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Analysis of the Lake Taihu Basin Water Resources System and Circular Economy

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ABSTRACT: Water resources possess both social and natural attributes. A water resources system is usually a large and complicated system, which possesses regional background, as well as a specific framework, function and dynamic balance. Evaluation of the water resources system needs measures according to both the water resources carrying capacity and water environment carrying capacity, and the supervision from the viewpoint of sustainable development. The water resources system of Lake Taihu basin, China, started to experience a period of degeneration from 1960, and the year of 1980 was a turning point of degeneration. In order to prevent further degeneration of the lake water, it is hypothesized that one must use the concept of circular economy. When based on the water resources system, this concept employs the "3R principle", leads to saving water and using water efficiently and improves, harmonizes and counterpoises water resources carrying capacity and water environment carrying capacity. Consequently, humans can coexist with water harmoniously, and achieve sustainable development, ensuring sustainable social-economic development with sustainable use of water resources.

INTRODUCTION

Lake Taihu basin is located at the southern end of the Changjiang River Delta, bordering the Changjiang River on the north, facing the Hangzhou Bay on the south, Tianmu mountain on the west and East China Sea on the east. Lake Taihu basin covers an area of 2.338×10^3 km^2, with more than 189 lakes having a coverage larger than 0.5 km^2. The basin has a fairly high drainage density, with the total length of its watercourse being almost 1.2×10^5 km. The Taihu hydrographic net, which runs across Jiangsu Province, Zhejiang Province and Shanghai City, constitute the main part of the lower stretch of the Changjiang River. The key part of the whole net is Lake Taihu, whose main sources are streams Shao and Nan. The lake flows out through more than 70 channels on the east. These channels, combined with other runoff from areas on the east, flow into the Changjiang River and East China Sea by way of the Liu River and the Huangpu River.

Lake Taihu basin has long been regarded as a place rich in resources and ingenuity. The GDP of this place in the year 2002 was as high as 1.24×10^{12} yuan, which is almost 12% of the total GDP of China. In the following year, this percentage grew to 13% and the economy in terms of income of this area grew from

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16% upto 19% of the total national income, although it accounts for only 0.4% for the country's area and 3% of the population. It has become one of the most developing areas of the country. However, with the rapid economic development, the water resources system of Lake Taihu basin has experienced a degenerate period since 1960. The water quality standard has lowered 1 level almost every 10 years, and this has been more serious in recent years. How to control the degeneration in order to use water recourses more scientifically and efficiently is capturing these days a great deal of attention among researchers both in China and overseas (She, 1997; Huang, 2000; Wang, 2001; Liu and Chen, 2001; Wang, *et al*., 2004; Sun, 2005).

BASIC CONCEPT OF WATER RESOURCES SYSTEM

Water Resources and Water Resources System

According to studies both in and out of China, water resource can be defined as the renewable part of a water body, which is adequate in amount and quality, and has been or can be used continuously for man's exploitation. It has 3 following attributes:

1. It is limited in amount.
2. It possesses both social attributes and natural attributes.
3. It is measured by quantity as well as a quality standard.

The dualism of water resources determines the comprehensive characteristics of a water resources system. This dualism stems from a combination of both natural water and social water, as well as a mix of natural water resources, usable water resources, available water supply, and water demand and consumed by social economy, etc. A water resources system is also a complicated large system, which possesses a regional background, as well as a specific framework, function and dynamic balance.

Evaluation of a water resources system requires the evaluation of carrying capacity, and supervision from the viewpoint of sustainable development. The water resources system carrying capacity has two meanings, one is water environment carrying capacity, and the other is water resources carrying capacity. The carrying capacity of water environment refers to the ability to carry and contain pollutants and polluted water in areas, where water resources are renewable and continuously do self-cleaning and maintain a good ecosystem. On the other hand, the water resources carrying capacity refers to the ability to supply for socio-economic development and maintain a good ecosystem in the drainage area or region. The carrying capacity of water environment and the carrying capacity of water resources both depend on and restrict each other. The co-relationship and matching of them determine the status of the function, structure and balance of a water resources system.

