SCHEDULING WATER USE IN THE LOWER YELLOW RIVER TO MEET ECOLOGICAL REQUIREMENTS

Prepared by Tsinghua University

Australia-China Environment Development Partnership

River Health and Environmental Flow in China

Project Code: P0018

February 2011

Acknowledgements

This report is the result of work undertaken as part of the River Health and Environmental Flow in China Project. The project forms part of the Australia-China Environment Development Partnership, a collaboration between the Australian and Chinese Governments, which is funded by the Australian Agency for International Development (AusAID).

International WaterCentre Pty Ltd

PO Box 10907, Adelaide St

Brisbane, Qld, 4000

Tel: +61 7 31237766

Email: info@watercentre.org

www.watercentre.org

Australian Government
AusAID

YELLOW RIVER

清華大學
Tsinghua University

INTERNATIONAL WATERCENTRE

Preface

The Yellow River, the second longest river in China, is one of important birthplaces of Chinese civilization. Since the founding of New China, remarkable achievements have been made in the development and management of the Yellow River, which have almost eliminated the long-term threat of the Yellow River flooding, eased drought and water shortages in the basin, and solved the difficulties of drinking water of nearly 300 million people in the rural area. There's no doubt that these efforts have greatly promoted the economic and social development along the banks of the Yellow River and in the surrounding areas.

Though great achievements have been made, we have to face the fact that the development and operation of water conservancy projects have changed the natural hydrological regime and affected related a range of environmental factors. Since the 1990s, as the ecological problems in the basin have become more and more serious, it has been necessary to review our approaches to dealing with the Yellow River, as we have realized that the protection of river ecology must be enhanced such that our river management practices ensure that exploitation of the river is sustainable. To achieve the harmonious coexistence of humans and the Yellow River, water conservancy projects should be operated in a way that emphasises ecological considerations, with a view to improving and sustaining the health of the river.

This report describes an assessment of the water requirements of different users within the basin, and looks to reconcile the needs of those users with ecological water requirements. This study takes account of water management issues related to flood-control, water supply, ice-prevention, and ecological environment protection. It focuses on the major control structures on the Yellow River mainstream and analyses the relationship between river ecological water use and social economic water use. Finally, this report proposes a plan for scheduling water releases to meet the ecological needs of the downstream of the Yellow River. This plan is designed to provide a reference and basis for making reasonable, rational decisions about the allocation of water resources and ecological protection in the Yellow River Basin.

The ecological issues in the lower reach of Yellow River are very complex, and further research about the specific effects of water conservancy projects in the upper and midstream on downstream ecosystems is required. Limited by level and time, this research still has many shortcomings, and any comments from the reader to enable us to further improve this work through future research would be most welcome.

This research has been funded by the Australia-China Environment Development Partnership as part of the River Health and Environmental Flow in China Project. Many relevant departments have given great assistances to us in the process and we would like to express our sincere thanks to them.

Contents

1 Overview

1.1 Background

This report forms an important component of the pilot study of Yellow River, part of the River Health and Environment Flow in China Project, under the Australia-China Environment Development Partnership (ACEDP). The environmental flows pilot study in the Yellow River has two main components: (i) to assess the environment flow requirements in key sections of the river and (ii) to assess water use scheduling options to achieve those requirements in the lower reach of Yellow River. The pilot study aims at identifying an integrated water allocation and scheduling system, with consideration of flood-control, water supply, ice-prevention, and ecological environment protection, with the requirement of maintaining the health of the lower reach of Yellow River, offering the reference and basis for the water resources optimal allocation regulation by seeking rational water allocation schedule and analyzing the relationship between the instream ecological water needs and consumptive socio-economic water use.

1.2 Study scope

The project study scope is the lower reach of the Yellow River, i.e. the mainstream from Huayuankou to the estuary. Given that the health of the lower reach of the Yellow River is impacted by discharge and water use of the upstream, the modeling has been extended to the entire basin. Moreover, establishing an ecological water use scheduling model needs consideration of the water use requirements from the upstream to downstream, and across different departments, sectors, and functions.

The study scope: the research takes the Tangnaihai on the upstream as the upper boundary and the Lijin as the lower boundary, including the mainstream of the river, most tributary areas and reaches and mainstream large reservoirs.

The reference years: the base year is 2005; the short-term planning year is 2020 and the long-term planning year is 2030.

The Yellow River Basin is shown as Fig. 1-1.

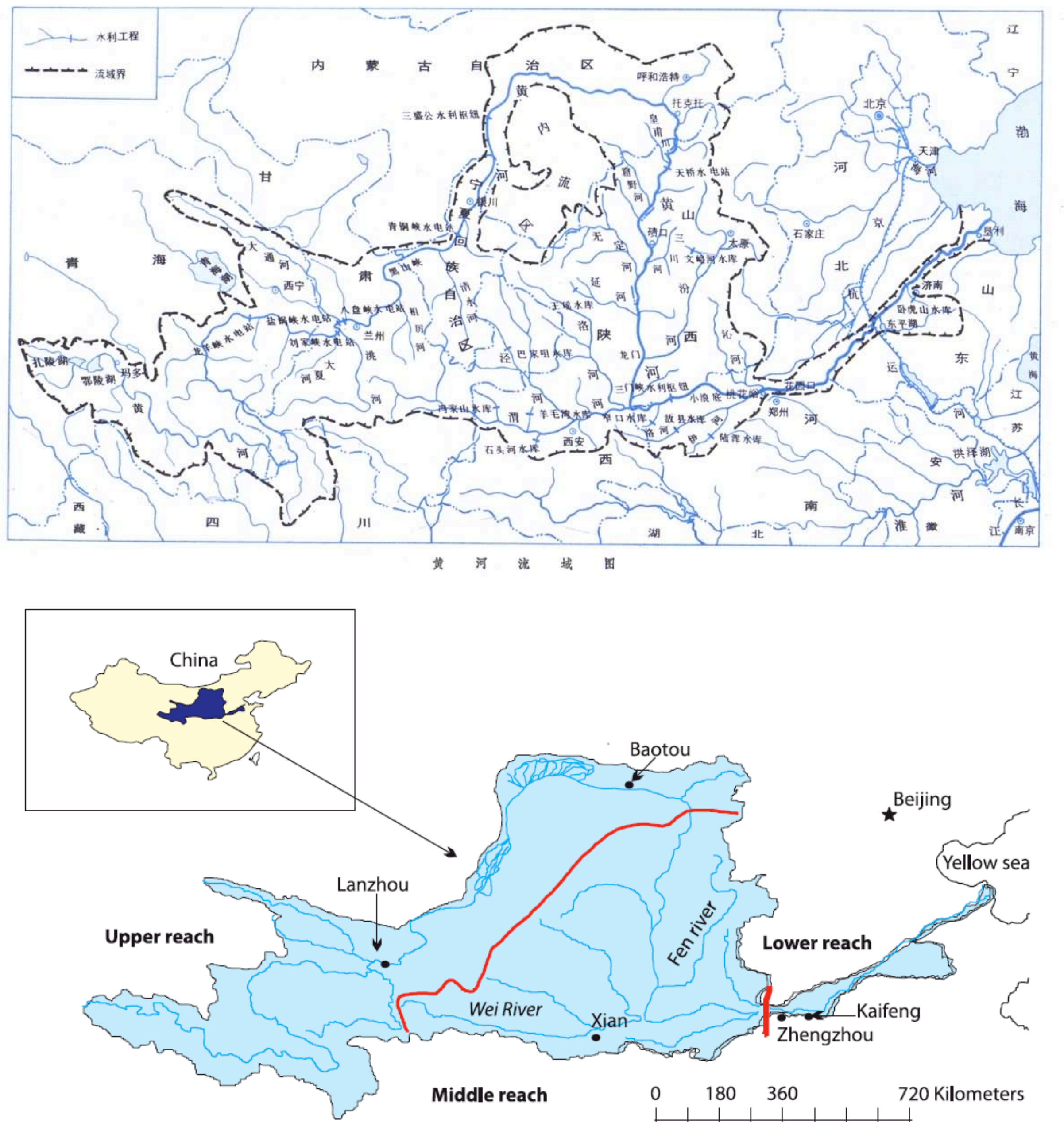

Fig. 1-1 The Yellow River Basin

1.3 Research methodology

The project work involved the following key steps:

（1）**Data collection and investigation.** Collect the water resources development and utilization data, hydrological data, reservoir parameters, scheduling rules, ecological water demand, water supply region etc.

（2）**Macro-economic water resources analysis.** On the basis of the exact ecological water demand, the Yellow River macro-economic water resources allocation analysis model was built. Thereby the domestic, economic and external ecological water demand of the Yellow River in different developments and reference years was calculated, compared to that identified in the water resources master plan.

（3）**Build a water allocation model**. A water allocation model for the lower reach of the Yellow River was built that was able to determine the optimal ecological water use. By the water resources systematic analysis theory and method, the Yellow River basin is generalized and a water resources model developed, including the main reservoirs, river reaches and most water use region. The GAMS optimal technique and multi-target optimal methods were introduced and used.

（4）**Strategic analysis of the results**. By analyzing the optimal ecological water use scheduling plan under different water demand and water infrastructure specifications, studying the impacts of the ecological water scheduling from water conservancy arrangement, the project has identified a recommended ecological water use scheduling plan, which balances the different competing interests in the basin.

The research methodology is shown as Fig. 1-2

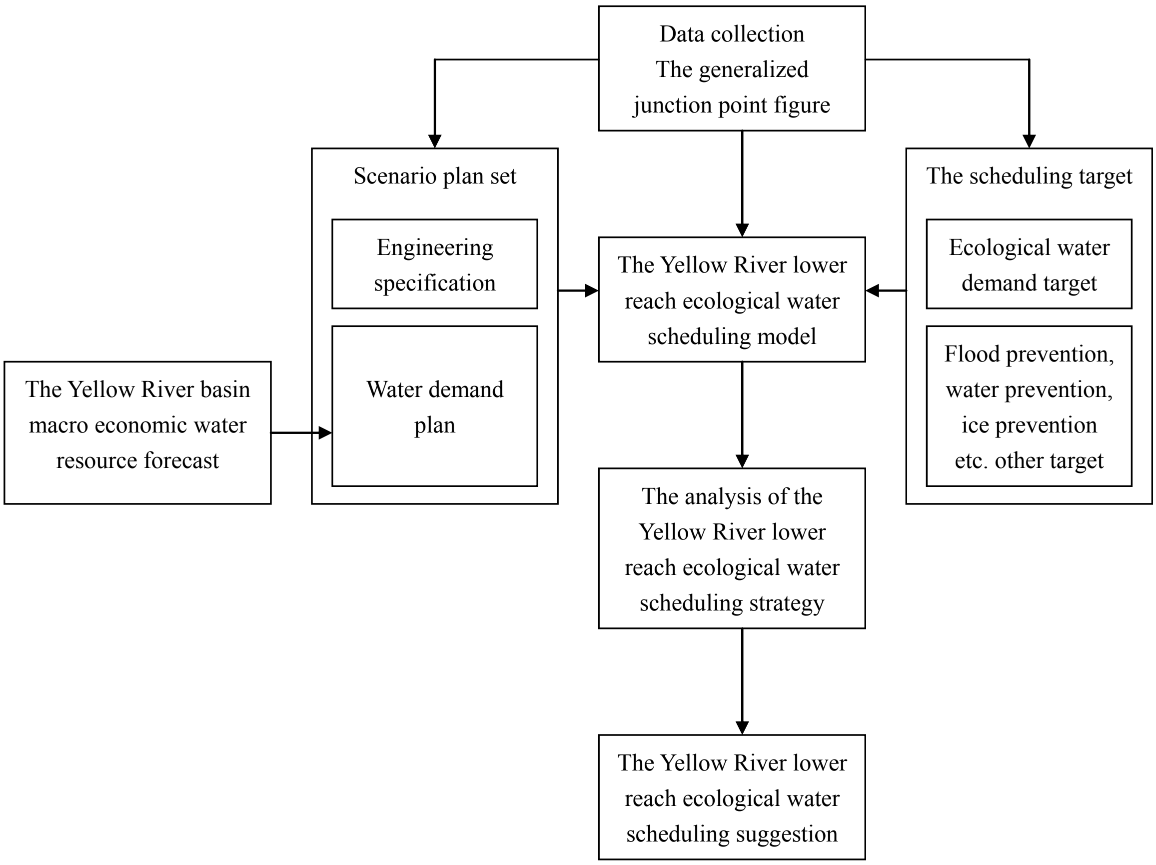

Fig. 1-2 The research methodology

2 Macro-economic water resources model

Given the multi-objective characteristic of water resources, ecological water use can't be considered as an independent issue, to the exclusion of other water uses. Rather, for the purposes of water allocation, ecological water scheduling should be based on the integrated water resources utilization. A water resources scheduling plan should then adopt an integrated approach to considering domestic water demands, industrial water demands and ecological water demands in establishing a recommended ecological water use scheduling plan.

The Yellow River macro water resources rational allocation model is a tool to synthetically analyze the basin domestic water use, industrial water use and ecological water use. With this model, the water resources entitles, which are related to the economic production, domestic living and the ecology environment system, will be integrated and coupled. By macro-analysis on the water quality and quantity, the rational allocation plan for ecological and economic water use system is presented to provide the basic data of water demand outside river channel for ecological water scheduling and analyze the economy of different water scheduling plans.

2.1 Macro-economic water resources principle

Water resources system is a complex large system including society, economy, environment, ecology and water resources, with impacts from both the natural factors and society, economy, culture, tradition and so on. The water resources scheduling must stand on the water life time limitation and renewability to do the synthesized dynamic balance research with the systematic engineering method, among which, the relationship between the economy and water resources is the key problem in the system. Precisely and effectively analyzing the relationship between them is critical for the water resources allocation.

There is a series of intrinsic, mutual interdependent and interactional relationship between the macro economy system and water resources system. The development speed of the macro economy will affect the water demand increasing speed. The economy structure change and urbanization process will affect the proportion between city industrial water use and irrigation water use. The emitted pollutants during the economy development process might pollute the water resources and reduce the effective water resources. The investment amount of enlarging water supply ability and increasing waste water recycling fee in the economy accumulation will affect other economy departments' investment proportion and the structure of the water resources development, utilization and protection. Therefore, in order to study the water resources allocation, the regional macro economy system should be researched first.

The economy development forecasting model is an important way for analyzing the region economy development to study the regional structure, spatial transference, technique diffusion, regional trade, location selection, ownership market effect etc. in the region economy. There is fast development in our country's macro-economic water resources analysis research during last decade. The basic theory is: the macro economy development speed will affect the water demand increasing speed; the economy structure change and urbanization process will affect the proportion between city industrial water use and the agricultural water use; the pollutants during the economy development process will reduce the effective water resources; the economy accumulation will contribute to different economy departments' development, utilization and protection including water resources. So the main method will be on the regional economy input-output analysis under the constraints of water and soil resources.

2.2 Macro-economic input-output model

The input-output analysis is put forward by American famous economist W Leontief to study the macro economy structure and macro economy activity after referring to the planned economy idea and balance method.

The input-output model will be divided into static model and dynamic model according to whether the analyzing process includes time change factor. The core principle of the static input-output model is that the region will produce certain products under certain input and the industries within the region will get to balance at some degree.

To investigate a $n \times n$ departments' regional economy activities, such as Tab. 2-1:

Tab. 2-1 Input-output balance table

		Intermediate product				End product				Total products
		Dept.1	Dept.2	…	Dept.n	consume	accumulation	Net output	Sub-total	
Consumed materials	Department 1	X_{11}	X_{12}	…	X_{1n}				Y_1	X_1
	Department 2	X_{21}	X_{22}	…	X_{2n}				Y_2	X_2
	⋮	⋮	⋮	…	⋮				⋮	⋮
	Department n	X_{n1}	X_{n2}	…	X_{nn}				Y_n	X_n
	Depreciation of fixed assets	D_1	D_2	…	D_n					
New value	Remuneration	S_1	S_2	…	S_n					
	Net income	M_1	M2	…	M_n					
Total		X_1	X_2	…	X_n					

For the horizontal row, all the intermediate products and the end products are the total products. The vertical columns are constitutes of different departments. They are:

$$\sum_{j=1}^{n} X_{ij} + Y_i = X_i \qquad (i = 1,2,\cdots,n) \tag{2-1}$$

$$\sum_{i=1}^{n} X_{ij} + D_j + V_j + M_j = X_j \qquad (j = 1,2,\cdots,n) \tag{2-2}$$

Let: $a_{ij} = X_{ij} / X_j \quad (X_i \neq 0, i, j = 1,2,\cdots,n)$ be the direct consumption coefficient, representing the product amount in No. i department which is needed by No. j department to produce a unit product. (2-1)(2-2) has the vector format:

$$\mathbf{AX} + \mathbf{Y} = \mathbf{X} \tag{2-3}$$

$$\hat{\mathbf{C}}\mathbf{X} + \mathbf{D} + \mathbf{V} + \mathbf{M} = \mathbf{X} \tag{2-4}$$

Wherein: $$\hat{\mathbf{C}} = \operatorname{diag}\left\{\sum_{i=1}^{n} a_{i1}, \sum_{i=1}^{n} a_{i2}, \cdots, \sum_{i=1}^{n} a_{in},\right\}$$

Rewrite formula (2-3) to get $\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y}$. The formula $(\mathbf{I} - \mathbf{A})^{-1}$ is called Leonief inverse matrix. Because X and Y are independent with the time, the model is static. It's called static input-output model or Leonief Model.

