Chapter 1
An Introduction to Lake Taihu

1.1 Hydrography and Drainage Basin

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1.1.1 Lake Morphology and Drainage Basin

1.1.1.1 Morphological Characteristics

Lake Taihu is a well-known freshwater lake in the middle to lower valley of the Changjiang River, China. It is located in the broad Taihu plain, on the south side of the Changjiang delta, at $30°55'40''$–$31°32'58''$ N and $119°52'32''$–$120°36'10''$ E. Taking the mean water level of Lake Taihu as 3.0 m above sea level (a.s.l.), its total area is 2, 427.8 km^2, in which about 89.7 km^2 is occupied by 51 islands and islets, and the actual water area is 2, 338.1 km^2, making Taihu the third largest freshwater lake in China.

Lake Taihu is 68.5 km long in the north–south direction and on average 34 km wide from east to west. The maximum width, maximum depth, and mean depth are 56 km, 2.6 m, and 1.9 m, respectively. Therefore, it is a typical shallow lake. The topography of the lake bottom is flat, with a mean declivity of $0°0'19.66$. The mean elevation of the lake bottom is 1.1 m above sea level (a.s.l.) (Fig. 1.1). The morphological characteristics of Lake Taihu are summarized in Table 1.1.

The map of the lake floor, and calculations derived from this map (Fig. 1.1, Table 1.2), show (i) areas of very shallow water (<1.5 m deep) along the shore zone and in Eastern Taihu Bay, total area 452.2 km^2, and occupying 19.3% of the total lake area; (ii) the area of deepest water (>2.5 m), mainly in the western Taihu region (maximum of 2.5–2.6 m, west and north of Pingtaishan Island in west Taihu), total area 197.3 km^2, and occupying 8.4% of the total area; and (iii) areas

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Fig. 1.1 Bathymetric map of Lake Taihu

of moderate depth (1.5–2.5 m), which dominate the lake, total area 1, 688.6 km^2, occupying 72.3% of the total area. There is no deep trench in Lake Taihu, nor are there large-scale shoals. The lake is a submerged plain, on the floor of which are the remnants of buried rivers, evidence of its prior topographic character.

From natural and anthropogenic causes, Lake Taihu has five bays: Eastern Taihu Bay, Xukou Bay, Gonghu Bay, Meiliang Bay, and Zhushan Bay from east to west, with Dongdongtingshan (Dongshan Peninsula), Tanshan Mountain, Junzhang Mountain, and Guanzhang Mountain separating them. Currently, as a consequence of the slow exchange of streams, shallow water, and the action of prevailing winds, some bays have become seriously polluted or eutrophic.

1.1.1.2 Topographic Characteristics of the Drainage Basin

Based on topographic characteristics, the lake basin can be divided into four regions: the massif region in the western basin, the low plain region in the middle basin,

Table 1.1 Morphological characteristics of Lake Taihu[1,2]

Area (km^2)	Water area (km^2)	Catchment area (km^2)	Supply coefficient	Shoreline length (km)	Length (km)	Width (km)	Mean depth (m)	Maximum depth (m)	Volume ($\times 10^8 m^3$)	Annual transfer coefficient
2,427.8	2,338.1	36,895	15.8	405	68.5	34	1.9	2.6	44.28	1.18

[1] The data were obtained by direct measurement on the topographic map produced in the 1980s.

[2] Excluding Wuli Bay, which is 5.7 km^2.

Table 1.2 Distribution of different depth zones in Lake Taihu

Water depth (m)	< 1	1–1.5	1.5–2.0	2.0–2.5	> 2.5	Total
Area (km^2)	131.7	320.6	719.3	969.3	197.3	2338.1
Percentage (%)	5.6	13.7	30.8	41.5	8.4	100

the high plain region along Changjiang River shore, and the Lake Taihu region (Fig. 1.2).

(1) Massif region in the western basin. Based on a customary partition of the lake basin, the ground above 12 m elevation is defined as the low hill and massif region, situated at the west of the basin, with an area of 7,338 km^2. This region includes the Maoshan low hill, massif, and hummock region, and the Yili River low hill and massif region within Jiangsu Province, Xitiaoxi River vale, and plain region, and the Tianmu Mountain and massif region within Zhejiang Province. This area is the riverhead or upstream zone of most rivers feeding Lake Taihu (Fig. 1.2).

(2) The low plain region in the middle basin. This region lies below 5 m, is typified by a dense water web and a flat landform, and has an area of 19,350 km^2. It is divided into three parts. (i) The South Jiangsu province low plain region, mainly including the Tao-Ge (Lake Tao and Lake Ge) low plain around Lake Tao and Lake

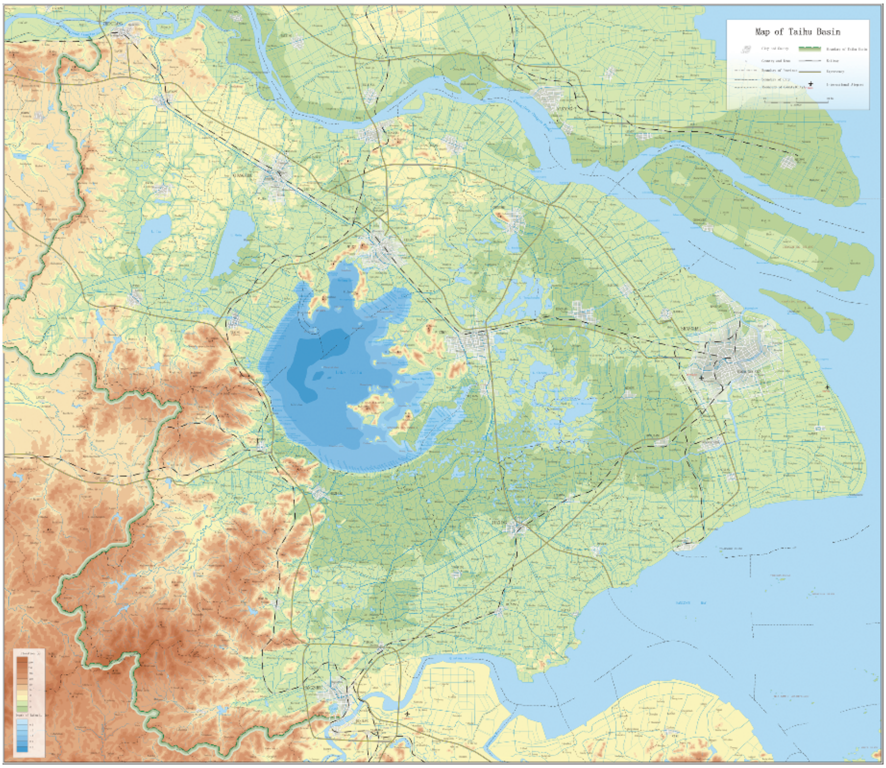

Fig. 1.2 Map of Lake Taihu. A detailed electronic version of this map can be viewed on the enclosed CD-Rom

Ge to the west of Taihu; Wujinggang-Xicheng (the area between Wujinggang River and Xicheng Canal) low plain with the Beijing-Hangzhou Canal (Grand Canal) as its axis, lying to the east of the Tao-Ge region and the northern suburbs of Wuxi City; and the Yangcheng-Dianliu low plain, around the lake cluster of Yangcheng and Dianliu Lake. (ii) From Hangzhou-Jiaxing-Huzhou (in brief, Hang-Jia-Hu) to West Zhejiang low plain; Hang-Jia-Hu Plain lies to the east of the Tiaoxi Diversion River, along both sides of the Beijing-Hangzhou Canal, at an altitude of 2.5–5.0 m; the plain is 110 km long from east to west, and 60 km wide from south to north; it is the largest low plain of the Taihu basin. Adjacent to it, in the west, is the West Zhejiang low plain, in the Changxing region, at an altitude of 4–5 m. The West Zhejiang low plain is vulnerable to mountain flood water. (iii) Along the Huangpu River low plain, including the Pudong and Puxi regions lying on east and west bank of the Huangpu River, respectively; the terrain is low, usually at an altitude of 2.5–3.5 m. The area is densely populated, and thus this low plain has been intensively used. The water level is high, and farmland (i.e., polders) is at low altitude, and for many years polders have been built. The polder area is currently 14, 542 km^2 in total, occupying 39% of the Taihu basin (Fig. 1.2).

(3) the high plain region along Changjiang River shore. Lying along the Changjiang River, the western end of this region lies at the east of Zhenjiang City, and the eastern end is Changshu City; the region is 135 km long from east to west, 30–50 km wide from south to north, and with an altitude of 6–12 m at its western end and 5 m at its eastern end. It is formed from sediment deposited by the Changjiang River and has an area of 7,015 km^2. The estuary high plain region extends from Hangzhou in the west, to Zhapu in the east, and is a narrow, discontinuous high plain, about 100 km long, with altitude of 6–7 m (5 m at the eastern end). The part of the estuary high plain in this region is far smaller than the part of the Changjiang River shore plain. The west massif region, the Changjiang River shore plain, and the estuary high plain region constitute the high margins around the Taihu basin.

(4) Lake Taihu region. This region includes the water surface, islands and islets, and belts between the lake regions. Lake Taihu is situated at the center of a dish-shaped basin, with shallow water, a flat bottom, and a mean altitude of only 1.1 m a.s.l. Its total area is 3,192 km^2 (occupying 8.6% of Lake Taihu basin), including 2,338.1 km^2 of water surface, 89.7 km^2 of islands and isles, and 764 km^2 of lowland along the shore.

The areas of the Lake Taihu basin situated at different altitudes are given in Table 1.3.

Table 1.3 Areas of the Lake Taihu basin situated at different altitudes

Height (m)	Distribution area (km^2)	Percentage (%)
< 2	6,200	17.2
2–3	13,890	38.1
3–4	2,280	6.2
4–5	2,750	7.5
> 5	11,766	31.8
Total	36,985	100

1.1.2 Formation and Development

As the Lake Taihu basin is in one of the most economically developed areas in China, with a long history of intense land and water use, research on its formation and development has long attracted attention from Chinese and international scholars. Within the last century, numerous publications, including more than 100 books, have focused on the lake, each advancing different theories and views. The principal literature (in chronological order) includes *Terrestrial Development of the Yangtze River Drainage Basin*, *Constitution and Degradation of Lake Taihu* (Wang & Ding, 1936), *Geographic Problems of the Lower Reach of the Yangtze River* (Wissman, 1941), *Geomorphic Development of the Estuary of the Yangtze River* (Chen et al., 1959), *Comprehensive Investigation Report of Lake Taihu* (Nanjing Institute of Geography, 1965), *Sea Level Change in Holocene and Formation and Development of Lake Taihu* (Yang et al., 1985), *Research on Modern Sediment in the Delta of the Yangtze River* (Yan & Xu, 1987), *Formation and Development of Lake Taihu and Modern Sedimentation Action* (Sun et al., 1987), *Lake Taihu* (Sun & Huang, 1993), and *Planning and Comprehensive Management of Lake Taihu Basin* (Huang, 2000).