ELEMENTS AND RELATIONSHIP INSIDE WATER RESOURCES SYSTEM

A water resources system can be divided into two subsystems: the natural water subsystem and the social water subsystem. For the natural water subsystem, the total water resources (including both surface and subsurface water) are made up of water resources in situ, passing by and diverted. While the ecological water requirements of a natural system are satisfied by the natural water subsystem, the residual water is called usable water resources. There exist significant relationships between ecological water requirement and water environment carrying capacity, between usable water and water resources carrying capacity, as well as between water environment carrying capacity and water resources carrying capacity.

As to the social water subsystem, it is mainly socio-economic water requirement, using the available water supply from the usable water resources provided by the natural subsystem. The socio-economic water requirement includes consumed water and surplus water. The surplus water has an impact on water environment carrying capacity through point-source, area-source and inner-source pollution (Wang *et al*., 2003).

As an example, the mean annual water resources in situ of the Lake Taihu drainage area are 1.62×10^{10} m^3, including 1.37×10^{10} m^3 of the surface water resources and 2.5×10^9 m^3 of subsurface water resources. In the year 2001, the water consumption had reached 2.85×10^{12} m^3, and water resources in situ of this drainage area could not meet the demand. Along with the rapid development, the sewage water also increased year by year. At present, the sewage released by industry and live activities in the drainage area has reached 5.0×10^9 m^3/a. The conflict between supply and requirement and water pollution problem could be resolved by drawing water from the Changjiang River.

In the year 2002, the test of diversion from the Changjiang River to Lake Taihu got started (Gao *et al*., 2006). The water quality of Lake Taihu has been improved by regulating the still water with the dynamic water, that is, diluting the polluted water with the clean water, and replenishing the exhausted with the abundant. The sketch map of diversion from the Changjiang River to Taihu Lake is in Figure 1.