Besides introducing the direct consumption coefficient a_{ij}, the dynamic input-output theory also introduces the capital coefficient b_{ij} to reflect the capital structure in the whole economy. When it's applied to the research for several years' reproduction process, all the variables in the model will be the function of time. Y_i represents No. i department's product which is used as the final product. Because the investment product is related to the extended reproduction, Y_i can be divided into two parts: the investment product F_i and the final net product V_I. F_i is the production fund, including the basic construction investment, circulating fund etc., which is divided by different departments:

$$F_i = \sum_{j=1}^{n} F_{ij} \quad (i = 1,2,\cdots,n) \tag{2-5}$$

F_{ij} represents the No. i product amount which is used as the production fund by No. j department. The investment coefficient is introduced as:

$$b_{ij} = \frac{F_{ij}}{x_j} \qquad (i,j=1,2,\cdots,n) \tag{2-6}$$

represents the production fund (fixed assets and circulating fund) amount of No. i department's product which is needed by No.j department to produce the unit product. Assume that it takes 1 year to form producing capacity from investment, then:

$$F_{ij}(t) = b_{ij}(x_j(t+1) - x_j(t) \qquad (i,j=1,2,\cdots,n) \tag{2-7}$$

Introduce $Y_i = F_i + V_i$ and formula (5-6) into formula (5-3) and express it with vector format:

$$\mathbf{AX}(t) + \mathbf{B}[\mathbf{X}(t+1) - \mathbf{X}(t)] + \mathbf{V}(t) = \mathbf{X}(t) \tag{2-8}$$

Wherein $\mathbf{B}$ is capital coefficient matrix, and the formula (2-8) can also be rewritten as:

$$\mathbf{BX}(t+1) = (\mathbf{I} - \mathbf{A} + \mathbf{B})\mathbf{X}(t) - \mathbf{V}(t) \tag{2-9}$$

This is the dynamic input-output model which is firstly invented by von Neumann, so it's also called von Neumann –Leontief input-output model.

The input-output model takes the whole economy in a region as a unitary system for consideration to show the correlative dependence among different departments in the national economy. In the static model, the investment is regarded as the exogenous variables to be included into the final demand with the name of accumulation. The dynamic model synchronously computes the investment and production to examine the relationship between the production accumulation and the extended reproduction on the time series. In the practical economic activities, the investment may come from the inside accumulation, or the outside investment, or the both, which depends on the concrete issues.

The input-output model can reflect many contents of the national economic activities, such as the allocation and utilization of the aggregated social product, the value composition of the aggregated social product, the gross and source of national income, allocation and utilization of the lab resources, gross and allocation of the productive fixed assets, the economic growth and so on. To evaluate the economic gross development and corresponding structure characteristic, the gross domestic product (GDP) is generally adopted, whose value equals to the sum of the added value of all the department, including discount, wage, profit and tax. It can be expressed as:

$$\text{GDP} = \sum_{j=1}^{n} Q_j \cdot U_j = \sum_{i=1}^{m} Q_i^{'} \cdot P_i = \sum_{k=1}^{l} \alpha_k \cdot X_k \tag{2-10}$$

In the formula, *l, m, n* are industry sector numbers, end products and all the product numbers; *X, Q', Q* represent department total output value, end products and total product amount; *α, P, U* are the proportion of the industry sector added value to the gross product, then the end product price and the proportion of the product added value.

The input-output model is commonly written as the mathematical programming format for optimization.

2.3 Macro-economic water resources model

Besides the constraint of economic department's input-output balance, there are some other geographical factors and resources constraints for the sustainable development of the region which is limited by the water resources. With the openness of the mathematic programming model, the water resources restraint condition can be written into the macro economy input-output model to form the macro economic water resources analysis model, which can well describe the interaction between the social economy and the water resources system and answer the question of how the water resources supports the regional economy development. The structure of the macro economic water resources model is as the following:

（1）macro economy module

The macro economy module includes the relationship among the different parts in the macro economy input and output. Using 5 equation sets. (a) the integral balance structure, (b) society accumulation and consume, (c) restriction of the input and output, (d) the output of different industries and GDP, (e) fixed assets and circulating fund etc. for description, such as the following:

$$\begin{aligned}(\mathrm{I-A})\cdot \mathrm{X}(t,\mathrm{d},\mathrm{s}) = {} & \mathrm{B}_{\mathrm{Home}}(t,s)\cdot \mathrm{X}_{\mathrm{Home}}(t,d) + \mathrm{B}_{\mathrm{Social}}(t,s)\cdot \mathrm{X}_{\mathrm{Social}}(t,d) + \mathrm{B}_{\mathrm{Fixinvest}}(t,s) \\ & \cdot \mathrm{X}_{\mathrm{Fixinvest}}(t,d) + \mathrm{B}_{\mathrm{StockC}}(t,s)\cdot \mathrm{X}_{\mathrm{Stock}}(t,d) + \mathrm{X}_{\mathrm{Export}}(t,d,s) - \mathrm{X}_{\mathrm{Import}}(t,d,s)\end{aligned} \tag{2-1a-1}$$

$$\mathrm{P}_{\mathrm{Investup}}(t)\cdot \mathrm{X}_{\mathrm{GDP}}(t,d) \geq \mathrm{X}_{\mathrm{Fixinvest}}(t,d) + \mathrm{X}_{\mathrm{Stock}}(t,d) \geq \mathrm{P}_{\mathrm{Investlo}}(t)\cdot \mathrm{X}_{\mathrm{GDP}}(t,d) \tag{2-1b-1}$$

$$\mathrm{X}_{\mathrm{Home}}(t,d) = \mathrm{P}_{\mathrm{Home}}(t)\cdot \mathrm{X}_{\mathrm{GDP}}(t,d) \tag{2-1b-2}$$

$$\mathrm{X}_{\mathrm{Social}}(t,d) = \mathrm{P}_{\mathrm{Social}}(t)\cdot \mathrm{X}_{\mathrm{GDP}}(t,d) \tag{2-1b-3}$$

$$\mathrm{P}_{\mathrm{Importup}}(t,s)\cdot \mathrm{X}(t,d,s) \geq \mathrm{X}_{\mathrm{Import}}(t,d,s) \geq \mathrm{P}_{\mathrm{Importlo}}(t,s)\cdot \mathrm{X}(t,d,s) \tag{2-1c-1}$$

$$\mathrm{P}_{\mathrm{Exportup}}(t,s)\cdot \mathrm{X}(t,d,s) \geq \mathrm{X}_{\mathrm{Export}}(t,d,s) \geq \mathrm{P}_{\mathrm{Exportlo}}(t,s)\cdot \mathrm{X}(t,d,s) \tag{2-1c-2}$$

$$P_{Delta}(t,d)\cdot X(t,d)\geq\sum_{s} X_{Export}(t,d,s)-\sum_{s} X_{Import}(t,d,s)\geq -P_{Delta}(t,d)\cdot X(t,d) \quad (2\text{-}1c\text{-}3)$$

$$X(t,d,s)\leq P_{Cita}(t,s)\cdot X_{Sfixasset}(t,d,s) \quad (2\text{-}1d\text{-}1)$$

$$X_{GDP}(t,d,s)=\sum_{s} P_{GDP}(t,d,s)\cdot X(t,d,s) \quad (2\text{-}1d\text{-}2)$$

$$X_{Stock}(t,d)=P_{Stock}(t)\cdot X_{Fixinvest}(t,d) \quad (2\text{-}1e\text{-}1)$$

$$X_{Deltafix}(t,d,s)=P_{Finalfixed}(t,s)\cdot(P_{Alpha0}(t,s)\cdot X_{SFixinvest}(t,d,s) +P_{Alpha1}(t,s)\cdot X_{SFixinvest}(t\text{-}1,d,s)) \quad (2\text{-}1e\text{-}2)$$

$$X_{Sfixasset}(t,d,s)=(1\text{-}P_{Disprate}(t,s))\cdot X_{Sfixasset}(t\text{-}1,d,s)+X_{Deltafix}(t,d,s) \quad (2\text{-}1e\text{-}3)$$

$$\sum_{s} X_{SFixinvest}(t,d,s)+X_{Waterinv}(t,d)=X_{Fixinvest}(t,d) \quad (2\text{-}1e\text{-}4)$$

（2）farming, forestry and animal husbandry sidelines module

For the farming, forestry and animal husbandry sidelines in the social economy, because of the prices scissors, the general currency type macro economy models can't reflect the practical effects of these industries and the water consumption of these industrials is so huge that it's an important factor in the macro economy water resources system, so they will be described with the physical equation. They include 3 types of equations: (a) area constraint equation, (b) output value constraint equation, (c) water consumption constraint equation:

$$X_{Acrop}(t,d,c)\geq P_{Acroplo}(t\text{-}1,d,c)\cdot X_{Acrop}(t\text{-}1,d,c) \quad (2\text{-}2a\text{-}1)$$

$$X_{Acrop}(t,d,c)\leq P_{Acropup}(t\text{-}1,d,c)\cdot X_{Acrop}(t\text{-}1,d,c) \quad (2\text{-}2a\text{-}2)$$

$$X_{Acrops}(t,d)=\sum_{c} X_{Acrop}(t,d,c)/[1+P_{Cropagn}(d)] \quad (2\text{-}2a\text{-}3)$$

$$X_{Aforest}(t,d,f)\geq P_{Aforestlo}(t\text{-}1,d,f)\cdot X_{Aforest}(t\text{-}1,d,f) \quad (2\text{-}2a\text{-}4)$$

$$X_{Aforest}(t,d,f)\leq P_{Aforestup}(t\text{-}1,d,f)\cdot X_{Aforest}(t\text{-}1,d,f) \quad (2\text{-}2a\text{-}5)$$

$$X_{Atrees}(t,d)=\sum_{f} X_{Aforest}(t,d,f) \quad (2\text{-}2a\text{-}6)$$

$$X_{Agrass}(t,d,p)\geq P_{Agrasslo}(t\text{-}1,d,p)\cdot X_{Agrass}(t\text{-}1,d,p) \quad (2\text{-}2a\text{-}7)$$

$$X_{Agrass}(t,d,p)\leq P_{Agrassup}(t\text{-}1,d,p)\cdot X_{Agrass}(t\text{-}1,d,p) \quad (2\text{-}2a\text{-}8)$$

$$X_{Ycrop}(t,d,c)=P_{Ycrop}(t,d,c)\cdot X_{Acrop}(t,d,c) \quad (2\text{-}2b\text{-}1)$$

$$X_{Mcrop}(t,d,c)=P_{Mcrop}(t,d,c)\cdot X_{Ycrop}(t,d,c) \quad (2\text{-}2b\text{-}2)$$

$$X_{Mcrops}(t,d)=\sum_{c} X_{Mcrop}(t,d,c) \quad (2\text{-}2b\text{-}3)$$

$$X_{Mforest}(t,d,f)=P_{Mforest}(t,d,f)\cdot X_{Aforest}(t,d,f) \quad (2\text{-}2b\text{-}4)$$

$$X_{Mtrees}(t,d)=\sum_{f} X_{Mforest}(t,d,f) \quad (2\text{-}2b\text{-}5)$$

$$X_{Mpasture}(t,d)=P_{Mlivestk}\cdot X_{Livestk}(t,d) \tag{2-2b-6}$$

$$X_{Livestk}(t,d)=\sum_{p} P_{Livestk}(t,d,p)\cdot X_{Agrass}(t,d,p) \tag{2-2b-7}$$

$$X_{Wcrop}(t,d,c)=P_{Wcrop}(t,d,c)\cdot X_{Acrop}(t,d,c) \tag{2-2c-1}$$

$$X_{Wcrops}(t,d)=\sum_{c} X_{Wcrop}(t,d,c) \tag{2-2c-2}$$

$$X_{Wforest}(t,d,f)=P_{Wforest}(t,d,f)\cdot X_{Aforest}(t,d,f) \tag{2-2c-3}$$

$$X_{Wtrees}(t,d)=\sum_{f} X_{Wforest}(t,d,f) \tag{2-2c-4}$$

$$X_{Wgrass}(t,d,f)=P_{Wgrass}(t,d,p)\cdot X_{Agrass}(t,d,p) \tag{2-2c-5}$$

$$X_{Wlivestk}(t,d)=P_{Wlivestk}(t,d)\cdot X_{Livestk}(t,d) \tag{2-2c-6}$$

$$X_{Wothagri}(t,d)=P_{Wothagri}(t,d)\cdot X_{Mothagri}(t,d) \tag{2-2c-7}$$

$$X_{Wpasture}(t,d)=\sum_{p} X_{Wgrass}(t,d,p)+X_{Wlivestk}(t,d)+X_{Wothagri}(t,d) \tag{2-2c-8}$$

（3）water resources module

The water resources module mainly describes the water resources supply and demand balance in the macro economy system, including (a) water use equation, (b) sewage equation, and (c) water resources supply and demand balance equation:

$$X_{opu}(t,d)=P_{Wpopcity}(t,d)\cdot X_{Popcity}(t,d)+P_{Wpopvil}(t,d)\cdot X_{Popvil}(t,d) \tag{2-3a-1}$$

$$X_{agri}(t,d)=X_{Wcrops}(t,d)+X_{Wtrees}(t,d)+X_{Wpasture}(t,d) \tag*{(2-3a-1)}$$

$$X_{Windu}(t,d)=\sum_{s_1} X(t,d,s_1)\cdot P_{Windu}(t,s_1) \tag*{(2-3a-1)}$$

$$X_{Wserv}(t,d)=\sum_{s_2} X(t,d,s_2)\cdot P_{Wserv}(t,s_2) \tag*{(2-3a-1)}$$

$$X_{Wwaste}(t,d)=X_{Windu}(t,d)\cdot P_{Wwindu}(t)+X_{Wserv}(t,d)\cdot P_{Wwserv}(t) +X_{Wpopu}(t,d)\cdot P_{Wwpopu}(t) \tag{2-3b-1}$$

$$X_{Wwtreated}(t,d)=X_{Wwaste}(t,d)\cdot P_{Wwteated}(t) \tag*{(2-3b-1)}$$

$$X_{Wtotal}(t,d)=X_{Wpopu}(t,d)+X_{Wserv}(t,d)+X_{Windu}(t,d)+X_{Wagri}(t,d) \tag{2-3c-1}$$

$$X_{Wtotal}(t,d)\leq P_{wresources}(t,d)\cdot P_{Wusecoef}(t,d)+X_{Wwtreated}(t,d) \tag*{(2-3b-1)}$$

（4）land resources module

The land resources module mainly describes the land utilization policy constraint, especially for farming, including (a) constraint of arable area growth, (b) constraint of farming-suitable area, and (c) constraint of total irrigation area:

$$X_{Atotal}(t,d) \geq P_{Atotallo}(t,d) \cdot X_{Atotal}(t\text{-}1,d) \tag{2-4a-1}$$

$$X_{Atotal}(t,d) \leq P_{Atotalup}(t,d) \cdot X_{Atotal}(t\text{-}1,d) \tag{2-4a-2}$$

$$X_{Atotal}(t,d) \leq P_{Amax} \tag{2-4b-1}$$

$$\sum_{p_1} X_{Agrass}(t,d,p_1) + \sum_{f_1} Xaforest(t,d,f_1) + \sum_{c} Xacrop(t,d,c) \leq X_{Atotal}(t,d) \tag{2-4c-1}$$

（5）water pollution module

The water pollution module uses COD emissions for description:

$$X_{COD}(t,d) = (\sum_{s} P_{CODrate}(t,s) \cdot X(t,d,s) + P_{CBOD}(t,d) \cdot X_{Popcity}(t,d)) \cdot P_{TCOD}(t) \tag{2-5a-1}$$

（6）water engineering investment module

The water engineering investment module reflects the development, utilization and stimulation of the economy exerting the water resources, including broadening sources, reducing expenditure, pollution management and so on.

$$X_{Build1}(t,d) = \sum_{j} P_{cost1}(d,j) \cdot X_{IO}(t,j) - \sum_{j} P_{cost1}(d,j) \cdot X_{IO}(t\text{-}1,j) \tag{2-6a-1}$$

$$X_{Build3}(t,d) = P_{Wsave}(t) \cdot (XAsave(t,d) - XAsave(t\text{-}1,d)) \tag{2-6a-2}$$

$$X_{Build2}(t,d) = P_{Wwprice}(\mathrm{t}) \cdot (P_{Wwteated}(t) \cdot X_{Wwaste}(t,d) - P_{Wwteated}(t\text{-}1) \cdot X_{Wwaste}(t\text{-}1,d)) \tag{2-6a-3}$$

$$X_{Waterinv}(t,d) = X_{Build1}(t,d) + X_{Build2}(t,d) + X_{Build3}(t,d) \tag{2-6a-4}$$

wherein：

c=all crops, such as grains, oil plants, cotton, vegetables etc.	A=input-output coefficient matrix
f=all forest, such as plantation, natural forest etc.	I=identity matrix
f_1=all plantation	s=subarea
p=all grassland, such as artificial watering grassland, natural grassland etc	t=time, representing level years
p_1=all artifical grassland	X_{Acrop}=all crops growing area
$P_{Acropup}$，$P_{Acroplo}$=the upper and lower limit of the crop’s planting area’s growth rate	X_{Mcrops}=the total output value of the farming
$P_{Aforestlo}$，$P_{Aforestup}$＝the upper and lower limit of the forest area	X_{Acrops}=all the farming area
$P_{Agrasslo}$，$P_{Agrassup}$＝the upper and lower limit of the grassland area	X_{Wcrops}=total water consumption of the farming
P_{Alpha0}，P_{Alpha1}=the fixed assets coefficient in this and last time period	$X_{Aforest}$＝all forest area
P_{Amax}=arable irrigation area	X_{Agrass}＝all grassland area

