Developments in Ecosystems, volume 1
Edited by M.H. Wong

Chapter 12

An Integrated Analysis of Sustainable Human–Water Interactions in Wetland Ecosystems of Taihu Lake Basin, East China

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Abstract. The authors in this chapter have made integrated analyses in driving forces, states and human responses in water resource, water environment, water ecosystems and water security in Taihu Lake Basin, East China. The results have shown that landuse, water resource exploitation and environmental impacts from engineering and management activities as key driving forces have caused great degradations of wetland ecosystems in the basin, so the two critical human responses to these negative changes are to use ecological engineering measures other than typical environmental engineering and life-cycle-oriented ecological management other than typical end-of-pipe management so as to maintain sustainable human–water interactions for wetland ecosystem management of the basin.

12.1. Some Background Details of the Taihu Lake Basin

The Taihu Lake basin is located in the east of China, 30°5′–32°8′N and 119°8′–120°55′E. The total area is 36,500 km^2, 0.45% of the area of China, 53% of the lake's surface belongs to Jiangsu Province, 33.4% to Zhejiang Province, 13.5% to Shanghai and 0.1% to Anhui Province (Fig. 1). There are seven medium or large cities closely linked with the lake basin, including Shanghai, Suzhou, Wuxi, Changzhou, Hangzhou, Jiaxing and Huzhou, 26 counties or county level cities, and 951 towns. The arable land area is 1.35 million ha (Sun et al., 1993; She, 1997).

This basin is in the subtropical monsoon climatic zone. The annual average temperature is 14.9–16.2°C. The temperature in July, is 27.7–28.6°C and in

DOI: 10.1016/S1572-7785(04)01012-3

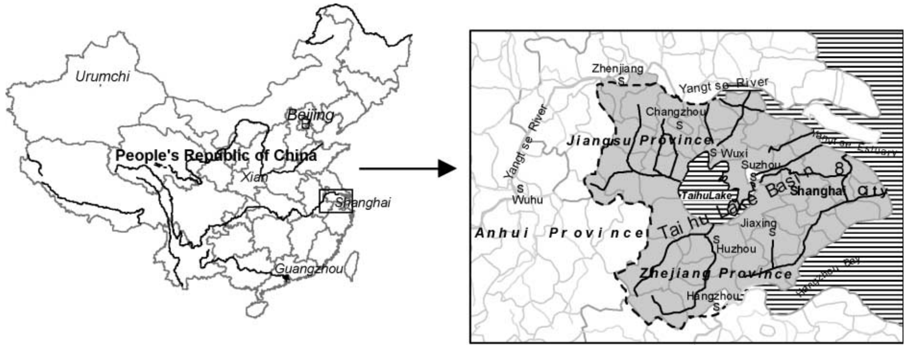

Figure 1: The geographic position of Taihu Lake Basin in China.

January, 1.7–3.9°C. The annual precipitation is 1,000–1,400 mm (Sun et al., 1993).

The topography of Taihu Lake Basin is as follows: 75% of the area, or 27,400 km^2, is plain, 25% are hilly and mountainous areas, and 17.5% water surface, including rivers and lakes. The altitude in the plain areas is 2–10 m asl, with the lowest area in the center. The central area, with an elevation of less than 3 m, encompasses the three lakes: Taihu, Yangcheng and Dianshan. In the hilly and mountainous areas, the highest point in the Tianmu Mountains, Longwangshan peak, has an altitude of 1,587 m (Table 1) (She, 1997; Nanjing Institute of Geography & Limnology, Chinese Academy of Science, 1988).

The total population in the basin was 41.51 million in 2000 with the density of 1,137 persons/km^2. There is a well-developed urbanized area, on average a city per 4,400 km^2, and a town per 38.38 km^2. The GDP per capita is RMB 256,000 in 2000 (China State Statistical Bureau, 2001).

Table 1: Topography in Taihu Lake Basin.

Altitude (m)	**Area (km^2)**	**Share of the plain (%)**
<4	9,225	33.7
(in which area of lakes)	(3,159)	(11.5)
4–5	10,740	39.2
5–6	2,280	8.3
6–7	2,750	10.0
>7	2,380	8.7
Total	27,375	100.0

12.2. Concepts and Methodology for this Research

12.2.1. Basic Concepts

Here, an essential concept of HREEES (humans, resources, environment, ecosystem, engineering, security) systems is introduced.

HREEES Systems are considered as a kind of important *human–environment interactive ecosystem (HEE)*. Generally, there are the three basic categories of the HEE, which are, respectively, environment-dominated, human-dominated and human–environment interactive subject ecosystems (shown in Fig. 2). The environment in the HEE has two components: natural and man-made. For example, a developed city is usually a human-dominated ecosystem. However, a city may be one of the three kinds of HEE ecosystems mentioned above.

The formation of the HREEES Systems can be driven mainly by human landuse, resource exploitation and environmental and ecological impacts or disturbances together with other non-human forces. From a human perspective, the two key parts in the HREEES Systems are human and environment dimensions, which are self-organized through mass, energy and information flows and therefore generate the dynamics of structure and functions in the HREEES Systems (Fig. 3).

12.2.2. The Methodology of Research

Using the concept of the HREEES Systems, we can form an overall image of a human–water ecosystem, including humans (population, cultural and social progresses), water resources, water environment, water ecosystems and water security, which forms various interactions driven mainly by landuse, resource exploitation, environmental and ecosystems impacts (L.R.E.). The methodological

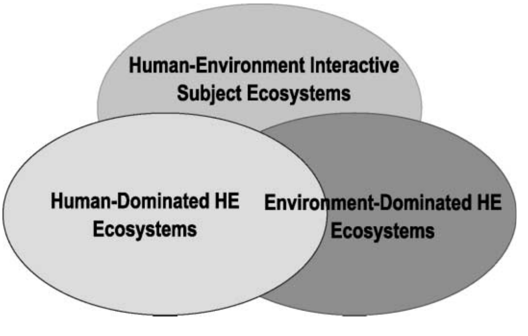

Figure 2: The three basic categories of human–environment ecosystems (HEE).

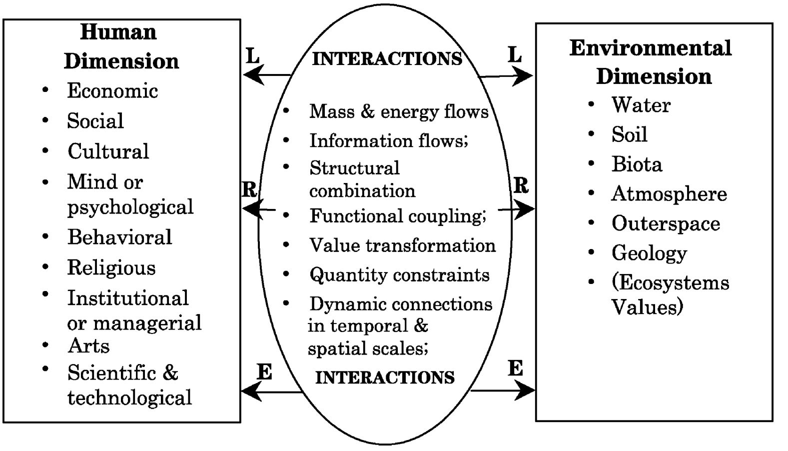

Figure 3: An integration interaction for the formation of the HREEES Systems by landuse (L), resources exploitations (R) and environmental and ecological impacts (E).

framework of driving forces–states–responses can be used to describe the complicated changes in the human–water wetland HREEES ecosystem in the Taihu Lake Basin at different rates and on different scales according to time and location, and the sustainable measures can also be explored in terms of the security of the wetland HREEES Ecosystems (Fig. 4).

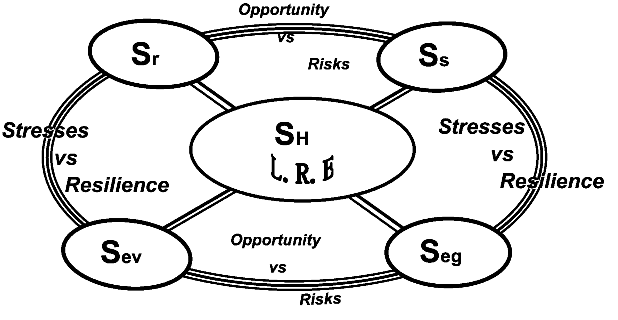

Figure 4: Research methodology chart of human–water HREEES Ecosystems. Notes: (1) **SH**: human developmental security such as population growth, cultural and social progresses; (2) **L.R.E.**: driving forces from human's landuse, resources exploitations, environment and ecosystems impacts; (3) **Sev**: water environmental security; (4) **Seg**: engineering security for water; (5) **Sr**: water resources security; (6) **Ss**: aquatic ecosystems security; (7) "▬▬ ═══" temporal, spatial pathways of driving forces state responses (DSR) for human water interactions; (8) "▬▬" security circles.

