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Environmental water requirements and sustainable water resource management in the Haihe River Basin of North China

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Key words: Environmental water requirements (EWR), water scarcity, management instruments, South–North water transfer scheme, water price policy, agricultural water saving

SUMMARY

Lack of consideration of environmental water requirements (EWR) in water resource allocation has caused several environmental problems in the Haihe River Basin, North China. This highlights an urgent need to study EWR and ensure instruments for sustainable water resource management in the basin. In this study, EWR scenarios were calculated for 2010 and 2030, giving values are 6.58 billion m³ in 2002, 9.22 billion m³ in 2010, and 11.62 billion m³ in 2030. Three policies and management instruments were used to address EWR, including the South–North water transfer scheme, water price policy modifications and agricultural water saving. Compared with lack of adoption of such measures, these three management instruments may mitigate acute water scarcity and lead to some improvements. This paper attempts to establish a link between adoption of measures, impact on water user sectors and environmental consequences. It also provides a basis for discussion about the effectiveness of these measures and notes additional controversies among technical, political and economic instruments.

INTRODUCTION

Water resources are the most important factor for promoting or limiting structure, process and function of an ecosystem. Sustainable water resource management is essential for protecting the aquatic environment and for meeting current and future demand. In the past two decades, much attention has been given to the study of environmental water requirements (EWR) (Rowntree and Wadeson 1998; Hughes 2001; Shield and Good 2002). In the USA, the concept of EWR was first defined as the instream flow requirement (Lin 2000). Gleick

(1996) presented a framework for the basic ecological water requirement in which he defined the basic quality and quantity of water needed to minimize changes in ecosystem processes and to protect biodiversity and ecological conformity. In 1990, the Chinese Hydrology Encyclopaedia defined EWR as the water used to modify water quality, harmonize ecosystems and improve natural amenities (Cui 1990). In addition, this definition recognized the minimum instream flow needed to support aquatic habitats, wetlands and urban green areas. At the

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beginning of this century, strategic research focusing on China's sustainable water resource protection was performed by many academicians and specialists. This research aggregated the EWR in several large river basins, such as the Yellow, Huaihe and Haihe Rivers, and estimated the requirement to be 80 billion m³ for the whole country (Qian and Zhang 2000).

As a result of economic growth, rapid industrialization and urbanization in China, water availability is more threatened today than ever before. Authorities need to possess the foresight to recognize the environment as a water use sector, not only as a part of domestic or human livelihoods, but also as an independent value in terms of water resource allocation. Ecologists mainly emphasize the needs of the environment and of ecosystems, while economists and social scientists tend to be concerned only with human use. Hence, establishing a link between these two views towards the sustainable management of water resources in China has emerged as a clear priority. Within this context, it is necessary to develop case studies that assess EWR to ensure sustainable water resource management in China. The Haihe River Basin is one of the most important in North China and thus provides a useful case study. The combination of socio-economic and political factors, together with a growing population, have multiplied the effects on water resource scarcity; in addition to a lack of consideration of EWR in water resource management, leading to deteriorating ecological conditions. The object of this study is to determine EWR for this basin. Three instruments for ensuring the reasonable allocation of EWR for water resource sustainable management and availability were assessed. Few previous studies have reported on instruments ensuring EWR and its assessment, especially in China.

STUDY AREA

The study area is located in the Haihe River Basin. The river runs through the political centre of the country as well as the social development and economic centre of the North China Plain. Two municipalities with populations of more than ten million (Beijing and Tianjin) are downstream. The basin consists of three river systems: the Haihe,

Luanhe and Tuhai Majia Rivers. These flow through eight provinces and autonomous regions, fanning out from the mountain area in the northwest to the sea. The basin comprises an area of 317,800 km², about 3.3% of China's total area (Yang *et al.* 2005). It accommodates 123.94 million people, 9.5% of the Chinese population, and its production value accounts for 12% of GDP, about 1112.5 billion RMB.

The basin has a semi-humid and semi-arid temperate continental climate. The average annual temperature is from 0 to 14°C. Annual water surface evaporation is 1000–1400 mm, and soil surface evaporation is 400–500 mm. Most of the rivers originate in the Yanshan and Taihang Mountains and the Loess Plateau and flow through the North China Plain towards the Bohai Gulf. The elevation varies from above 1000 m in the west to less than 50 m in the east. As the basin has been continuously influenced by human activities for 1500 years, little natural original vegetation has survived, although some natural secondary and artificial forests still remain in mountain areas.