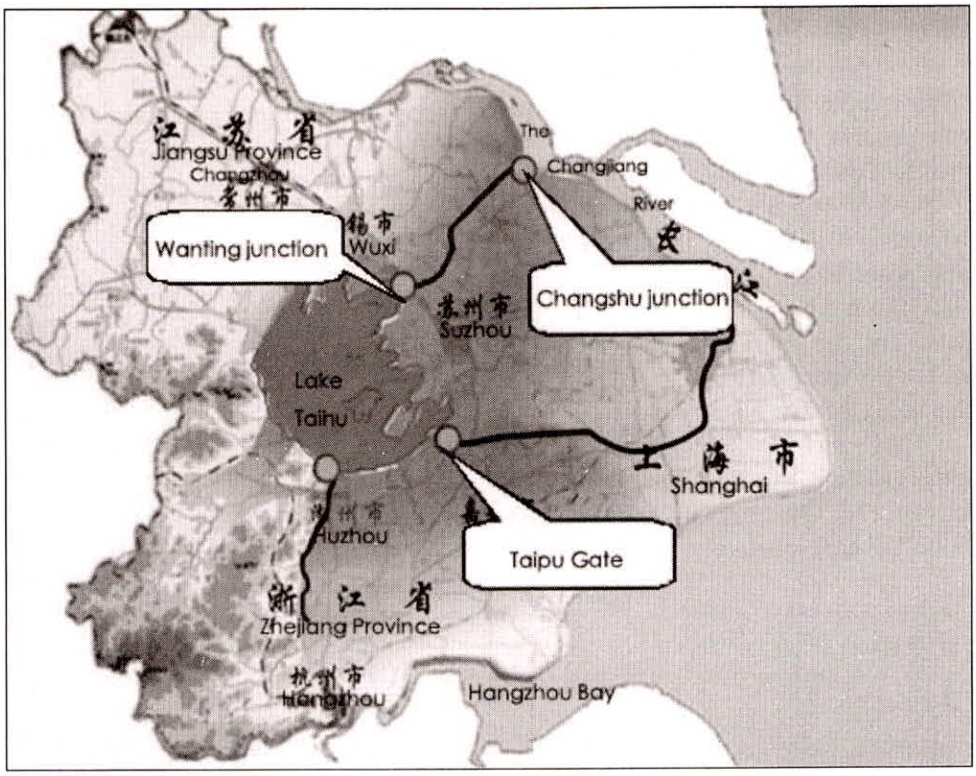

Fig. 1: Sketch map of diversion from the Changjiang River to Taihu Lake

In 2002, from January 30th to March 31st, the total amount of water drawn from the Changjiang River to Changshu junction of the Wangyu River added up to 1.028×10^9 m^3, of which 6.47×10^8 m^3 came into Lake Taihu through Wanting junction, and 6.2×10^8 m^3 through Taipu Gate to the lower reach of the drainage area, and 3.8×10^8 m^3 of water was supplied to Shanghai City.

In 2004, from January 1st to December 21st, the total amount of water drawn from the Changjiang River to Changshu junction added up to 2.2×10^9 m^3, of which 1.012×10^9 m^3 came into Lake Taihu through Wanting junction, and 1.429×10^9 m^3 through Taipu River to the lower reach of the drainage area.

In 2005, from January 1st to April 30th, the total amount of water drawn from the Changjiang River to Changshu junction of Wangyu River added up to 1.32×10^8 m^3, of which 5.71×10^8 m^3 came to the lower reach of the drainage area through Taipu River.

In 2006, from January 1st to May 17th, the total amount of water drawn from the Changjiang River to Changshu junction added up to 2.81×10^8 m^3, of which 7.56×10^8 m^3 came to the lower reach of the drainage area through Taipu River.

By such diversions in the recent years, the water supplied to the drainage area has effectively increased, and as a result the water environment has greatly improved. For example, during the period from December 17th to 21st in the year 2004, all kinds of water-quality index were found improved, the main index like COD_{Mn} and TP of water supplied from the Xitang River to Suzhou had met level II ~ III. All these have enhanced the carrying capacity of the water resources system of Lake Taihu basin.

DEGENERATION OF WATER RESOURCES SYSTEM IN LAKE TAIHU BASIN

Lake Taihu drainage area is one of the most densely populated areas in China and of the world. The mean individual water resources in Lake Taihu basin only accounts for 18% of that of the country, and water resources for every unit of area only accounts for 13% of that of the country. It is still under the national average level, even though it now receives water being diverted from the Changjiang River.

With the rapid development of economic society, the water resources system in Lake Taihu basin has been degenerating (Qin, *et al.*, 2002; Huang, 2003; Yang and Wang, 2003). The water quality of Lake Taihu in the 1960's could be classified into class I to II, while in the 1970's, it turned into class II. In the early 1980's, the water quality of Lake Taihu fell into class II to III, and later in the 1980's, it totally fell into class III, some of the areas were even worse and turned into class IV and V. In the 1990's, water quality of Lake Taihu even more deeply deteriorated, becoming worse than class IV, and the quality of 1/3 water even reached class V. In general, the water quality of Lake Taihu dropped one class every 10 years during the past 40 years, and the speed of degeneration has been most rapid in recent 10 years. It is thought that the year of 1980 was a turning point of the degeneration of Lake Taihu. Before 1980, the index of TN (Total Nitrogen, TN) changed greatly, and the index of COD (Chemical Oxygen Demand, COD) increased a bit. After 1980, the increase of the index of TN began slowing down, and the indexes of COD and TP (Total Phosphorous, TP) started steadily growing up. Figures 2, 3 and 4 show the variations of TN, TP and COD_{Mn} *i* over past 25 years in the Taihu Lake, respectively.

From the 1950's to the 1970's, except for the Suzhou River, Huangpu River and Jiangnan Channel, the water quality of other river channels in Lake Taihu basin was fairly good. The water from the whole network of other river channels could be regarded as a good source. It is since 1980 that the water quality of river channels in Lake Taihu basin started deteriorating. In 1983, the water quality of 40% river channels fell into class IV or even worse, while in 1987, that percentage turned into 61.1%. In 1992, that percentage turned into 73.1%, while in 1996, it even increased to 86.1%. In the year 2000, that percentage got back to 80.6%. Table 1 and Figure 5 show the water quality of reaches evaluated in Lake Taihu basin over 20 past years.