12.3. Hydrology, Water Resources and Water Disasters in the Taihu Lake Basin

12.3.1. Hydrology in the Taihu Lake Basin

The Hydrological System in the Taihu Lake Basin. The sources of the water system in the Taihu Lake Basin include the Jingxi River and the Tiaoxi River. The former originates from Tao Lake, the Ge Lake water system and the piedmont areas of Yixing and Liyang Mountain and Mao Mountain. The latter originates from Tianmu Mountain. The main water outlets of Taihu Lake have four routes. The first goes through the Shadunkou and Wangyuhe Rivers into the Yangtze River at Huazhuang of Changshu city. The second runs through Xukou, then through Loujiang River into the Yangtze River by Liuhe in Taichang county. The third goes through Kuajingkou, then into the Wusong River to the Huangpujiang River. The last runs through Taipu Gate and some small lakes, to the Dapuhe River and the Huangpujiang River, then into the Yangtze River.

The Taihu Lake Basin consists of 219 river courses. The total length of these rivers is 120,000 km, and the main watercourses have been extended to about 1,200 km. Major rivers in the Taihu Lake Basin include the Grant Canal, and the Huangpujiang, Tiaoxi, Nanxi, Taipu, and Wangyu Rivers. The topography in the basin is flat and the rivers form a fan-shaped drainage system at the lower reaches. There are 189 lakes with an area greater than 0.5 km^2, and 9 lakes with an area greater than 10 km^2. The overall area of the lakes in the basin is 3,159 km^2, and that of the reservoirs is 73 km^2 (Table 2) (Wang et al., 1989; Sun et al., 1993).

Hydrological Zones of the Taihu Lake Water Ecosystem. According to the hydrological characteristics of the basin, we can divide the basin into seven hydrological subregions as follows (Sun et al., 1993; Han & Mao, 1995; She, 1997).

(1) West Taihu Lake Region This region includes Zhenjiang, Changzhou, Wujin, Danyang, Jintan, Liyang, and Yixing city. The rivers, connecting and crisscrossing with the Yangtze River, Canal and Taihu Lake, mainly come from Mao Mountain and Yixing-Liyang Mountain. Most of the water in these rivers flows into Taihu Lake. There are some reservoirs in this region, which, together with Taohu Lake and Gehu Lake, can buffer some floodwater, and adjust runoffs flowing into the Nanxi River.

(2) East Taihu Lake Region There are many cities and counties located in this region, including Changshu, Suzhou, Wuxian, Wujiang, Kunshan, Taicang and so on. This region can be further divided into two small areas by the Shanghai-Nanjing railway line: to the north of the line is the area of Yangchenghu Lake, and to the south is the area of Dianshanhu Lake and Maohu Lake. The area of

Table 2: Lakes in Taihu Lake Basin.

Region	Lake area (km^2)									
	>10 km^2		10–5		5–1		1–0.5		Total	
	No.	Area	No.	Area	No.	Area	No.	Area	No.	Area
YCDM	6	264.34	8	52.10	34	72.62	22	15.20	70	404.26
PHJH			4	29.30	44	78.95	43	20.10	91	128.35
Puxi					1	1.63	3	1.52	4	3.15
Pudong										
Chengxiyu			1	5.29	2	2.79	1	0.65	4	8.73
Huxi	2	235.85	3	21.57	5	13.17	3	2.27	13	272.86
Zhexi							6	3.52	6	3.52
Taihu	1	2,338.1							1	2,338.1
Total	9	2,839.29	16	108.26	86	169.19	38	43.26	189	3,158.97

YCDM: Yangcheng Lake, Cheng Lake, Dianshan Lake and Mao Lake; PHJH: the plain of Hangzhou, Jiaxing and Huzhou city.

Dianshanhu Lake and Maohu Lake is the secondary area for buffering and storing water coming from Taihu Lake.

(3) Chengxiyu Region This area lies between the Chengxi Canal and the east bank of the Wangyuhe River. In the northern part of this region is the Yangtze River and in the south is Taihu Lake. It includes the cities of Wuxi, Jiangyin, Changshu and Zhangjiagang. Floodwater in this region will mainly flow into the Yangtze River. Some water flows into the Grand Canal, and exchanges water with Yangchenghu Lake, Dianshanhu Lake and Maohu Lake; other flows water into the Wangyuhe River, then into the Yangtze River. In the flood season, this region can buffer some water from Taihu Lake and in the dry season, this region can pump water from the Yangtze River for irrigation and navigation.

(4) West Zhejing Region This region includes Changxin, Anji and Lin'an in Zhejiang province. The Tiaoxi River is the largest in this area. Some of the water from the mountainous areas is absorbed by the reservoirs, and of the other runoffs flow directly into Taihu Lake or lakes on Hangzhou-Jiaxing-Huzhou Plain via the East Tiaoxi River.

(5) East Hangzhou-Jiaxing-Huzhou Plain Region This region includes the area from the south of the Taipu River to the east of the Tiaoxi River. To the east of the region are the Huangpujiang and Zhangjinghe Rivers. To the southeast is the Qiantangjiang River and Hangzhou Bay. The region consists of the rich Hangzhou-Jiaxing-Huzhou plain and the southern area of the Taipuhe River in

Zhejiang province. The southeast of this area is slightly higher and the center is low. There are many rivers and lakes crisscrossing the area, into which the floodwater from the Tiaoxi River is often discharged.

(6) Huangpujiang River Valley Region This region includes Dianshanhu Lake, as well as cities and counties such as Shanghai, Jiading, Baoshan, Pudong, Shuangsha, Nanhui, Fengxian, Songjiang, Jinshan and Qingpu. It is close to the sea and located in the lower reaches of the Taihu Lake Basin. The water comes from Taihu Lake and tide. Tidal water is plentiful and evenly distributed between seasons and years. However, the tide brings about water disasters such as salt tides and waterlogging, so this region is affected by tide and the threat of flood. Its capacity to buffer floodwater is low. Another problem in this region is serious water pollution. In the low rainfall season, the water quality is affected by the inflowing salt tide.

(7) The Central Area of Taihu Lake The length of the Taihu Lake from north to south is 68.5 km, and its average width from east to west is 34 km, the maximum width being 56 km. The average depth of water is 1.9 m and the deepest is 2.9 m. The water surface area is 2,427.8 km^2, which is 139.9 km^2 less than in the 1960s. Deducting the area of several islands, the actual water surface is 2,338.1 km^2. The lake volume is 4.43 billion m^3.

12.3.2. Water Resources in Taihu Lake Basin

Available Quantity of Water Resource. The annual amount of available water can be estimated according to the following formula (Sun et al., 1993; She, 1997):

$$W_\mathrm{t} = W_\mathrm{r} + W_\mathrm{g} - W_\mathrm{rp}$$

In the formula, W_t is the annual volume of available water (10^8 m^3), W_r is the runoff volume from precipitation (10^8 m^3), W_g is the volume of groundwater supply (10^8 m^3). W_rp is the repeated amount which is the difference between the annual underground water replenishment and the annual river runoffs (10^8 m^3).

(1) Amount of precipitation The precipitation in the basin is 1,000–1,400 mm. In the Hangzhou-Jiaxing-Huzhou plain, the precipitation is higher than in the northern region. The precipitation in the Huangpujiang Watershed system is higher than in the western part of the basin. The southern mountainous areas get more precipitation than the northern plain areas. The precipitation varies greatly throughout the year and from year to year due to the influence of the monsoon. The precipitation in the more rainy years is 1–1.5 times higher than that in the less rainy years. The relative variability is 15–30%. The peak value for precipitation appears in the period from June to August, making up about 35–40% of the annual precipitation; the lowest value is from December to February at only 11–14%.

(2) Amount of runoff flow The runoff coefficient in the Taihu Lake Basin is 0.26–0.4. The coefficients in the mountainous area and the Hangzhou-Jiaxing-Huzhou plain are higher than those in the northern plain areas. The average annual runoff in the basin is 14.17 billion m^3 (Table 3), of which 5.54 billion m^3 is in Jiangsu Province, 7.07 billion m^3 in Zhejiang Province and 1.56 billion m^3 is in Shanghai. The area of Jiangsu Province is about 8,000 km^2 greater than that of Zhejiang Province; however, the runoff in Jiangsu Province is 1.53 billion m^3 less than the runoff in Zhejiang Province. In Zhejiang Province, the average volume of water generated is 582,000 m^3/km^2 in Shanghai 305,000 m^3/km^2 but in Jiangsu Province, only 274,000 m^3/km^2.

(3) Volume of groundwater The groundwater table in the basin is high. Its recharge mainly depends on the precipitation. The total amount of shallow groundwater in Taihu Lake Basin is 5.52 billion m^3 the amount of replenishment is 2.32 billion m^3. In the eastern areas of the Huangpujiang Watershed, the recharge volume is the greatest, 0.61 billion m^3; then, in the west of the Taihu Lake Basin, it is 0.59 billion m^3. In these areas, the groundwater resource is relatively plentiful.

(4) Local water resources The local water resource is the sum of the surface water and the groundwater excluding the river outflow, or the sum of the local outflow and the replenishment of the subsurface water. In the Taihu Lake Basin, the annual local water resource is 16.5 billion m^3, 41% of which (6.79 billion m^3) is in Jiangsu Province, 45.7% (7.55 billion m^3) in Zhejiang Province and 11.3% (2.16 billion m^3) in Shanghai.