Large-scale exploitation of water has pushed Haihe River Basin water resources to the limit and has resulted in a series of environmental problems and crises. Rivers drying up, wetlands disappearing, groundwater levels declining, and water pollution are the major challenges facing this basin. Since the 1960s, surface water has been over-extracted from the basin. About 1900 dams have been built for irrigation and power generation, causing more than 4000 km of the plains rivers to become seasonal rivers. Total water discharged to the sea has declined from 24 billion m³ in the 1950s to 1 billion m³ in 2001. Since the 1950s, 94% of the wetlands on the Hebei Plain in this basin have been lost. The wetland acreage has declined from 110,000 km² to 670 km². There are 20 large depressions, naturally formed due to groundwater over-extraction, covering more than 40,000 km². The groundwater level declined from 5 m to 12 m between 1983 and 1999 in Hebei Province, and the annual rate of decline is up to 0.4 m a⁻¹. Water pollution has intensified since surface runoff reduced in the past decade. More than one-third of the river courses are contaminated and 90% of the urban and suburban rivers are heavily contaminated.

CALCULATION AND SCENARIO ESTIMATES FOR EWR IN THE HAIHE RIVER BASIN

Methodology

Methods used to estimate EWR range from pure hydrological models to holistic multidisciplinary methodologies (WRI 2003). In this study, the basin was divided into five ecosystems: natural vegetation, natural wetland, natural river, artificial wetland (reservoir), urban greenbelt, and urban surface water. All have surface evapotranspiration as the most important consumption characteristic of environmental water. The formulae used in this study have been described in detail in our earlier research (Miao *et al.* 2003).

$$Q_v = \sum_{i=1}^n 1000 \cdot E_i \cdot S_i \quad (1)$$

$$E_i = E_i + E_c + E_l + E_s + E_w \quad (2)$$

Q_v = natural vegetation EWR ($\text{m}^3 \text{a}^{-1}$), n = number of vegetation types, S_i = acreage of the i type of vegetation (km^2), E_i = evapotranspiration of the i type of vegetation (mm a^{-1}). E_l = transpiration of plants (mm a^{-1}), E_c , E_p , E_s , E_w are evaporation of the canopy, undergrowth, litter and soil (mm a^{-1}), respectively.

$$Q_R = Q_E + Q_L + Q_B \quad (3)$$

Q_R = natural river EWR ($\text{m}^3 \text{a}^{-1}$), Q_E = evaporation of the river ($\text{m}^3 \text{a}^{-1}$), Q_L = leakage of the river ($\text{m}^3 \text{a}^{-1}$), Q_B = base flow of the river ($\text{m}^3 \text{a}^{-1}$) (calculated according Tennant 1976 or 7Q10).

$$Q_W = \sum_{i=1}^n 1000 \cdot E_i \cdot S_i \quad (4)$$

$$h = \max\{h_1, h_2, h_3, \dots\} \quad (5)$$

Q_W = natural wetland EWR ($\text{m}^3 \text{a}^{-1}$), E_i = evapotranspiration of i wetland (mm a^{-1}), S_i = acreage of i wetland (km^2), determined from the minimal environmental water level. H = minimal environmental water level for natural wetland (m), h_1, h_2, h_3 are the minimal environmental water level for different ecosystem services of wetlands (m).

$$Q_{UG} = \Psi F \quad (6)$$

$$Q_{UW} = (E_U - P_U) S / 1000 \quad (7)$$

Q_{UG} = urban greenbelt EWR ($\text{m}^3 \text{a}^{-1}$), Ψ = urban greenbelt water requirement ($\text{m}^3 \text{a}^{-1} \text{m}^{-2}$) (in the study, Ψ was set to $1 \text{ m}^3 \text{a}^{-1} \text{m}^{-2}$ for Beijing and $0.5 \text{ m}^3 \text{a}^{-1} \text{m}^{-2}$ for other cities, according to the

economic development situation), F = acreage of urban greenbelt (m^2). Q_{UW} = EWR for urban water surface, including urban rivers and lakes ($\text{m}^3 \text{a}^{-1}$), E_U = evaporation of urban surface water (mm a^{-1}), P_U = rainfall of urban water surface (mm a^{-1}), S = acreage of urban water surface (km^2).