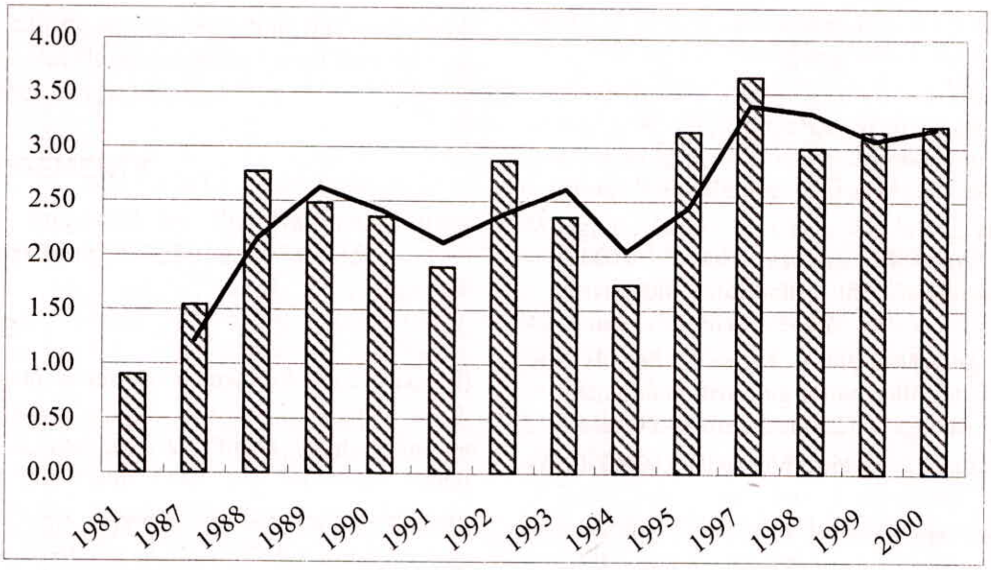

Fig. 2: Variations of Total Nitrogen (TN) over past 25 years in Taihu Lake (unit: mg/L)

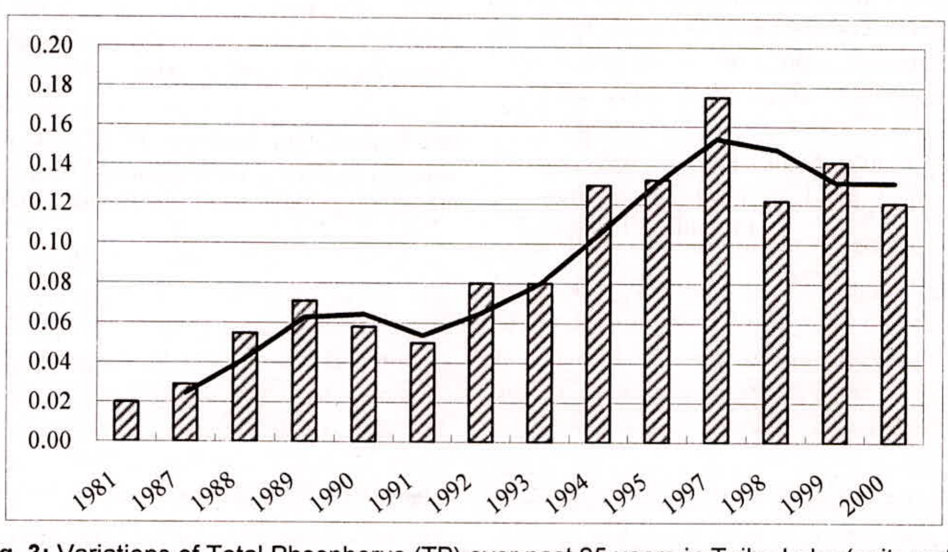

Fig. 3: Variations of Total Phosphorus (TP) over past 25 years in Taihu Lake (unit: mg/L)