(5) Volume of water inflow The upper reaches of the Taihu Lake Basin is a relatively closed watershed and there is no inflow; however, it is between the Yangtze River and the Qiantangjiang River and close to the East China Sea, so water from rivers and tides can be pumped into this basin. Therefore, the water resource from outside is plentiful. The total water inflow in the Basin is 71.69 billion m^3 ($P = 50\%$) (Table 4). In the part of the basin within Jiangsu Province, the water resource is mainly from the Yangtze River, and the inflow is up to 14.54 billion m^3 ($P = 50\%$), whereas in Shanghai, the inflow is tidewater from the Huangpujiang River and the total inflow is 55.48 billion m^3 ($P = 50\%$).

(6) Total volume of the water resource The total volume of the water resource in the Taihu Lake Basin under different rates of guarantee (P) 87.66 billion m^3 ($P = 50\%$), 85.5 billion m^3 ($P = 75\%$) and 78.87 billion m^3 ($P = 95\%$), respectively. In drier years, the water resource is 9.79 billion m^3 ($P = 50\%$) and the sum of the water resource in Jiangsu Province and Zhejiangjiang Province is 29.52 billion m^3 ($P = 50\%$) (Table 5) (Sun et al., 1993).

Volume of the Water Resource Per Capita in the Taihu Lake Basin. In the Taihu Lake Basin, the average annual volume of local water resource per capita is

Table 3: Local water resource in Taihu Lake Basin.

	Area (km^2)	**Annual precipitation (mm)**	**Annual runoff (mm)**	**Local runoff (10^8 m^3)**	**Ground-water (10^8 m^3)**	**River runoff (10^8 m^3)**	**Local water resource (10^8 m^3)**
West of the Basin	8,880	1,079	319	28.34	10.04	4.17	34.21
East of the Basin	5,307	1,044	285	15.10	7.47	3.67	18.90
Surface of Taihu	2,338	1,069	69	1.59			1.59
Plain along Huangpujiang river and the sea	5,110	1,141	582	15.59	11.09	5.05	21.63
Cheng-Xi-Yu areas	3,705	1,036	281	10.42	5.37	2.61	13.18
Shaoxi mountainous areas	5,797	1,333	305	40.20	11.41	11.41	40.20
Hangzhou-Jiaxing-Huzhou plain	6,357	1,333	582	30.50	9.82	5.04	35.28
Total				141.74	55.20	32.05	164.99

Table 4: Inflow amount in Taihu Lake Basin under different rates of guarantee (P).

	$P = 50\%$	$P = 75\%$	$P = 95\%$
West of the Basin (m^3)	54.19×10^8	61.21×10^8	70.14×10^8
East of the Basin (m^3)	60.84×10^8	53.18×10^8	70.36×10^8
Cheng-Xi-Yu area (m^3)	30.33×10^8	32.00×10^8	43.80×10^8
Plain along Huangpujiang river and the sea (m^3)	554.8×10^8	554.8×10^8	500.7×10^8
Shaoxi mountainous areas (m^3)		0.6×10^8	2.59×10^8
Hangzhou-Jiaxing-Huzhou plain (m^3)	16.72×10^8	24.62×10^8	24.21×10^8
Total (m^3)	716.88×10^8	726.41×10^8	711.8×10^8

Note: P denotes the rate of guarantee.

861 m^3, which is less than 1/5 of that in the country as a whole. The water resource per ha in the Taihu Lake Basin is less than 2/5 of that in the country as a whole. Furthermore, the water resource per capita is highest in Zhejiang (1,751 m^3), is lowest in Shanghai (228 m^3), and 469 m^3 per capita in Jiangsu Province. If the

Table 5: Amount of water resource in Taihu Lake Basin under different rates of guarantee.

	P (%)	River runoff (10^8 m^3)	inflow (10^8 m^3)	total (10^8 m^3)	Replenishment from subsurface water (10^8 m^3)	Total volume of water resource (10^8 m^3)
Jiangsu	50	54.64	145.36	200.01	12.43	212.43
	75	33.97	146.39	180.36	12.43	192.79
	95	7.98	184.3	192.28	12.43	204.56
Shanghai	50	20.41	554.8	575.21	6.04	581.25
	75	19.35	554.8	573.35	6.04	579.39
	95	5.88	500.7	506.58	6.04	512.62
Zhejiang	50	61.31	16.72	78.03	4.78	82.81
	75	39.41	25.22	64.63	4.78	69.41
	95	30.03	26.80	56.63	4.78	61.41
Total	50	136.18	716.88	853.34	23.25	876.59
	75	92.73	726.41	831.74	23.25	854.99
	95	43.89	711.8	755.49	23.25	778.74

Note: P denotes the rate of guarantee.

total water resources, including local water and inflow water resources, are counted together, the water resource per capita is 2,666 m^3 ($P = 50\%$). It is highest in Shanghai, 5,389 m^3, lowest in Jiangsu Province 1,807 m^3 and 2,334 m^3 in Zhejiang Province.

Water Supply and Demand

(1) Volume of water available The volume of water resource available in the basin is 35.16 billion m^3 ($P = 50\%$) and 36.73 billion m^3 ($P = 90\%$) (Table 6). The rate of water use is about 40–47%. In Jiangsu Province, the available water resource is 23.19 billion m^3, which exceeds the total amount of water resource due to the large-scale use of water from the Yangtze River and some reuse of water or wastewater. The ratio of reused water is 72.4%. In Shanghai, the water resource is abundant, but part is tidewater so that there are limitations on its use. It was expected that the available water resource could be increased to 34.47 billion m^3 ($P = 50\%$), 35.44 billion m^3 ($P = 75\%$) and 36.73 billion m^3 ($P = 95\%$) in 2000 (Table 6) (Nanjing Institute of Geography & Limnology, Chinese Academy of Science, 1988; Sun et al., 1993; Sun, 1995; She, 1997).

(2) Water demand The demand for water resource by different sectors including industry, agriculture and domestic uses under the different rates of guarantee is listed in Table 7. The average annual demand for water is 27.58 billion m^3 ($P = 50\%$), 28.86 billion m^3 ($P = 75\%$) and 32.03 billion m^3 ($P = 95\%$), of which the agriculture water demand accounts for 67.2% (18.54 billion m^3 ($P = 50\%$)). In addition, agriculture water use in Jiangsu province the largest consumption, accounting for 12.48 billion m^3, which is 67.18% of the total in the basin. The total amount of industrial water used is around 8 billion m^3, 4.45 billion m^3 of which is used in Shanghai. The domestic water consumption in the basin is relatively small, 0.54 billion m^3, representing only 2.0% of the total demand. The domestic water consumption in Shanghai is the highest, at 70.8% of the total

Table 6: Available water resource in Taihu Lake Basin.

Region	**50% rate of guarantee**		**95% rate of guarantee**	
	Total water resource (10^8 m^3)	**Available water resource (10^8 m^3)**	**Total water resource (10^8 m^3)**	**Available water resource (10^8 m^3)**
Jiangsu	212.43	231.89	204.71	231.89
Zhejiang	82.81	34.76	61.41	42.42
Shanghai	581.25	80.35	512.62	92.99
Total	875.93	351.63	778.74	367.30

Table 7: The demand for water in the Taihu Lake Basin with different guarantee rates.

Area	**Water demand by agriculture (× 10^8 m^3)**	**Water demand by industry (× 10^8 m^3)**	**Water demand by cities (× 10^8 m^3)**	**Water demand by rural areas (× 10^8 m^3)**	**Total (× 10^8 m^3)**
P = 50%					
West of the lake	51.37	11.52	0.23	1.12	64.25
East of the lake	48.81	3.86	0.35	0.85	53.86
Zheng-Xi-Yu area	24.66	16.72	0.47	0.77	42.61
Plain areas along Huangpujiang river and the sea	30.60	44.49	3.84	1.43	80.36
Shaoxi Brook	7.14	0.22	0.04	0.27	7.67
Hangzhou-Jiaxing-huzhou plain	23.26	2.47	0.49	0.87	27.09
Total	185.84	79.28	5.42	5.31	275.84
P = 75%					
West of the lake	54.29	11.52	0.23	1.12	64.25
East of the lake	45.28	3.86	0.35	0.85	50.35
Zheng-Xi-Yu area	26.68	16.72	0.47	0.77	44.63
Plain areas along Huangpujiang river and the sea	37.40	44.49	3.84	1.43	87.15
Shaoxi Brook	8.86	0.22	0.04	0.27	10.38
Hangzhou-Jiaxing-huzhou plain	28.00	2.47	0.49	0.87	31.83
Total	198.51				288.59
P = 95%					
West of the lake	63.21	11.52	0.23	1.12	76.09
East of the lake	54.20	3.86	0.35	0.85	59.26
Zheng-Xi-Yu area	30.54	16.72	0.47	0.77	48.49
Plain along Huangpujiang river and the sea	43.24	44.49	3.84	1.43	92.99
Shaoxi Brook	9.85	0.22	0.04	0.27	10.38
Hangzhou-Jiaxing-huzhou plain	29.26	2.47	0.49	0.87	33.09
Total					320.3

Note: *P* denotes the rate of guarantee.

in the basin (Nanjing Institute of Geography & Limnology, Chinese Academy of Science, 1988; Sun et al., 1993; She, 1997).