Concerning the origin and formation of Taihu, opinions may be summarized as falling into three main groups.

ⓐ Lagoon formation hypothesis. Because it lies close to the mouth of Changjiang River and the East China Sea, and there are abundant sea sedimentary deposits below the Taihu Plain, it is believed that modern Lake Taihu originated from an ancient lagoon. During the early and middle Holocene, about 6,000–7,000 years ago, the Taihu Plain was a large bay connecting to the sea. The barrier spits formed at the south bank of Changjiang River, and the north bank of the Qiantang River stretched to the east, then enclosing the Taihu area, and as a result, the original bay gradually changed into a lagoon, and finally this lagoon became a lake isolated from the sea. Taihu and other lakes in the Taihu Plain evolved from this ancient lagoon (Wang & Ding, 1936; Chen et al., 1959).

ⓑ Tectonic origin hypothesis. It has often been considered that geological forces formed the big lake basins in the world, such as the Caspian Sea, Lake Baikal, Lake Victoria, and the fault depression lakes in Yunnan Province in China. Subsidence of the earth's crust, caused by tectonic movements, does indeed form lake basins. Large lakes such as Taihu may also owe their origin to fault-block differential movement in the Mesozoic or early Pleistocene, with the central subsiding part forming a lake basin, and water subsequently accumulating in it; in other words, the fault depression forms a lake.

ⓒ Flood water retention hypothesis. When dissemination of flood water is not immediate, waterlogging in lowlands can form a lake. Since the 1980s, the scientists from Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, have carried out systematic surveys around Lake Taihu and other lakes in the Taihu Plain, using a chain of deep and shallow drill cores in and around the lake, and a sub-bottom profiler, to detect the sediment as much as 40 m beneath the lake bottom. Their results indicate that the entire lake bed is composed of hard loess, except for local embedded rivercourses and hollows. Lake water directly lies over the loess formation, and the Taihu Plain is an alluvial plain, which became covered with loess before Lake Taihu came into being. As a consequence of inundation of this loess plain, waterlogging in the lowlands formed Lake Taihu. The age of formation of Lake Taihu, inferred from an ancient buried well of the Chunqiu and Zhanguo Period, should be about 2,000–2,500 years ago (Sun et al., 1987).

1.1.3 Influence of Lake Formation on the Aquatic Environment

As a result of the lack of immediate and direct flood drainage, water is retained in the lowland to form a lake. Thus, in the early stage of its formation in the Tang Dynasty (430–479 A.C.), Taihu was an expanse of water without clear boundaries. After the Tang and Song Dynasties, dams were built, opening up many inlets and outlets of waterways. According to literature from the Ming Dynasty (1368–1644 A.C.), there were 140 outlet channels from Wuloukou (at the outlet of the Wulougang River) to Liangxikou (at the outlet of the Liangxi River) in eastern Taihu, and 180 inlet channels in western Lake Taihu, giving a total of 320 rivercourses.

However, as a result of silting and anthropogenic activities, the number of rivercourses has markedly decreased. The sedimentation rate at the Wangyu River in the 1990s (measured using ^{210}Pb) was 3 cm/acre (a), and the sedimentation rate at the estuary of Dapugang River was 3–5 cm/a; silting thickness after 30 years exceeded 1 m. This sedimentation resulted in only 240 rivercourses remaining in the 1960s, 219 in the 1980s, and 97 in the 1990s. Recent investigation showed that there are 125 rivercourses. At the same time, the number of outlet channels declined from 150 to 90 from the 1960s to the 1990s, and now only 17 remain. The reduction in lake area, and in the number of inlet and outlet channels, has had two significant effects on the aquatic environment of Taihu; namely, an increase in water retention time and exacerbation of flood disasters.

1.1.3.1 Increase in Water Retention Time

Based on data from 1954–1988, the mean yearly inflow and outflow was approximately 57.37×10^8 m^3, and the retention period was about 281 days. After the 1990s, this period increased to 309 days, and this longer retention time accelerated the deterioration of the aquatic environment and the process of eutrophication. Both Lake Taihu and Lake Dianchi have relatively long retention periods and have become eutrophic. Therefore, dredging some primary inlets and outlets to enhance drainage capability, and to quicken renewal of the water in the lake, will be helpful for restoration of the aquatic environment. In contrast, other freshwater lakes such as Lake Dongting, Lake Poyang, and Lake Hongze in the middle and lower reaches of the Changjiang River have short retention periods, ranging from 20 to 168 days (Table 1.4), and have maintained a good water quality.

Table 1.4 Water retention time of six freshwater lakes in China

Lake	Taihu	Dongding	Boyang	Hongze	Chaohu	Dianchi
Water exchange time	309 d	20 d	57 d	35 d	168 d	2.5 a

d: days; a: year.

1.1.3.2 Exacerbation of Flood Disasters

In the 20th century, major flood disasters occurred in the Taihu basin in 1931, 1954, 1991, and 1999. These four floods, caused by "plum rain," each lasted for a long period and became a hazard throughout the drainage basin.

For the 1991 flood, the influence of change in retention time on lake level was calculated. As a result of the filling up of inlets and outlet channels and lakes, as well as lake reclamation, there was a decline in the capacity for flood water storage and drainage. According to the basic equation on regulation and storage of flood water by lakes:

$$H_i - H_0 = a_i \left(\sum P + \sum V - \sum Q\right) / A \tag{1.1}$$

here, H_i is water level of a certain day (in meters), H_0 is the water level before flood (m), P is daily rainfall (m^3), V is the flux entering the lake (m^3), Q is the flux leaving the lake (m^3), A is lake area (m^2), a is an uncertain integrative factor, including infiltration and leakage, which can be calculated by the following equation:

$$a = (H_{li} - H_0) \cdot A_{l1} / \left(\sum P_{li} + \sum V_{li} - \sum Q_{li}\right) \tag{1.2}$$

Evaporation volume during rainfall can be ignored. Here, subscript 1 shows the range of lake surface area. Based on 2, 338.1 km^2 of actual water area of Lake Taihu, and a capacity for flood regulation and storage of $47 \times 10^8\ m^3$, it is simulated as follows:

ⓐ The influence of reduced lake area (as a result of reclamation and silt sedimentation) on capacity for flood regulation and storage. From 1954 to 1991, the reclamation area of Lake Taihu totaled 140 km^2, and the lost volume of flood storage was $4.7 \times 10^8\ m^3$, occupying 12.9% of overall lake volume. According to the sedimentation rate (range, 0.16–2.99 mm/a) of each region, total siltation is approximately $1.56 \times 10^8\ m^3$. Thus, 4.2% of storage volume was lost from 1954 to 1991, and this may cause a rise in water level. Under the circumstance that precipitation, and inlet and outlet flux, in 1991 were equal to that of 1954, the water level in Taihu would increase by 0.266 m.

$$\Delta H_{li} = H_0 + \Delta H_{2i} = 0.266 \tag{1.3}$$

where H_2 is the water level in 1954. This increase in water level is the result of reclamation and silting.

ⓑ Silting of inlets and outlets channels, and anthropogenic stoppage of flooding water discharge. In the 1950s, there were 84 outlet channels, whereas after the 1990s there were only 17; thus, one-third of the drainage capacity had been lost. In the flood of 1954, observed discharge volume of flooding water was 36 × 10^8 m^3, whereas in the flood of 1991 it was only 21.53 × 10^8 m^3. If it is presumed that the flux entering the lake ($\sum V$), precipitation ($\sum P$), and actual effective area of this lake were the same in 1991 as in 1954, and drainage capacity decreased by one-third compared with 1954, the rise of water level of Lake Taihu may be estimated as

$$H_3 = H_{3i} - H_0 - a_i \left(\sum P + \sum V - 1/3 \sum Q\right) / A_1 \tag{1.4}$$

$$H_3 = H_0 + \Delta H = H_2 + 2a_i/3A_2 \sum Q_2 \tag{1.5}$$

with A_1 the lake dimensions in 1991 and A_2 the lake dimensions in 1954. If other conditions remain unchanged, and drainage capacity decreases by one-third, then water level will rise to $2a_i/3A_2 \sum Q_2$.

ⓒ Effects of reduction in volume and drainage capacity. Compared to the situation in 1954, storage volume in 1991was reduced by 17.1%, and drainage capacity by one-third, and thus water level will rise by

$$\Delta H_4 = H_{4i} - H_0 = a_i \left(\sum V_{4i} + \sum P_{4i} - 1/3 \sum Q_{4i}\right) / A_4 \tag{1.6}$$

Assuming that $V_4 = V_2$, $P_4 = P_2$, and $V_4 = (1 - 0.171)A_2$ (due to silting, the volume of lake reduces by 17.1%), thus:

$$\Delta H_{4i} = a_i \left(\sum V_2 + \sum P_2 - 1/3 \sum Q\right) / 0.829 A_2 = \Delta H_{2i} + 2a/3A_2 \sum Q / A_2 \tag{1.7}$$

These results show that the water level would rise 1.5–1.8 m above the highest water point of 1954 (Fig. 1.3).

Figure 1.3 reveals that if the lake with the actual storage and drainage conditions of 1991 were subjected to the flood volumes of 1954, the water level would rise

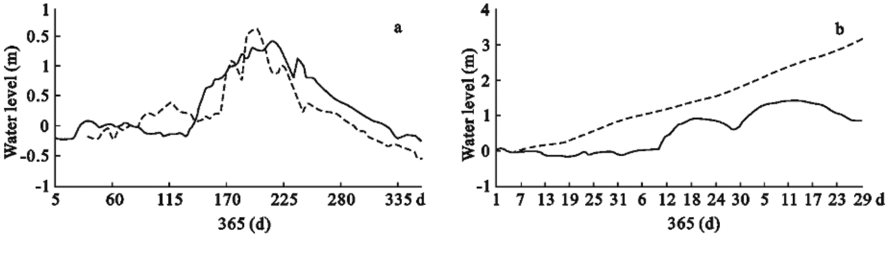

Fig. 1.3 Simulated lake level during flooding. (**a**) Increment of lake level in 1991 (*solid line* is measured; *dashed line* is calculated, assuming the flooding of 1954 were to occur in 1991). (**b**) Simulated lake level during flooding in 1954 and 1991 (*dashed line* is the 1954 flood; *solid line* is the flood in 1991)

1.6–1.8m above the highest level of 1954. Compared with 1954, water levels in 1991 would also rise more rapidly, and decrease more slowly.