Environmental water requirement calculation

Natural vegetation requires water, so-called 'green' water, to support its production and biodiversity; thus protecting the habitat of numerous birds and animals. Natural vegetation in the basin includes 17 types of ecosystem, such as conifer forest, deciduous broadleaf forest, shrubs, grasslands, etc. The area of natural vegetation is about $67,600 \text{ km}^2$, 21% of the total acreage in the basin. Forest plays an important role, but constitutes only 5% of natural vegetation and is quite fragmented. Natural vegetation in the basin requires 21.09 billion m^3 of water for evaporation and transpiration according to equation (1), and absorbs 7.2% of total annual rainfall, of which 70% is concentrated in July and August, the peak period of precipitation (Wei *et al.* 2004). Hence, the amount of water consumed by natural vegetation affects the total runoff and hydrological cycle; however, this water mainly comes from rainfall and does not compete obviously with other uses, and will not be included in EWR in the following discussion.

Some methods to estimate instream river flow have been developed and promoted in the USA, such as the wetted perimeter method (Gippel and Stewardson 1998) and the Tennant method (Tennant 1976). Both are based on historic average flows, the lowest flow month, or annual flow in the studied rivers. The length of the main rivers in the Haihe Basin is 5,574 km. The EWR of natural rivers are 1.69 billion m^3 according to equation (3), which is about 6.4% of the total average annual surface runoff (Wei *et al.* 2004). The goal of ecological restoration is to recover 1900 km of water-courses around Beijing and Tianjin by 2010, after completion of the east route of the South-North Water Transfer Project, which was launched in December 2002. The subsequent middle route of the project will restore 2200 km of plain rivers for the basin by 2030. Instream flow will increase correspondingly to 2.27 billion m^3 and 2.93 billion m^3 .

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At the end of the twentieth century there were 670 km² of natural wetlands in the Haihe Basin, only a third of the area found in 1990, with an average water depth from 1.0 to 5.9 m. Considering surface evaporation and percolation, EWR was 2.14 billion m³ in 2000 from equation (4). According to the target of the natural wetland protection strategy plan (HWCC 2001), three areas of wetland, Tuanbowa, Dalangdian and Qianqingwa, will be improved, and 471 km² of wetland will be restored before 2010. In addition, another six areas of wetland or marshland of 559 km², Ninjinbo, Dongdian, Qingdianwa, Xiqilihai, Great Huangpuwa and Enxianwa, will also be restored by 2030. The requirement has to be met with 3.64 billion m³ of water in 2010 and 5.11 billion m³ in 2030.

Reservoirs constitute a special kind of artificial wetland. An integrated aquatic ecosystem usually exists in reservoirs, whether on a large or small scale. There are more than 1900 reservoirs in the basin, with a total volume of 28.5 billion m³. The surface under normal storage volume is 1610 km². Therefore, EWR for reservoirs is 1.67 billion m³ according to equation (4), and is expected to remain steady in 2010 and 2030 (Wei et al. 2004).

Urban greenbelt is an independent competing water user because it mainly depends on irrigation. A strong positive relationship exists between urban EWR and urban GDP (Wei et al. 2003). Among 25 cities in the Haihe Basin, the six largest cities have an urban population of more than 1 million each, 13 middle-sized cities have urban populations from half to one million, and six small cities have populations from 200,000 to half a million. The urban population of 35.65 million is 30% of the total in the basin. The area of the urban greenbelt has an EWR of 646.7 km² or 0.43 billion m³ in 2000 from

equation (6). Urban rivers and lakes have a surface area of 626.6 km² and EWR of 0.65 billion m³ from equation (7). According to the target for Urban Construction Planning, the area of urban greenbelt in the basin will increase to 1459 km² in 2010 and 1892 km² in 2030. Assuming pressure on rivers and lakes in the cities will not increase in future, the urban EWR would improve by 50% and 77% in the scenario years 2010 and 2030. The total EWR in 2002, 2010 and 2030 in the Haihe River Basin is shown in Table 1.