(3) The equilibrium between water supply and demand The water resources in the Taihu Lake Basin can meet demand under different rates of guarantee (Table 8) (Nanjing Institute of Geography & Limnology, Chinese Academy of Science, 1988): there is a 7–14 billion m^3 surplus of water. However, in recent years, industrial and agricultural production has increased rapidly. In typical years, the shortage of water is 2 billion m^3, but in a very dry year it can be more; for example, in 1978 the shortage was 12 billion m^3.

The total volume of water demand in the Basin is 57 billion m^3 if the rate of guarantee is 95% during the peak period of water consumption (1971 was a typical year), of which the demand for water in agriculture is 20.2 billion m^3, for industry 27 billion m^3, for domestic uses 2 billion m^3 and for the environment 6.8 billion m^3. However, the average annual water resource in total is 16.5 billion m^3. In 1971, a dry year, it was 8 billion m^3 ($P = 94\%$), in 1978, a seriously dry year, only 1.6 billion m^3 ($P = 98\%$) (Sun et al., 1993; Sun and Mao, 1994; Sun, 1995).

12.3.3. Water Disasters in the Taihu Lake Basin

The Taihu Lake Basin has very frequent flooding and drought (including coastal storm tides). In the last century, there were six individual years in which flooding occurred. In 1954, the Taihu Lake Basin was hit by a large flood with 21.2 billion m^3 of flooding; 523,300 ha of land were affected by the disaster, of which 248,670 ha suffered greatly: direct economic losses were 1 billion RMB yuan. It appears that the frequency of large floods is about every 5–10 years (Sun et al., 1993).

There were six individual years in which drought occurred within the 20th century. For example, a serious drought in 1934 caused a water shortage of 1.3 billion m^3, affecting 68,700 ha of land (Sun et al., 1993).

Although the Taihu water system has been improved, it still faces a severe risk of flooding. Recently there have been some changes as follow (Wang, 1994):

(1) In the 1950s, there was 900 mm of rain in the flooding periods and the water level in Taihu Lake was only 4.0 m asl (above sea level); nowadays, there is 300–400 mm rain in the flooding periods but the water level in Taihu Lake still goes beyond 3.5 m (the warning water level in Taihu Lake is 3.5 m asl).
(2) In the early years of the 1990s, high water level appeared three times, the highest water level in Taihu Lake was 4.79 m in 1991, 4.51 m in 1993 and 4.32 m in 1995.

Table 8: Water equilibrium under different rates of guarantee in the Taihu Lake Basin (in 10^8 m^3).

Area	Water resources	Available water resource	Total demand for water	Surplus or shortage of water	
				Surplus	Shortage
P = 50%					
West of the lake	90.29	98.17	64.25	37.8	3.89
East of the lake	76.38	73.85	53.86	29.18	9.21
Zheng-Xi-Yu areas	45.76	64.50	42.61	21.88	
plain areas along Huangpujian and the sea	581.25	80.35	80.36		8
Shaoxi brook	31.39	7.67	7.67	0	0
Hangzhou-Jiaxing-huzhou plain areas	51.42	27.09	27.09	0	0
Total	876.49	352.44	275.84	140.16	21.39
P = 75%					
West of lake	81.58	90.26	67.19	23.11	0
East of lake	70.39	79.94	50.35	29.59	0
Zheng-Xi-Yu area	40.82	61.63	44.63	17.00	0
Plain areas along Huangpujian and the sea	579.39	87.15	87.15	49.3	0
Shaoxi brook	20.95	9.39	9.39	0	0
Hangzhou-Jiaxing-huzhou plain area	48.46	31.83	31.83	0	0
Total	841.59	360.2	290.54	119.02	0
P = 95%					
West of lake	80.93	93.82	76.09	20.80	3.06
East of lake	76.26	74.75	59.26	15.91	0.42
Zheng-Xi-Yu area	47.52	63.32	48.49	18.37	3.54
Plain areas along Huangpujian and the sea	512.62	92.99	92.99		
Shaoxi brook	18.05	9.33	10.38	0	1.05
Hangzhou-Jiaxing-huzhou plain areas	43.36	33.09	33.09	0	0
Total	778.74	367.30	320.30		

Note: *P* denotes the rate of guarantee.

(3) In 1991, there was a rainfall with a frequency of every 20 years, and a high water level with a frequency of above 50 years had appeared.
(4) In the flooding period, the maximum daily water level rise increases year by year. In 1954, the maximum daily water level rise was only 9 cm/day, but in 1991, it became 13 cm/day, and reached 22 cm/day in 1995.

12.4. Water Quality Changes in the Taihu Lake Basin

12.4.1. Pollution Sources from Urbanization and Industrialization

Pollution sources include wastewater discharge from various urban activities. According to the statistical data in 1994, the total discharge of wastewater into the basin was 3,200 million t per annum (now 3,500 million); chemical oxygen demand (COD_{Cr}), 282,404 t; total nitrogen (TN), 79,522 t; total phosphorus (TP), 5,660 t (Table 9). The discharge of wastewater into the basin accounts for 1/10 of national discharges and 1/3 of that into the Yangtze River Valley. Wastewater discharge per unit area reached 109,000 t per annum. 80% of the wastewater was untreated, or treated but not meeting the State Standard for Wastewater (Cai, 1995).

The chemical fertilizer applied in the basin is 2–3 million t annually (1,500–3,000 kg per ha), and pesticide, 750,000–1,200,000 t (42 kg per ha). The efficiency of use of chemical fertilizer is less than 50%. Nearly half the chemical fertilizer flows into waters.

The ranking of contribution (CR) for different pollution sources of COD_{Cr} to the water pollution of rivers and lakes from high to low is industry, domestic, husbandry, precipitation and dustfall; the ranking of CR for TP into rivers and lakes from high to low is domestic, husbandry, fisheries, plantation, precipitation and dustfall; and the ranking of CR for TN into rivers and lakes from high to low is domestic, plantation, husbandry, fisheries, precipitation and dustfall. In addition, the COD discharged into the Yangtze River from the Huangpujiang River per year is 50.8 thousand t, Hg, 3.0 t, Cu, 238.9 t, Zn, 1,300 t, Al, 249.0 t, Cd, 1.80 t, oils, 0.483 t (Cai, 1995).

In about 48 small cities and towns in the Taihu Lake Basin in 1987 (Cai, 1995), the total wastewater discharge was about 371 million t/yr, of which industrial wastewater accounted for nearly 90%. The number of towns whose total wastewater exceeded 10 million t/yr is 12. There were 14 towns whose total wastewater was 5–10 million t/yr. Those whose wastewater was less than 5 million t increased to 22. In 1985, the wastewater discharged by the major industrial pollution sources in 12 cities and counties was 209.7 million t, of which the

Table 9: Pollution sources in Taihu Lake Basin (1994).

Pollution sources	**Wastewater amount (10^4 t/yr)**	**COD_{Cr} (t/yr)**	**CR of COD_{Cr} (%)**	**TN (t/yr)**	**CR of TN (%)**	**TP (t/yr)**	**CR of TP (%)**
Industrial wastewater in major trades	53,901	111,061	39.3	12,544	15.8	591	10.4
Domestic sewage	32,290	119,029	42.2	19,948	25.1	3,394	60.0
Farmland loss and erosion[a]	12,8373			18,355	23	164	2.9
Scattered inhabitants[a]	15,671	11,377	4.0	1,896	2.4	433	7.65
Husbandry[a]	1,203	16,761	5.9	9,591	12.0	255	4.5
Sum[a]	14,5247	28,138	10.0	29,842		852	
Fisheries	83,774			13,195	16.6	533	9.4
Domestic pollution of lakes	216	417	0.15	21	0.03	3	0.05
Precipitation on lake surface	3,341	23,595	8.4	2,760	3.4	60	1.06
Dustfall				421	0.5	33	0.58
Ships		164	0.06	22	0.03	2	0.03
Water loss and soil erosion				800	1	192	3.39
Total	318,769	282,404		79,552		5,660	

[a] Non-point sources in rural areas.

treated wastewater was only 11.7%, while those up to the State emission standard after treatment only occupied 1.8%.

Pollution discharge every 10,000 yuan of output value in the Taihu Lake Basin are, respectively: papermaking, 1,673 t; chemical industry, 1,358 t; food, 324 t; tannery, 248 t; electroplating, 247 t; and textile and printing and dyeing, 174 t.

12.4.2. Present State of Water Quality in the Taihu Lake Basin

In the basin, according to the State Water Quality Standard, some reservoirs in Tianmushan areas in Zhejiang province have Class I water quality, and east and west Tiaoxi River has relatively good water quality. The water quality of the Taipuhe and Wangyuhe Rivers (the two main river courses) and the rivers surrounding Taihu Lake is very bad.

The Water Quality of Different Sections of River Courses. In the basin, the river sections whose water quality is worse than Class V for all periods 181.9 km, which is 18.84% of the total assessed length of rivers. The sections whose water quality was above Class V in all three periods were 65.35% of the total evaluated length of the sections.

The length of contaminated river whose water quality is worse than Class IV in the flood season, non-flood season, and in one full year is 786, 883 and 841 km, respectively, accounting for 68, 77 and 73 of the total assessed sections. The pollution is mainly caused by COD, NH_3-N and other organic pollutants (Table 10) (Cai, 1995).