A declining capacity for flood regulation and storage, and an increased retention period of lake water, will exacerbate flood calamities. In the flood of 1954, the maximum precipitation in 90 days was 890.5 mm, and the highest water level was 4.65 m; in 1991, the maximum precipitation across the drainage basin in 90 days was 681.2 mm, and the highest water level was 4.79 m; whereas in 1999, maximum precipitation was 672.8 mm, and the highest water level 5.08 m. Clearly, the precipitation in 90 days in the 1990s was much less than that in 1950s, and the maximum lake level during flooding in 1990s was much higher than that in the 1950s. It is evident that lake reclamation and silting of rivers and lake area have direct effects on the limnetic environment.

1.2 Hydrography and Water Resources

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1.2.1 Hydrography

Lake Taihu basin is a depression of land, in which water from all sides gathers to the center and then diffuses in all directions, forming a complex hydrosystem that contains interlaced rivers, dense water nets, and dotted depression lakes of different sizes.

As a result of human activities, the structure of the water system in the basin has changed dramatically in the past decades, especially after the floods of 1991. The present system mainly consists of regional backbone watercourses and small interior rivers. The backbone watercourses, most of which had taken shape before 1991, are designed to meet irrigation and transportation requirements. After the floods, central and local governments spent more than 10 billion Chinese yuan to have the watercourses dredged, riverbanks reinforced, and dams built. As a result, the whole area attained higher standards of flood prevention and gained a greater diversion and outlet capacity. There are still 125 inflowing and outflowing watercourses.

The western parts of the basin are hilly and the eastern parts are lowland plains; thus, rivers tend to flow from west to east. The northern boundary between upstream and downstream is Zhihugang River in Wuxi City, and the southern boundary is Wulougang River in Wujiang County. Rivers in the west mainly flow into Lake Taihu and belong to the upper reaches. In the upper reaches, rivers form an arborescence, and in the lower reaches, the drainage system is fan shaped. The total length of the rivers in the basin is 12,000 km, and the river net density is 3.24 km/km^2; thus, a river or other watercourse is encountered at 600- to 800-m intervals. There are also 189 lakes of different sizes, covering an area of 3,159 km^2.

1.2.1.1 The Upper Reaches

According to their sources, the water systems in the upper reaches can be classified into four systems: Tiaoxi Rivers (including Dongtiaoxi River and Xitiaoxi River), Yili River, Lake Tao and Lake Ge, and Wujinggang–Zhihugang Rivers.

(1) Tiaoxi river (Xitiaoxi River and Dongtiaoxi River) system

The Tiaoxi river system originates from the Tianmu mountainous area, southwest of Lake Taihu, and has a catchment area of 5, 931 km^2. This system can be further divided into Xitiaoxi (West Tiaoxi River), Dongtiaoxi (East Tiaoxi River), and rivers around Changxing County and Huzhou City, which all flow into Lake Taihu (Fig. 1.2).

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The Xitiaoxi River has its source at the foot of Tianmu Mountain, in the west of Zhejiang Province. The river collects waters in Anji and Huzhou and forms a 145-km-long main stream. The Dongtiaoxi River has its source at the southern foot of Tianmu Mountain and collects water in Lin'an, Yuhang, and Deqing (see Fig. 1.2). Its 165-km-long main stream meets the Xitiaoxi River at the Daqiangang River (i.e., Daqiankou) and the Xiaomeigang River (i.e., Xiaomeikou), and then flows through various rivers and canals (such as Xiaomeikou) and finally flows into Lake Taihu. Part of the currents flow east into Youtang River, merging with the surface flow of the Hangzhou-Jiaxing-Huzhou plain (Fig. 1.2). Thereafter, some of the converged current runs along Lake Taihu's southern bank and finally flows into the lake. Part of the currents flows east into Huangpujiang River, by the way of Grand Canal. In all, about 70% of the amount of water in the Tiaoxi River system flows into Lake Taihu. The Xitiaoxi and Dongtiaoxi Rivers converge at the west of Huzhou and then travel into Lake Taihu by way of the Changdougang and Xiaomeigang Rivers (Fig. 1.2). The planned water diversion project at the middle reaches of the Xitiaoxi River will be able to discharge water from the Xitiaoxi River into Lake Taihu. Rivers in the Changxing area carry the water yield from the Changxing County plains, and its western hilly areas, to Lake Taihu through several rivers and canals, such as Jiapugang River, Hexixingang River, Changxinggang River, and Yangjiapugang River. Among these rivers, the Jiapugang River is a separate river system that opens into the lake. Hexixingang and Changxinggang chiefly discharge the incoming flows from the upper reaches watercourses and rivers, while Yangjiapugang discharges the incoming flows from Siantang River, which meets the Xitiaoxi River in its low reaches, so part of its flow runs into the latter.

(2) Yili river system

The Yili, also called the Nanhe River, has a basin of $3,091\,\text{km}^2$ (calculated from a 1:10000 relief map). It originates from the western part of the Lake Taihu basin, at the common boundary of Jiangsu, Anhui, and Zhejiang Provinces (see Fig. 1.2). The Yili system gathers water from the Guodi mountainous area, the hilly areas at the south of Maoshan Mountain (Fig. 1.2), and in the plains along the Yili River. Most water produced in the west of the basin flows first into the Nanhe and Beixi rivers, then into three seasonal lakes (Lakes Xijiu, Tuanjiu, and Dongjiu) (Fig. 1.2), and finally into Lake Taihu, passing the three channels to Dapugang River, Chengdonggang River, and Hongxianggang River (Fig. 1.2).

(3) Lake Tao and Lake Ge river system

This system covers an area of $4,480\,\text{km}^2$. It contains water from the Lake Tao and Lake Ge districts, and the Beijing-Hangzhou Canal area, including the east of Mao mountain and the south of the Changjiang River shore high plain (see Fig. 1.2). The system also collects water from Lake Tao, Lake Ge, and the Taige Canal. The backbone watercourses flowing into the lake here are the Taige Canal, Caoqiao River, Yincungang River, and Shaoxianggang River. Lakes Tao and Ge, which are in the middle of the area, are regulation lakes (Fig. 1.2). The south part of the area exchanges water with the Yili River via watercourses such as the Danjinlicao, Mengjin, and Wuyicaohe Rivers (Fig. 1.2).

(4) Wujinggang-Zhihugang river system

This system covers an area of 1,000 km^2 around Wuxi city, and contains water from the low plain of Wujinggang-Xicheng, west of the Xicheng Canal. Wujinggang River and Zhihugang River are the two main watercourses leading to Lake Taihu (see Fig. 1.2). They are the most heavily polluted parts of the Lake Taihu area.

1.2.1.2 Lake Taihu Water System

Lake Taihu is the largest natural reservoir in the basin and serves to regulate floods in the basin. From the west, the lake receives water of several sub-basins, such as the Tiaoxi and Yili Rivers and the Taige Canal. To the east, the water goes sequentially through the Liangxi River, Wangyu River, and Eastern Taihu, Taipu River, and Guajingkou (outlet of Guajinggang River at the east end of Eastern Taihu Bay) (see Fig. 1.2).

1.2.1.3 River System in the Low Reaches

The low reaches can be divided into the following three systems: Changjiang River (Yangtse River) northward drainage system, Huangpujiang River system, and Hangzhou Bay southward drainage system. Each system drains surface runoff from two-thirds of the plains of the Lake Taihu basin, in addition to the Lake Taihu floods. Connected by regional backbone watercourses, these three water systems are interconnected.

(1) The Changjiang River northward drainage system is composed of a dozen watercourses between Jiangyin and Shanghai, including the Baiqugang River (Dongqing River), Wangyu River, Qiputang River, and the Xinliu River. Wangyu River, one of Lake Taihu's two main outlets (besides the Taipu River), discharges Lake Taihu's floods. The Wangyu River, in addition to the Grand Canal, which goes through the east of Lake Taihu, and four districts of Lake Yangchenghu, Lake Chenghu, Lake Dianshan, and Hangzhou-Jiaxing-Huzhou plain, belongs to the Changjiang River watercourse system, as it intersects with the interlaced rivers and lakes within the Changjiang River basin.

(2) The Huangpujiang River lies between the Changjiang River northward drainage and the Hangzhou-Jiaxing-Huzhou water system. Located in Lake Taihu's lowest reaches, its sources are the Wusongjiang River, Lake Cheng, Lake Dianshan, Taipu River, and part of Dongtiaoxi River flow in the Hangzhou-Jiaxing-Huzhou region. As one of Lake Taihu's main drainage watercourses, the Huangpujiang River can drain more than 60% of flood waters. The Taipu River, with a drainage capacity of half of Lake Taihu's water collection, is located at the Huangpujiang River's upper reaches. The Wusongjiang River is also in the Huangpujiang's upper reaches and mainly discharges waterlogging in drainage areas; it accepts only a small amount of water from Lake Taihu. There are three branches of flow that converge in the Huangpujiang River's upper reaches: the north branch comprises Xietang River, Xihe River (not shown in Fig. 1.2), and Lanlugang River; the middle branch comprises the Yuanxiejing and Yuhuitang Rivers (not shown in Fig. 1.2);

and its south branch is formed by the Liugang River (not shown in Fig. 1.2) which receives incoming water from Hangzhou-Jiaxing-Huzhou. Because the water level of the Huangpujiang River is affected by estuary tides as far as its source, water levels will consequently reach high levels during floods, and the flood water cannot then discharge efficiently; conversely, in winter, the water level is low and the water from Lake Taihu discharges quickly.

(3) The Hangzhou Bend south drainage system consists of the Haiyantang River, Changshan River, a few backbone watercourses of the Yanguan River (Yanguanshanghe River, Yanguanxiahe River) basin, and several other regions. All the backbone watercourses carry surplus runoff from Hangzhou-Jiaxing-Huzhou area into Hangzhou Bay, by way of Nantaitou gate, Changshan gate, and Yanguan gate. Dongtiaoxi River offshoots, Lake Taihu and Taipu river, are connected to the west and the north part of the local river nets, and provide emergency drainage in years of great floods.