$P_{Aprice}(t)$=unit reclamation cost	X_{Asave}=all water-saving irrigation area
$P_{Atotallo}$，$P_{Atotalup}$=the lower limit of the cultivated land increment rate	X_{Atotal}=the total cultivated land area
$P_{CODrate}$＝COD emission rate by 10 thousand Yuan for different industries	X_{Atrees}=the total forest area
P_{Cita}=the fixed assets yield rat for all industries	X_{build1}=the water conservancy project investment
P_{cost}=the project investment divided by different region	X_{Build2}=land reclamation investment
$P_{Cropagn}$=multiple factor	X_{build2}=sewage project investment
P_{Delta} the maximum proportion of the import and export balance to the gross output	$X_{Deltafix}$=the fixed investment increment during this time
$P_{Disprate}$ the fixed assets depreciation rate	X_{Export}=department export
$P_{Finalfixed}$=the final total coefficient of the fixed assets	$X_{Fixinvest}$=fixed assets investment
P_{GDP}=added value rate	X_{Home}=consumption of resident
P_{Home}=residents consumption coefficient	X_{Import}=department import
$P_{Importlo}$，$P_{Importup}$，$P_{Exportlo}$，$P_{Exportup}$ the allowed upper and lower limit of the import and export	X_{IO}=0/1 variables, representing the project will be on or not
$P_{Investup}$，$P_{Investlo}$ the upper and lower limit of GDP investment rate coefficient	$X_{Livestk}$=artifical feeding livestock
$P_{Livestk}$＝livestocks per unit grassland can feed	X_{Mcrop}=all crops' output value
P_{Mcrop}= all crop's unit price	$X_{Mforest}$＝all forests output value
$P_{Mforest}$＝all forest's unit price	X_{Mtrees}=forest total output value
$P_{Mlivestk}$= unit price for each livestock	$X_{Popcity}$=urban population
P_{PCOD}= unit town resident COD emission	X_{Popvil}=rural population
P_{Social}= social consumption coefficient	$X_{Sfixasset}$=all the fixed assets inventory
P_{Stock} investment coefficient of circulatiing fund	X_{Social}=social consumption
P_{TCOD}=COD remnant rate for corresponding sewage treatment rate, such as the secondary treatment, remnant rate is 7%	X_{Stock}=circulating stock
P_{Wcrop}= irrigation norm for all the crops	X_{Wagri}=water use for agriculture
$P_{Wforest}$＝unit consumption rate for all forest	$X_{Waterinv}$=water project investment
P_{Wgrass}＝unit consumption rate for all grassland	X_{Wcrop}=all the crops water use
P_{Windu}= water consumption norm for all industries by 10	$X_{Wforest}$＝all the water consumption

thousand Yuan	for foest
$P_{Wlivestk}$= unit livestock water consumption norm	X_{Wgrass}＝all the water consumption for grassland
$P_{Wothagri}$= water consumption norm of sideline fishery by 10 thousand Yuan output value	X_{Windu}=the total water use for industrial
$P_{Wpopcity}$= water consumption norm of living water consumption for urban resident	$X_{Wlivestk}$=the total water use for livestock
$P_{Wpopvil}$= water consumption norm of living water consumption for rural resident	$X_{Wothagri}$=the total water use for fishery
$P_{wresources}$= water resources gross	$X_{Wpasture}$＝the total water use for pasture
P_{Wsave}=investment for unit water saving irrigation area	X_{Wpopu}=total living water
P_{Wserv}= water consumption norm of service industries by 10 thousand Yuan output value	X_{Wserv}＝total service water use
$P_{Wusecoef}$= net utilization rate of water resources	X_{Wtotal}=the total water use of all industries
P_{Wwindu}= industrial waste water discharged rate	X_{Wtrees}=the total water consumption for forest
P_{Wwpopu}= living waste water discharged rate	$X_{Wwtreated}$=sewage treatment amount
$P_{Wwprice}$= unit increment waste water treatment investment	$X_{Wwtreated}$=the total discharged sewage
P_{Wwserv}= service industry waste water discharged rate	X_{Ycrop}=the total output of the crops
$P_{Wwteated}$=wastewater treatment rate	
P_{Ycrop}= all crops unit yield	

（7）target module

The support capacity of the water resources to the regional economy doesn’t only depend on the water resources endowment but also the water resources development method and the social economy development model, which connects to the social total adjustment target. To consider the different factors in the river basin and integrally reflect the structure and relation among the economic society, ecology and water resources system, several targets, such as sustainable development of economy, sounder public order, less or no pollution on ecology and environment etc., are selected. Per accumulation value in the programming period for the whole river basin is selected as the target. The exact description is: the economic target takes the gross domestic product sum as the maximum; the environment target takes the COD emission as the minimum and the social target takes the grain possession as the maximum. By corresponding sequences the target equations are:

$$J_{GDP} = \max\{\sum_t \sum_d X_{PGDP}(t,d)\} \tag{2-7a-1}$$

$$J_{COD} = \min\{\sum_t \sum_d X_{PCOD}(t,d)\} \tag{2-7a-2}$$

$$J_{FOOD} = \max\{\sum_t \sum_d X_{PFOOD}(t,d)\} \tag{2-7a-3}$$

GDP is selected as the economic target because it's the international universal index to completely reflect the economy activities. What’s more, the data is complete and reliable which is well supported by the statistical data. COD is selected as the environment index because it's the universal water quality index which is feasible to measure and be converted into other index, such as NH3 and BOD. The COD index can also be easily used to estimate the environment investment. Per capita grain possession is closely connected to the policy and the public order, also the economic development. The grain production is a big problem to China, even the whole world. The grain production is a main factor of the agricultural water use, so it has great meaning to select per capita grain possession as the social target.

The above-mentioned equations build up the macro economy water resources model, which comprises three control targets and the relevant sub-layer local strategic decision variables, including the economic decision variables (output value of all industries, fixed assets investment, fixed assets stock, fixed assets increment, import and export from all the industries etc.), agricultural decision variables (all the crops irrigation area, yield and value etc.), environmental decision variables (waste water emission, COD emission and waste water treatment degree etc.) and water resources decision variables (water demand for all the industries, ecological water demand, supply-demand balance etc.). There is interaction and impact between these targets and the decision factors, which is inter-contradictory, inter-prompting, mutual restraint and inter-competing. These effects and impacts have connections with the water resources to form a unity of contradiction with the water resources as the key factor.

2.4 A discussion of the model

In the water resources macro-economic system which is formed by the economy, society, resources and the environment, the economic sub-system is the base of the whole system and the water resources sub-system is the tie of all the sub-systems. The economic development will both pollute the environment and promote the environment management, both cause the ecological environment deterioration and increase the investment to the environment protection, both increase the water demand of all the industries and provide the economic basis for the water supply development. As the obstacle of the regional economic development, water resources has become the key natural resources for all the targets’ competition. Each sub-system competes for the fund and water resources, so as to develop the whole system to the direction which benefits themselves. To keep the system long-term harmoniously and regularly developing, the allocation proportion of the fund and the resources in the sub-system should make reasonable adjustment with the system developing, so the model must have dynamic constraint mechanism.

（1）propagation reproduction mechanism, relation between accumulation and consumption

The propagation reproduction mechanism is the main constraint mechanism for water resources support capacity analysis model. According to Marx's political economic theory, the propagation reproduction process is the recycling production process of capital – production – product – profit – capital, i.e., the process is that part of the profit in the last production is turned into the capital and carry on a new propagation and reproduction process. The exact portion of the profit which will be turned into the capital or consumption is decided by the accumulation and consumption relationship. The proportion of the accumulation to the consumption is the main factor to control the reproduction scale. Considering the water resources constraint condition, arranging the relation between the accumulation and the consumption and assuring the propagation reproduction process is one of the questions which must be faced in water resources planning research.

（2）the relation between the product transferred into and out

In modern society, it's not necessary for a region to produce the needed products because the business trade activities can compensate the deficiency of the regional productivity. Besides exploring the water resources, the only way to solve the conflict between water resources supply and demand is to improve the industrial structure and develop water-saving economy. One of the important meanings of industrial structure adjustment is regulate the product into and out transfer structure. The rule to deal with the transfer relationship is basically to keep the transfer balance because it's abnormal for a country or region to keep trade surplus or trade deficit for a long time.

（3）input-output constraint relation

The input-output relation can study the balance between output and demand among different economy departments in one region, describe the relation between the economy structure and the production condition and reveal the change processes of different departments in the production, the interdependence and mutual restrictions among different departments.

（4）relation between water pollution and control

The environment pollution in the macro economy, environment and water resources system exclusively refer to the water environment. The air pollution, noise pollution and solid waste pollution etc. will be omitted because they don't have close connection with water resources.

The wastewater emission can't be avoided in the economic development process, which not only pollutes the environment but also prevents the fresh water from utilization to increase water resources crisis. To control the vicious circle, the industrial sewage should be treated before emitted into the river channel. The treatment won't only control the pollution, but also provide water resources for the industry and agriculture, which enhances the reutilization rate. This has both the environmental benefit and economic effect. Certainly this needs investment for the treatment, but the only source is the national economy income, so it's a restraint factor for the propagation reproduction. While researching the water resources supporting capacity, the relation between the investment and the profit of the sewage treatment should be analyzed to get the reasonable treatment level.

（5）reasonable adjustment of agriculture structure

The farming is the biggest water consumption. The reasonable adjustment of agriculture structure has decisive effect on enhancing the water utilization efficiency, maintaining good ecological environment and improving the water resources supporting capacity. The agriculture production structure has two layers. The first layer is the agriculture, forest, animal husbandry, sideline and fishery structure and the second layer is all the crop's planting structure inside the farming industry, including planting proportion of the grains, oil plants, cotton, vegetables, melon and fruit etc.

（6）water resources utilization project

To meet the increasing water demand because of the social economy development, different water conservancy projects need to be built where conditions permit, including surface water project, groundwater project, inter-basin water diversion project, sewage treatment project and water saving project. Building new water resources project to enhance the water supply ability is the most direct way to enhance the water resources support capacity.

（7）water balance constraint

The industry and agriculture's developing, the living of animals and plants and people's daily life all need water. The living water use involves every family and the industrial water use is the cornerstone of the national economy development, so there is high requirement for the water quality and assurance rate. The agricultural water use is usually irrigation water, which has lower requirement for the water quality and assurance rate. Though the water uses need different requirement, all the above water use should meet the constraint of the water supply-demand balance.

Besides the above main constraints, the policy, market, tradition etc. constraint can be added, such as the government crops policy, the local consumption characteristics, and the treated water can't be used as the living water and so on. These constraint equations can be controlled by the upper and lower limits in the models.

3 Ecological water use scheduling model

3.1 Overview of water resources scheduling development

Water resources are with many utilizations and functions, such as water supply, electricity generation, irrigation, shipping, aquatic product, environment protection and so on. By the water conservancy project scheduling, the adjustment, control and management of the water resources it can be actualized to meet the water demand of different departments, assure the water resources function and presents the synthetically utilization benefit. The most part of the water conservancy project scheduling is the reservoir scheduling. Form the end of the 19^{th} century and the beginning of the 20^{th} century, the modern sense reservoir appeared, most reservoirs scheduling is only limited to the single reservoir single-target scheduling (Chan, Jianxia et al., 2010). Recent years, with the fast development of the population, agricultural and industrial production, the water resources demand becomes more and more huge and the water shortage in some regions is more and more serious. Then the idea of integral utilization of water resources is proposed and the reservoir scheduling is being changed into a new stage of multi-reservoirs combination and multi-targets scheduling, in which the integrated targets of flood control, water supply, electricity generation, shipping and so on are focused.

The reservoir will definitely change the natural hydrological cycle of the river channel. After a big water conservancy project is built, the first change is the river run-off and its original season allocation and then some environmental factors related to run-off accordingly, such as hydrologic characteristic, hydraulics characteristic, sediment load, nutrient substance, water quality, temperature, the self-clean ability and so on. These changes will directly or in-directly affect the inhabitation area and living habit of biological resources in the river basin, changing their structure, composite, distribution character and fertility. The traditional reservoir scheduling is mainly on social economic targets and seldom on ecological demands of the downstream of the reservoir, which will cause the bad destruction to the lower reach ecological system. Since the 1990's, as more and more ecological environmental problems happened, people pay more and more attention on the ecological environment and emphasize the water resources scheduling skill to make full use of the water resources inside and outside the river channel to improve the water quality and ecological environment. That is so called the ecological water use scheduling (shortly, the ecological scheduling) which brought new concept into the reservoir scheduling and water resources management.

（1） **Flood control scheduling.** The flood control scheduling is one of most important issue and usually deal with the utilization scheduling (water supply, irrigation, power generation, shipping etc.). The principle of flood control scheduling is reservoir spillway water rules, that is a reservoir operation should be make full use of the flood control capacity to efficiently store the flood, reduce flood peak, decrease the flood damages, to correctly deal with the conflict between the flood control and other function based on assuring the dam safety, and to fully actualize the reservoir's economic profit.

The reservoir flood control scheduling is generally operated according to the flood control chart in flood season, which is composed by the reservoir water levers at different time to show the storage capacity which indicate the available storage for flood water storing at the time of the flood season.

Flood control is the highest task of reservoir operation. For the river channel flood control, because of the fast change of the water level in channel, it is usually to set up the warning water level and assisted with relevant project measures of reducing the flood peak flow, or to enhance discharge capacity of river channel including embanking, dredging, flood diversion, floodwater storage etc. measures. Those all to ensure the safety during the flood season,

（2）**Water supply scheduling.** Water supply scheduling is the most often used water resources developing and utilizing method in the water conservancy project scheduling. Water supply infrastructures are these of storage works, inner-basin diversion works and inter-basin diversion works. Among them, especially some inter-basin water diversion projects are the focus of the world because of huge project scale, long construction period, wide range, good economic profit, complex environmental effects etc. factors. Water supply works scheduling is normally according a operation chart too, and it should be subject to flood control scheduling in flood season.

（3）**Ecological scheduling.** Again, ecological scheduling is in terms of ecological water use scheduling. The ecological scheduling aims at protection environment and solving ecological problems by improving the hydrological condition in the lower reach and restoration basin's ecological situation. The ecological restoration is to recovery the ecological function which has been lost or degenerated because of human disturbance. One task is to reasonably allocate the water resources to maintain the minimum ecological water demand and to provide the artificial pulse flooding to simulate natural hydrological cycle. Up to now, the ecological scheduling in China includes: ecological water demand scheduling, water quality scheduling, sediment scheduling and integral scheduling etc. (Wang, Yuankun, 2008).

Ecological water demand scheduling will maintain the water amount in the river channel which meets the water quality requirement, and keep the river ecological structure, function and pattern, and prevents the ecological deterioration since of the flow decreasing or stopping, and improves the basic structure and function of the river system and protect the aquatic organism in the river. On the base of maintain the river basic ecological water demand, the impact from the hydrological condition change imposing on the aquatic organism diversity is integrally considered. The reservoir discharging process simulates the natural hydrological condition, by rationally controlling the reservoir discharging flow and time and artificial producing the flood peak to reduce the change on the aquatic organism living model such as propagation, spawn etc. which induced by flow changes in order to maintain the population viability of the riparian species.

Water quality scheduling includes controlling the reservoir eutrophication, adjusting the discharging temperature, improving the water quality and defending the estuarine saline intrusion. Lowering the upstream water level and increasing the reservoir discharging flow can enhance the water flow and destroy the eutrophication condition to reach the object of controlling the reservoir eutrophication. Increasing the outlet of reservoirs in drought periods cannot only compensate the drought but also wash away the dirt, so the lower reach environment capacity will be efficiently enhanced and the water quality will be improved.

Sediment scheduling mainly prevents the reservoir and river channel from being blocked on the sediment-laden river, such as the Sanmenxia Reservoir in Yellow River. The reservoir stores the clean water and discharges the sediment by regulating the discharging method to adjust the sediment content and the flow process of the water, trying to reduce the scouring intensity of the river channel in the lower reach.

Integrated scheduling includes all items or some of the above.

（4）**Ice prevention scheduling.** The ice run flood is the unique hydrological phenomenon of river located in the high latitude area. There might be ice flood in the freeze-up period in the winter or the break-up period in the spring. By using the upper reach reservoir in the frozen river, the flow can be increased before frozen to drive up the ice cover, and discharge the reservoir at the appropriate time before the thaw, in order to prevent the occurrence of ice flood.

Now the Yellow River water conservancy project scheduling most accords to the direct requirement. On the premise of assuring the basin flood prevention, ice prevention and the lower reach sediment decrement, the water conservancy project scheduling basically belongs to the water supply or electricity generation scheduling with appropriate balance to the others.

Because the Yellow River water resources distribution is not evenly on the time scale, during the normal level period and drought period, the social economic water demand increases and the river run-off reduces. It won't meet the requirement of the ecological water demand for the river channel ecological system and produces the ecological environmental problems. So there is very important meaning in the Yellow River basin to carry on the ecological water demand scheduling. By daily discharging the reasonable environmental flow and simulating natural hydrological pulse process in the river channel key period of the ecological water demand, such as fish migration and ovipositing period, to reduce the negative impacts on the lower reach's ecologies. This is the basic realization of the ecological scheduling.

3.2 Frame of the ecological water use scheduling model

The aim of the model is to scheduling ecological water use in control projects and key sections of Yellow River, including generalizing hydraulic relationships of the whole Yellow River, confirming the basin water consumption unit (agriculture, industry, ecology etc.) and water supply unit (river, reservoir etc.) and set up the topological relations among different units, to simulate the Yellow River basin water resources cycling utilization relationships, to set up the Yellow River basin water resources model. By the model and targets priorities and scenarios, to optimize water allocation scheduling is prospected.

The ecological water scheduling optimal model construction contains the steps of problem identification, target identification, scenario design, optimal scheduling, forming the optimal design collection, optimal plan selection and so on.

(1) Problem identification. With investigating the basin historical situation and water resources development condition, and analyzing the existent ecological environment problem of the river channel, the task is to diagnose and identify the ecological environmental problems together with stakeholders.

(2) Targets identification. The ecological targets in the programming period are identified after combining the existent social economic situation with the identified ecological problems.

(3) Scenario design. To set weight is a multi-objectives solving skill which can indicate the value of the water in different department and the decision-maker's preference.

(4) Optimal scheduling. The optimal ecological water scheduling plan is identified after integrally considering the social economic water and ecological water. The guidelines are to take the environmental flow as one of the optimal scheduling objective functions.

(5) Forming the optimal design collection. After combining the different weight, water resources allocation results and different engineering condition, different scheduling plans under different scenarios are deduced, so getting the optimal design collection.

(6) Optimal plan selection. After the comparison of different optimal plan selection, the needs satisfaction of the social economic water supply and environmental flow maintenance etc. targets and the integral impacts are summarized to study the impact on integral benefit, especial the ecological benefit from the water conservancy development, layout and the operation rules to provide the decision support to the decision makers.

3.3 Objectives and constraints

（1）Objectives

As what mentioned above, the reasonable and feasible ecological water scheduling should be based on the integral consideration of the economic and ecological water use of outside river channel together with what inside river channel. For the water allocation, we have to obey the rules of unified dispatching of river basin, coordination of the upstream and downstream and sections control. Where there is water shortage, the relation between the ecological water demand and economic water demand is evaluated according to the water use characteristics of different departments.

So, the ecological water scheduling goal functions is set up:

$$MinZ = \sum_{i=1}^{n} (w_1 SW_{Ilack}^{i} + w_2 SW_{Alack}^{i}) + \sum_{j=1}^{m} w_3 SW_e^{i} \qquad (3\text{-}1)$$

Wherein, $R^{i}{}_{Ilack}$ is the water shortage of the living, industry and urban environment in the No. *i* water supply area; $R^{i}{}_{Alack}$ is the shortage of the agriculture in the No. *i* water supply area; $R^{i}{}_{e}$ is the shortage of the ecological water in the No.*j* section. w_1, w_2 and w_3 are the weight coefficients. *n*– the water supply numbers, *m* - the ecological section numbers.