Water Quality of the Lakes. The water quality changes in Taihu Lake can be divided into three stages. In the early 1980s, the water quality of Taihu Lake was predominantly Class II, in the late 1980s, the water quality underwent a transition period from Class II to Class III and, in the middle 1990s, the water quality in Taihu Lake was mainly Class III.

The water quality of rivers into or out of Taihu Lake deteriorated day by day. By 1995, over half of the rivers had Class V or worse in 1995. The main pollutants were TP, TN and COD_{Mn}. In the flood season, the water quality was better than in the non-flood season (Table 11).

Overall, from the early 1980s up to now, the water quality in Taihu Lake degraded by one class, from Class II to Class III. Most areas of Taihu Lake reached eutrophic level. Wulihu Lake and Meilianghu Lake have reached the over-eutrophication level.

The area of Dianshanhu Lake is 63.73 km^2. In 1992, the area of Class III in the whole year was 33.20 km^2 (52.1% of the total area) and that of Class IV,

Table 10: The water quality for different sections of some rivers in Taihu Lake Basin in 1992.

River name	**Assessed river length (km)**	**Class II**		**Class III**		**Class IV**		**Class V**		**Worse than Class V**	
		Length	**Ratio (%)**	**Length**	**Ratio (%)**	**Length**	**Ratio (%)**	**Length**	**Ratio (%)**	**Length**	**Ratio (%)**
Canal in the south of Yangtze	299.5			51	17	81	27.1	42	14.0	125.5	41.9
Taipu River	48			10	21	13	27.0	25	52.0		
Huangpujiang River	81.3					56.4	69.4	24.9	30.6		
Suzhouhe River	45.8							11.6	25.3	34.2	74.7
East Tiaoxi River	152.5	28.5	18.7	59.0	38.7	65.0	42.6				
West Tiaoxi River	197.5	47.0	23.8	51.5	26.1	68.5	34.7	30.5	15.4		
Wangyuhe River	3					3	100				
Liuhe river	10					10	100				
Licaohe River in Danjin	10					10	100				

Note: this assessment was conducted during three different periods: the flood season, the non-flood season and for the total year (Cai, 1995).

Table 11: The state of the water quality in Taihu Lake Basin, 1992.

Rivers and lakes	**Length of river courses (km)**	**Length of assessed river courses (km) (*A*)**	**Length of polluted river courses (km) (*B*)**	**B/A (%)**	**Main pollutants**
Canal in the south of Yangtze River	312	299.5	248.5	83	Non-ionized ammonia, COD, BOD_5
Huangpujiang River	113	81.3	81.3	100	DO, non-ionized ammonia, volatile phenol, COD_{Mn}
Taipuhe River	57.6	48	25	52	Volatile phenol
Wangyuhe River	60	3	3	100	NH_3-N, DO, COD_{Mn}
Taihu Lake				21.6% is moderate eutrophication; and 78.4% over eutrophication	TN,TP

Note: Length of polluted river courses refers to Class IV or worse.

30.53 km^2 (47.9%). The perennial mean concentration of TP was 0.103 mg/l and the mean concentration of TN was 2.217 mg/l (Shi & Liu, 1989; Song et al., 1992).

Yangchenghu Lake (119.0 km^2) is, on average, Class III the whole year. The perennial average TP was 0.056 mg/l, TN, 3.02 mg/l. All the areas had moderate levels of eutrophication for TP and high levels of eutrophication for TN.

The area of Gehu Lake is 187.0 km^2. The area with Class II was 46.7 km^2 (occupying 25.0%) and that with Class IV, 140.3 km^2 (75.0%). Perennially, 50% of the lake exhibited moderate levels of eutrophication.

The total area of the four lakes mentioned above is 2,707.73 km^2. The area of Class II during the whole year was 1,631.70 km^2 (60.3% of the total area) that of Class III, 411.21 km^2 (15.20%) and that of Class IV, 663.83 km^2 (24.5%).

12.5. Driving Forces for Changes in the Taihu Lake Wetlands Ecosystems

12.5.1. Driving Forces for Water Resources Changes

The major factors resulting in changes in water resources are as follow (Sun & Mao, 1994; Han & Mao, 1995; Sun, 1995; Wang & Cheng, 1996; She, 1997):

Small runoff and uneven distribution Precipitation is the main source of runoff in Taihu Lake Basin. The variation of the precipitation in any one year and between years is very great due to the annual variation in intensity and frequency of the monsoon. In summer, precipitation is twice as large as in winter. In general, the maximum precipitation occurs in the plum rain period (a kind of typical raining season in the lower reach of Yangtze River from June to July) and the typhoon period (from August to September). The runoff during these four months is the largest, about 50–70% of the total runoff each year. The runoff modulus in the basin is only 378,000 m^3/km^2/yr, its total amount is less than 5.31 billion m^3/km^2/yr in the Yangtze River Watershed.

No effective engineering measures to control lake water In the basin, there are many other lakes besides Taihu Lake. There is no floodgate at most of the river mouths, and many riverways connecting to the lakes are not under control. Every year, more than a billion m^3 of unused water runs freely into the East China Sea.

Large scale land reclamation causes many lake wetlands and rivers to disappear There are many low-lands and lake shoals below 4 m (Wusong sea level), all reclaimed as dyked land. According to an investigation in 1990, there were about 7,000 reclamation sites, of which 500 (total area of 500 km^2) were dyked (Sun et al., 1993; Han & Mao, 1995; Sun, 1995).

Water quality of lakes and rivers decreased, reducing the availability of water resource Water shortages due to water pollution in the Taihu Lake Basin have occurred frequently in recent years. The eutrophication in Taihu Lake, Yangchenghu Lake and many others becomes progressively more serious. In the period from July to August in 1994, the weather was very dry, the water was polluted in the Huangpujiang River and the pollution extended upstream. The length of the polluted zone was 30–40 km. The water-withdrawal pipes of the waterworks along the Huangpujiang River were surrounded with polluted water (Cai, 1995; Wang & Cheng, 1996).

Water quality at the lower reaches affected by tidewater The mouth of the Yangtze River has a relatively strong tide. The Huangpujiang River is one of the main rivers flowing into the mouth of the Yangtze River, which experiences tides twice a day. In general, the tide entering Shanghai is usable freshwater. The average annual amount of tidewater is 44.25 billion m^3, but from November to April next year, salted tidewater will enter the mouth of the Yangtze River, and water in Huangpujiang River easily degrades. In brief, although tidewater makes up for the shortage of surface runoff, it causes salted tidewater to flow upstream and reduces the water quality.

Water use per product is high, bringing about an increase in water demand Compared with developed countries, the water demand per unit product and per unit output value in China is evidently high. The use of water per ton of steel production is 20–40 t, but in developed countries, only 3–5 t; the use of water per ton of paper production in China, is 200–500 t and in developed countries, around 100 t; the use of water per RMB 10,000 of output value in China is close to 400 t, but in developed countries, only about 40 t. In China, the rate of water recycling is about 25%, whereas in developed countries, it was 60% even in the late 1960s (Sun, 1995).

12.5.2. Driving Forces for Water Security Changes

There are several driving factors for the changes in flooding and drought in the Taihu Lake Basin as follow (Sun et al., 1993; Wang, 1994).

(1) There is an uneven distribution of annual and multiple-year rainfalls in the Taihu Lake Basin. The spatial distribution of annual rainfall assumes a pattern with high levels in the southwest and low levels in the northeast. The annual distribution of rainfall in the Taihu Lake Basin has two peaks, in June and September; the lowest value occurs in December and January. The rainfall in June and July largely comes from intermittent drizzle. In Shanghai, the rainfall in Autumn, caused by typhoon weather, accounts for 30 and 38% of total annual rainfall.

The discrete coefficient (C_v value) of monthly rainfall at the Xishan hydrological station (Table 12) shows that the multiple-year rainfall is much

Table 12: The discrete coefficient of monthly rainfall in Xishan (C_v).

Month	**1**	**2**	**3**	**4**	**5**	**6**	
C_v	0.6958	0.5718	0.5062	0.4173	0.4688	0.4541	
Month	**7**	**8**	**9**	**10**	**11**	**12**	**Year**
C_v	0.5287	0.7303	0.7185	0.8955	0.7350	0.8100	0.1904

larger than the annual rainfall (Sun et al., 1993). That is to say, since Autumn, the C_v value obviously rises, indicating an increase in multiple-year rainfall. The period from Autumn to October is one of high water demand for crop growth, but the monthly rainfall decreases gradually; furthermore, Autumn is the high evaporation period, thus the increase in multiple-year rainfall easily caused water disasters in the period. Although the C_v value in June and July was smaller than that in other months, the monthly rainfall was very large, so the uneven rainfall readily caused flooding and waterlogging disasters.

(2) The inflow is larger than the outflow in Taihu Lake: in the 1991 flooding period, the water level in the lake was high, and the inflow from the upper reach of the west Taihu Lake was large and fast, making the water level in the lake rise above its highest historical point. For example, in 1991, the water level in Xishan Station of Taihu Lake reached a record 4.79 m by July 15 and stayed at this level until July 16, 14 cm above the highest level recorded in 1954.

Due to high-speed economic development in recent years, urban flooding protection facilities and rural embankment also developed greatly. The new dikes and flood-discharging stations have allowed the water-discharge capacity to rise, and it now exceeds 7,000 m^3/sec. However, the capacity for in-discharging and out-discharging has not balanced; the capacity to discharge water from watercourses to rivers and sea is only half that from diking areas to watercourses.