1.2.1.4 Constitution of Inflowing and Outflowing Rivers and their Distribution

As the center of the basin, Lake Taihu is of extreme importance in flood control, water resource regulation, and environment protection. To a large extent, it is Lake Taihu that has brought the rapid regional economic growth to areas such as the Suzhou-Wuxi-Changzhou (in brief, Su-Xi-Chang) and Hangzhou-Jiaxing-Huzhou (in brief, Hang-Jia-Hu) districts, and Shanghai. Lake Taihu will continue playing an important role as the processes of irrigation construction and environment improvement accelerate.

Lake Taihu is a typical lowland shallow lake. It is characterized by shallow water, a fast water cycle, and numerous incoming rivers. There were 225 rivers and canal entrances around the lake before the 1980s, and as the shoreline is 405 km long, there was 1 entrance approximately every 2 km. When the embankment around Lake Taihu was built, 54 original entrances were blocked, although 27 locations have 1.5-m-aperture culvert gates. Among the other 171 entrances, 45 were kept open; the remainder are controlled by building gates.

A total of 37 rivers leading to Lake Taihu are found along the Yixing shoreline (see Fig. 1.2). The Shaoxianggang River, the entrances of which were all kept open, is a watercourse dug in 2002 to connect Lake Taihu with Lake Ge Basin. Regional backbone rivers into Lake Taihu are the Taige Canal and 6 rivers: Dapugang River, Chengdonggang River, Hongxianggang River, Shaoxianggang River, Shatanggang River, and Yincungang River (Fig. 1.2). Other smaller rivers are the Dagang, Wuxigang, Huangdugang, Zhudugang, Kandugang, and Xindugang Rivers.

There are 23 rivers along the Wuxi shoreline (see Fig. 1.2), all of which, except for the Wujinggang and Zhihugang Rivers, run into Lake Taihu. All are passages from Lake Taihu to the Grand Canal of Wuxi section with added or reduced flows. Gates have been fixed for these 23 rivers. The backbone rivers here are Liangxi River, Lihe River, Daxi River, Wujinggang River, Zhihugang River, and Wuli Bay. Wuli Bay used to be an arm of Lake Taihu until, in 1991, a gate was built to separate them. Thus, Wuli Bay should be considered as a "watercourse" connected to Lake Taihu.

There are 75 watercourses leaving Lake Taihu along the Suzhou shoreline (see Fig. 1.2). The Wangyu River and Taipu Rivers serve as two major drainage and diversion channels. If there is insufficient water in Lake Taihu, the Wangyu River carries supplemental water from the Changjiang River. When there is a water shortage in Shanghai, or water quality deterioration in Huangpujiang River, the Wangyu River delivers water from Lake Taihu to the Huangpujiang River (Fig. 1.2).

Altogether, there are 37 watercourses flowing along the Huzhou shoreline (see Fig. 1.2). The Changdugang River is the largest incoming river in the Lake Taihu basin. Its upper reaches are the Dongtiaoxi River and Xitiaoxi River, which collect more than half of the water entering Lake Taihu catchment's upper reaches. All the rivers run east to Lake Taihu. Of those rivers that run west to Changdugang River, some flow into the lake, while others flow out. Nine of the rivers running into the lake are kept open; the others are controlled by sluice gates.

Although Lake Taihu has many inflowing and outflowing rivers, they are all short, with low flow volumes (Table 1.5).

1.2.2 Water Resources and Water Balance

The Lake Taihu basin is located in the fan-shaped delta of the main Changjiang River. The Changjiang drainage basin has the most water of all river basins in China. With a capacity of 9.61×10^{11} m^3, it accounts for 34.1% of China's total water resources. There is 2,358 m^3 of water per capita in the Changjiang basin and 480 m^3 per capita in the Lake Taihu basin.

In 2001, the whole Lake Taihu basin had an annual precipitation of 4.41×10^{10} m^3. Annual runoff was 1.78×10^{10} m^3, of which 1.52×10^{10} m^3 was from surface water and 2.6×10^9 m^3 was from ground water. The runoff yielding coefficient is 4.8×10^5 m^3 per kilometer squared.

1.2.2.1 Rainfall

Atmospheric precipitation is the main source of surface water in the Lake Taihu basin. The local distribution of annual precipitation is influenced by factors such as climate, terrain, and moisture sources. In general, the south of the basin receives more precipitation than the north, and the mountainous west receives more precipitation than do the plains to the east. Annual precipitation in the whole basin in 2000 was 1,182 mm.

The basin can be classified as humid (annual precipitation, 800–1,600 mm). In its southwest, because of orographic rain, the Tianmu mountain area has the highest annual precipitation, 1,300–1,900 mm. In the northwest and north of the basin (Maoshan Mountain, Jintan, Changzhou, Kunshan, Wusongjiang River), annual precipitation is less than 1,050 mm. Across the basin, the highest annual precipitation

Table 1.5 Major inflowing and outflowing rivers of Lake Taihu[1]

River	Inflow				Outflow				Annual runoff ($\times 10^8$ m^3)
	Day (d)	Maximal daily mean flux (m^3/s)	Mean flux (m^3/s)	Inflow total runoff ($\times 10^8$ m^3)	Day (d)	Maximal daily mean flux (m^3/s)	Mean flux (m^3/s)	Outflow total runoff ($\times 10^8$ m^3)	
Xitiaoxi	235	273.0	35.0	7.10	124	−57.8	−12.89	−1.38	5.72
Sanliqiaogang	102	52.0	9.0	0.79	263	−19.2	−5.25	−1.19	−0.40
Dongtiaoxi	119	400.0	71.3	7.33	246	−122.0	−45.39	−9.65	−2.32
Changxinggang	301	61.0	7.0	1.82	64	−10.4	−2.21	−0.12	1.70
Gulougang	343	52.0	3.9	1.14	18	−1.9	−0.73	−0.01	1.13
Chendonggang	338	147.0	34.2	9.98	26	−38.7	−10.07	−0.23	9.76
Caoqiaohe[1]	347	72.9	18.5	5.56	18	−14.8	−5.47	−0.09	5.47
Yincungang									
Wujinggang	339	49.8	6.6	1.95	26	−7.1	−2.89	−0.06	1.88
Zhihugang	244	78.1	8.3	1.75	27	−14.1	−5.56	−0.13	1.62
Liangxi	174	60.7	11.8	1.78	60	−23.3	−9.58	−0.50	1.28
Wuli Bay	6	71.1	47.3	0.25	0	0.0	0.00	0.00	0.25
Daxigang[1]	230	53.1	11.4	2.27	135	−35.8	−10.66	−1.24	1.03
Yuantangqiaogang									
Wangyu	116	240.0	82.8	8.30	249	−177.0	−44.10	−9.49	−1.19
Xinyunhe	32	33.1	15.4	0.43	333	−183.0	−31.47	−9.05	−8.63
Dapugang	14	4.2	2.7	0.03	348	−14.2	−5.78	−1.74	−1.71
Xigang	7	16.5	8.7	0.05	358	−44.3	−18.72	−5.79	−5.74
Taipu	8	73.2	27.5	0.19	357	−296.0	−119.47	−36.85	−36.66

[1] If the number of days of inflow and outflow total less than 365, the difference represents number of days of no-flow.

recorded was 1,593 mm (in 1999), and the lowest was 680.5 mm (in 1978); the ratio of the highest to the lowest precipitation is 2.34.

Because the basin is affected by the monsoon, both monthly and yearly precipitation is subject to strong variation. When comparing precipitation of periods of 4 consecutive months, the highest amount occurs from June to September, some 45–55% of the annual total (Table 1.6); the second highest amount occurs from May to August. June and July tend to get the most monthly precipitation and January or February the least. Flood season comes earlier in the south of the basin than in the north, and earlier in the mountainous regions than in the plains.

The coefficient of variation of annual precipitation, C_v, is an indicator of precipitation perennial change: the greater the value of C_v, the more variable the precipitation. Normally C_v fluctuates between 0.17 and 0.3 in the basin; in the northwest to Danyang, C_v is higher (0.26–0.30), and in Hangzhou-Jiaxing-Huzhou district and Shanghai, it is lower (0.18–0.20). Precipitation was 1,130 mm in a median frequency (50% frequency of reoccurrence), 1,030 mm in a low frequency (25% frequency of reoccurrence), and 1,280 mm in a high frequency (20% frequency of reoccurrence).

1.2.2.2 Runoff

Subtracted by surface and land evaporation and evapotranspiration, the remaining amount of precipitation is surface and subsurface runoff. Because both climate and the underlying surface vary across the Taihu basin, each region has a distinctly different yearly runoff. The highest yearly runoff, $3.98 \times 10^9\,\text{m}^3$, occurred in west Zhejiang Province, and the lowest was $5.35 \times 10^9\,\text{m}^3$ in the region around the lake. The mean yearly runoff depth, which depends greatly on precipitation and runoff generation, is highest in west Zhejiang Province (533 mm/a), and lowest in lake around areas (156 mm/a). Within the Lake Taihu basin, the highest yearly runoff depth occurs in the Tianmu mountainous region (800–1000 mm), followed by the Hangzhou-Jiaxing district. There is a relatively small yearly runoff (only about 300 mm) in the south of Jiangsu Province.

Most of the runoff (33%) occurs in summer (from June to August); the least (11%) occurs in winter (December–February). Runoff volume varies greatly from year to year, with a maximum difference (eightfold) recorded at the Huxisha River monitoring station.

Yearly runoff, and the precipitation distribution within a year, are at maximum in the flood season and vary in different seasons. There is considerable regional variation in the 4 successive months when the maximum occurs; for example, in Zhejiang province, it is from April to July; in Jiangsu province, from May to August; and in Shanghai, it is from June to September. Runoff shows strong fluctuations, both within and between years.

1.2.2.3 Evaporation

There are numerous factors affecting lake evaporation rate, making it hard to directly measure the actual value and to calibrate the various measured or calculated results.