In the objective function, Z makes minimum of total water shortage from all water demand elements and the environmental flow control sections. Meanwhile, weight coefficients are induced to show the preferences to the 4 water use targets for decision-makers.

（2）Constraints

The water scheduling nodes contains run-on water, water diversion, water subsiding, reservoir, reach, control section etc. types, which is mainly calculated with the water balance equation and the reservoir water scheduling model.

a. reservoirs and sluices

①water balance constraint:

$$V(t+1) = V(t) + I(t) - W(t) - Q(t) - E(t) \qquad (3\text{-}2)$$

Wherein, $V(t+1)$ and $V(t)$ are the initial reservoir water storages at the t and t +1 time period respectively; $I(t)$, $W(t)$ and $Q(t)$ are the inflow, water supply and abandoned discharging during the t time period respectively; $E(t)$ is the reservoir evaporation and leakage in the t time period.

② reservoir capacity constraint

$$V_{ins} \le V(t) \le V_{\max} \qquad (3\text{-}3)$$

Wherein, V_{ins} is the reservoir dead storage; $V_{\max}$ is the limited storage for particular purpose, i.e. flood control capacity for flood-season or the active capacity in the non-flood season.

③ outlet discharge constraint:

$$Q(t) \le Q_{\max} \qquad (3\text{-}4)$$

Wherein, $Q_{\max}$ is the reservoir outlet discharge ability

④water diversion capacity constraint:

$$W(t) \le Q_{w\max} \qquad (3\text{-}5)$$

Wherein, $Q_{w\max}$ is water diversion capacity.

b. river channel

①water balance constraint:

$$I(t) = Q(t) + W(t) + L(t) \qquad (3\text{-}6)$$

Wherein, $I(t)$、$Q(t)$, $W(t)$ and $L(t)$ respectively are the upstream entering water, downstream discharging water, water supply and water loss during the time period.

②discharge constraint:

$$Q(t) \le Q_{\max} \quad (3\text{-}7)$$

Wherein, $Q_{\max}$ is the river discharge ability.

c. water supply item

$$W(t) = W(t)_{cons} + W(t)_{return} \quad (3\text{-}8)$$

$$W(t) \le W(t)_{demand} + W(t)_{up} \quad (3\text{-}9)$$

$$W(t) \ge W(t)_{demand} - W(t)_{lack} \quad (3\text{-}10)$$

Wherein, $W(t)_{demand}$ is the time-period water demand; $W(t)_{cons}$ is the time-period water consumption; $W(t)_{return}$ is the time-period return water; $W(t)_{up}$ is the time-period supplied water over-demand; $W(t)_{lack}$ is the lack of time-period water.

d. ecological control section

$$Q(t)_{eco} = Q(t)_{ed} + Q(t)_{inc} - Q(t)_{lack} \quad (3\text{-}11)$$

Wherein, $Q(t)_{eco}$ is the flow in ecological section; $Q(t)_{ed}$ is the environmental flow requirement; $Q(t)_{inc}$ is the increment of the environmental flow; $Q(t)_{lack}$ is dissatisfied environmental flow;

e. junction node

water balance constraint:

$$Q(t) = \sum_{i=1}^{k} I(t)_i \quad (3\text{-}12)$$

Wherein, $Q(t)$ is the outflow at the junction node during the time t period; $I_i(t)$ is the inflow at the t junction node from the i branch; *k* is the total branch numbers at the same junction node.

e. channel

$$Q(t) = \alpha \times I(t) \qquad (3\text{-}13)$$

Wherein, $Q(t)$ is the inflow of channel; $I(t)$ is the outflow of channel.

3.4 Parameters and inputs

（1）Hydrological series

The ecological water scheduling directly starts from the upper boundary runoff. The flow entrance of the mainstream upper boundary adopts the 30 years actual measurement data from 1971 to 2000. For the time period of data missing, the data is supplemented with the difference compensation and water balance method.

（2）Social economic water demand

The water demand is divided into two groups, the first group is the living and industrial water (including the basic ecological environment water demand outside river channel) and the second group is the agricultural water. According to the three results of the macro-economic water resources allocation model in this study, the social economic water is resolved into the third water resources districts and provinces and is inputted water demands as four departments in reference years, the living water, industrial water, outside river channel ecological water and agricultural water.

The model is mainly considering the surface water allocation, but the groundwater supply is also considered. Referring to the Yellow River comprehensive water resources planning, The planned exploitable ground water in the base year and the future years are achieved, refers to appendix Tab. 1.

（3）Low-risk and medium-risk environmental flow

The model adopts the water section control rule. For the lower reach of the Yellow River, both the Huanyuankou and Lijin sections are selected and applied the recommended result of the environmental flow evaluation. The low risk environmental flow and the medium risk environmental flow are inputted into the model. For the middle and upper reaches, refer to the “Yellow River Environmental Flow” (Liu, Xiaoyan, 2009) and “the impacts and ecological scheduling on the river channel of the Yellow River mainstream control project”, input the model the minimum and appropriate environmental flow of Shizuishan (in Nixia Municipality), Toudaoguai (Inner Mongolia Municipality), Longmen (Shanxi Province) and Tongguan (Shaanxi Province) the 4 sections, respectively corresponding to the medium risk environmental flow and the low risk environmental flow.

3.5 Solving

The software of GAMS is used to do the solving. The GAMS (General Algebraic Modeling System) is application-oriented Mathematical Programming software developed by the World Bank’s experts. The language is simple and can be easily solved so that the users’ work efficiency is greatly enhanced and the application on the policy-analysis and decision-making of the mathematical programming technique. In American management planning department, GAMS is one of the most widely used mathematical programming techniques.

Considering the agricultural irrigation requirements, ten days is selected as the basic time element. A year is divided into 36 computing time period in the model scheduling. There are 1080 time periods in total during the 30 years.

4 Ecological water use scheduling analysis

The ecological water scheduling in Yellow River basin is to coordinate the relation between the social ecological water and the river ecological water. It is to analyze and optimize scheduling of the existent and planned water conservancy projects to find key measures to further enhance the protection of the ecological system. By the way, the ecological effect of the under-construction and planning project is analyzed and argued, so as to provide the relevant ecological water scheduling strategy.

4.1 Key ecological protection objectives

4.1.1 Key objectives

The report contains two layers ecological water scheduling, i.e. low risk ecological water scheduling and medium risk ecological water scheduling. The low risk ecological water scheduling is to make the river flow meets the low risk environmental flow as possible, assuring the river in the ecological safety state. It aims at keeping the health of the river channel and the aquatic marginal wetland and keeping the river capital healthy at the low risk level; the medium risk ecological water scheduling main target is try to let the river flow meet the medium risk environmental flow as possible, maintaining the river channel basic healthy and keeping the river assets healthy at the high risk level (Gippel et al., 2011). The key protection objective of the ecological water scheduling is the lower reach of the Yellow River, meanwhile coordinating the upstream and middle stream ecological water requirements.

4.1.2 Ecological water demand of key sections

（1）Ecological sections in lower reach Yellow River

The lower reach Yellow River is the main research objective. The lower reach ecological sections are Huanyuankou and Lijin. The low risk and medium risk environmental flow adopt from the recommended value of the report by Gippel et al. (2011). Referring to Tab.4-1 ~ Tab.4-4.

表 4-1 Low-risk environmental flow regime for Reach 1 of the lower Yellow River. Compliance point is Huayuankou.

Flow component	Hydrologic criteria	Mean annual frequency/duration	Inter-annual frequency	Timing
Cease to flow	No cease to flow	Continuous	100% of the time	All year
Low flow	Dec ≥ 307 Jan ≥ 280 Feb ≥ 321 Mar ≥ 377 Apr ≥ 463 May ≥ 430	Continuous	≥ 75% of the time	Dec - May
High flow	Jun ≥ 434 Jul ≥ 783 Aug ≥ 1,137 Sep ≥ 1,124 Oct ≥ 866 Nov ≥ 543	Continuous	≥ 75% of the time	Jun - Nov
Low flow pulse	≥ 2,000	≥ 1 per year / 1 – 30 days; rates of rise and fall within natural range	≥4 in 5 years	Nov - May
Bankfull	3,000 – 4,000	≥ 1 per year / ~10 – 30 days duration; rates of rise and fall within natural range	≥4 in 5 years	Jun – Sep

表 4-2. **Medium-risk environmental flow regime for Reach 1 of the lower Yellow River. Main risk is to Reach 1 riverine wetlands. Compliance point is Huayuankou.**

Flow component	**Hydrologic criteria**	**Mean annual frequency/duration**	**Inter-annual frequency**	**Timing**
Cease to flow	No cease to flow	Continuous	100% of the time	All year
Low flow	Dec ≥ 185 Jan ≥ 174 Feb ≥ 191 Mar ≥ 229 Apr ≥ 284 May ≥ 263	Continuous	≥ 75% of the time	Dec - May
High flow	Jun ≥ 265 Jul ≥ 466 Aug ≥ 754 Sep ≥ 744 Oct ≥ 534 Nov ≥ 335	Continuous	≥ 75% of the time	Jun - Nov
Bankfull	3,000 – 4,000	≥ 1 per year / ~10 – 30 days duration; rates of rise and fall within natural range	≥4 in 5 years	Jun – Sep

表 4-3 Low-risk environmental flow regime for Reach 4 of the lower Yellow River. Compliance point is Lijin.

Flow component	Hydrologic criteria	Mean annual frequency/duration	Inter-annual frequency	Timing
Cease to flow	No cease to flow	Continuous	100% of the time	All year
Low flow	Dec ≥ 303 Jan ≥ 189 Feb ≥ 314 Mar ≥ 332 Apr ≥ 379 May ≥ 342	Continuous	≥ 75% of the time	Dec - May
High flow	Jun ≥ 332 Jul ≥ 436 Aug ≥ 447 Sep ≥ 446 Oct ≥ 441 Nov ≥ 412	Continuous	≥ 75% of the time	Jun - Nov
Bankfull	3,000 – 4,000	≥ 1 per year / ~10 – 30 days duration; rates of rise and fall within natural range	≥4 in 5 years	Jun – Sep

表 4-4. Medium-risk environmental flow regime for Reach 4 of the lower Yellow River. Compliance point is Lijin.

Flow component	**Hydrologic criteria**	**Mean annual frequency/duration**	**Inter-annual frequency**	**Timing**
Cease to flow	No cease to flow	Continuous	100% of the time	All year
Low flow	Dec ≥ 212 Jan ≥ 116 Feb ≥ 217 Mar ≥ 224 Apr ≥ 239 May ≥ 227	Continuous	≥ 75% of the time	Dec - May
High flow	Jun ≥ 224 Jul ≥ 278 Aug ≥ 284 Sep ≥ 283 Oct ≥ 281 Nov ≥ 263	Continuous	≥ 75% of the time	Jun - Nov
Bankfull	3,000 – 4,000	≥ 1 per year / ~10 – 30 days duration; rates of rise and fall within natural range	≥4 in 5 years	Jun – Sep

（2）Ecological sections in the upper and middle stream

The ecological sections at the up and middle stream are Shizuishan, Toudaoguai, Longmen and Tongguan. The environmental flows refer to the recommended value the Yellow River Environmental Flow Research (Liu, Xiaoyan, 2009), see Tab. 4-5.

Tab.4-5 Recommended environmental flows at upper and middle stream

section	Protection level	Flow component	time	flow（m^3/s）	frequency	duration
Shizuishan	Medium risk	Low flow	Nov.~ Mar.	325	continuous	
		Pulse flow	Apr. ~ Jun.	400	At least once a year	Over 6 days
		Low flow	Apr. ~ Oct.	325	continuous	
		flood	Jul. ~ Oct.	Flood 1000～		Abt 20

				1500		days
	Low risk	Low flow	Nov.~ Mar.	330	continuous	
		Pulse flow	Apr. ~ Jun.	900	At least once a year	Over 6 days
		Low flow	Apr. ~ Oct.	330	continuous	
		flood	Jul. ~ Oct.	Flood 1000~1500		Abt 20 days
Toudaoguai	Medium risk	Low flow	Nov.~ Mar.	125	continuous	
		Pulse flow	Apr. ~ Jun.	400	At least once a year	Over 8 days
		Low flow	Apr. ~ Oct.	125	continuous	
		flood	Jul. ~ Oct.	Flood 1000～1500		Abt 20 days
	Low risk	Low flow	Nov.~Mar.	250	continuous	
		Pulse flow	Apr. ~ Jun.	800	At least once a year	Over 8 days
		Low flow	Apr. ~ Jun.	250	continuous	
		Low flow	Jul. ~ Oct.	300	continuous	
		flood	Jul. ~ Oct.	Flood 1000～1500		Abt 20 days
Longmen	Medium risk	Low flow	Nov.~ Mar.	130	continuous	
		Low flow	Apr. ~ Oct.	130	continuous	
	Low risk	Low flow	Nov.~ Mar.	240	continuous	
		Low flow	Apr. ~ Oct.	240	continuous	
Tongguan	Medium risk	Low flow	Nov.~ Mar.	150	continuous	
		Low flow	Apr. ~ Oct.	150	continuous	
	Low risk	Low flow	Nov.~ Mar.	300	continuous	
		Low flow	Apr. ~ Oct.	300	continuous	

（3）Ecological water demand of sections

According to the above section ecological recommended flow, the ecological water demand process of all the sections is achieved (see Tab. 4-6). The water demand process of the section of Shizuishan, Toudaoguai, Huanyuankou and Lijin is shown in Fig. 4-1.

Tab. 4-6 Monthly ecological water demand process of sections ($10^{\times 6}m^3$)

Section	ShiZuiShan		TouDaoGuai		LongMen		TongGuan		HuaYuanKou		LiJin	
	LR	MR	LR	MR	LR	MR	LR	MR	LR	MR	LR	MR
Jan	8.55	8.42	6.48	3.24	6.22	3.37	7.78	3.89	7.50	4.66	5.06	3.11
Feb	8.55	8.42	6.48	3.24	6.22	3.37	7.78	3.89	7.77	4.62	7.60	5.25
Mar	8.55	8.42	6.48	3.24	6.22	3.37	7.78	3.89	10.10	6.13	8.89	6.00
Apr	8.55	8.42	6.48	3.24	6.22	3.37	7.78	3.89	20.18	7.36	9.82	6.20
May	8.55	8.42	6.48	3.24	6.22	3.37	7.78	3.89	11.52	7.04	9.16	6.08
Jun	10.28	8.86	7.82	3.91	6.22	3.37	7.78	3.89	28.40	23.09	18.63	14.81
Jul	8.55	8.42	24.17	20.27	6.22	3.37	7.78	3.89	31.69	28.32	36.24	37.00
Aug	8.55	8.42	24.17	20.27	6.22	3.37	7.78	3.89	30.45	20.20	11.97	7.61
Sep	21.50	15.34	34.00	27.45	6.22	3.37	7.78	3.89	29.13	19.28	11.56	7.34
Qct	8.55	8.42	24.17	20.27	6.22	3.37	7.78	3.89	23.19	14.30	11.81	7.53
Nov	8.55	8.42	6.48	3.24	6.22	3.37	7.78	3.89	14.07	8.68	10.68	6.82
Dec	8.55	8.42	6.48	3.24	6.22	3.37	7.78	3.89	8.22	4.96	8.12	5.68
Year	117.31	108.44	159.68	114.84	74.65	40.44	93.31	46.66	222.23	148.65	149.54	113.40

Note: LR-Low-risk e-flow；MR-Medium-risk e-flow

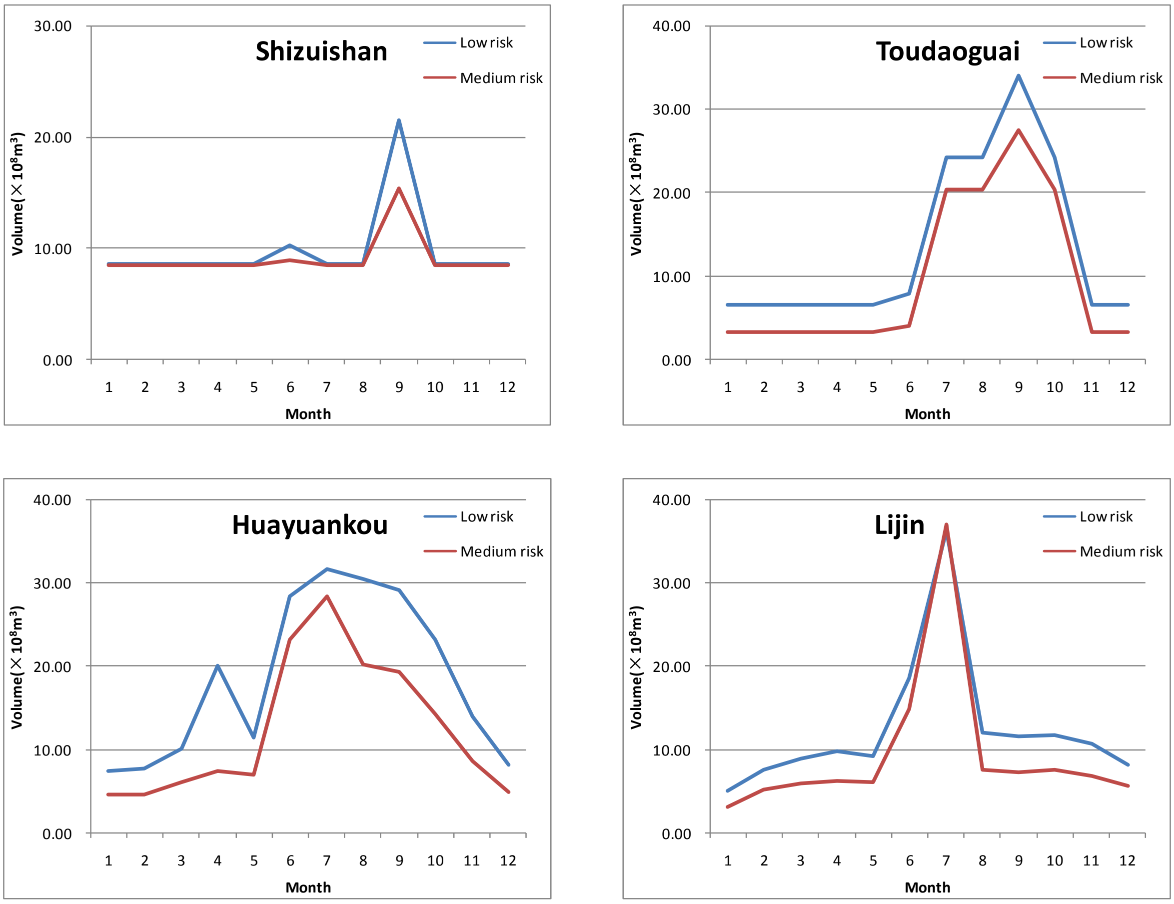

Fig 4-1 The monthly ecological water demand process at Shizuishan, Toudaoguai, Huayuankou and Lijin

4.1.3 Scheduled reservoirs and parameters

There are many water conservancy projects in the Yellow River basin but what can take the effect of the sediment united scheduling is the mainstream core storage project. In this study, the scheduled objectives are five key reservoirs, i.e., Longyangxia, Liujiaxia, Wanjiazhai, Sanmenxia and Xiaolangdi, and the planning reservoir is Guxian reservoir. The reservoirs parameters are listed in appendix Tab.2.