12.5.3. Driving Forces for Water Environmental and Aquatic Ecosystem Changes

The Great Increase in Pollution Emissions, the Polluted Drainage Entering Lakes, Resulting in the In-Equilibrium of Input and Output. According to statistics, every year the total wastewater discharge in the Taihu Lake Basin increases by up to 3.19 billion t: COD_{Cr}, 282,404 t; TN, 79,552 t; TP, 5,660 t. Every year the main pollutants flowing into the Taihu Lake are: COD_{Cr}, 131,233 t;

TN, 30,635 t; TP, 1,751 t. These especially P and N, apparently exceed the assimilative capacity of the Taihu wetland ecosystem.

The Losses and Imbalances of Ecological Processes by Irrational Industrial Development

(1) The destruction of lake wetlands ecosystems Lake wetland ecosystems in the basin are the filter areas of lakes, which serve to deposit, absorb, transport, and transform the input and output of organic matter such as N and P, etc. Artificial dams, breakwaters, dykes and other industrial activities along the Lake wetlands lead to serious degradation and destruction of the Taihu Lake ecosystem.

In 1981, there were still 66 species of vascular hydrophytes, belonging to 29 families and 49 genera, in Taihu Lake. The area of waterweeds is 14,446 ha, which occupies 6% of Taihu Lake. The yearly productivity for vascular hydrophytes is about 450,000 t, among which reeds are over 70,000 t, water oats (*Zizania latifolia*), about 225,000 t, and submerged hydrophytes 147,000 t. Every year, there are about 400,000 t of these aquatic plants harvested as feeds for pond fish farming, farm composts and materials for papermaking and knitting. Every year, over 2,160 t nitrogen, more than 750 t phosphor and much CO_2 are absorbed, transformed and accumulated through these plants. However, many waterweeds in Taihu Lake, and other lakes in the basin, are now severely damaged and displaced: vascular hydrophytes in west Taihu Lake and other originally weedy lakes have vanished or are being eliminated. Thus, the links and routes of wetland ecosystem processes are interrupted and even broken for transporting, transforming, accumulating and balancing the output and input of aquatic inorganic nutrients and organic matter through vascular hydrophytes. Moreover, the competition between the main aquatic plants (as submerged hydrophytes) and aquatic algae is undermined. Therefore, more nutrients in lakes are utilized by algae. The biomass and production of algae increases abruptly, leading to considerable eutrophication.

(2) The impacts of industrial development on the lake ecosystems In the Taihu Lake Basin, the intensity of various developing activities, especially landuse, is heavy: it is estimated that, as a result of fish-farming alone, the TP and TN flowing into the lake are 102 and 527 t every year, respectively. Inappropriate fishing methods and lake surface shipping has also damaged the aquatic ecosystem in the lake.

12.5.4. Driving Forces of Engineering for Wetland Ecosystem Changes

(1) The conflicts between increasing amounts of pollution emission and the great lack of facilities for wastewater treatment have exacerbated the negative changes to wetland ecosystems in the Taihu Lake Basin. For instance, the treatment capacity of concentrated domestic wastewater treatment plants built in Suzhou, Wuxi, and Changzhou city totaled only 230,000 t/day, less than 1/4 of the municipal wastewater, discharge in Jiangsu province. The insufficient capacity of industrial wastewater treatment, the low efficiency of treatment operations, and the poor rate of up-to-standard treatment mean that pollutant discharge into the lakes is non-stop.

(2) Reclamation projects such as dyke-making and blocking up the water flow have changed landuse patterns that altered ecological hydrological processes. These have reduced the capacity to regulate hydrological processes (such as water level and water storage) in some sections of large or middle-size lake wetlands. For example, reclamation in 1976 blocked the five waterways for outflow connecting through Zhangwandang marsh on the lower reach of Taihu Lake. Because of this, the water from the upper reach of the lake via this marsh, originally discharging water to the north, now flowed south and elevated the water level by 0.2 m in the north Jiaxing areas in the upper reach of the lake.

According to the statistical data in 1990, there are about 7,000 dykes in the Taihu Lake, having a total area of 11,000 km^2, of which 498 dykes with a total area of 528.55 km^2 were developed within the period 1949–1985 (Table 13). The number of lakes for reclamation has reached 239 (33.8% of the total area of lakes) since 1949. The number of lake ecosystems that have disappeared due to reclamation is 165, which is 23.3% of the total lakes in the region (Table 14). Dyking in some lowlands made some lakes enclosed. They thus became inner ports and inner lakes so that certain ecosystems processes, such as nutrient recycling, were stopped. Although the water existed in dyked areas, the capacity to regulate and balance ecological processes, such as mitigating floods in the basin, had been lost (Nanjing Institute of Geography & Limnology, 1988; Wang, 1994; Han & Mao, 1995).

(3) As the impermeability of land increases with the increase in urban landuse, so the ground runoff coefficient becomes correspond large, which alters the ecological hydrological processes. For example, during the flooding period in 1991, the runoff coefficient of the Wujing-Yangcheng-Wuxi areas that have many towns was 0.758, but the runoff coefficient in the areas along Taihu Lake was 0.664. In addition, the area of some natural waterbodies decreased to a large extent because engineering for urban expansions caused some original rivers and lakes to be filled and leveled up. In Changzhou city, due to urban

Table 13: Statistical data on reclamation dynamics by different zones.

Name of lakes	**1950s**		**1960s**		**1970s**		**1980s**		**Total**	
	Number of dykes	**Area (km^2)**	**Number of dykes**	**Area (km^2)**	**Number of dykes**	**Area (km^2)**	**Number of dykes**	**Area (km^2)**	**Number of dykes**	**Area (km^2)**
Taihu Lake Zone	7	9.23	39	67.73	68	82.16	2	1.05	116	160.17
Yaoge Lake Zone	3	2.01	28	28.63	91	147.32	4	4.18	126	182.14
Hangzhou-Jiaxing-Huzhou Zone	2	0.37	14	10.76	54	24.94	6	2.76	76	38.83
Dianmao Zone	1	0.45	26	17.36	84	58.63	5	2.05	116	78.49
YangchengZone	2	0.94	8	28.08	24	19.05	2	0.30	36	48.37
Jiashan-Pinghu Zone	1	0.35	10	4.41	13	8.91	4	6.88	28	20.55
Total	16	13.35	125	156.97	334	341.01	23	17.22	498	528.55

Table 14: The dynamics of reclamation in large or middle-size lakes in Taihu Lake Basin.

Names of lakes	Lake size (km^2)	1950s			1960s			1980s			Total		
		Number of dykes	The area of built dykes (km^2)	Conserved lake area (km^2)	Number of dykes	The area of built dykes (km^2)	Conserved lake area (km^2)	The area of built dykes (km^2)	Conserved lake area (km^2)	The number of built dykes	Conserved lake area (km^2)	The number of built dykes	The area of built dykes (km^2)
Taihu Lake	2,587.98	7	9.23	2,573.75	39	67.73	2,511.02	68	2,428.86	2	2338	116	160.17
Gehu Lake	253.78	–	–	253.78	19	22.71	231.07	49	146.37	–	146.37	68	107.41
Yang cheng Lake	122.87	1	0.10	122.77	–	–	122.77	5	119.13	1	119.03	7	3.84
Yaohu Lake	111.43	–	–	111.43	1	0.65	110.78	19	90.47	2	88.97	22	22.46
Dingshanhu Lake	65.32	–	–	65.32	1	0.80	64.52	–	64.52	1	63.80	2	1.52
Chenghu Lake	44.42	–	–	44.42	–	–	44.42	3	40.64	–	40.64	3	3.78
Total	3,185.80	8	9.33	3,176.47	60	91.89	3,084.58	144	2,889.99	6	2,886.62	218	299.18

expansion, half the small ponds have been filled up, and the area of rivers in the urban districts decreased to only 7.36 km^2. This has weakened the capacity of urban wetland ecosystems to regulate and balance ecological hydrological processes, and reduced their ecological services, such as flood control or mitigation (Sun et al., 1993).

12.5.5. Driving Forces of Management for Wetland Ecosystems Changes

The imperfect management of wetland lake ecosystems, such as through unsound laws and regulations, worsens the water pollution and speeds up degradation of lake wetland ecosystems, especially eutrophication in Taihu Lake. According to the investigation, in some developed cities such as Suzhou, Wuxi and Changzhou, the annual economic loss caused by water pollution will occupy 5–7% of the GNP. In 1993, the immediate loss due to environmental pollution in Shanghai was around RMB 6.2 billion, accounting for about 3% of the GNP of the city, which greatly exceeded the investment on environmental protection. In the basin, the annual economic loss due to water pollution is at least RMB 5 billion. Therefore, weak ecosystem management has become a great constraint with regard to solving the problem of environmental degradation of wetland ecosystems in the Taihu Lake Basin.

12.6. Integrated Human Responses to Building Sustainable Security for Ecosystems of the Taihu Lake Basin

To realize sustainable development of the Taihu Lake Basin, it is necessary to establish the perfect human mechanism with which to manage the human–water interactions in the ecosystem of the Taihu Lake Basin, and to promote or enhance the services of wetland ecosystems as water resources, water quality, and water culture. We now discuss integrated management responses to changes in the ecosystems of the Taihu Lake Basin, using the HREEES conceptual framework.