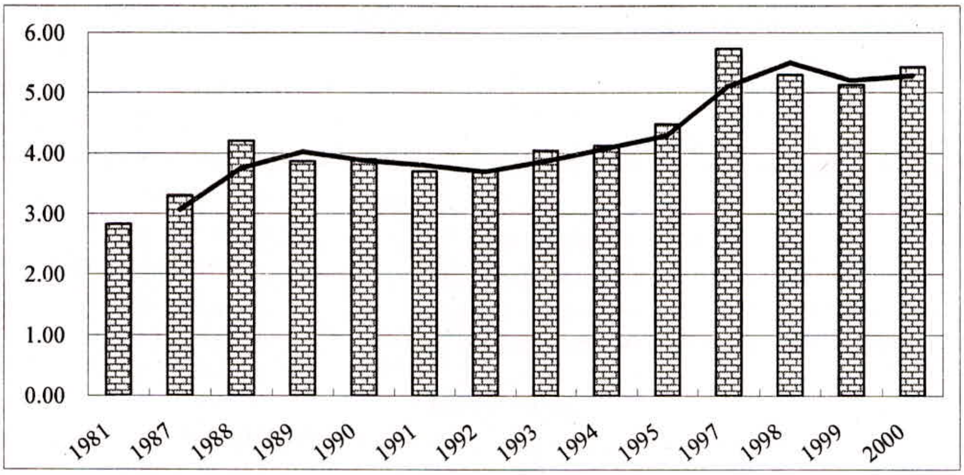

Fig. 4: Variations of Chemical Oxygen Demand of Manganese (COD_{Mn}) over past 25 years in Taihu Lake (unit: mg/L)

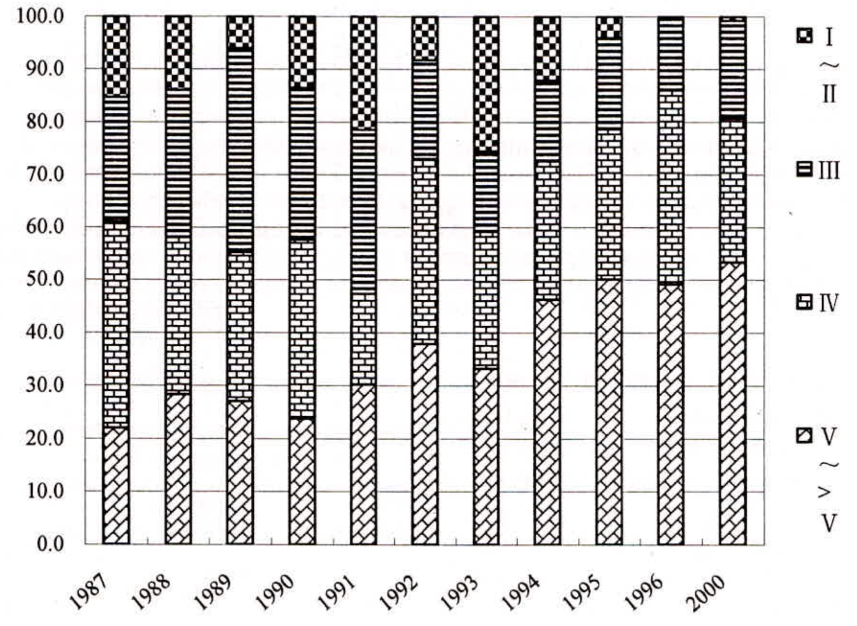

Fig. 5: Water quality of river channels evaluated in Lake Taihu basin over past 20 years

Table 1: Water Quality of River Channels Evaluated in Lake Taihu Basin Over the Past 20 years

Year	*Length of River Channels Evaluated (km)*	I~II (%)	III (%)	IV (%)	V~>V (%)
1987	1198.5	15.3	23.6	39.0	22.1
1988	1155.0	13.9	28.0	29.8	28.3
1989	1129.0	6.0	38.7	28.2	27.1
1990	1163.2	13.5	28.9	33.9	23.7
1991	1177.7	21.4	31.3	17.1	30.2
1992	1165.7	8.2	18.7	35.2	37.9
1993	1118.1	25.5	15.3	26.0	33.2
1994	1072.6	12.1	15.3	26.3	46.3
1995	977.0	4.1	17.2	28.5	50.2
1996	1239.7	–	13.9	36.9	49.2
2000	1598.0	0.7	18.7	27.2	53.4

Data from (Ye *et al.*, 2002).