EWR review

In discussing EWR, it is necessary to review the three main schools of thought on the water requirement concept. The first common attitude towards water requirements is to consider them as a given need that should be met. In fact, nearly all projections of future water demand have been based on this approach (WRI 2003) because future water demand can be calculated in a relatively simple way, using growth scenarios for population, agriculture, industry and economic needs, and assuming certain improvements in efficiency. The above projection for human use and EWR in the Haihe Basin follows this approach. A major drawback is that many factors, such as social customs, individual preferences, price mechanism, and water policy are ignored (Hoekstra 1998).

The second view of water requirements is that water use is a necessity only if it is related to basic human needs, such as drinking water (Gleick 1996). The basic needs can be described in terms of a ‘water footprint’, analogous to an ‘ecological footprint’, which is a function of population in a country or region (Hoekstra and Huynen 2002). Water

Table 1 Environmental water requirements in Haihe River Basin (billion m³ a⁻¹)

Year	2000		2010		2030	
	Area*	Volume	Area*	Volume	Area*	Volume
Natural wetland	670	2.14	1140	3.64	1600	5.11
Reservoirs	1610	1.67	1610	1.67	1610	1.67
Urban greenbelt	646.7	0.43	1500	0.99	1900	1.26
Urban rivers and lakes	626.6	0.65	626.6	0.65	626.6	0.65
Instream flow	5574**	1.69	7474**	2.27	9674**	2.93
Total		6.58		9.22		11.62

*Area (km²)

**Length of river (km)

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demand above the minimum requirement is considered a luxury and is largely subject to social and political desires. Thus, allocation of priorities is supposed to strongly influence the extent of water use by different sectors.

A third perception of water requirements is economic, in which water demand is considered in relation to the price charged (Kindler and Russell 1984; Ropetto 1985). According to this, water demand should achieve equilibrium through the price mechanism. Critics regard the economic view as an ideal of economists rather than a reflection of the actual world. As it is easily operated, the price mechanism has been chosen more and more frequently by authorities in water resource management.

Ecologists also believe that there is a minimum requirement for ecosystems. If the minimum requirements are not met, the health of ecosystems will be damaged. However, it is difficult to determine the minimum requirements. One aspect of this uncertainty is that an ecosystem is capable of adapting to some environmental change, which is known as its resilience. Ecosystem degradation is a long-term, complex process and difficult to measure with available indicators. In this case, EWR are treated as specific requirements, although there is much uncertainty. EWR are divided into instream use (retained ‘in river’ or ‘in lake’ for aquatic habitats) and offstream use of flow from the river to other places. Furthermore, ecological requirements are divided into consumption and non-consumption use. Instream use represents the flow towards air and soil, which change water characteristics through evaporation, transpiration and infiltration. Offstream use implies the stock in surface runoff and can possibly be re-used. Table 2 shows EWR categorization in the Haihe Basin, where 83.6% of EWR is instream use and a quarter of the total is non-consumptive requirement. This distinction is expected to be helpful to decision-makers

when considering allocation priorities, as it clarifies the difference in strategies.

INSTRUMENTS FOR ADDRESSING EWR

In the foreseeable future, a fundamental issue is how EWR will be met in the Haihe Basin. EWR are 9.22 billion m³ for 2010 and 11.62 billion m³ for 2030, and account for approximately a quarter of average total annual runoff. This is also nearly half of the surface flow during the drought decade in the 1990s. With the river currently almost fully utilized, and with industrial growth, urbanization and agricultural demand claiming further water resources, the challenge to balance human demand with environmental requirements will be tremendous and difficult to meet.

There are many instruments for addressing EWR and water scarcity in the basin. All are based on the following three criteria: increasing total supply, reducing specific demand, and reallocating scarce water under available mechanisms. For convenience, these instruments are divided into three groups: (1) technical schemes, such as hydrological projects to increase water supply, and water saving technologies to improve water efficiency; (2) command and control instruments, which can be designed to directly control water use sectors through water use per unit production quota, recycling rate, and total water use targets for each sector; and (3) economic incentives or market-based instruments, including water pricing, subsidies for water suppliers, etc.