According to "the adjust and control of the basin water and its application" (Wang, Guangqian et al., 2006), "the Yellow River ice prevention preplan in Year 2011~2012", "the scheduling rules in the initial operation stage of Xiaolangdi sediment retention" and "the scheduling rules in the later operation stage (the first phase) of Xiaolangdi sediment retention", the water level limitation at different time for reservoirs is achieved and listed in appendix Tab. 3.

4.2 Scenarios setup

4.2.1 Consists of scenarios

On the base information of the Yellow River water resources, economy, society, water conservancy project and so on, according to the sustainable water resources development and utilization, as well as ecological water demand rules, it is analyzed of combination of water infrastructure, water demand plan, operation rule, and scheduling targets etc. to form basic scenarios for further programming. The infrastructure includes the existent and the future planned. The water demand plan includes results of the macro-economic water resources model and that from national integrated water resources plan. The operation rule is the ecology-oriented scheduling optimal operation rule witch is to meet the requirement of ecological and environment to the river channel and reservoir flow. The assembly of the conditions can form all kinds of scenarios for the model program and analysis.

（1）Target weights scenarios

In the water allocation, the rule of basin unified scheduling; coordinating the upper and lower stream and the sections is followed. Setting weights for targets reflects the decision-makers' preference to different water use targets. The process is to generate 500 sets weight randomly, and then to seek solutions for the base year low risk ecological water demand situation and medium risk ecological water demand situation respectively. Some maximum differences non-inferior are selected to show the preferences and the correspondingly sets of weight are figure out as basic weights listed at Tab.4-7. It can be seen that the three water demand departments' weights are wider difference which indicates that only the integrally considering the water demands, the optimal allocation and integral utilization of the water resources can be realized.

Tab. 4-7 Weight coefficient of preferences

Preference sets	Agricultural water shortage	Industrial & living water shortage	Ecological water shortage
	w1	w2	w3
1	0.200	0.200	0.600
2	0.376	0.302	0.322
3	0.300	0.350	0.350
4	0.279	0.387	0.334
5	0.209	0.533	0.258
6	0.200	0.550	0.250
7	0.250	0.500	0.250
8	0.318	0.369	0.314
9	0.391	0.337	0.272
10	0.390	0.350	0.260
11	0.360	0.400	0.240

12	0.392	0.348	0.260
13	0.359	0.402	0.238
14	0.400	0.350	0.250
15	0.380	0.400	0.220
16	0.381	0.498	0.121
17	0.400	0.400	0.200

（2）Water resources infrastructure scenarios

The key scale water conservancy project can affect the future ecological water scheduling patterns, including the water storage project and inter-basin water diversion project.

The key storage project which is planned to newly added on the Yellow River basin is Guxian reservoir. It lies between the middle reach Zhikou to the Yumenkou, with 490 km^2 controlling basin area, 645 normal storage water level, 477.6 million m^3 effective capacity and 350 million m^3 profit promoting capacity. The task is mainly to prevent the flood, reduce the sediment, coordinating the power generation, water supply, irrigation, scheduling water and sediment and integral utilization.

The key water diversion project which will affect the research area contains the water transferring from the Yangtze to Yellow river project, the east and middle route project of South-to-North Water Transfer Project and the first stage project of the west route of South-to-North Water Transfer Project.

The water transferring from the Yangtze to the Yellow River

In the plan, the water is taken from two sites. One is the Han River mainstream at Huangjinxia reservoir and the other is the branch Ziwu river Sanhekou reservoir. The planned yearly water transferred is 150 million m^3 with 79 km long water diversion route. The tunnel is 79 km long and the pump lift is 210 m of the Huangjinxia pump station. The project is above Xianyang and the Wei river branch, Hei river, will flow into Wei river. The water supply area is mainly the Guanzhong area in the Wei River basin. Most of it is the urban industrial and living waste water, coordinating the agricultural irrigation and ecological water.

The east and middle route project of South-to-North Water Transfer Project

Transferring the water from the lower reach of the Yangtze reduces the water crises in the north China. he east route takes the water from the Yangtze main stream near Yangzhou, Jiangsu, and sends the water to the north along the Beijing-Hangzhou Grand Canal till to supply the water to the east of Huang-Huai-Hai plain and the eastern Shandong. The middle route project introduces the water from the Taocha brake of Danjiangkou reservoir and reaches Fangchengyakou through the watershed of Yangtze river basin and Huai river basin. Along the border of the Tangbai river basin and west of Huang-Huai-Hai plain, it crosses the Yellow River near Zhengzhou city, Henan Province, and then goes to the north along the Jing-Guang railway and flows to Beijing and Tianjin. According to the Yellow River basin water resources integral planning report, before the east and middle route of the South-to-North water transfer project takes the effect, the Yellow River lower reach supplies to Hebei and Tianjin 200,000,000 m3 water each year. After it takes the effect, the water supply area contains part of Hebei and Tianjin and some area with water shortage in the Yellow River basin. It is planned to supply to Hebei province 620,000,000 m^3 water each year. It stops the water supply to Tianjin.

The west route project of South-to-North Water Transfer Project

It's the key water transfer project to transfer the water into the upper reach of the Yellow River from the Yangtze River upper main and branch stream, which compensates the deficiency of the Yellow River. It's the important strategy to solve the drought and water shortage in northwest part of our country. The west route first stage of the South-to-North water transfer project transfers the water from the area above the Yalongjiang upper reach, Daqu and Hequ of the Xianshuihe of the Yalongjiang branch, Sequ and Dukehe of the Xiyuanchuosijia Rive of Dadu River, Make River and Ake river of the Zumuzu rive of the east source of the Dadu Rive to the Jiaqu of the Yellow River. The transferred water scale is 800,000,000 m3, among which 400,000,000 is planned m3 to supply to Shiyanghe river.

Different water storage engineering and water transferring engineering forms different engineering specification. The Guxian reservoir will opens during the twelfth five years period and the project limit is 10 years. It's supposed to take effect in 2025. The Han-to-Wei project will take effect in 2020, and the middle route of the South-to-North water transfer project will take effect in 2015 and the west route of the South-to-North water transfer project will take effect in 2030. The research studies the impact on the social economic and ecological water from the reservoir by different level years. Tab. 4-8 shows the engineering specifications at different level years and the combination of two projects.

Tab. 4-8 the combination of the water infrastructures

Sets of water infrastructure	Corresponding reference years	Water storage project	Transferred water
0	2005、2020、2030	The existent project	
1	2020、2030	The existent project	Add the Han-to-Wei, the east and middle route of the South-to-North project
2	2030	Add Guxian reservoir	Add the Han-to-Wei, the east and middle route of the South-to-North project
3	2030	Add Guxian reservoir	Add the Han-to-Wei, the east, middle and west route of the South-to-North project

（3）Water demand scenarios

The water demand scenarios are consisted of that in the high, medium and low economic development speeds predicted in macro-economic water resources model. The references years are 2005 as the base year, 2020 and 2030 as the planned level years.

The population and economic data in base year of relevant provinces' in the Yellow River basin is listed in Tab. 4-9 and Tab.4-10.

Tab. 4-9 Regional population in 2005 (10,000)

Provinces	Total population	Town population	Rural population	Urbanization rate
The YR basin	11192.5	4318.7	6873.8	38.6
Qinghai	454.9	175.5	279.4	38.6
Gansu	1811.8	472.9	1338.9	26.1
Ningxia	596.2	207.7	388.5	34.8
Inner Mongolia	820.8	450.7	370.1	54.9
Shanxi	2823.1	1188.3	1634.8	42.1
Shanxi	2187.8	920.8	1267.0	42.1
Henan	1709.6	523.3	1186.3	30.6
Shandong	788.3	379.5	408.8	48.1

Tab. 4-10 Regional GDP in 2005 (100 million Yuan)

Province	Agriculture	Industry	Architecture	Service industry	Total GDP
The YR basin	1408	6130	1001	5768	14307
Qinghai	40	87	50	155	333
Gansu	164	472	118	669	1424
Ningxia	72	229	52	253	606
Inner Mongolia	188	847	175	1027	2237
Shanxi	319	1407	242	1252	3219
Shanxi	168	1006	112	1003	2288
Henan	292	1264	140	757	2452
Shandong	165	817	113	653	1747

Combing the data from “the Yellow River water resources integral programming report”, “the provincial water resources gazette collection in 2005” and “China water resources gazette in 2005”, the water use data in 2005 used in the model is listed in Tab.4-11.

Tab. 4-11 The water use of the Yellow River basin in 2005 (100 million m^3)

Secondary area /Provinces	Agriculture	Industry	domestic	Ecology outside river channel	Total water demand
Above the Longyangxia	2.02	0.14	0.11	0.01	2.28
Longyangxia to Lanzhou	23.51	8.10	2.12	0.29	34.02
Lanzhou to Hekouzhen	162.32	12.85	3.96	1.58	180.70
Hekouzhen to Longmen	10.45	2.64	1.63	0.14	14.86
Longmen to Sanmenxia	76.49	28.01	10.73	1.50	116.73
Sanmenxia to Huayuankou	16.78	12.44	3.06	0.27	32.55
Below Huayuankou	33.96	6.47	3.01	0.20	43.66
Interior drainage area	3.92	0.44	0.13	0.44	4.94
Qinghai	14.84	3.47	1.13	0.09	19.53
Gansu	0.10	0.01	0.00	0.00	0.20
Ningxia	28.89	11.89	3.42	0.33	44.53
Inner Mongolia	76.69	3.58	1.21	1.22	82.70
Shanxi	83.58	7.46	2.29	0.77	94.10
Shanxi	48.60	15.52	6.66	1.27	72.05
Henan	29.54	10.73	4.29	0.30	44.86
Shandong	33.29	12.96	3.89	0.27	50.41
Qinghai	14.01	5.50	1.87	0.18	21.56
Total for Yellow River Basin	329.45	71.09	24.75	4.44	429.73

According to the social economic development strategy plan of provinces in the basin and the national economic development plan published, the macro-economic water resources model is employed to analysis and predict water demands. Three economic developing scenarios, high, medium and low and the relevant water resources demand are figure out. The prediction of main economic index and water demand are listed in appendix Tab.4~Tab.8, as well as Fig.4-2 and Fig.4-3.

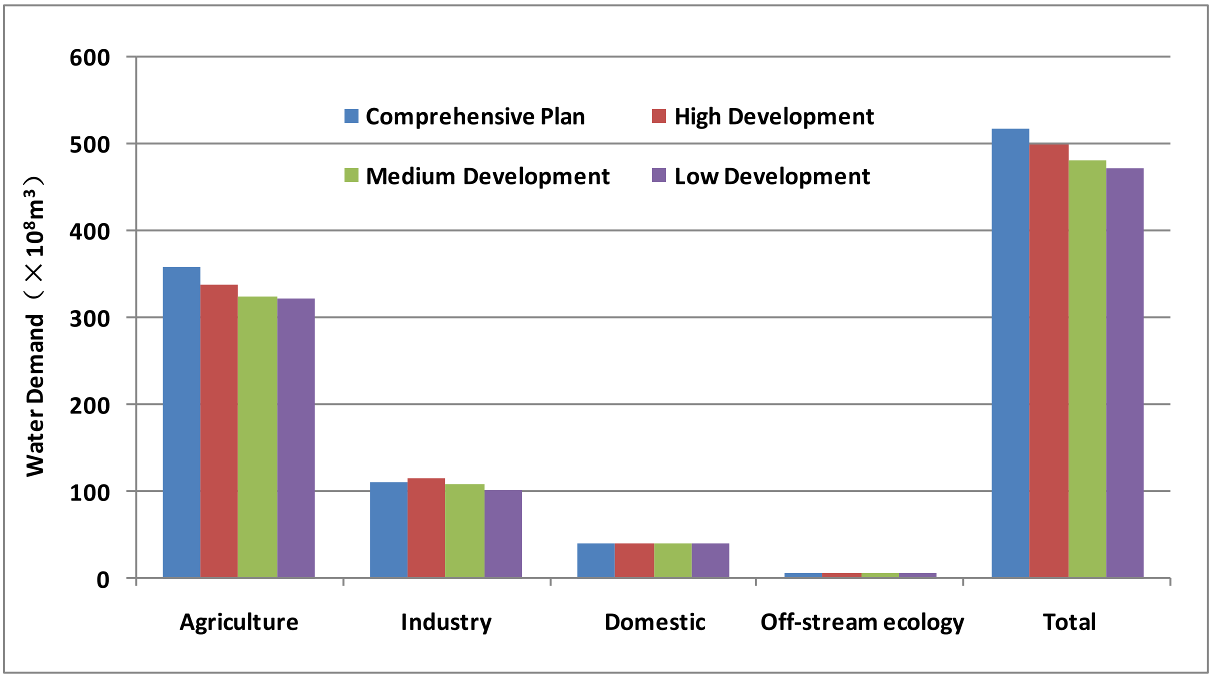

Fig. 4-2 water demands in the Yellow River at Year 2020

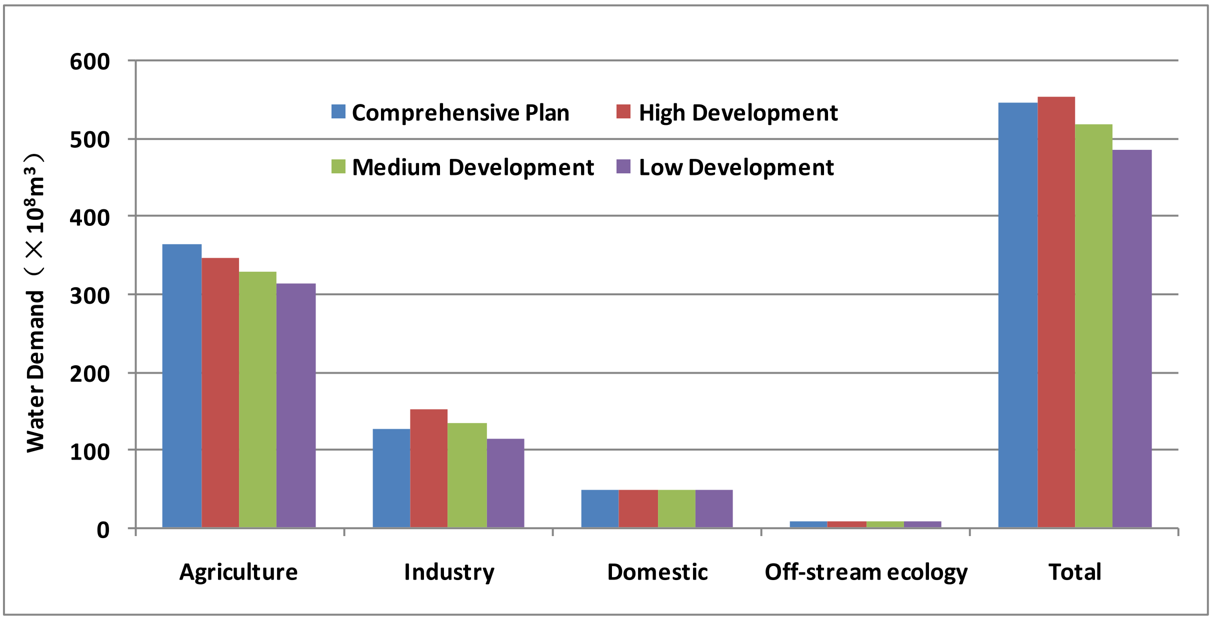

Fig. 4-3 water demands in the Yellow River at Year 2030

Besides water supply within basin, there is also water supply for outside Yellow River basin include for Shiyang River basin in Gansu, as well as Henan, Shandong, Hebei and Tianjin provinces. In the future, the more water is planned for Shiyang Basin and Shanxi Province. Referring to the *"Yellow*

River water resources integral programming report", the water supply outside Yellow River basin are listed in appendix Tab.8-9.

Combing different preferences, water demands and infrastructures forms the integration scenarios of the ecological scheduling. Some possible scenarios are selected for the further analysis and listed in Tab.4-12. The scenarios are to be optimized by the ecological scheduling analysis model.

Tab. 4-12 Integration scenarios and contents

Reference years	Water demands	Infrastructures	Preferences
2005	Base year	set 0	17 items
2020	Unified plan	sets 0, 1	17 items
	High economy	sets 0, 1	17 items
	Medium economy	sets 0, 1	17 items
	Low economy	sets 0, 1	17 items
2030	Unified plan	sets 0, 1, 2, 3	17 items
	High economy	sets 0, 1, 2, 3	17 items
	Medium economy	sets 0, 1, 2, 3	17 items
	Low economy	sets 0, 1, 2, 3	17 items

4.2.2 Evaluation criteria of scenarios

The multi-objective optimization can't get the simple optimal solution but only the non-inferior solution among contradictory targets. Non-inferior solutions form solution sets under scenarios. The increment of one target value in non-inferior solution only can be achieved by reducing other targets' value, i.e., it depends on the decision-makers prefer or wish to reduce one target's value to exchange another target's increment. Generally speaking, the optimal solution of the multi-target problem depends on the balance result of the decision-makers.

For the convenience of comparing and balancing the solution values on the targets for the decision-maker and analyzer under the different scenarios and selecting the optimal scheduling plan, the evaluation index system of the plan is built to compare the scheduling sets. The main evaluation indexes contains the social economic water deficit, the ecological section water deficit, the ecological section water deficit rate, the ecological section duration rate and the river channel ecological water deficit, on sum the 5 parameters. The river channel ecological water deficit can be achieved by the ecological section water deficit.