CONCEPT OF CIRCULAR ECONOMY

Circular economy is defined as the formation of ecological economics, which is developed following the law of substance circle and energy flow of natural ecosystems. Thus, an economy system is evolved, bringing it into the substance and energy circular utilization process of the natural ecosystem. It is characterized by cleaner production, resource circular utilization and waste efficient recovery. The birth of circular economy develops the useful and discards the useless of traditional development patterns. It is the necessary result of societal progress. The essence of circular economy lies in the adjustment of production relations, and the target is to maintain sustainable development (Niu, 2004; Wu, 2004; Feng, 2004). The difference between circular economy and traditional economy is shown in Table 2.

Circular economy has three operational principles: Reducing, Reusing and Recycling, also called 3R principles. They constitute the basic thought, but the significance of each principle is not the same. Only the Reducing principle has the first status. Circular economy first aims to avoid producing waste.

The idea of circular economy was first germinated in the 1960's, when the environmental conservation movement arose. Kenneth Ewert Boulding, an American economist, put forward the "spaceship theory" (The Economics of the Coming Spaceship Earth, 1966), which is considered to be a presentation of early circular economy theory. The emergence of circular economy has promoted research on resources and environment of the 1970's and later widened the study of sustainable development, as well as connected the circular economy to the ecosystem. In the 1990's, the study of intelligent economy had given circular economy even more meaning in respect of high-tech industrialization and a learning type society. Thus, circular economy is a way to realize harmony and balance between resources and environment, and man and nature, and it is of great significance in realizing a new type of industrialization in our country.

Table 2: Comparison between Traditional Economy and Circular Economy

Items	*Traditional Economy*	*Circular Economy*
General description	Open linear economy based on uni-direction flow of matter—shepherd economy	Economic network of closed energy and material cycle
Main characteristics	Three dimensional split in economy, society and environment	Three dimensional conformity in economy, society and environment
Resources flowing mode	Depletion of natural resources → Traditional industrial products and supplies → Waste Disposal	Use of natural resources → Green industry products and supplies → Renewable resources
The exploitation of resources	Unrenewable resources, extensive management; High exploitation, low utilization; Focuse on short-term and single-functioned utilization	Recycling resources and scientific management; low exploitation, high utilization; focused on persistence and intensive management
Waste emission	High emissions of waste, unfriendly to environment	Low even zero emission of waste, friendly to environment
Target pursued	Economic benefit (maximization of profit)	Economic benefit, Environmental benefits and Sustainable development of society
Economy growth mode	Quantity-oriented material growth	Quality-oriented services growth
Environment administration mode	Open looped governance of end	Looped entire process control, stage prevention
Basic principle	Traditional theory such as Political Economics, Welfare economics, etc.	Ecosystems theory, Industrial Ecology theory, etc.
Index of estimation	Non-green single economic indicators (GDP, GNP, National income, average consumption, etc.)	Green system of national accounts including green accounting and green audit (green GDP, etc.)

RESTORING AND IMPROVING THE WATER RESOURCES SYSTEM OF LAKE TAIHU BASIN USING THE CIRCULAR ECONOMY CONCEPT

Enhancing the utility of resources is of great significance to the sustainable use of natural resources. Circular economy can enhance the utility of natural resources to the greatest extent, and save large amounts of resources which then can be taken used by later generations. At the same time, it can also reduce the discharge of contaminants and alleviate environmental pressure. It is believed that to restore the degenerated water resources system of Lake Taihu basin and finally to solve the problem of water quantity-induced water shortage, the circular economy notion must be used and Scientific Developmental Concept must be insisted on. Thereafter, based on the water resources system of Lake Taihu basin, the function of Lake Taihu basin according to its carrying capacity of the water resources system can be measured and identified. It relates to all kinds of measures, such as law, administration, engineering, economy, science and technology, etc. (Ye and Huang, 2001; Qian and Zhang, 2001; Wu and Zhang, 2005). Here only two of them are emphasized in what follows.