South–North Water Transfer Scheme

In order to mitigate increasing water scarcity in northern China, the central government has initiated the South–North Water Transfer Scheme

Table 2 Categorization of current EWR in the Haihe Basin (billion m³a^{−1})

Types	Instream	Offstream	Consumption	Non-consumption
Natural wetland	2.14		2.14	
Reservoirs	1.67		1.67	
Urban greenland		0.43	0.43	
Urban rivers & lakes		0.65	0.65	
Instream	1.69			1.69
Total	5.50	1.08	4.89	1.69

(SNWT). The project will transfer water from the Yangtze River, through a long canal flowing from middle-south China to the Yellow River Basin, Huaihe Basin, and northern Haihe Basin. The SNWT is expected to add about 6.06 billion m³ in 2010 and 9.57 billion m³ in 2030, which may significantly restore and improve aquatic ecosystems in the Haihe River Basin (Pei *et al.* 2004). However, transferring water over a long distance might have environmental consequences in both the water-exporting region and the water-importing region. Although additional water is indeed necessary to restore and maintain aquatic ecosystems in the water-importing region, the physical and chemical characteristics of the soil may change because of the different water quality. Several similar projects, such as the west coast water canal in Canada and the USA, have been evaluated by natural and social scientists. Hence, the effect of the SNWT on the Haihe River Basin needs further study in the future.

Water price reform

Economics regards demand as a function of price. Although water is a form of public commodity, water prices will be able to modify water demand. In the absence of metering, fixed charges have been widely used in the agricultural sector, which contribute to water resource waste because consumers have absolutely no economic incentive to save water since each additional unit is free of charge (Whittington 2003). Urban water users, to date, have used a common type of volumetric charge – the uniform volumetric charge. A steady water price does not reflect increasing water scarcity; however, water price reform has been promoted since 1998. The increasing block price system has been adopted in some cities in the basin. Some special industries that use more water are legally required to pay more (at a special price).

Increasing water price is a typical tool for reallocating water resources, perhaps best used only for intrasectoral allocation, but not for intersectoral allocation. The problem is: who will pay for the fish, animals, birds and ecosystems? A simple answer may be ‘the government’, but what is the valuation of environmental water? How to value wetland, forest and aquatic ecosystems? Before these questions can be answered, the need for environmental water might be further ignored.

Agriculture water saving

Agricultural water use is the principal element of water resources utilization in the Haihe River Basin. The average agricultural water use is about 30 billion m³a⁻¹, which is 80% of total water consumption in this basin in the past 20 years. In the region’s long history of agricultural production, the problem of water resource waste still exists and water use efficiency (WUE) is surprisingly low. Yang *et al.* (2003) noted that the yield of agricultural water is 0.45 RMB t⁻¹ while that of environmental water is 1.63 RMB t⁻¹. Hence, agricultural water saving measures are crucial to alleviate water resource scarcity and ensure EWR.

It is accepted that, in irrigation areas, water-saving agriculture occurs if the WUE is 0.70 and water production efficiency is > 1.2 kg m⁻³. If these values exceed 0.85 and 1.8 kg m⁻³, it becomes high-efficiency water use agriculture (Duan 2002). The water scarcity problem is so serious in the Haihe Basin that water saving must adopt high-efficiency water use agriculture. There are many ways to save water in irrigation: in this article we consider agronomic measures, implementing water-saving irrigation and rebuilding low-efficiency irrigation systems as examples to analyze potential water saved in the Haihe Basin.

Through implementing agronomic measures, i.e. adjusting agricultural structure, using plastic film or stalk coverage, and optimizing irrigation systems, the proportion of irrigation will be cut to 10 to 20%. But the proportion of irrigation is already very low, and agronomic measures are effective only in those irrigation areas that draw water from the Yellow River adopt furrow (surface, flood) irrigation. In these areas, it is expected to save 10% of the original water demand (4,500 m³ ha⁻¹ a⁻¹). If we calculate this for 333,000 ha where we can extend this agronomic measure, it will save 0.15 billion m³ a⁻¹. Paddy fields have some water saving potential using technology for shallow irrigation. In the Haihe Basin, paddy field shallow irrigation will save 0.2 billion m³ a⁻¹, of which 50% can be repeatedly recycled, so that the actual amount of water-saving is 0.1 billion m³ a⁻¹. Hence, in the Haihe Basin, the total amount of water-saving from agronomic measures is 0.25 billion m³ a⁻¹.