Table 1.6 Seasonal precipitation at six locations in the Lake Taihu basin

Rainfall gauge location	Province/ municipal region	No. of years	Spring (Mar.–May) (% of year)	Summer (Jun.–Aug,) (% of year)	Autumn (Sep.–Nov.) (% of year)	Winter (Dec.–Feb.) (% of year)	Annual precipitation (mm)	Flooding season (Jun.-Sep.) (% of year)
Xujiahui	Shanghai	107	24.8	39.7	22.6	12.9	1143.1	51.7
Changzhou	Jiangsu	41	25.1	42.4	19.3	13.2	1058.4	52.3
Wuxi	Jiangsu	40	26.4	41.2	18.9	13.5	1066.3	51.0
Suzhou	Jiangsu	50	27.2	38.5	20.1	14.2	1057.0	49.9
Hangzhou	Zhejiang	44	26.7	35.7	22.3	15.3	1290.3	49.0
Jiaxing	Zhejiang	52	27.5	35.5	22.0	15.0	1155.4	48.8

By examination of many years of monitoring data from the hydrological experimental station in Yixing, the yearly surface evaporation of Lake Taihu varies from 800 to 1,000 mm, with a mean of 950 mm. The evaporation capacity in the western Zhejiang's mountainous region (i.e., west Zhejiang Province district, with fluctuations between 800 and 900 mm) is lower than that in the plain areas (rather constant at around 1,000 mm). The area along the lake has higher evaporation, as much as 1,100 mm per year.

Water surface evaporation variation within a year is unimodal. Evaporation in January and February is low, accounting for only 3.5–4.1% of that for the whole year; evaporation in June and August is the highest, accounting for 13.5–16.4% of that for the whole year (Table 1.7). For seasonal evaporation, winter has the lowest, just 11.3–12.1%, and summer the highest, about 39.0–42.1%, of the yearly amount. Spring and summer have about 22.6–26.4% of the year's total, respectively.

Table 1.7 Monthly distribution of surface evaporation at three locations in the Lake Taihu basin (in percentage)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Yixing	3.6	3.5	6.5	6.8	9.3	11.4	13.5	14.5	11.4	8.6	6.4	4.5
Shanghai	3.8	4.1	6.3	8.3	10.1	11.6	13.5	13.9	10.0	8.4	5.8	4.2
Hangzhou	3.5	3.8	5.8	8.2	10.0	10.7	16.4	15.0	9.5	7.7	5.4	4.0

Land evaporation includes water surface (except for lake surface) evaporation, soil evaporation, and evapotranspiration. The land annual evaporation ranges from 600 to 800 mm, which is about 70–80% of that of the Lake Taihu surface. The general trend is that the south has higher evaporation rate than the north, and mountainous areas have a higher rate than do the plains. For the entire basin, the gross evaporation can be computed in terms of the evaporation from land and water surface. During the period 1956–1979, the gross evaporation in Lake Taihu basin was 2.77×10^{10} m^3/a, an amount equivalent to 63% of the normal precipitation in the same period.

1.2.2.4 Storage Capacity of the Lake

Lake storage capacity is the volume of water storage, an important component in the lake's water resources. The actual measured value of Lake Taihu at lowest water level was 1.78 m a.s.l. (in 1934), and the highest water level was 5.08 m a.s.l. (in 1999). The normal water level is 3.07 m (derived from the years 1954–2001, in Xishan Island station). During the flood of 1999, Lake Taihu had its highest water level, 5.08 m with a gross storage of 9.3×10^9 m^3. During the flood in 1991, its highest water level was 4.78 m and its gross storage was 8.6×10^9 m^3. Table 1.8 shows the water level and water capacity volume.

Table 1.8 Water level, area, and capacity of Lake Taihu in 1984

Water level	0.39	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Area (km^2)	0	197.3	1,166.6	1,886.0	2,126.0	2,233.1	2338.1	2338.1	2338.1	2338.1	2338.1
Volume ($\times 10^8$ m^3)	0	0.1	3.3	11.0	21.9	33.2	44.3	56.0	67.7	79.4	91.1

1.2.2.5 Water Balance of Lake Taihu

There are many rivers and canals around Lake Taihu; those in the upper reaches flow into the lake, while those in the low reaches flow from it. The field survey conducted in 2001 revealed 125 watercourses around the lake, 33 of which flowed into it. Most of the river network had become blocked, and only 13 watercourses discharged efficiently. Furthermore, because the terrain around the lake is lower and flat, rivers run in all directions and counterflow (reverse flow) happens rather frequently, especially in dry years.

In view of the aforementioned situation, conventional hydrometry is unreliable for calculating the incoming and outgoing flow of the lake. Since 1956, Jiangsu Province and Zhejiang Province have made collaborative efforts to monitor the hydrology of Lake Taihu. Because there are numerous watercourses running in two directions, it was necessary to choose a limited number of locations for fixed-point observation and undertake tour gauging around the lake from one watercourse to another. This survey was performed from the bridges of the highway around Lake Taihu. The area between the lake and the highway was included; the area of this land was about 2, 264 km^2, the outflow of which, W, should be added when calculating the lake's inflow V.

Lake Taihu water balance formula:

$$P + V = \mathrm{E} + Q + q \pm \Delta V \tag{1.8}$$

$$V = V' \pm W \tag{1.9}$$

In the formula, P represents lake surface precipitation of a given period, V and Q are the lake's incoming and outgoing runoffs, respectively, of that period, E is lake surface evaporation, q is industrial and agricultural water consumption of that period, ΔV is lake basin's pondage variation of that period, V' is the gauged runoff, and W is the runoff of the area between the lake and the highway (subsurface runoff is excluded). The data for the Lake Taihu water balance in different years are given in Table 1.9.

In recent decades, the Lake Taihu water regime has changed as sluice gates have been built to control the outflowing watercourses. Presently, Lake Taihu has the characteristics of a reservoir as the water balance can be brought under human control. The characteristics of the new water balance of Lake Taihu have been analyzed and specified as follows:

Table 1.9 Water balance of Lake Taihu during 1966–1988

Year	Hydrological frequency (%)	Input (10^8 m^3)				Output (10^8 m^3)				
		Inflow river runoff	Precipitation	Change of pondage	Total	Outflow river runoff	Evaporation	Change of pondage	Total	Water used
1969	50	61.51	25.17	5.04	91.72	67.04	22.87		89.91	0.14
1977	10	75.32	33.91		109.2	87.84	20.97	5.13	113.94	0.34
1978	95	30.55	15.06	7.88	53.49	30.67	24.16		54.83	0.46
1987	17	67.18	32.56		99.74	74.94	19.95	4.35	99.24	3.6
1988	70	42.47	24.26	6.14	72.87	40.90	22.71		63.61	4.0
1966–1988					52.74				52.29	

(1) Multiyear averaged annual inflow and outflow of Lake Taihu is 5.25×10^9 m^3, and its gross storage is 4.43×10^9 m^3. Lake Taihu water exchange time (the time for all lake water to be replaced) is 300 days, which is much longer than that of the other freshwater lakes in China; this means that Lake Taihu has a slower water exchange and that this will impede its self-purification and accelerate eutrophication.

(2) The Lake Taihu water recharge coefficient is 7.0, which is the ratio of the basin's catchment area to lake area. Poyang Lake (the largest freshwater lake in China) and Dongting Lake (the second largest freshwater lake in China) also belong to the Changjiang River basin, yet have markedly different water recharge properties. Poyang Lake's water recharge coefficient is 56 and Dongting's is 42. Furthermore, every water balance element of these two lakes differs from that of Lake Taihu. In Taihu, the incoming and outgoing flow is only 60% of total inflow and outflow; for Poyang and Dongting Lakes, the incoming and outgoing flow is 98% of the total inflow and outflow.

(3) Lake Taihu has approximately the same amount of inflow and outflow in flooding years as in normal years. However in 1978 and 1988, which were relatively dry years, water consumption was hard to estimate, and the flow ran in changing directions. So, survey monitoring alone resulted in much deviation in measuring incoming and outgoing flows. There tends to be more evaporation in dry years than in flood years. In 1987, the lake's evaporation was higher than its surface precipitation. The amount of incoming flow in dry years is only about 40% of that in wet years.

1.3 Pollution and Eutrophication

Wenyu Huang, Gang Xu, Qinglong Wu, and Boqiang Qin

1.3.1 Development of the Water Quality in Lake Taihu and Its Rivers

In 1960, water quality in Lake Taihu was good; total inorganic nitrogen concentration (TIN) was only 0.05 mg/L, phosphorus (PO_4^{3-}-P) was 0.02 mg/L, and the organic pollution index, COD_{Mn}, was 0.9 mg/L [Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences (NIGLAS), 1965]. However, by 1981 the water quality had deteriorated, TIN had increased to 0.894 mg/L (nearly 18 times higher than in 1960), and COD_{Mn} increased to 2.83 mg/L; phosphorus had not markedly increased. By 1988, TIN and total nitrogen (TN) were 1.115 mg/L and 1.84 mg/L, respectively (Sun & Huang, 1993); in 1998, levels rose to 1.582 mg/L and 2.34 mg/L, respectively (according to the investigation of the Taihu Laboratory for Lake Ecosystem Research, Chinese Academy of Sciences). Total phosphorus (TP) and COD_{Mn} also increased markedly from 0.032 mg/L and 3.30 mg/L in 1988 to 0.085 mg/L and 5.03 mg/L in 1998, increases of 2.66 and 1.53 fold, respectively (Table 1.10).

In 2000, the mean concentration of total P in Lake Taihu was 0.1 mg/L, and that in Meiliang Bay and Wuli Bay was also high, 0.26 and 0.2 mg/L, respectively. The mean concentration of TN was 2.3 mg/L, and in Meiliang and Wuli Bays the values

Table 1.10 Changes in water quality indices of Lake Taihu from 1960 to 1999 (mg/L)[1,2,3,4]

Year	TIN	TN	PO_4^{3-}-P	TP	COD_{Mn}
1960[1]	0.05		0.02		1.90
1981[2]	0.894	0.9	0.014		2.83
1988[2]	1.115	1.84	0.012	0.032	3.3
1994[3]	1.135	2.05	0.010	0.086	5.77
1995[3]	1.157	3.14	0.011	0.111	5.53
1998[4]	1.582	2.34	0.007	0.085	5.03
1999[4]	1.79	2.57	0.004	0.105	4.99

[1] Nanjing Institute of Geography, Chinese Academy of Sciences, 1965.

[2] Sun & Huang, 1993.

[3] The editorial group of "the '9th 5-year-period' and the year of 2010 plan of water pollution protection for Lake Taihu," 1998.

[4] The mean of 14 samples of Taihu Laboratory for Lake Ecosystem Research, Chinese Academy of Sciences.