Integrated Management of Water Resources

Non-fluent administration management system of water resources is the rootcause of low effectiveness of water resources utility and wastefulness, which has greatly aggravated the water crisis of Lake Taihu basin and even of the country. To the water resources system itself, implementation of circular economy entails implementing integrated management of the water resources system. It has mainly two aspects: one is the integrated management of the drainage basin, and the other is the integrated management of water resources of the terrain, primarily the city. Therefore, the integrated management of the water resources institution (the committee of drainage basin management and the water resources bureau), which is comprised of drainage basin units and centered on the city, must be urgently be established. To that end, one must follow the principle of the combination of drainage basin management and area management, and the mode of "one pipe governing water, lots of pipes managing water". This would permit to implement the integrated management of rivers, lakes and seas, cities and the countryside, the quantity and quality of water, the surface and ground water, water resources in situ, water transiting territories and transferred to other localities, water supply and demand, water use and contamination elimination, etc. This would also help with constructing the system related to the integrated management of water resources which includes the water source—water supplying—water using—water draining—contamination eliminating—water recycling, in order to facilitate the use of the circular economy notion, coordinating diverse water resources projects, unifying planning, carrying out all kinds of water-saving measures, making the using and managing of water resources more scientifically.

The "3R Principle": Saving and Using Water Scientifically

Lake Taihu basin must insist on the circular economy way and "3R Principle", construct the society that saves water and prevents contamination. In this respect, Lake Taihu basin has tremendous potential and space for development. At the present time, the general water consumption quantity per acre of the basin in the average year is 550 m^3 or so. If we save water by 10 percent, mere irrigation can save 9.0×10^8 m^3 of water per year, that is equivalent to one forth of the living water consumption, and would also reduce area source contamination. In Lake Taihu basin, general industrial and living water consumption is 7.0×10^9 t/a (not including industrial cooling water), contaminated water discharged to rivers and lakes is 5×10^9 t/a, the discharged quantity of the contaminant COD is 1.3×10^6 t/a. Its effectiveness of water use is at the leading position, which accounts for one half of our country's average level 5045 m^3 (data in 2000), but still falls far behind that of developed countries. At present, the GDP consumption of water per 1.0×10^4 U.S. dollars is 2689 m^3 in Lake Taihu basin, which is 5 times larger than 514 m^3 in the United States and twice larger than the average level of the world. Industrial water recycling in Japan, USA, and the former Soviet Union had reached above 75% in the 1980's. Although the industrial water recycling of large quantity water-consuming factories in Shanghai City had arrived 79.2% in 2000, the basin as a whole is still below that level, which is merely 50% or so. The average living water consumption quantity per capita in the city in Lake Taihu basin is 358 L/d, whereas 15 European countries maintain the level of 160 L/d.

Thus, the key is how to save and use water scientifically. First of all, to build up and strengthen the notion of saving water, especially in the country where water is terribly short, there is urgent need to save water in the whole nation through school education, professional training and mass media.

Second, to encourage water-saving and clean production, one must put the system of using water by ration into practice, strengthen the management of water demands, and set up the base for the production system that is characterized by circular economy.

Third, one must exploit and utilize non-traditional water resources, such as rainwater use, seawater desalting, waster water recycling, flood water use, etc.

Fourth, one must adjust measures to local conditions, lift water price moderately and change gradually the condition that wate price deviates from the value of water.

Fifth, one must advocate rational and clean consumption, and incorporate the consumption process into the circular economy system.

In this way, the aim of "two taking-the-lead" of Lake Taihu basin can be fulfilled, healthy life of the river and lake can be maintained, and the sustainable social-economic development with the sustainable use of water resources can be ensured.

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