12.6.1. Human Responses I (Water Resources): Sustainable Development and Uses of Water Resources

The overall strategic responses of sustainable development, uses, protection and recycling of water resources are: developing new forms of water resources, saving water, and regulating the storage capacity of reservoirs to increase availability; at the same time, implementing strict measures to protect and improve water quality, strictly control the overall volume of wastewater emission, and increase the reuse and recycling ratio of utilized water.

Developing Various Forms of Water Resources and Increasing the Availability of Water

(1) Developing various forms of water resources to withdraw water from rivers To better meet the increasing demand for water, it is necessary to develop new forms of water resource and increase the utilization ratio of water resources. The main measures are as follow: to establish water transport facilities; to promote and strengthen implementation of water conservancy projects along the rivers in south Jiangsu Province; and to develop the water withdrawal works of big rivers. These water withdrawal works mainly include two activities: (i) the renewal or renovation of old water withdrawal facilities from the Yangtze River and the dredging of the silted waterways to expand the total capacity of water withdrawal from Yangtze River and (ii) the implementing of the Fu-chun-jiang River Water Withdrawal Project in Zhejiang province.

The Taihu Lake plain has advantages in its natural geographic conditions, with the Yangtze River in the north and the Qiantangjiang River in the south. The water resource in the Yangtze River is rich. Normally, 1–1.5 billion m^3 of water can be withdrawn per year from the Yangtze River. If a new project at Yuhe is finished, then water will be able to be drawn from the Yangtze River at a rate of 150 m^3/sec in periods of high water demand. The imbalance between demand and supply can be mitigated by increasing the quantity of water drawn.

(2) Protecting and utilizing the high quality of water resources There exist some areas with high quality water resources in the Tiaoxi drainage area to the southwest of the Taihu Lake Basin. It is the best quality water within the Taihu Lake Basin, meeting Class II of the national standard GB 3828-88. The precipitation of the Tiaoxi drainage area is high, being 1,450 mm annually, which is about 1.5 times the average for the Taihu Lake Basin. If good quality water resources are well protected, as much as 0.4 billion m^3 of water could be supplied to meet the increasing demand in the adjacent cities.

(3) Sustainable exploitation, usage, and the control of underground water resources A Water Resource Administration Council should be established to enhance the sustainable management of underground water resources, to prevent excessive extraction of underground water resources, and to ensure the sustainable exploitation, usage and protection of underground water resources. Very efficient water supply systems should be established in newly developed areas of a city. In areas which have suffered from excessive extraction, proper measures should be taken to establish an effective supervision system for preventing subsidence of the land surface and the recharging of ground water into the underground water system (Yan & Zhang, 1997).

(4) Sufficiently protecting, reusing and recycling of limited water resource, and preventing water pollution Water pollution leads to low quality water, which greatly affects the availability of water resources. Since the ground water situation in cities is even worse, protecting water quality, preventing and controlling pollution, and fully reusing or recycling the limited available water are the main ways to improve the quality of local water, and to resolve the contradiction between supply and demand (Yan, 1994).

Increasing the Water Storage Capacity of Rivers, Lakes and Reservoirs, and Regulating the Annual and Seasonal Changes of Water Resources. The water storage of lakes in the Taihu Lake Basin reaches 6.8 billion m^3 with 72.8% in large and medium sized lakes. There are over 500 small dykes formed by blocking about 500 km^2 of the lake. This has directly reduced the area, and thus the capacity of lakes for water storage. Blocking lakes should be strictly limited, and some blocked fields of lakes should be returned to lakes. For deeper areas of lakes with sediment silt, the capacity to store water can be increased by dredging, which removes mud and eliminates obstacles from the river beds.

Promoting Measures for Saving Water in Agriculture, Industry and Cities. The international and domestic technology of water-saving in agriculture and industry should be promoted. Saving water in industry should be first realized by increasing the reuse rate of utilized water, as well as by establishing recycling systems for wastewater in order to improve the water environment. Water-saving engineering in agricultural irrigation can be developed by popularizing advanced irrigation technology, and by improving water use management.

12.6.2. Human Responses II (Environment): Protection of the Water Environment

Defining the Overall Amount of Control for Pollution Emissions. The annual emission in the Taihu Lake Basin has reached over 3.5 billion t per year, 80% of which is not treated: even if treated, it does not reach the State standard for emission to rivers and lakes. Used water flowing into and out of Taihu Lake should meet class III standard for ground water. It is essential for us to define the overall amount of control (Table 15) (Qin & Chen, 1996).

Maximum amounts of emission to be allowed in the Taihu Lake Basin in 2010 are as follows: TP 2,285 t/yr; TN 9,635 t/yr; COD_{Cr} 185,234 t/yr (Table 16). The maximum amounts of emission allowed by Zhejiang and Jiangsu Provinces are listed in Table 17.

Table 15: Targets for overall pollution amount control.

Controlled area	Index	Present emission (t/yr)	Maximum allowed emission (t/yr)	Maximum amount allowed to enter Taihu Lake (t/yr)	Province
Wuli lake-Meiliang lake seriously polluted control areas	COD_{Cr}	48,838	21,136	8,742	Jiangsu Province
	TP	1,225	319	91	
	TN	17,549	1162	412	
West Taihu Lake lake pollution controlled areas	COD_{Cr}	60,570	44,238	22,844	Jiangsu Province
	TP	1,478	859	245	
	TN	17,528	1,537	545	
West of Zhejiang Province pollution controlled areas	COD_{Cr}	56,784	38,614	16,023	Zhejiang Province
	TP	982	336	101	
	TN	14,120	1,131	401	
Wangyu River pollution controlled areas	COD_{Cr}	27,623	11,049	4,585	Jiangsu Province
	TP	671	204	58	
	TN	7,661	612	217	
Lakeside pollution controlled areas	COD_{Cr}	18,298	11,894	435	Jiangsu Province and Zhejiang Province
	TP	651	190	54	
	TN	11,926	1148	407	
East Taihu Lake–Taipu lake pollution controlled areas	COD_{Cr}	11,919	5791	2403	Jiangsu Province, Zhejiang Province and Shanghai city
	TP	161	133	38	
	TN	3,233	522	185	
Total	COD_{Cr}	22,4032	13,2722	59,532	
	TP	5,168	2,041	587	
	TN	72,017	6,112	2,167	

Note: The target of total amount control is allocated to the emission management authorities of subordinate district by every province in different periods.

Table 16: Maximum allowed amount of emission and amount into Taihu Lake in 2010.

Control index	Maximum amount into Taihu Lake	Maximum amount of emission
TP (t/yr)	719	2,285
TN (t/yr)	5,483	9,635
COD_{Cr} (t/yr)	90,761	185,234

Note: The maximum amount of emission allowed in 2010 includes precipitation, dust (sources unable to control): TP-93t/yr; TN-3181t/yr; CODCr-23,595 t/yr.

Zoning Polluted Water Areas by Protection Requirements. In order to control pollution and eutrophication of Taihu Lake, it is important to zone the polluted water areas by protection requirements and to determine the priority protection areas. The water areas in Taihu Lake can be zoned by protection requirement as follows (Qin & Chen, 1996):

- Meiliang Lake (including Wuli Lake): 135 km^2
- Gonghu Lake: 147 km^2
- East Taihu Lake: 158 km^2
- Water areas near Xukou area: 150 km^2

Considering the distribution of pollution loading and the regional targets for water quality protection, the following six areas can be identified:

- Meiliang Lake–Wuli Lake serious pollution control areas
- West Taihu Lake pollution control areas
- West Zhejiang province
- Wangyu River pollution control areas:
- Lakeside pollution control areas
- East Taihu Lake–Taipu River pollution control areas.

Table 17: Maximum amount of emission allowed by each province in 2010.

Control index	Jiangsu Province	Zhejiang Province	Total
TP (t/yr)	1,774	418	2,192
TN (t/yr)	5,163	1,291	6,454
COD_{Cr} (t/yr)	112,239	49,400	161,639

These six areas of water quality protection occupy more than 80% of Taihu Lake. The TP from the six areas of water quality protection reaches 5,168 t/yr (91% of the total amount in Taihu Lake); TN is 72,017 t/yr (91%); and COD_{Cr} is 224,032 t/yr (79%). The characteristics of each area of water quality protection are listed in Table 15.

As protection objectives for water quality in the year 2010, the following will be implemented: keeping the quality of water in main rivers flowing into and out of Taihu Lake up to class II of National Standard GB38338-88, and the maximum amount of pollution emission at TP 2,041 t/yr, TN 6,112 t/yr, COD_{Cr} 132,722 t/yr.

Controlling Pollution Sources and Reducing the Total Amount of Wastewater and Other Pollution Emissions

Targets of Pollution Source Control. The main targets of pollution source control are as follows:

(1) Wastewater discharged into the main streams, the first-class branches and the source areas for drinking water should meet the State's standard of Class I, and the wastewater that is discharged directly into Taihu Lake should meet the local standard if it is stricter than that mentioned above.
(2) Wastewater discharged into the areas of IV and V should meet the standard of Class II.
(3) Wastewater discharged into the urban sewage systems needing secondary treatment should meet the standard of Class III.