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Table 1.11 Water quality in five regions of Lake Taihu in 2000

Region	COD_{Mn} (mg/L)	TP (mg/L)	TN (mg/L)	TLI_c[1]
Wulihu Bay	8.1	0.2	6.6	64.8
Meiliang Bay	7.8	0.26	5.6	55.9
Western littoral zone	7.0	0.17	3.1	55.7
Lake center	5.5	0.10	1.6	55.9
Eastern littoral zone	5.9	0.11	2 .4	54.5

[1] TLIc, an index of weighted sum based on concentration of Chl a, TN, TP, and transparency.

were 5.6 and 6.6 mg/L, respectively. The highest biomass of algae in 2000 was 2.1×10^8 cell/L, much higher than that in 1999. The water quality in the different regions in 2000 is shown in Table 1.11.

According to the current national environmental quality standard of surface water (GB3838–2002), Lake Taihu was a class I–II water body in the 1960s, and then severely deteriorated, becoming class II in the 1970s, class II–III at the beginning of the 1980s, class III in the late 1980s, and class IV in the middle 1990s (with one-third of the lake area being class V). By the year 2000, of the total surface area of the lake, class III water accounted for 6.7% (156.7 km^2), class IV water accounted for 85% (1, 989.7 km^2), and class V and worse accounted for 8.2% (191.6 km^2). Some 83.5% of Lake Taihu had a high level of nutrients, and only 16.5% had a moderate level of nutrients (east Lake Taihu and the lake centre). These data demonstrate that, every 10 years, the water quality in Lake Taihu dropped by one grade (State Environmental Protection Bureau, 2000). Furthermore, after 1990, the decline markedly accelerated.

Before the 1980s, deteriorating water quality, mainly evident as increases in total nitrogen and COD_{Mn}, was closely related to the development of agricultural production. The 1980s were a turning point for the environment of Lake Taihu, and although increases in total nitrogen diminished, the levels of phosphorus and chlorophyll *a* (Chl a) increased. During the 1980s and 1990s, deterioration of the water quality was mainly evident as increases of phosphorus and chlorophyll, resulting from urbanization, secondary and tertiary industry, and the consequent increase in living standards in the basin.

In the beginning of the 1970s, blooms of blue-green algae first appeared in Wuli Bay of Wuxi, and subsequently their scale and frequency constantly increased. In the mid- to late 1980s, algal blooms occurred two to three times every year, and expanded to Meiliang Bay. In the middle and late 1990s, algal blooms occurred four to five times every year and gradually expanded to most of the lake. In 2000, the center of Lake Taihu also suffered a bloom of blue-green algae. Because Meiliang Bay area is the main water source for Wuxi City, the algal bloom seriously affected the water supply, and directly influenced productivity and people's lives, leading to great economic losses. At present, even though the trend of deterioration of the water environment has been contained to some extent, the ecosystem is still degrading (Table 1.12).

Since the 1980s, the river inflow to Lake Taihu has been increasingly polluted, and this situation continues to date. In 1998, water quality monitoring results in

Table 1.12 Comparison of the main pollutant parameters in Meiliang Bay, Lake Taihu between December 1998 and December 2000[1]

Year	TIN	TN	PO_4^{3-}-P	TP	COD_{Mn}	Chl a
1998	1.180	1.892	0.002	0.0714	4.270	10.829
1999	1.241	2.654	0.002	0.260	5.267	11.097
2000	1.156	1.990	0.006	0.038	4.100	7.210

[1] Concentrations are given as mg/L, except for Chl a, which is given as μg/L; data are monthly observation results from the Taihu Laboratory for Lake Ecosystem Research, Chinese Academy of Sciences.

23 sections on the border of the lake loop in Jiangsu Province indicated that the sections with class V, IV, and III water quality accounted for 22%, 48%, and 30% of the total, respectively. Among the 23 river sections were 10 (some 43.5%) in which water quality did not reach surface water quality. There were five rivers in which water quality was worse than class V, namely, the Liangxi and Zhihugang in Wuxi City, Wujingang and Taige Canal in Wujing County, Changzhou, and the Yuecheng in Suzhou City.

The inflow, over a total length of 1,598 km, was inspected by the Taihu Basin Authority (TBA) of the Ministry of Water Conservancy in December 2000, and the water quality was appraised according to national surface water environmental quality standard (GB3838–2002). Some 80% of sites had water quality of class IV or worse, and 53% of the sites were class V or worse; only 19.5% of sites reached class III or better. Within the 20 provincial boundary river sections monitored, 85% of sections had water quality of class IV or worse. Within the 35 sections monitored along the river mouth that enters the lake, 80% had water quality of class IV or worse (Table 1.13). In July 2000, the Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, investigated the Dapu River in Yixing and determined that levels of the main pollutants TN, TP, and COD_{Mn} were at the highest levels ever recorded, exceeding 4.5 mg/L, 0.2 mg/L, and 7.5 mg/L, respectively. These data demonstrate that the Lake Taihu river water pollution has not markedly improved, despite the State Council's "zero point action" (the so-called zero point action is a movement aiming at industrial pollution control at the end of 1998, which was organized by the State Council) of 1998.

1.3.2 Pollutant Emissions and Amounts Flowing into the Lake

Studying the budget of the inflow and outflow of nitrogen, phosphorus, and the chemical oxygen demand (COD) of the lake help determine the main nutrient pathways and pollutant sources. The data presented here were collected in 1998, and concern the whole Lake Taihu basin, including 33 cities such as Shanghai, Hangzhou, Suzhou, Wuxi, Changzhou, Jiaxing, Huzhou; 17 counties and cities are in Jiangsu, 13 counties and cities are in Zhejiang, and the remaining 3 in Shanghai.

Table 1.13 Water quality assessment for categorization of rivers in Lake Taihu basin in 2000

Time	II		III		IV		V		> V	
	River length (km)	Percentage (%)	River length (km)	Percentage (%)	River length (km)	Percentage (%)	River length (km)	Percentage (%)	River length (km)	Percentage (%)
Dry period	4	0.2	329	20.6	363	22.7	505	31.6	397	24.9
Wet period	21	1.3	260	16.3	513	32.1	465	29.1	339	21.2
All year	12	0.7	299	18.7	434	27.2	484	30.3	369	23.1

1.3.2.1 Pollutant Emission and the Amounts Entering Rivers in Lake Taihu Basin

(1) Amount of wastewater entering the lake from major industrial pollution sources:

Based on an investigation by the environmental protection administration, the amount of wastewater pollutants from important industrial sources entering the Lake Taihu basin in the dominant Jiangsu Province in 1998 were COD_{Cr}, 93,822.1 t/a, TN, 2,686.0 t/a, and TP, 191.4 t/a. When all three provinces affecting the basin were considered, the emissions into the whole basin were COD_{Cr}, 160,478.2 t/a, TN, 4,041.8 t/a, and TP 264.74 t/a (Table 1.14).

(2) Domestic pollution sources

ⓐ Amount of pollutant emission

The domestic pollutant discharge coefficients were COD_{cr} 21.9 kg per·capita for the urban population, TP 0.62 kg per·capita, and TN 3.65 kg per·capita; and COD_{Cr} 21.9 kg per·capita, TP 0.55 kg per·capita, and TN 3.65 kg per·capita for the rural population. In the study district, the urban and rural populations were 7.7083 and 17.1854 million, respectively, in 1998. Thus, the amount of pollution produced by the urban population was COD_{Cr} 168,811.8 t/a, TP 4,779.15 t/a, and TN 28,135.3 t/a, respectively; and by the rural population, COD_{Cr} 376,360.3 t/a, TP 9,451.97 t/a, and TN 62,726.7 t/a, respectively. In total, the quantities of domestic pollutants produced were COD_{Cr}, 54 5,172.1 t/a, TP, 14,231.12 t/a, and TN, 90,862.0 t/a.

ⓑ Amount of pollution entering the lake

Because most urban sewage enters a water body through primary treatment tanks, there is deposition and loss of solid matter, estimated at 90%. Pollutants from rural residents were dispersed, and the percentage loss of both COD and TN was estimated as 12.1% while that of TP was 33.6%. Thus, the pollutants from domestic sewage that entered the lake were CODCr 197,470.2 t/a, TP 7,477.10 t/a, and TN 32,911.7 t/a.

(3) Amount of pollution from agriculture production

According to the Nanjing Institute of Environmental Science, State Bureau of Environmental Protection, farmland (rice paddy and dry land) yielded the pollution

Table 1.14 The regional distribution of industrial wastewater pollutants from major sources into the Lake Taihu basin in 1998

Province	City	COD_{Cr} (t/a)	TN (t/a)	TP (t/a)
Jiangsu	Suzhou	46, 942.3	1, 051.0	82.58
	Wuxi	16, 259.2	1, 193.2	77.71
	Changzhou	26, 460.0	348.4	28.10
	Zhenjiang	4, 160.6	93.4	3.01
	Total	93, 822.1	2, 686.0	191.40
Zhejiang	Hangzhou	14, 893.0	286.8	24.10
	Jixing	33, 846.3	499.1	23.11
	Huzhou	15, 881.7	250.9	17.32
	Total	64, 621.0	1, 052.5	64.53
Shanghai	Three counties	2, 035.1	287.6	8.81
Total		160, 478.2	4, 041.8	264.74

Table 1.15 Pollutant concentrations from different agricultural sources in the Lake Taihu basin (1998)

Agricultural source	COD_{Cr} (mg/L)	TN (mg/L)	TP (mg/L)
Paddy fields	62.82	13.45	1.030
Dry fields	30.30	4.30	0.695
Runoff from land	58.12	5.90	0.850
Seepage from rice fields	16.66	3.26	0.204

loads shown in Table 1.15, and from this we derive the resulting runoff pollution shown in Table 1.16. The total pollutants from farmland passed to Lake Taihu were COD_{Cr}, 272,805.7 t/a, total nitrogen, 53,970.0 t/a, and total phosphorus, 3,990.41 t/a. Drainage and seepage were the primary and secondary ways by which these pollutants left the paddy fields.

(4) Soil erosion

According to calculations by the Jiangsu Provincial water and soil conservation office, the areas in the basin with slight soil erosion reached about 1,292.86 km^2, those with a moderate degree of soil erosion 206.96 km^2, and those with a severe degree of soil erosion 40.13 km^2. The annual loss of soil was 0.4–2.0 mm in the "slight area," 2.0–4.0 mm in the "moderate area," and 4.0–6.0 mm in the "severe area." Loss of soil was about 2.97 million t/a, and approximately 0.4 million t silt entered the lake. In the upstream regions of the Taihu basin, the mean concentration of total phosphorus in soils was 0.032–0.048% and total nitrogen was 0.18–0.23%. Thus, through soil erosion, the silt entering the lake basin carried about COD_{Cr} 8,585 t/a, 800 t/a total nitrogen, and total phosphorus 192 t/a.