The total irrigated area in the basin is 7.73 million ha and the required water-saving area is 4.8 million ha, which is 62.2% of the total irrigated area.

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The quantities of land needed for water-saving in well-irrigated areas and channel irrigation areas are 2.67 million ha and 2.13 million ha, respectively. The water-saving in the channel and well-irrigated areas are 1,200 m³ ha⁻¹ and 1,350 m³ ha⁻¹, where the irrigation ratios are 50% and 80% (HWCC, 2001). Hence, water-saving is 1.28 billion m³ a⁻¹ and 2.81 billion m³ a⁻¹ for these areas. Total water-saving by implementing water-saving irrigation is 4.09 billion m³ a⁻¹.

According to statistical data, the present water-saving irrigation systems are not yet highly efficient and there are about 1.07 million ha of water-saving irrigation which have potential to save water (HWCC 2001). After rebuilding the original low-efficiency irrigation systems, WUE could be improved by 10%, and the total amount of water saved would be 0.48 billion m³ a⁻¹. Hence, the total water-saving potential of agriculture in the Haihe Basin is 4.82 billion m³ a⁻¹.

Comparing the availability of instruments

In general, there are many instruments available to attain the target EWR. The best instrument would be one that meets the target with the greatest reliability. Each available instrument can be characterized by a set of attributes, relating to such things as impacts on water use sectors and environmental consequences. A signal can be given to each instrument, depending on how well its attributes match with the objectives. This perspective is useful as it draws attention to what attributes a ‘good’ instrument might have. Table 3 is an attempt to draw

together options available for adapting to the challenges of water scarcity and environmental requirements. The results were drawn by revising Hellegers’ method (Hellegers and van Ierland 2003) that describes the relationship between instruments and their impact on water use sectors and environmental consequences using qualitative analysis. Compared with no adaptation, three instruments, the South–North water transfer scheme, water price policy modification and agricultural water saving, may mitigate the acuteness of the water scarcity problems and improve environmental quality. Quantitative analysis will have to rely on the application of advanced assessment models such as WEAP (Levite *et al.* 2003), STREAM (Aerts *et al.* 2000) and AQUA (Hoekstra 1998), and the integration of numerous data types for inputs and parameters. It is expected that such methods could be applied to related research in the future.

CONCLUSIONS

There is no doubt that water scarcity has been a bottleneck for social and economic development in the Haihe Basin. This article calculated EWR and estimated scenarios for 2010 and 2030. According to the target declared by the basin management authority, EWR will be up to a quarter of average annual runoff, and has to be considered a priority. Furthermore, the policies or instruments that could be used to address this situation, which directly concern decision-makers, are analyzed through rapid assessment. This paper aims to show the relationship between policies and water use

Table 3 Impact assessment of instruments on scarce water*

Water use sectors	No adaptation		SNWT		Agriculture water saving		Water price reform	
	2010	2030	2010	2030	2010	2030	2010	2030
Agriculture	+/-	+/-	+	+	--	--	-	-
Industries	+	-	+	++	+	+	+	++
Domestic	+	+	+	++	+/-	+/-	+	+
Natural vegetation	-	--	+/-	+/-	+	+	-	--
Wetland	-	--	+	+	+/-	+/-	-	--
Urban environment	+	+	+	++	+	+	+	++
Biodiversity	-	--	+	+	+	+	-	--
Water quality	-	--	+	+	-	-	-	--

*Five categories are distinguished: ‘+’ stands for a positive impact on the ability to meet water need or water demand, ‘-’ for a negative impact and ‘+/-’ indicates the possibility of a positive as well as a negative impact. A ‘++’ can be interpreted as a strong positive impact, and ‘--’ represents a strong negative impact

sectors, ecosystems and the environment. Compared with no adoption of measures, three management instruments, the South–North water transfer scheme, water price policy modification and agricultural water saving, may mitigate the acuteness of water scarcity and cause some improvements. The paper only focuses on how to meet water needs or water demands of different water user sectors and their environmental consequences. The social and economic consequences, such as economic growth, jobs, human health and food security, have not yet been included, but will be addressed in future research.

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