Ensuring That the Industrial Pollution Sources Meet Their Appropriate Standards. Some necessary measures include: (1) Adjusting the industrial structure to reduce the discharges of wastewater and other pollutants; preventing projects producing heavy pollution from being started; and where current enterprises produce heavy pollution that cannot be improved to the State's standard, then these enterprises should be closed, stopped, combined, transferred or relocated; (2) Introducing the new procedures and technologies to control the wastes generated; (3) Promoting reuse and recycling of the raw materials in the life cycle of the production; (4) Treating and recycling urban wastewater; (5) Promoting non-point pollution source control in farmland; some non-point pollution from fertilizer and pesticides should be strictly controlled; (6) Improving non-point pollution control of lakes by replacing integrated netted fishery in drinking water withdrawal sites such as Wuli Lake, Meiliang Lake, Gong Lake, East Taihu Lake (and Xukou nearby areas); and also by stopping mechanized fishing, changing tourism boats into electricity-driven ones and so on.

12.6.3. Human Responses III (Wetland Ecosystems): Improving Structure and Function of Wetland Ecosystems, Rehabilitating Disturbed or Destroyed Ecosystems, and Improving Their Ecological Capacity of Services

Based on some ecological principles such as dissipation, hierarchy, recycling and self-organization, improvement in the structure and function of wetland ecosystems can be implemented in various ways such as: increasing loops of material recycling in chains and webs; linking parallel loops or processes into self-organized systems; using or reusing products, by-products and wastes through a hierarchy of layers and levels of efficiency; and restoring the structure and functions of destroyed or degraded wetlands ecosystems, etc. The purposes of these efforts are to improve ecological services of self-cleaning, self-regulating, self-maintenance and self-organization, and to enhance multi-production of different-level products simultaneously (Hu, 1997).

12.6.4. Human Responses IV (Wetland Ecosystems Engineering)

One of the most important human responses is the ecosystem engineering approach, in order to improve or enhance the dynamics of wetland ecosystems. Some key ecosystem engineering pilot projects should be set up to realize the purpose of ecological restoration or enhancement in the Taihu Lake Basin. Eight pilot projects such as agricultural non-point pollution source control, ecological agriculture, sedimentary mud dredging projects, etc., are included (Table 18) with a total investment of RMB 54 million.

12.6.5. Human Responses V (Ecosystems Management): Building a Modern Ecological Culture for Realizing the Sustainable Management of Wetland Ecological Security

One of the key actions for promoting the transition of management towards sustainable secure water resources, water environment and wetland ecosystems is the modern ecological culture developing in the Taihu Lake Basin (Hu & Wang, 1997). Some of the main points of this are as follow:

Promoting Institutional Transition of Wetland Ecosystem Management for Improving Efficiency, Equity, and Wetland Ecosystem Security Management in the Taihu Lake Basin

(1) Provincial or city governments in the basin should be responsible for wetland ecosystem security and develop strict regulations, backed by legislation, as a

Table 18: Key ecosystem engineering pilot projects in the Taihu Lake Basin.

Items	Investments RMB 10^4	Remarks
Farming waste recycling project	400	First protection area of the west parts along with Taihu Lake
Proposd reservior project	450	First protection area of the west parts along with Taihu Lake
Big aquatic vegetation restoration project	700	Shallow water area of the northeast parts along with Taihu Lake
Algae collection and integrated utilization project	300	Meiliang lake area
Ecological agriculture project	500	Zhejiang province
Bank protection belt project	750	First protection area of the west parts along with Taihu Lake
Sedimentary mud dredging project	300	Dredging up 100,000 m^3 of bottom mud
Cleaning production project	2,000	Zhejiang and Jiangsu provinces

priority for action to improve the management and utilization of wetland ecosystems.

(2) Promoting price system reform for water resource uses in the basin. Currently the water price is too low to make local people change their old behavior of using water indiscriminately. Adjusting the water price can strengthen the public consciousness for saving water.

(3) Governments at different levels should further promote an ecological culture of recycling, reuse, retrieval and reduction, by implementing industrial structure adjustments and by conducting demonstrations of clean production projects.

(4) All of the developmental projects must be matched with environmental impact assessment.

(5) Stringent control should be in place to reduce agricultural contamination. Efforts should be made to popularize ecological agriculture. Superfluous use of fertilizer should be limited in an economic way. The use of organic fertilizer should be encouraged. Chemical products containing nitrogen and phosphorus which contribute to eutrophication of lakes should only be used in limited amounts in the basin.

(6) Promoting the transition of the traditional model of citizens' consumption into sustainable consumption. Domestic discharge of nitrogen and phosphorus from wastewater should be reduced in an effective way. Use of detergents

containing phosphorus should be banned in first- and second-class protection areas in the Taihu Lake Basin. In the third-class protection areas it could be retained in a limited amount.

Redirecting Economic Capital to Invest in Ecologically Healthy Products, and the Enhancement of Ecosystem Services. Economic investments need to be redirected from the single objective of profit maximization to a joint objective of maximizing both economic profits and ecological services. Environmental or ecological projects in the Taihu Lake Basin should be carried out jointly with infrastructure construction and other industrial development. According to the current estimate, the total investment on priority projects for water environmental protection and ecological building is RMB 20.4 billion (Table 19) (Qin & Chen, 1996).

Table 19: Investment of priority projects for water environment and ecosystems in Taihu Lake (RMB 100 million).

Engineering types	**Jiangsu Province**	**Zhejiang Province**	**Shanghai city**	**Total**	**Rate (%)**
Wastewater treatment projects (including hotels and restaurants)	52.50	27.84	0.2	80.54	39.45
Industrial source abatement projects	2.88	2.59	0.021	5.50	2.69
Non-point source pollution treatment projects	5.44	3.16	–	8.60	4.21
Inner source pollution treatment projects	7.04	–	–	7.04	3.45
Water conservancy and drinking water guarantee projects	15.2	14.19	7.38	36.77	18.0
Pollution interception and river channel treatment projects	12.13	24.06	–	36.19	17.72
Clean production projects	16.75	12.25	–	29.0	14.20
Pollution treatment pilot projects	0.34	0.20	–	0.54	0.26
Total	112.29	84.30	7.60	204.18	100
Rate (%)	54.99	41.28	3.72	100	

Promoting Research on Key Engineering and Management of Wetland Ecosystems in Taihu Lake Basin. To realize wetland ecosystem security, it is necessary to promote scientific research, especially on eutrophication of lakes, and to develop key ecological technologies for solving the degradation of lake ecosystems. The topics, which need be tackled as key scientific projects include:

(1) Agricultural non-point source pollution technology in river networks areas
(2) Aquatic vegetation restoration
(3) Sedimentary mud dredging and secondary pollution prevention
(4) Monitoring network technologies, including warning systems for protection of important and sensitive areas, and decision-making support systems for integrated management of the Taihu Lake Basin
(5) Gross-amount pollution control technologies
(6) Life-cycle assessment for products, enterprises and industrial parks
(7) Ecological mechanism of "water bloom" in Taihu Lake
(8) Sewage interception technology in Wuli Lake and Meiliang Lake
(9) Pollution control for animal breeding

Promoting Ecological Education to Enhance Ecological Thinking in the General Population. The transformation of awareness and behavior from interest-and-reputation dominated to ecological-norms dominated is a key factor in ecological education to promote sustainable ecosystems management (Hu & Wang, 1997). Thus, encouraging the population to think in terms of ecological norms, morality, values and beliefs needs to become an important part of ecological education. Information technology, other high technology, and ecological industrial technology need to be integrated in order to contribute to ecological education: that is to say, to promote ecological educational through technology integration and to develop modern technology through ecological education. This will be beneficial for rebuilding technology, engineering and institutions, and may play a positive role in finally establishing sustainable ecosystem management in the basin.

12.7. Conclusions

Using the concept of HREEES Systems, this research has made an integrated analysis of human–water interactions in lake wetland ecosystems of the Taihu Lake Basin, East China. The DPR (driving forces–states–responses) methodological model is used to analyze the human driving forces of urbanization and industrialization, which cause changes in the resources, environment, ecosystems, and security of lake wetland ecosystems in the Taihu Lake Basin. The analyses has shown that landuse, water resource exploitation and environmental impacts or disturbances from engineering and management activities are key driving forces for the changes of wetland ecosystems in the structure and functions in the Taihu Lake Basin. Thus, the two critical transitions of mechanisms, from ordinary environmental engineering into ecological engineering and from typical end-of-pipe management into life-cycle-oriented ecological management, are leading factors required to enhance the security of the Taihu Lake wetland ecosystems. Integrated responses to wetland ecosystem changes in the Taihu Lake Basin should be focused on building an ecological basis for engineering and management. Scientific research and the development of a modern ecological culture of management is necessary to direct human–water interactions towards sustainable co-evolution in the lake wetland ecosystems of the Taihu Basin.

Acknowledgements

This research has been supported by the Natural Foundation for Natural Sciences of China with the grant number 30070145 and 40171042, and the Project of Knowledge Innovation of Chinese Academy of Sciences (KZCX3-SW-424). The authors thank the anonymous reviewers, who gave some constructive comments and help to improve the text of this paper.

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