(5) Amount of pollution from livestock and poultry production

The Nanjing Institute of Environmental Science estimated total pollution loads originating from livestock and poultry in 1998 (Table 1.17), and from this, the percentage and load flowing into the Taihu basin were calculated (Tables 1.18, 1.19). The pollutant load that flowed into the Lake Taihu basin from livestock and poultry production was calculated as COD_{Cr} 37,850 t/a, total nitrogen 6,710 t/a, and total phosphorus 2,820.00 t/a. The COD_{Cr} derived primarily from poultry excrement and secondarily from pig excrement; total nitrogen derived primarily from poultry excrement, secondarily from pig urine; and total phosphorus derived primarily from poultry and secondarily from sheep excrement.

Table 1.16 Runoff pollutant load of agricultural non-point sources in Lake Taihu basin (1998)

Agricultural source	COD_{Cr} (t/a)	TN (t/a)	TP (t/a)
Runoff from land	28168.9	2859.6	410.53
Dry fields	28803.6	4143.5	664.89
Paddy fields	132696.1	30698.8	1896.98
Seepage from rice fields	83137.1	16268.1	1018.01
Total	272805.7	53970.0	3990.41

Table 1.17 Total pollution load originating from livestock and poultry in 1998 (10^4 t/a)

Item	Cattle excrement	Cattle urine	Hog excrement	Hog urine	Poultry excrement and urine	Sheep excrement and urine	Total
COD_{Cr}	1.564	0.151	27.121	7.745	19.936	1.237	57.754
TN	0.220	0.202	2.806	2.840	4.545	2.003	12.616
TP	0.060	0.010	1.778	0.447	2.507	0.694	5.496

Table 1.18 Percentage of pollution from livestock and poultry production flowing into the Taihu basin in 1998 (in %)

Item	Cattle excrement	Cattle urine	Hog excrement	Hog urine	Poultry excrement and urine	Sheep excrement and urine
COD_{Cr}	6.16	5.00	5.58	5.00	8.59	5.50
TN	5.68	5.00	5.34	5.00	8.47	5.30
TP	5.50	5.00	5.25	5.00	8.42	5.20

Table 1.19 Pollution load from livestock and poultry production flowing into the Taihu basin in 1998 (10^4 t/a)

Item	Cattle excrement	Cattle urine	Hog excrement	Hog urine	Poultry excrement and urine	Sheep excrement and urine	Total
COD_{Cr}	0.096	0.008	1.513	0.387	1.713	0.068	3.785
TN	0.013	0.010	0.015	0.142	0.385	0.106	0.671
TP	0.003	0.001	0.009	0.022	0.211	0.036	0.282

(6) Amount of pollution from aquaculture

The area with production fishponds in the basin was estimated at 53, 704 hm^2 for 1998. Taking the pollutant discharge coefficients/hm^2 as COD_{Cr} 745 t/a, TN 101 t/a, and TP 11 t/a, the pollutant discharge from fishponds was COD_{Cr} 40,009.9 t/a, total nitrogen 5,424.2 t/a, and total phosphorus 590.72 t/a.

In addition, the aquaculture area in Lake Taihu itself was about 3, 300 hm^2 in 1998, 95% of which was for the cultivation of river crab, and the remaining 5% for fish culture. About 8,500 t food for these species is put into the lake every year, equal to about 782.0 t/a COD_{Cr}, 279.7 t/a total nitrogen, and 44.2 t/a total phosphorus.

The total pollutant discharge from aquaculture in the Taihu basin and lake are, therefore, COD_{Cr} 40,791.9 t/a, total nitrogen 5,703.9 t/a, and total phosphorus 634.92 t/a.

(7) Amount of pollution from lakeside tourism

According to statistics for the main hotels and domestic pollution sources around the lake in Wuxi and Suzhou City, about 20,000 people visit Lake Taihu every day. The pollutant discharge coefficients, including those of the night soil, are COD_{Cr} 300.4 t/a, total nitrogen 162.2 t/a, and total phosphorus 11.20 t/a. If it is assumed that 50% of the pollution from tourism enters the water body, the discharge loads into the lake are 150.2 t/a COD_{Cr}, 81.1 t/a total nitrogen, and 5.60 t/a total phosphorus.

(8) Atmospheric pollution from rainfall and dust on the lake surface

According to calculations by the Nanjing Institute of Environmental Science, State Bureau of Environmental Protection, COD_{Cr} entering the lake from rainfall amounts to 23,595.0 t/a, total nitrogen is 2,759.5 t/a, and total phosphorus is 60.10 t/a. Dust on the lake surface adds a further 420.9 t/a total nitrogen and 33.0 t/a total phosphorus.

(9) Shipping pollution

Nearly 2,200 fishing boats work in Lake Taihu. If it is assumed that the fishermen live on their boats for half a year, the sanitary sewage, excrement, and urine discharged into the lake amounts to COD_{Cr} of 98.2 t/a, total nitrogen 38.9 t/a, and total phosphorus 3.26 t/a. In addition, shipping in Lake Taihu and its rivers involve some 87,000 boats per year. Assuming two persons as crew per ship, their pollution discharge amounts to COD_{Cr} 3,981.9 t/a, total nitrogen 1,577.1 t/a, and total phosphorus 128.8 t/a. Thus, the total pollutants entering the water body from fishing and shipping are COD_{Cr} 4,080.1 t/a, total nitrogen 1,616.0 t/a, and total phosphorus 132.1 t/a.

(10) Total pollution

The foregoing calculations show that, in 1998, the total pollutants entering the Lake Taihu basin were COD_{Cr} 745,609.9 t/a, total nitrogen 108,937.1 t/a, and total phosphorus 15,609.89 t/a (Table 1.20). The principal pollution sources varied for each of these three main pollutants. For COD_{Cr}, the main pollution source was agriculture (36.59%), followed by sewage (26.47%) and industrial waste (21.51%). For total nitrogen, the main source was agriculture (49.54%), followed by domestic sewage (30.22%) and livestock and poultry production (6.16%). For total phosphorus, the main source was domestic sewage (47.89%), followed by agriculture (25.56%) and livestock and poultry production (18.06%).

1.3.2.2 Estimates of Pollutants Entering Lake Taihu from the Area of Jiangsu Province

Some nutrients enter Lake Taihu via rivers that flow into the lake, whereas other nutrients, such as those from soil erosion, aquaculture, tourism, rainfall, dust precipitation, and shipping, enter the lake directly. The pollutants entering the lake via the main rivers of the dominant Jiangsu Province in 1998 were COD_{Cr} 117,646.3 t/a, total nitrogen 19,241.4 t/a, and total phosphorus 961.2 t/a, and via other rivers were COD_{Cr} 53,404.7 t/a, total nitrogen 6,099.7 t/a, and total phosphorus 355.66 t/a. Thus, the total pollutants entering Lake Taihu by the rivers were COD_{Cr} 171,051.0 t/a, total nitrogen 25,341.1 t/a, and total phosphorus 1,316.86 t/a.

The pollutants transported by surface runoff were, according to the Nanjing Institute of Environmental Science, as follows: from lakeside vegetated areas, COD_{Cr} 1,521.4 t/a, total nitrogen 231.5 t/a, and total phosphorus 17.8 t/a; from lakeside urban areas (towns and villages) COD_{Cr} 1,287.4 t/a, total nitrogen 26.3 t/a, and total phosphorus 2.84 t/a; and from the lakeside highway COD_{Cr} 38,215.7 t/a, total nitrogen 7,693.0 t/a, and total phosphorus 1,072.20 t/a.

Table 1.20 Sources of pollutant emission in Lake Taihu basin in 1998

Sources of pollutants	COD_{Cr}		TN		TP	
	Emission (t/a)	Percentage (%)	Emission (t/a)	Percentage (%)	Emission (t/a)	Percentage (%)
Industry	160,478.2	21.51	4,041.8	3.71	264.74	1.70
Sewage	197,470.2	26.47	32,911.7	30.22	7,477.10	47.89
Agriculture	272,805.7	36.59	53,970.0	49.54	3,990.41	25.56
Soil erosion	8,585.0	1.15	800.0	0.73	192.00	1.22
Poultry production	37,850.0	5.08	6,710.0	6.16	2,820.00	18.06
Aquaculture	40,791.9	5.47	5,703.9	5.24	634.92	4.07
Tourism	150.2	0.02	81.1	0.07	5.60	0.04
Precipitation	23,595.0	3.16	2,759.5	2.53	60.10	0.39
Dust fall	–	–	420.9	0.39	33.00	0.21
Shipping	4,080.1	0.05	1,616	1.41	132.1	0.86
Total	745,806.3	100.0	109,014.9	100.0	15,610.0	100.00

The actual loads and percentages of pollutants entering Lake Taihu from each of ten different sources in Jiangsu Province are shown in Table 1.21. The dominant source of COD_{Cr} was rivers (71.13% of the total), followed by the lakeside highway (15.89%), and precipitation (9.82%). A similar pattern pertained for total nitrogen, which was mainly brought in by rivers (64.69% of total), followed by the lakeside highway (19.64%) and precipitation (7.04%). Although total phosphorus was also mainly brought in from rivers (45.96% of total) and the lakeside highway (37.15%), an additional source, namely soil erosion, was also important (6.65%).

The pollutant load entering the lake from each of the 13 main rivers in Jiangsu Province is shown in Table 1.22. The COD_{Cr} was mainly received from the Taige Canal and the Caoqiao, Tiaoxi (Xitiaoxi and Dongtiaoxi), and Zhihugang Rivers (each of which contributed approximately 13% of the total). Total nitrogen was mainly received through the Zhihugang River (23.64% of the total), the Taige Canal, and the Wujingang, Caoqiao, and Liangxi Rivers (each of which contributed approximately 8% of the total). Total phosphorus was mainly received through the Wujingang and Zhihugang Rivers (21.15% and 15.07% of the total, respectively), followed by the Shedugang and Liangxi Rivers (9.76% and 7.46%, respectively).

Among the pollutants entering the lake during 1987–1988, the amount of COD_{Cr} was 145,419.8 t/a (COD_{Cr} was converted to COD_{Mn} by 2.98 times), TN was 28,106.0 t/a, and TP was 1,988.53 t/a (Huang, 2001). Compared with the amount in 1998, the pollutants of COD_{Cr}, TN, and TP entering the lake increased by 95,067 t/a, 11,065 t/a, and 897.8 t/a, respectively in 10 years; that is, COD_{Cr}, TN, and TP increased 65.4%, 39.4%, and 45.1%, respectively. The rapid increases obviously worsened water quality and accelerated eutrophication of the lake. High demands on the management of the environment of Lake Taihu, especially in pollution control, would be required.