（1）Social economic water deficit: it's the lose value between the social economic water demand and the scheduled social economic water supply, which is the sum of all the time section water deficit of all the sections. It reflects the unsatisfied content of the social economic water supply;

（2）The ecological section water deficit: it depends on the scheduled ecological section flow and the inner-year process of the ecological water demand. When the scheduled run-off is smaller than the ecological water demand, the difference is the ecological section water deficit.

The river channel ecological water deficit is achieved by the ecological section deficit. The river channel time ecological water deficit equals to the maximum ecological water deficit of all the section time on the river channel, adding all time period maximum ecological water deficit can get the river channel ecological water deficit;

(3) the ecological section water deficit rate: the ecological section water deficit/ the ecological section water demand ×100%;

(4) the ecological section duration rate: it refers to percentage of the time duration (day, ten days or month) which meets the ecological section flow to the total time, i.e.

$$P = \frac{\text{the time duration (day, ten days or month) which meets the ecological section flow}}{\text{the total time (day, ten days or month)}} \times 100\%$$

In the research, the ecological section moth duration rate is used to evaluate the assurance state of all the ecological section water demand.

4.3 Ecological water use rational schedule seeking

To find rational ecological water use allocation schedule, the analysis and seeking strategies are set as below.

4.3.1 Analysis under the current (base) condition

The current (base) condition is as the basic comparison plan, to demonstrate the sound water allocation schedule under current water demands condition and existent water conservancy infrastructures. With the model, the satisfaction of ecological social economic water demand will be analyzed preferences. The results are listed in Tab. 4-13 to Tab.4-15.

Tab. 4-13 The water demand deficits in base year (100 million m^3)

preference	Low risk ecological water demands deficits					Medium risk ecological water demands deficits				
	Domestic & industrial	Agricultural	Social, economic	ecological	total water deficit	Domestic & industrial	Agricultural	Social, economic	ecological	total water deficit
1	12.32	21.16	33.48	0.47	33.95	6.81	12.55	19.36	0.06	19.42
2	15.55	16.89	32.45	1.33	33.77	8.82	9.48	18.30	1.10	19.40
3	3.03	23.27	26.30	7.20	33.50	1.59	14.94	16.54	2.77	19.30
4	1.34	23.72	25.05	8.36	33.42	0.74	15.15	15.89	3.47	19.36
5	0.59	24.31	24.90	8.80	33.70	0.59	15.15	15.74	3.61	19.34
6	0.58	24.31	24.89	8.81	33.70	0.58	15.15	15.72	3.63	19.35
7	0.66	22.92	23.59	10.04	33.63	0.67	14.44	15.11	4.15	19.26

8	1.70	21.03	22.72	10.53	33.25	0.89	13.00	13.89	5.35	19.24
9	5.49	16.08	21.56	11.95	33.52	4.48	9.31	13.79	5.40	19.19
10	5.45	14.27	19.72	14.32	34.03	4.47	9.30	13.77	5.41	19.18
11	1.70	17.19	18.89	15.32	34.21	0.85	12.83	13.68	5.53	19.20
12	5.48	12.09	17.57	16.52	34.09	4.47	9.20	13.68	5.54	19.22
13	1.70	15.04	16.74	17.54	34.28	0.85	12.73	13.58	5.66	19.24
14	5.48	10.23	15.71	18.94	34.65	4.48	9.12	13.59	5.66	19.25
15	1.73	12.98	14.71	20.04	34.74	0.93	12.52	13.45	5.79	19.24
16	0.67	12.61	13.28	21.68	34.96	0.67	12.61	13.28	6.12	19.41
17	2.78	11.05	13.82	21.07	34.89	2.87	10.51	13.38	5.92	19.30

Tab. 4-14 Ecological water demands deficit of low ecological risk in the base year (100 million m^3 ,%)

preferences	Section of Huayuankou			Section of Lijin		
	Water deficit	Deficit rate	Monthly probability	Water deficit	Deficit rate	Monthly probability
1	0.42	0.19	99.44	0.00	0.00	100.00
2	0.54	0.24	99.44	0.00	0.00	100.00
3	1.92	0.87	96.94	4.91	3.28	92.78
4	1.99	0.89	96.94	6.17	4.12	91.67
5	2.19	0.98	96.94	6.52	4.36	91.11
6	2.16	0.97	96.94	6.57	4.39	91.11
7	2.22	1.00	96.94	6.80	4.55	90.83
8	2.16	0.97	96.67	6.86	4.58	90.56
9	2.42	1.09	96.67	7.18	4.80	89.44
10	2.60	1.17	96.11	8.34	5.58	88.89
11	2.53	1.14	96.11	8.78	5.87	88.33
12	2.93	1.32	95.56	9.63	6.44	87.22
13	3.04	1.37	95.00	9.88	6.61	87.50
14	3.38	1.52	94.72	10.58	7.08	86.11
15	3.39	1.53	94.72	11.07	7.40	85.56
16	3.95	1.78	93.89	11.98	8.01	84.72
17	3.56	1.60	94.17	11.67	7.80	85.00

Tab. 4-15 Ecological water demands deficit of medium ecological risk in the base year (100 million m^3 ,%)

preferences	Section of Huayuankou			Section of Lijin		
	Water deficit	Deficit rate	Monthly probability	Water deficit	Deficit rate	Monthly probability
1	0.00	0.00	100.00	0.00	0.00	100.00
2	0.10	0.07	99.72	0.00	0.00	100.00
3	0.25	0.17	99.17	2.34	2.07	96.11
4	0.26	0.18	99.17	2.62	2.31	95.56
5	0.37	0.25	98.89	2.76	2.43	95.56
6	0.38	0.26	98.89	2.76	2.44	95.56
7	0.44	0.29	98.89	2.96	2.61	95.28
8	0.35	0.24	98.89	3.36	2.97	94.72
9	0.43	0.29	98.89	3.44	3.03	94.72
10	0.41	0.28	98.89	3.47	3.06	94.72
11	0.47	0.31	98.89	3.43	3.02	94.72
12	0.52	0.35	98.89	3.44	3.03	94.72
13	0.45	0.30	98.89	3.51	3.10	94.72
14	0.52	0.35	98.89	3.50	3.09	94.72
15	0.54	0.36	98.89	3.51	3.10	94.72
16	0.51	0.34	98.89	3.77	3.33	95.00
17	0.46	0.31	98.89	3.66	3.23	94.44

Plotting social economic and ecological water deficit under preferences together as Fig.4-4, we can make tradeoff easily. The ideal solution is the zero point of both the social economic and ecological water deficit.

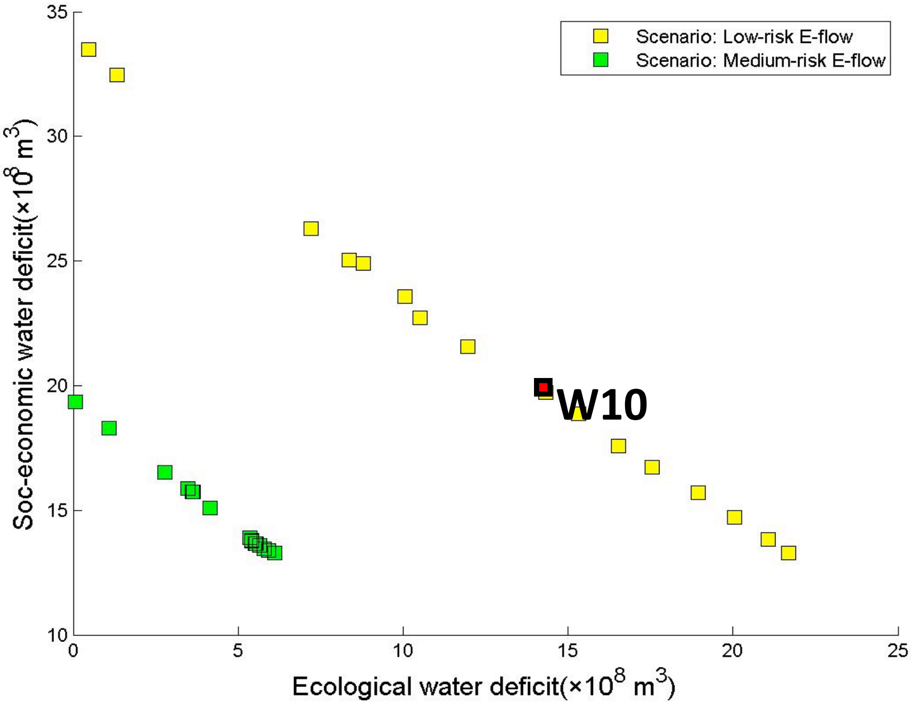

Fig. 4-4 The non-inferior sets in the base year

From all above we may find that with the ecological scheduling under the medium ecological risk water demand in all the preferences, the ecological water demand deficit and deficit rate in all main sections of Yellow River are small and with higher probability. so it's appropriate to select the low risk ecological water demand as the ecological scheduling target to get the healthier river state. (Hereinafter the ecological water deficit especially refers to the low risk water deficit of the ecological water demand.) After integrally considering the social economic development speed and the requirement of the low risk ecological water demand, the low risk ecological scheduling with preferences 10 is recommended as the reservoir scheduling alternative option. In this option, it is more prefer to the social economy and slightly inclines to the agriculture. There is as the same consideration as current actual situation. Correspondingly, the living, industrial and urban environment water demand deficit is 545 million m^3, and the agricultural water deficit is 1,427 million m^3, and the ecological water deficits are 260 million m^3 and 834 million m^3 at Huayuankou and Lijin respectively. The total ecological water deficit in Yellow River mainstream is 1433 million m^3. Compared to preference 16 which ecological target weight is smallest, the recommended scheduling preference 10 has 644 million m^3 reducing on social economic water supply and the low risk ecological water deficit reduces 736 million m^3. That is to say, the ecological scheduling is benefit from sacrificing a certain of social economic water supply.

4.3.2 Analysis on water demands of integrated water resources plan

（1）optimal scheduling analysis for future of year 2020

For the analysis of the programming in reference years, according to the future infrastructure and predicted the water demand assemblies in Tab. 4-12, the situation for year 2020 is focus on water resources infrastructure scenarios 0 and 1 and the water demand in 2020. The water deficits of different departments are listed in Tab. 4-16 to Tab.4-18. The non-inferior set of the social economic and ecological water deficit is shown in Fig. 4-5 and Fig. 4-6.

Tab. 4-16 The water demand deficits in infrastructure 1 of year 2020 (100 million m^3)

preference	Low risk ecological water demands deficits					Medium risk ecological water demands deficits				
	Domestic & industrial	Agricultural	Social, economic	ecological	total water deficit	Domestic & industrial	Agricultural	Social, economic	ecological	total water deficit
1	19.44	37.98	57.42	0.41	57.82	12.48	28.12	40.60	0.05	40.65
2	23.67	32.13	55.81	1.87	57.68	16.98	22.93	39.91	0.79	40.70
3	6.64	40.96	47.60	9.85	57.45	5.44	31.20	36.65	3.85	40.50
4	3.33	41.55	44.88	12.55	57.43	2.39	32.58	34.97	5.79	40.76
5	2.14	45.47	47.60	10.87	58.47	2.14	34.67	36.80	4.34	41.14
6	2.11	46.69	48.80	9.92	58.71	2.11	35.54	37.65	3.68	41.33
7	2.25	42.36	44.61	13.20	57.81	2.25	32.17	34.43	6.26	40.68
8	3.87	40.49	44.37	12.87	57.23	3.47	30.75	34.22	6.14	40.37
9	11.63	31.96	43.59	13.65	57.23	11.16	22.40	33.55	7.10	40.65
10	11.51	30.63	42.14	15.59	57.74	11.15	22.40	33.55	7.10	40.65
11	4.17	36.29	40.45	17.54	58.00	3.44	30.37	33.81	6.65	40.46
12	11.56	30.54	42.10	15.63	57.73	11.22	22.26	33.48	7.17	40.65
13	4.16	36.29	40.45	17.54	58.00	3.43	30.38	33.81	6.65	40.46
14	11.56	24.43	35.99	23.27	59.25	11.22	22.03	33.25	7.48	40.73
15	4.25	29.83	34.08	25.65	59.73	3.52	28.46	31.98	8.95	40.92
16	2.22	28.22	30.45	30.47	60.92	2.23	28.20	30.43	11.22	41.65
17	5.52	27.64	33.17	27.14	60.30	6.18	24.53	30.71	10.97	41.68

Tab.4-17 Ecological water demands deficit of low ecological risk in year 2020 (100 million m^3 ,%)

preferences	Section of Huayuankou			Section of Lijin		
	Water deficit	Deficit rate	Monthly probability	Water deficit	Deficit rate	Monthly probability
1	0.40	0.18	99.44	0.00	0.00	100.00
2	0.66	0.29	99.17	0.36	0.24	99.44
3	2.61	1.18	95.83	7.12	4.76	88.61
4	2.81	1.27	95.56	9.73	6.51	86.11
5	2.68	1.21	96.11	8.30	5.55	88.61

6	2.58	1.16	96.11	7.45	4.98	89.72
7	3.10	1.40	95.00	10.18	6.81	85.56
8	2.83	1.27	95.83	9.78	6.54	85.83
9	3.01	1.35	95.28	9.80	6.55	86.67
10	3.01	1.35	95.28	10.47	7.00	85.56
11	3.48	1.57	94.17	10.73	7.17	85.28
12	3.05	1.37	95.28	10.47	7.00	85.56
13	3.48	1.57	94.17	10.73	7.17	85.28
14	4.42	1.99	92.78	13.83	9.25	80.56
15	4.84	2.18	91.94	14.29	9.56	80.00
16	7.39	3.32	89.72	17.36	11.61	78.61
17	5.04	2.27	91.67	14.93	9.99	78.89

Tab.4-18 Ecological water demands deficit of medium ecological risk in year 2020 (100 million m^3 ,%)

preferences	Section of Huayuankou			Section of Lijin		
	Water deficit	Deficit rate	Monthly probability	Water deficit	Deficit rate	Monthly probability
1	0.00	0.00	100.00	0.00	0.00	100.00
2	0.10	0.07	99.72	0.00	0.00	100.00
3	0.41	0.27	98.89	3.03	2.67	95.28
4	0.72	0.49	98.61	4.69	4.14	93.33
5	0.44	0.30	98.89	3.66	3.23	95.83
6	0.47	0.32	98.89	2.96	2.61	95.83
7	0.74	0.50	98.61	4.90	4.32	93.33
8	0.70	0.47	98.61	4.83	4.26	93.33
9	0.96	0.64	98.06	5.15	4.54	92.78
10	0.95	0.64	98.06	5.15	4.54	92.78
11	0.85	0.57	98.33	4.74	4.18	93.33
12	1.01	0.68	98.06	5.15	4.54	92.78
13	0.86	0.58	98.33	4.74	4.18	93.33
14	1.02	0.68	98.06	5.33	4.70	92.78

15	0.82	0.55	98.61	6.19	5.46	91.67
16	0.84	0.57	98.33	7.69	6.78	89.72
17	0.87	0.58	98.33	7.31	6.45	90.00

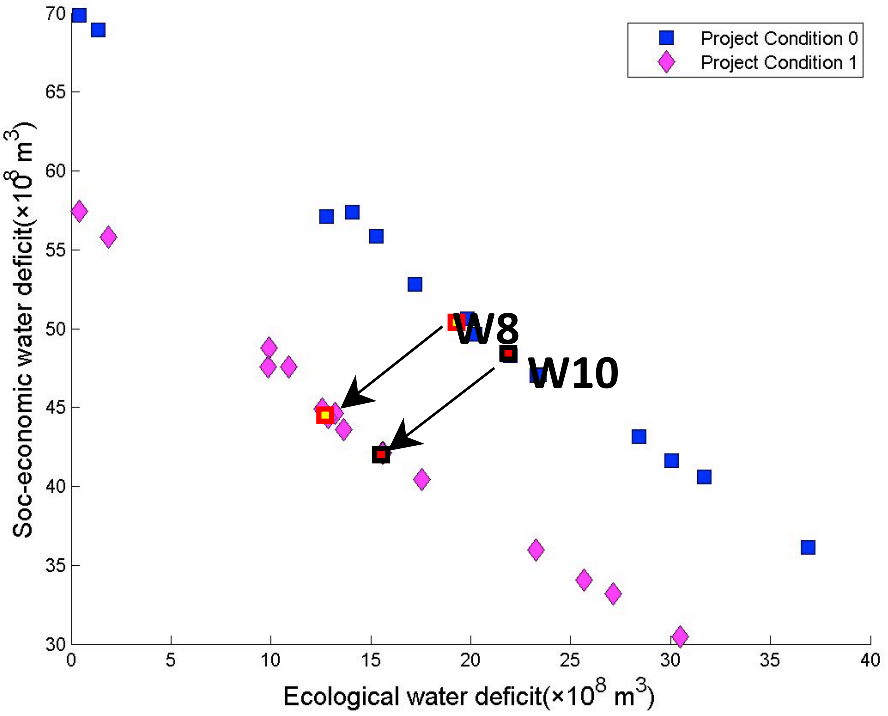

Fig. 4-5 The non-inferior sets in low ecological risk at year 2020

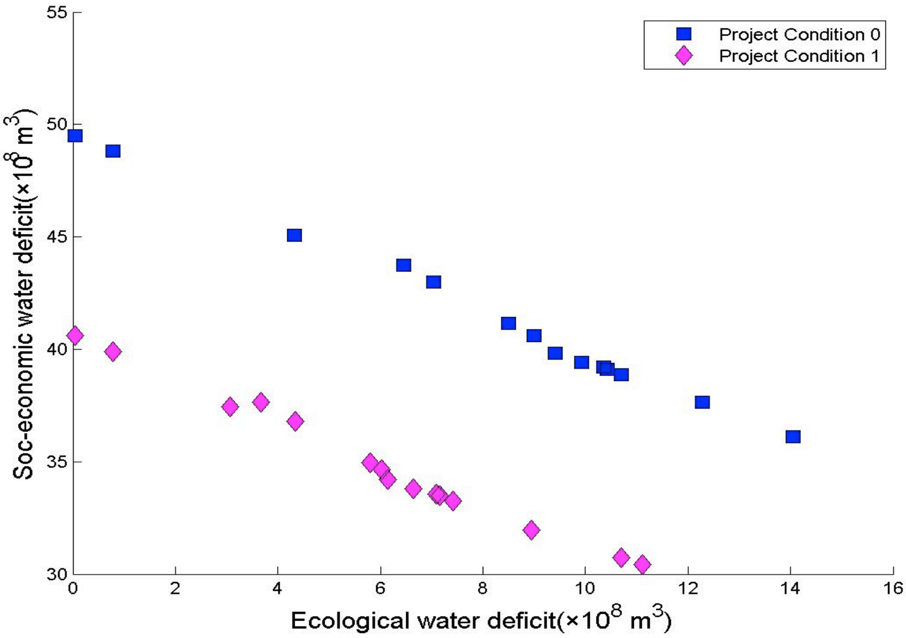

Fig. 4-6 The non-inferior sets in medium ecological risk at year 2020

From Fig. 4-5 and 4-6 we can find, for the year 2020 water demand, the increased diversion water from inter-basin transferring project (east and middle route of the South-to-North water transfer project, Han-to-Wei project) can obviously reduce the social economic and the ecological water deficit in the Yellow River basin. But as the great increased water demand within basin, the total water deficit is larger than that in 2005, especially in agricultural, even when there is the inter-basin water transferring.

