.40	2.67	1.53	3.27	20.14	5.97	6.43	12.08	4.64	3.11	68.34
	2000	3.08	3.26	2.55	1.75	1.40	0.97	4.74	3.05	2.67	6.75	11.02	7.34	48.59
	2001	9.35	6.17	6.51	2.83	1.97	1.36	3.43	5.57	1.68	2.38	3.73	1.55	46.53
	2002	2.39	1.14	1.17	1.52	1.74	1.88	25.07	1.72	1.40	1.30	1.39	1.17	41.90
	2003	0.84	0.77	1.02	0.80	0.98	1.53	3.37	5.60	48.47	65.89	41.73	21.67	192.68
	15.91	6.65	4.96	3.86	12.64	33.36	39.05	43.26	17.88	7.31	6.30	5.52	15.91	196.70

5. According to the flow process comparisons of three hydrologic gauging stations and the comparison of monthly values between the non-impact and impact periods, it is obviously that UWFR has improved the water flow process especially during the dry seasons. The most important indicator was that the Flow Cutoff Events were avoided.

5 Conclusions

As a result of water resources management reforming, the practice of YRB has great value for the river basins with conflicts between economic water use and hydrologic water use. But how to evaluate the impacts of UWFR of the river basins is a challenging scientific problem. To address this issue, a model framework is presented in this paper, which couples the complex relationship between macro economic systems and water resources system. Using a "with-without" scenario analysis method, the evaluation of economic and hydrologic impacts of UWFR in the YRB is done in accordance with the practices in that area. The results show that UWFR improved both the efficiency of water use in society and the water supply for ecosystem. And also the results have gained approbation from Bureau of water resources management and regulation of Yellow River Conservancy Commission.

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