Similar to the base year, we select the low risk ecological water demand as the ecological target of the reservoir scheduling for discussion. Integrally considering social economic development speed and improvement of people's knowledge about the ecological environment protection, preference 8 is selected as the ecological scheduling alternative option for 2020 seen in Fig.4-5. Compared to the preference 10 in base year, the preference is lighter the agricultural weight and increases the industrial and ecological weights, and then get the equivalent weight in three departments. Firstly to mention, the solution of preference 8 is the smallest in total water deficit among all the preference in year 2020. The domestic, industrial and urban environment water deficit is 387 million m^3, and the agricultural water deficit is 4049 million m^3, and the ecological water deficit is 1287 million m^3. The ecological water deficits are 283 million m^3 and 987 million m^3 and the ecological water probability of 95.28% and 84.44% at Huayuankou and Lijin section respectively,. The preference prefers more to ecology than the preference 10 recommended in base year.

（2）optimal scheduling analysis in future year 2030

For the analysis of the programming reference years, according to the future infrastructures and the water demands assemblies in Tab. 4-12, the scenarios of year 2030 is focus on infrastructures 0, 1, 2 and 3, in all preferences. The non-inferior of water deficits of departments are shown in Fig 4-7 and Fig 4-8. If the west route of the South-to-North water transfer project can't take effect as expected in 2030, i.e., the infrastructure scenario 2, the water deficit of all the departments is listed in Tab.4-19, Tab.4-21 and Tab.4-22. On the contrary, the west route of the South-to-North water transfer project takes effect as expected i.e. the infrastructure scenario 3, the water deficit of all the departments is listed in Tab. 4-20, Tab.4-23 and Tab.4-24.

Tab. 4-19 The water demand deficits in infrastructure 2 of year 2030 (100 million m^3)

	Low risk ecological water demands deficits					Medium risk ecological water demands deficits				
preference	Domestic & industrial	Agricultural	Social, economic	ecological	total water deficit	Domestic & industrial	Agricultural	Social, economic	ecological	total water deficit
1	23.26	44.35	67.61	0.46	68.06	15.69	33.05	48.74	0.05	48.80

2	29.09	37.58	66.67	1.42	68.09	22.11	26.43	48.54	0.46	49.00
3	9.86	47.25	57.12	10.63	67.74	7.33	37.07	44.40	4.26	48.66
4	5.17	48.52	53.70	14.09	67.79	3.99	38.70	42.69	6.29	48.98
5	3.72	55.55	59.26	10.21	69.47	3.72	42.97	46.69	3.04	49.72
6	3.69	56.97	60.66	9.10	69.75	3.69	43.88	47.57	2.33	49.90
7	3.84	49.08	52.92	15.41	68.33	3.84	38.69	42.53	6.38	48.92
8	6.24	46.21	52.45	15.00	67.45	5.31	36.27	41.58	6.98	48.56
9	14.53	37.46	51.99	15.68	67.67	14.87	26.15	41.01	7.93	48.94
10	13.86	35.81	49.66	17.98	67.64	14.29	26.77	41.07	7.74	48.80
11	6.26	42.03	48.29	19.24	67.53	5.32	35.86	41.18	7.44	48.62
12	13.97	35.70	49.66	17.90	67.57	14.38	26.69	41.07	7.75	48.82
13	6.19	42.11	48.29	19.29	67.58	5.26	35.92	41.19	7.44	48.63
14	14.34	29.95	44.29	24.14	68.43	14.94	24.10	39.04	10.32	49.36
15	6.47	36.19	42.66	26.16	68.82	5.31	32.20	37.51	11.87	49.38
16	3.84	31.98	35.82	34.33	70.15	3.86	31.94	35.80	14.66	50.46
17	7.91	33.44	41.35	27.56	68.91	8.62	27.67	36.29	13.83	50.12

Tab. 4-20 The water demand deficits in infrastructure 3 of year 2030 (100 million m^3)

preference	Low risk ecological water demands deficits					Medium risk ecological water demands deficits				
	Domestic & industrial	Agricultural	Social, economic	ecological	total water deficit	Domestic & industrial	Agricultural	Social, economic	ecological	total water deficit
1	14.00	27.58	41.58	0.05	41.64	10.85	24.85	35.70	0.00	35.70
2	18.35	23.07	41.41	0.20	41.62	15.37	20.34	35.71	0.00	35.71
3	5.88	32.77	38.65	2.89	41.54	3.81	31.75	35.56	0.14	35.71
4	3.95	33.06	37.01	4.56	41.57	3.81	31.75	35.56	0.14	35.71
5	3.72	37.29	41.01	1.34	42.35	3.66	32.10	35.76	0.11	35.87
6	3.69	38.18	41.87	0.66	42.53	3.66	32.10	35.76	0.11	35.87
7	3.72	32.18	35.90	5.53	41.43	3.73	31.78	35.50	0.21	35.71
8	4.22	31.88	36.10	5.32	41.42	3.81	31.75	35.56	0.14	35.71

9	12.99	22.86	35.85	5.54	41.39	15.22	20.34	35.56	0.14	35.71
10	12.68	22.96	35.65	5.59	41.23	15.20	20.21	35.42	0.25	35.67
11	4.13	31.49	35.62	5.58	41.21	3.81	31.61	35.42	0.25	35.67
12	12.77	22.88	35.65	5.60	41.25	15.20	20.21	35.42	0.25	35.67
13	4.09	31.54	35.62	5.59	41.22	3.81	31.61	35.42	0.25	35.67
14	12.93	22.60	35.52	5.73	41.25	15.21	20.16	35.37	0.29	35.66
15	4.13	31.32	35.45	5.73	41.18	3.84	31.53	35.37	0.29	35.66
16	3.81	31.48	35.29	5.96	41.25	3.81	31.48	35.29	0.44	35.73
17	8.62	26.82	35.43	5.76	41.19	10.65	24.72	35.37	0.29	35.66

Tab.4-21 Ecological water demands deficit of low ecological risk an infrastructure 2 of year 2030 (100 million m^3 ,%)

preferences	Section of Huayuankou			Section of Lijin		
	Water deficit	Deficit rate	Monthly probability	Water deficit	Deficit rate	Monthly probability
1	0.40	0.18	99.44	0.00	0.00	100.00
2	0.83	0.37	98.89	0.37	0.25	99.44
3	2.86	1.29	95.56	7.84	5.24	87.50
4	3.37	1.52	94.17	11.03	7.37	85.56
5	2.56	1.15	96.11	8.03	5.37	88.06
6	2.43	1.09	96.11	7.06	4.72	90.00
7	3.91	1.76	93.61	11.19	7.48	84.44
8	3.59	1.61	93.89	10.89	7.28	85.28
9	3.80	1.71	93.89	11.17	7.47	83.61
10	3.93	1.77	93.61	12.02	8.04	83.06
11	3.92	1.77	93.33	12.52	8.37	83.33
12	3.94	1.77	93.61	12.04	8.05	83.06
13	3.93	1.77	93.33	12.52	8.37	83.33
14	4.95	2.23	91.67	15.32	10.25	78.61
15	5.07	2.28	91.11	15.78	10.55	77.78
16	10.03	4.51	87.22	21.21	14.18	76.39
17	5.49	2.47	90.56	16.59	11.09	76.94

表 4-22 Ecological water demands deficit of medium ecological risk

an infrastructure 2 of year 2030 (100 million m^3 ,%)

preferences	Section of Huayuankou			Section of Lijin		
	Water deficit	Deficit rate	Monthly probability	Water deficit	Deficit rate	Monthly probability
1	0.00	0.00	100.00	0.00	0.00	100.00
2	0.10	0.07	99.72	0.00	0.00	100.00
3	0.78	0.52	98.61	3.31	2.92	94.17
4	0.71	0.48	98.61	5.42	4.78	92.50
5	0.57	0.38	98.89	2.49	2.19	95.83
6	0.58	0.39	98.89	1.77	1.56	96.94
7	0.79	0.53	98.33	5.51	4.86	91.94
8	0.79	0.53	98.33	5.44	4.80	92.50
9	0.79	0.53	98.33	6.10	5.38	91.11
10	0.87	0.58	98.33	5.83	5.14	91.67
11	0.82	0.55	98.33	5.45	4.81	92.22
12	0.79	0.53	98.33	5.92	5.22	91.39
13	0.82	0.55	98.33	5.46	4.82	91.94
14	0.94	0.63	98.33	7.50	6.61	89.17
15	0.84	0.57	98.06	8.32	7.34	88.06
16	1.13	0.76	97.78	9.73	8.58	86.67
17	1.10	0.74	97.78	9.17	8.09	87.22

表 4-23 Ecological water demands deficit of low ecological risk an infrastructure 3 of year 2030 (100 million m^3 ,%)

preferences	Section of Huayuankou			Section of Lijin		
	Water deficit	Deficit rate	Monthly probability	Water deficit	Deficit rate	Monthly probability
1	0.05	0.02	99.44	0.00	0.00	100.00
2	0.20	0.09	99.44	0.00	0.00	100.00
3	0.79	0.36	98.61	2.12	1.42	96.11
4	1.11	0.50	97.78	3.51	2.35	95.00
5	0.61	0.27	99.17	0.90	0.60	98.89
6	0.45	0.20	99.44	0.38	0.25	99.44

7	1.54	0.69	97.50	4.30	2.88	94.17
8	1.37	0.61	97.50	4.09	2.73	94.17
9	1.49	0.67	97.50	4.27	2.86	94.17
10	1.68	0.76	97.22	4.29	2.87	93.89
11	1.63	0.74	97.50	4.36	2.91	93.89
12	1.69	0.76	97.22	4.29	2.87	93.89
13	1.63	0.74	97.50	4.36	2.92	93.89
14	1.76	0.79	97.22	4.44	2.97	93.89
15	1.70	0.77	97.50	4.49	3.00	93.89
16	1.72	0.77	97.22	4.59	3.07	93.89
17	1.70	0.77	97.50	4.50	3.01	93.89

表 4-24 Ecological water demands deficit of medium ecological risk an infrastructure 3 of year 2030 (100 million m^3 ,%)

preferences	Section of Huayuankou			Section of Lijin		
	Water deficit	Deficit rate	Monthly probability	Water deficit	Deficit rate	Monthly probability
1	0.00	0.00	100.00	0.00	0.00	100.00
2	0.00	0.00	100.00	0.00	0.00	100.00
3	0.00	0.00	100.00	0.14	0.13	99.44
4	0.00	0.00	100.00	0.14	0.13	99.44
5	0.00	0.00	100.00	0.11	0.09	99.72
6	0.00	0.00	100.00	0.11	0.09	99.72
7	0.07	0.04	99.72	0.21	0.19	99.44
8	0.00	0.00	100.00	0.14	0.13	99.44
9	0.00	0.00	100.00	0.14	0.13	99.44
10	0.11	0.07	99.72	0.25	0.22	99.44
11	0.11	0.07	99.72	0.25	0.22	99.44
12	0.11	0.07	99.72	0.25	0.22	99.44
13	0.11	0.07	99.72	0.25	0.22	99.44
14	0.14	0.10	99.44	0.29	0.25	99.44
15	0.14	0.10	99.44	0.29	0.25	99.44

16	0.14	0.10	99.44	0.29	0.25	99.44
17	0.14	0.10	99.44	0.29	0.25	99.44

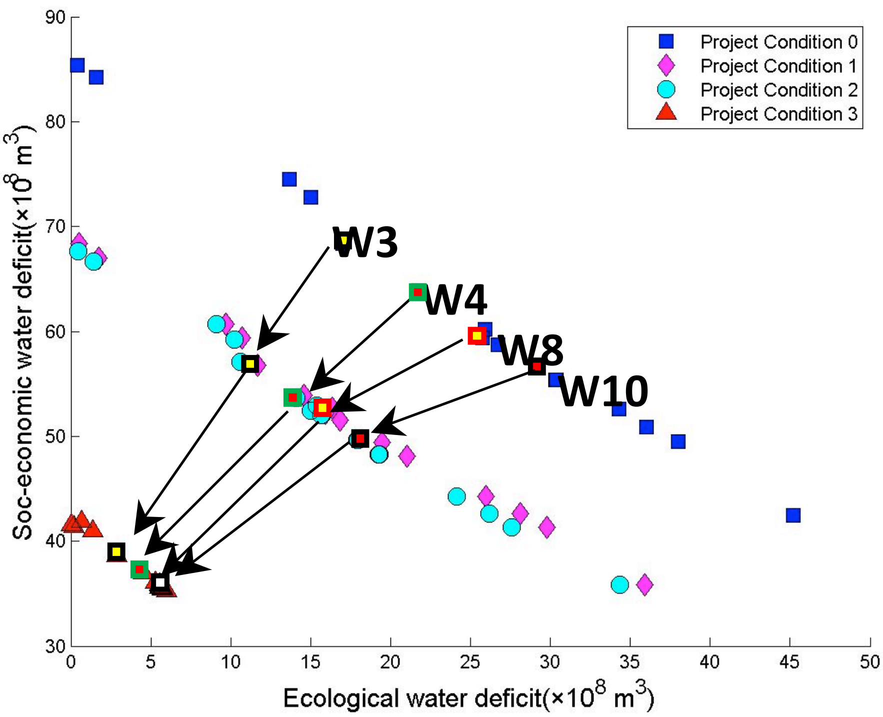

Fig. 4-7 The non-inferior sets in low ecological risk at year 2030

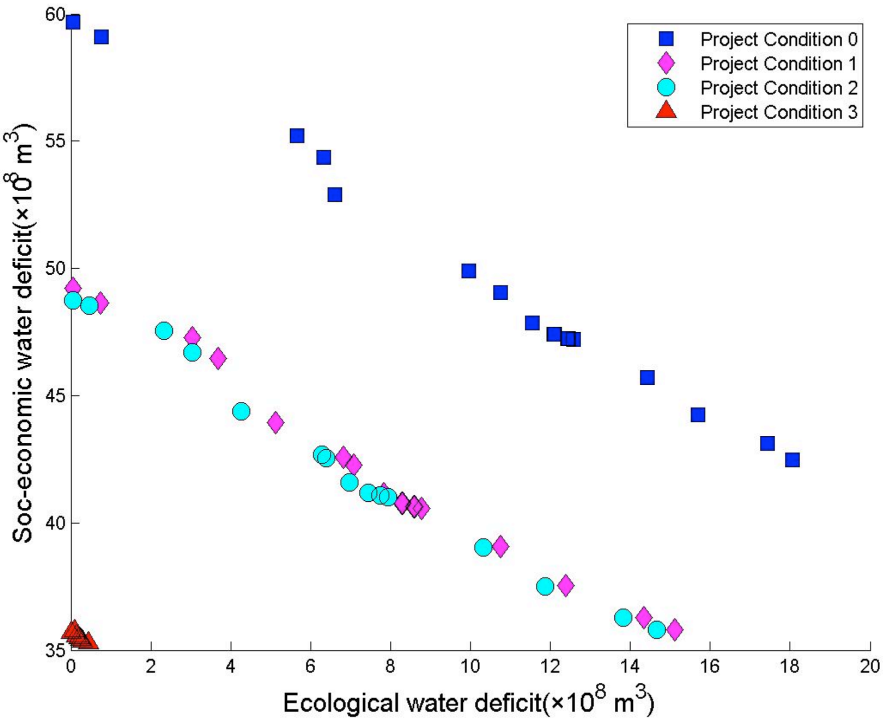

Fig. 4-8 The non-inferior sets in medium ecological risk at year 2030

From results above, it can be seen that the yearly 8,000 million m^3 water diversion from the west route of the South-to-North water transfer project has good effect on alleviating both ecological and the social economic water deficit of Yellow River basin, and the decrement of the ecological water deficit is larger than that in social economic water deficit as recommended preference. Furthermore, it also shows that the south route of the South-to-North water transfer project can almost meet the ecological water demand under the medium risk ecological target, and near that in the base year for the low risk ecological water demand target. This might be imaged that the west route water diversion project of South-to-North water transfer project were significant for ecological protecting in the Yellow River. Otherwise, the construction of the Guxian reservoir has limited effect to appease the water deficit in the basin. The result shows that the nature of the Yellow River is mainly the problem of water resources shortage. In current situation, only to increase the storage ability is limited to improving both ecological and social economic water supply. To increase the total usable water resources in the basin is the sound way to solve the water shortage in the basin. What's more, because of the social economic development, the water demand of all the departments will be increased, so even there is inter-basin water diversion, the social economic water deficit won't reach that in the base year as considering the ecological water demand. So, to further reduce the social economic water deficit, it should takes advantages of basin itself, to continue strengthen the water-saving, put the strictest water resources management forward, and reduce the social economic water demand.

For the infrastructure scenario 2 that the west route won't take effect as expected, we select the low risk ecological water demand as the reservoir scheduling target and also pay attention on the medium risk ecological water demand, so the ecological weight won't too small. After the integrally consideration, the preference 4 is selected as the recommend alternative option, as shown in Fig. 4-7. By this preference, the domestic, industrial and urban environment water deficit will be 517 million m^3, the agricultural water deficit will be 4,852 million m^3, and the ecological water deficit will be 1,409 million m^3. The ecological water deficits are 337 million m^3 and 1,103 million m^3, and with ecological water probability of 93.89% and 83.89% at Huayuankou and Lijin sections respectively. This preference is prefer more to ecology than the preference 8 recommended by the 2020 level year.

For the infrastructure scenario 3 that the west route takes effect, the preference 3 with low risk ecological scheduling is selected as the recommended alternative option as shown in Fig. 4-7. By the option, the domestic, industrial and urban environment water deficit will be 588 million m^3, the agricultural water deficit will be 3,277 million m^3, and the ecological water deficit will be 289 million m^3. The ecological water demand at Huayuankou section and Lijin section can be met basically. The preference doesn't prefer more to ecology than the preference 4 recommended at the year 2030 of without the west route.

（3） discussion and comparison of the recommended options

As shows above, for the different reference years, as the ecological civilization advancd and social living standard improved, the most development strategies will along the way of preference from preferring to agricultural, and then to industrial, and then to ecological gradually. As the development direction, the social economic and ecological water deficit under different alternative options is listed in Tab. 4-25.

Tab. 4-25 the water deficits of the recommended option in reference years (100 million m^3)

Target year	Water Deficit			
	Industry & domestic	Agriculture	Social economy	Low-risk e-flow
2005（W10）	5.45	14.27	19.72	14.32
2020（W8）	3.87	40.49	44.37	12.87
2030（P2+W4）	5.17	48.52	53.70	14.09
2030（P3+W3）	5.88	32.77	38.65	2.89

For the recommend options, the economic and ecological water deficits in future years' are listed in Tab.4-26 and Fig.4-9 and Fig.4-10. This is helpful to discuss the significant of planning projects. In which, we use the option of without west South-to North Water Transferring project.

Tab. 4-26 future water deficits of infrastructure scenarios (100 million m^3)

Target year	Project Condition	Water Deficit			
		Industry & domestic	Agriculture	Social economy	Low-risk e-flow
2020	P0(W8)	6.12	44.26	50.38	19.28
	P1(W8)	3.87	40.49	44.37	12.87
2030	P0(W4)	7.58	56.27	63.85	21.75
	P1(W4)	5.10	48.79	53.90	14.58
	P2(W4)	5.17	48.52	53.70	14.09
	P3(W4)	3.95	33.06	37.01	4.56

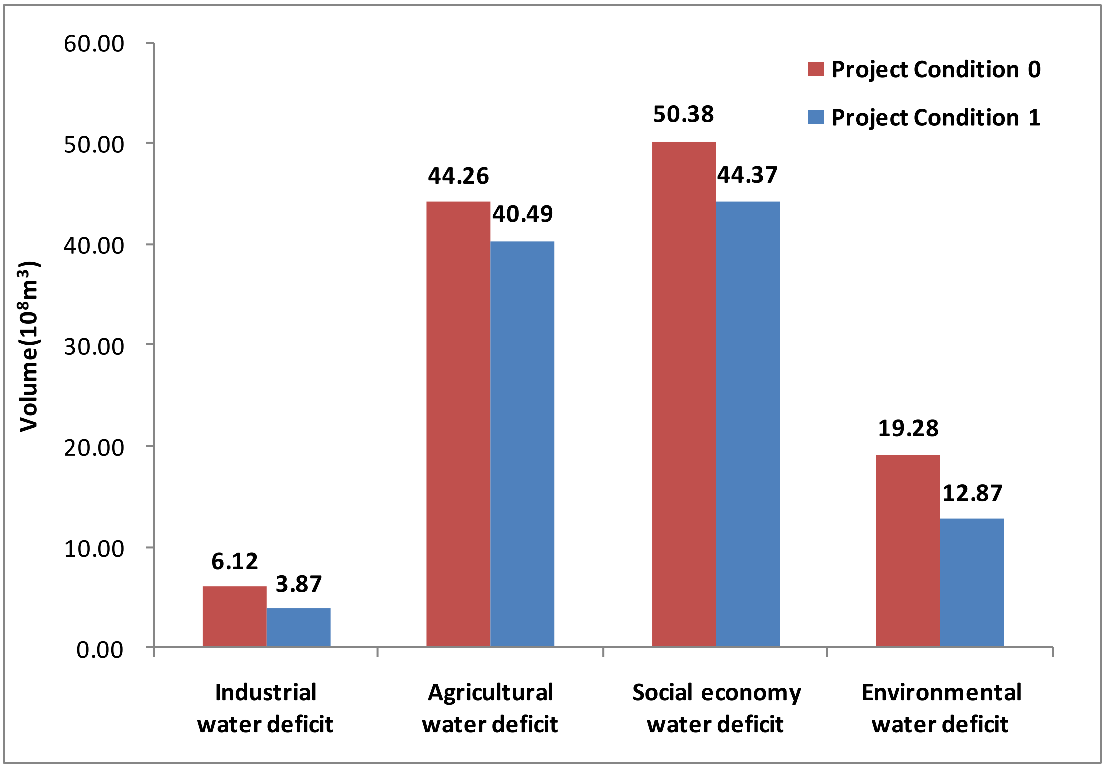

Fig. 4-8 the comparison figure of infrastructure scenarios in 2020

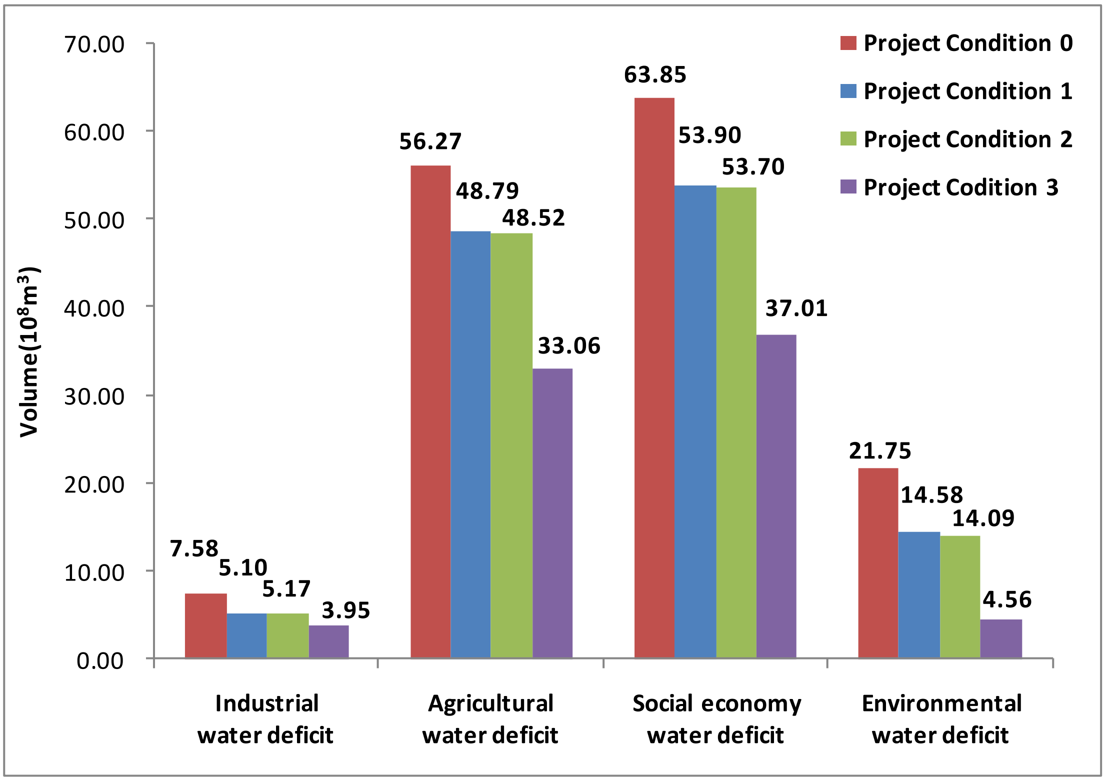

Fig. 4-9 the comparison figure of infrastructure scenarios in2030

4.3.3 Analysis under the macro-economic water demand prediction

With the results of the macro-economic water resources allocation model in the high, medium and low development speeds. the low risk ecological water demand and the same infrastructure scenarios as above, we select preference 10 for base year, 8 for year 2020, 4 for year 2030 without west SNWT and 3 for year 203o with SNWT. The corresponding water demand deficits are listed in Tab. 4-27 and Tab.4-28.

Tab. 4-27 social economic water deficits under the low risk ecological water demand (100 million m^3)

Develop Level	Target Year	social economic water deficits		
		Industry & domestic	Agriculture	Social economy
High	2005（W10）	5.45	14.27	19.72
	2020（W8）	3.94	31.26	35.20
	2030（P2+W4）	6.72	46.02	52.75
	2030（P3+W3）	7.38	28.89	36.27
Middle	2005（W10）	5.45	14.27	19.72
	2020（W8）	3.58	26.92	30.51
	2030（P2+W4）	4.94	36.36	41.29
	2030（P3+W3）	4.93	25.27	30.20
Low	2005（W10）	5.45	14.27	19.72
	2020（W8）	3.27	25.84	29.11
	2030（P2+W4）	3.63	30.67	34.31
	2030（P3+W3）	2.87	21.74	24.61

Tab. 4-28 ecological water deficit under the low risk ecological water demand (100 million m^3)

Develop Level	Target Year	Low-risk E-flow Water Deficit		
		Main River	Huayuankou	Lijin
High	2005（W10）	14.32	2.60	8.34
	2020（W8）	13.05	3.10	8.91
	2030（P2+W4）	15.11	3.53	11.89
	2030（P3+W3）	3.63	0.94	2.75
Middle	2005（W10）	14.32	2.60	8.34

	2020（W8）	12.21	2.72	8.81
	2030（P2+W4）	13.62	2.85	11.05
	2030（P3+W3）	1.93	0.58	1.39
Low	2005（W10）	14.32	2.60	8.34
	2020（W8）	11.56	2.47	8.36
	2030（P2+W4）	10.66	2.54	8.31
	2030（P3+W3）	0.43	0.20	0.24

4.3.4 Comparison of ecological water use schedules

The comparison of ecological water use allocation outputs are listed in Tab.4-29.

Tab. 4-29 water deficit of ecological water use schedules (100 million m^3)

Years	Water demand plan	Social economic water demand	Social economic water deficit	Ecological water deficit	Huayuankou water deficit	Lijin water deficit
2020	Integrated plan	617.72	44.37	12.87	2.83	9.78
	Higher Speed	600.63	35.20	13.05	3.10	8.91
	Medium Speed	582.00	30.51	12.21	2.72	8.81
	Lower Speed	573.17	29.11	11.56	2.47	8.36
2030 No WL	Integrated plan	650.82	53.70	14.09	3.37	1.52
	Higher Speed	658.14	52.75	15.11	3.53	11.89
	Medium Speed	623.18	41.29	13.62	2.85	11.05
	Lower Speed	589.60	29.11	10.66	2.54	8.31
2030 With WL	Integrated plan	650.82	38.65	2.89	0.79	0.36
	Higher Speed	658.14	36.27	3.63	0.94	2.75
	Medium Speed	623.18	30.20	1.93	0.58	1.39
	Lower Speed	589.60	24.61	0.43	0.20	0.24

5 Conclusions

5.1 Results

The research has focused on to devotement the macro-economic water resources allocation model and ecological water use scheduling model of whole and lower reach of the Yellow River. Then, by the models and together with national integrated water resources plan, the domestic, industrial, agricultural and production and ecological water demand outside river channel in the Yellow River basin is analyzed and predicted under frame of different reference years and different social economic development speeds. Moreover, sounder ecological water use scheduling regulation is analyzed and optimized under scenarios of different engineering conditions and ecological preferences. At last, a set of water resources allocation scheduling regulation is recommended for current and future reference years. Though all the above researches, the following conclusions can be shared:

1) When the medium risk ecological water demand is taken as the ecological scheduling target, under all the preferences, the ecological water deficit and deficit rate are all small both in Yellow River mainstream channel and lower reach key sections and the probability of meeting medium risk ecological water demand is high. So, the lower risk ecological water demand can be selected as the principle of water resources allocation scheduling to maintain healthier river state.

2) The ecological water use scheduling can well meet the requirement of the environment flow inside river channel but it may be benefit from sacrificing some social economic water supply in a wide current scenarios.

3) Increasing the water supply by inter-basin water diversion project, such as the east and middle route of the South-to-North water transfer project, Han-to-Wei project and the west route of the South-to-North water transfer project far future, can greatly reduce the social economic water demand deficit and ecological water demand deficit in the Yellow River basin, and which may more benefit to ecological water demand deficit as environment preferencors. This would mean greatly to protect the ecology of Yellow River.

4) The planned Guxian reservoir has limited function to appease the water deficit in the basin. The result shows that the nature of the water deficit in Yellow River is absolutely the shortage of resources. Under the current situation of well-developed water resources, to only increase storage capacity inner basin is functional limited for improving water demand deficit.

5) Up to 2030 reference years, as if the west route of the South-to-North water transfer project takes effect on time, the social economic water demand deficit won't be reduced to the level of base year level when considering ecological water demand. So, it should continue to strengthen the water-saving measure and carry on the strictest water resources management to control the water demand expansion. This is one of base and sustainable ways to meet the gap of social-economic and environmental water demand.

5.2 Suggestion

The following measures should be strengthened in the ecological scheduling management:

1) Optimization scheduling of water conservancy project. Most of the current water conservancy project scheduling doesn't consider the requirement of the ecological and environment water demand, which is bad to the Yellow River's ecological and environment protection. So, it is should be taken into account of scheduling existent water conservancy projects according to the lower reach ecological water demand and others. The scheduling plan should be optimized, especially, the large and medium reservoir scheduling have to act on the ecological water supply. For the planned or under construction water conservancy project, the ecological water supply should be one of regular targets and fully demonstrated in the project design and the operation.
2) Strengthen the water quality management. To meet the requirement water quality of the ecological water, it can be taken into management of state water function regionalization work, that is to set up the ecological function area on the necessary river reach and lake which meets the condition. Meanwhile, to set up the total pollutants discharge on the ecological protection zone, strengthen the trash port management and strictly control the non-point pollution. All above together may provide the aquatic ecological system a high quality water environment.
3) Strengthen the ecological water monitor and investigation. As the society economic development, the Yellow River basin aquatic ecological system has changed greatly. The aquatic animals and plants' species and the distribution, organism, water amount and the water quality should be monitored fully and frequently. The perfect early warning system and the corresponding emergency plan should be made according the monitored information.
4) Attention the effecting of inter-basin water diversion on the ecological protection and reasonable make use of the transferred water resources. To protect aquatic biological items, the key factor is to keep enough water. When the flux or the water of the river or lake is smaller than the minimum ecological water demand, it's necessary to realize the water replenishing by intra-water system and inter-water system to allocate and transfer water.

5.3 Prospects

It is suggested for continuous researches focusing on:

（1）Implementation of the ecological water use allocation and scheduling

Now China is still in the process of the high speed industrialization and urbanization, the social ecological water demand will keeps continuously increasing during a long time. The ecological water demand still faces tough challenges even the water-saving methods are taken. Now the ecological water demand evaluation is most started from the nature characteristic of the ecosystem and neglects the combination of the local actual water resources and the social economic water demand, so there is big difference between the theory result and the practice. It's hard to actualize the ecological water demand allocation in the actual configuration. This study is only from the macroscopic perspective to systematic analyze the ecological water supply probability under the current and future water infrastructure after the ecological water is scheduled. It doesn't go so deep as how the water conservancy project completes the scheduling according to the run-on water and the water use situation in the lower reach. This part will be launched in the following work.

（2）Coupling water quality and quantity, surface water and groundwater

To unify scheduling the water quality and quantity, and surface water and groundwater is the key and exist topics on the ecological water scheduling.

（3）Study on real-time, unified and multi-objectives scheduling system

To really meet the requirements of the Yellow River basin ecological water demand, it should depend on a real-time unified scheduling system. The system should developed coordinately consider the actualization of domestic, industrial, agricultural and ecological water demand, and multi-objectives water service, so as to really realize the water resources sustainable utilization. The system is also involving meteorology, hydrology, ecosystem, social production, information technology, management science etc. multi-subject and multi-layer. It needs to unite the actual facts in the Yellow River basin to do further detailed research.

Reference

[1] CHANG Jianxia, WANG Lixue. Water resources planning and utilization. Zhengzhou: Yellow River Water Conservancy Press, 2010. (In Chinese)

[2] WANG Yuankun, XIA Ziqiang, WANG Guihua. A new phase of reservoir regulation: ecological operation. Journal of China Hydrology, 2008, 28(1):7-9. (In Chinese)

[3] Gippel,C. J. 2011. Environmental flows assessment for the lower Yellow River: ecohydraulic modeling and flow recommendations. Technical Report 7. ACEDP – Australia-China Environment Development Partnership, River Health and Environmental Flow in China. Yellow River Conservancy Commission, Ministry of Water Resources and the International WaterCentre, Brisbane, September.

[4] LIU Xiaoyan et al. Research on Yellow River environmental flows. Zhengzhou: Yellow River Water Conservancy Press, 2009. (In Chinese)

[5] WANG Guangqian, WEI Jiahua. Water resources regulation modeling and its application for river basin. Beijing: Science Press, 2006. (In Chinese)

[6] The Yellow River ice prevention plan for 2011～2012. Yellow River Conservancy Commission of Ministry of Water Resources, 2011. (In Chinese)

[7] The operation scheduling rules of Xiaolangdi in early sand block stage. Yellow River Conservancy Commission of Ministry of Water Resources, .2004. (In Chinese)

[8] The operation scheduling rules of Xiaolangdi in later sand block stage (the first stage). Yellow River Conservancy Commission of Ministry of Water Resources, 2009. (In Chinese)

[9] WANG Yanhong. Analysis of the role and benefit of GuXian Project in the Yellow River. Yellow River, 2010,32(10): 119-121. (In Chinese)

[10] WANG Xuefeng, ZHAO Jianshi, WANG Zhongjing. Influence of western route of south-to-north water transfer project on Yellow River basin. Journal of Hydroelectric Engineering, 2007, 26(2): 19-26. (In Chinese)

[11] Five-year (2008~2012) planning of comprehensive management for Weihe River Basin in Shanxi Province. People's government of Shanxi Province. 2008. (In Chinese)

[12]Liao Sihui, CHENG Xushui, SHI Yong, MA Zhenzhen, ZHAO Jianshi, WANG Zhongjing．Study on ecological water use of Huaihe River with multi-level analysis platform and multi-objective optimization model． Journal of Hydroelectric Engineering, 2010, 29(4)：14-19, 27. (In Chinese)

Appendix