Analysis of pollutant composition of COD, TN, and TP from different sources in 1994 and 1998 will be able to show the changes in contributions from various pollutant sources. According to the sources of pollutants in 1994 (State Environmental Protection Bureau, 2000), for COD_{Cr}, industrial effluent accounted for 39%, urban domestic sewage for 42%, and agriculture and rural resident sewage for 10%; for total nitrogen, industrial effluents accounted for 16%, agricultural and breeding discharges for 10%, urban domestic sewage for 38%, and agriculture for 42%; and for total phosphorus, industrial effluents accounted for 10%, turban domestic sewage for 15%, and agricultural sewage for 69%. In 1998, the COD_{Cr} discharged within the basin was partitioned as follows: industry, domestic, and agriculture, 21.5%, 26.5%, and 42%, respectively; for TN, the contributions were industry, domestic, and agriculture 3.7%, 30.2%, and 55%, respectively; and for TP, the contribution rates were 1.7%, 48%, and 30%, respectively (Table 1.23).

The proportion of pollutant sources in 1994 and 1998, as documented by the State Environmental Protection Bureau in 2000, are compared in Table 1.23. The dominant source of each of the three main pollutants changed during this 4-year period: both COD and TN mainly originated from domestic sewage in 1994 and from agricultural non-point sources in 1998; for TP, the reverse pertained. Thus,

Table 1.21 Loads of pollutants entering Lake Taihu from different sources in the catchment of Jiangsu Province in 1998

Source of pollutant	COD_{Cr}		TN		TP	
	Total (t/a)	Percentage (%)	Total (t/a)	Percentage (%)	Total (t/a)	Percentage (%)
River	171,051.0	71.13	25,341.1	64.69	1,326.56	45.96
Aquaculture	782.0	0.34	279.7	0.71	44.20	1.53
Tourism	150.2	0.06	81.1	0.21	5.60	0.19
Soil erosion	8,585.0	3.58	800.0	2.04	192.00	6.65
Precipitation	23,595.0	9.82	2,759.5	7.04	60.10	2.08
Dust fall	–	–	420.9	1.08	33.00	1.14
Shipping	3,883.7	1.61	1,538.2	3.93	132.02	4.58
Discharge from forest	1,521.4	0.63	231.5	0.59	17.81	0.62
Discharge from urban area	1,287.4	0.54	26.3	0.07	2.84	0.10
Uncontrolled beach area	38,215.7	15.89	7,693.0	19.64	1,072.20	37.15
Total	240,486.4	100.0	3,9171.3	100.0	2,886.33	100.0

Table 1.22 Loads of pollutants entering Lake Taihu from the 13 main rivers in Jiangsu Province 1998

River	COD_{Cr}		TN		TP	
	Input (t/a)	Percentage (%)	Input (t/a)	Percentage (%)	Input (t/a)	Percentage (%)
Liangxi	8,941.1	5.23	2,112.3	8.34	99.0	7.46
Zhihugang	21,646.8	12.66	5,991.3	23.64	280.6	21.15
Wujinggang	9,867.6	5.77	2,176.3	8.59	199.9	15.07
Caoqiao	22,754.0	13.30	2,162.8	8.53	61.1	4.61
Taige Canal[1]	22,875.4	13.38	2,221.2	8.77	88.6	6.68
Shedugang	2,459.8	1.44	311.6	1.23	129.5	9.76
Dapugang	8,592.8	5.02	916.0	3.61	22.0	1.66
Wuxigang	2,861.9	1.67	469.4	1.85	8.3	0.63
Other rivers in Jiangsu	17,646.9	10.32	2,880.5	11.37	144.2	10.87
Changxinggang	11,570.0	6.76	1,715.3	6.77	77.46	5.84
Xitiaoxi[2]	11,348.5	6.63	981.1	3.87	46.28	3.49
Dongtiaoxi[2]	10,756.1	6.29	1,345.1	5.31	66.37	5.00
East to Lake	19,730.1	11.53	2,058.1	8.12	168.23	12.68
Total	171,051.0	100.0	25,341.1	100.0	1,326.56	100.0

[1] Connecting Lake Taihu and Lake Ge.

[2] The Xitiaoxi and the Dongtiaoxi Rivers together are called the Tiaoxi River.

Table 1.23 Proportion of pollution sources to Lake Taihu in 1994 and 1998

Year	Pollution source	COD_{Mn}		TN		TP	
		Output (t)	Percentage (%)	Output (t)	Percentage (%)	Output (t)	Percentage (%)
1994	Industrial sewage	11,106	39	12,544	16	591	10
	Domestic sewage	119,029	42	19,948	38	3,394	15
	Agricultural non-point	28,138	10	29,842	25	852	60
	Aquaculture			13,195	17	533	9
1998	Industrial sewage	160,478	21.5	4,042	3.7	264.7	1.7
	Domestic sewage	197,470	26.5	32,912	30.2	7,477	47.9
	Agricultural non-point	272,806	36.6	53,970	49.5	3,990	25.6
	Aquaculture	40,792	5.5	5,704	5.2	635	4.0

industrial pollution control could not yet create the desired and expected result for lake eutrophication control in Lake Taihu (Qin et al., 2002).

1.3.3 Causes of Worsening Water Quality

The Lake Taihu basin, extending across the provinces of Jiangsu, Zhejiang, Anhui, and the city of Shanghai, occupies only 0.4% of the area of the country, yet accounts for 14% of the country's gross industrial and agricultural output and 14% of revenue. The basin has become one of the most economically developed areas in China, and has the highest degree of urbanization, with the urban population of 0.76 million in 1980 growing rapidly to 1.12 million in 1999.

The rapid economic development in the basin has aggravated contradictions among the population, resources, the environment, and further economic development. The economic development, mainly driven by increasing resource input and workforce, has resulted in overconsumption of natural resources. The natural environment of Lake Taihu has already deteriorated sharply, and water pollution and eutrophication have become serious, as evidenced by indices such as total phosphorus, total nitrogen, biological oxygen demand $(BOD)_5$, CODMn, and volatile phenols that do not meet national standards, and water quality that has dropped by one grade in each period of 5–10 years (see Section 3.1, above). Because the serious pollution of the water in the basin now seriously restricts the sustainable development of the regional economy, it is necessary to discuss the causes of the water problems from the social and economic angle to redefine the targets for comprehensive restoration.

The main reasons for the continued deterioration of the environment of Lake Taihu are increased water use and discharge; changes in agricultural practices and in fisheries and aquaculture; insufficient wastewater treatment; and an unsuitable management system. Each of these aspects is now considered in detail.

(1) With the development of industry and urbanization, the water requirements and wastewater discharge have increased, and the amount of pollution entering the rivers and the lake has increased. Although the rapid development of the regional economy has facilitated increases in income and living standards, the per capita water requirements have increased very rapidly. For example, water consumption in Wuxi City has increased from just 105 L/d in 1980 to 175 L/d in 1990, and reached 284 L/d in 1999 (a nearly threefold increase in just 20 years). Meanwhile, the peak daily water delivery amount has increased by 11% annually. The total amount of domestic water use increased from 80.3 thousand t/d to 0.32 million t/d between 1980 and 1999. If the discharge coefficient is taken at 0.8, the daily domestic sewage discharged to the river system increased from 64 thousand t/d to 0.254 million t/d from 1980 to 1998. On average, nearly 100 t CODMn enters the network of waterways with sewage every day.

In parallel with development of the economy, water transport has shown unprecedented growth. There are now thousands of ships traveling on the canals and rivers in the Lake Taihu basin every day, discharging a large amount of domestic sewage and other pollutants directly into the water [as discussed in Section 3.2, part (9), above].

The rapid development of industry is also accompanied by increased demands for water. The water supplied from the urban water system for industrial consumption increased from 41.16 million t/a in 1980 to 122.46 million t/a in 1998 in Wuxi City. Although technological developments have improved the water recycling utilization ratio, the total use is increasing, as is the total amount of industrial sewage.

Industries vary in their water consumption, and in the volume and nature of their wastewater discharge. For example, in Wuxi City, the industry is dominated by textiles, metal smelting, chemical industry, food and tobacco processing, beverage manufacturing, papermaking, and machinery production (Table 1.24). These industries together used 73% of the total volume of freshwater (excluding that used in water processing and supply), and their CODMn discharges accounted for 86% of industrial wastewater for Wuxi City. Although some of these core industries have recently decreased their pollution output, total industrial pollution output is increasing very fast, along with increasing water demand. Because the output of pollutants is particularly high in certain industries, such as leather and petroleum refining, effective management of their water use and pollution discharge should have a great impact on water pollution control. As the core industries of Wuxi City, namely machinery, electrical equipment, and electronic manufacturing, they contribute less to wastewater discharge than do the textile and chemical industries. Electricity, gas, and water production and ferrous metal metallurgy produced fewer pollutants but they consumed great amounts of water in Wuxi City (Tables 1.24, 1.25).

(2) Changes in agricultural production and land use have had an increasingly important impact on the aquatic environment. Historically, the land in the Taihu area was mainly used for growing mulberry bushes (as food for silkworms) and rice, and for fish breeding. However, since the policy changes in the 1980s, there have been great changes in land use. Large amounts of former agricultural land are now used for industry; as city size has expanded, there is competition for land use, and the amount of cultivated land per capita has reduced to 0.045 ha. To compensate for the large loss of cultivated land, a guaranteed stable agricultural output (grain) has been achieved by adopting new techniques. For example, use of chemical fertilizers has increased rice and wheat output by 10.3% and 34.9%, respectively, over the decades. This practice increased the yield of grain per unit area in the Lake Taihu basin to $7{,}272\,\mathrm{kg/hm^2}$ at the end of the 1990s, which is approximately 1.4 times the mean for the whole country.

Cultivated land has mainly been lost from the plain of the Taihu basin. Although there is less space for agricultural development, investment and economic growth have increased. Although agricultural land has an output value of only 260,000 yuan (US $32,500)/hectare, industrial land has an output value of about 3 million yuan (US $375,000)/hectare. To improve output, agricultural land use has been adjusted, with the proportion of the economic cropping area to all agricultural production areas changing from 7:3 in the early 1980s to 6:4 in the late 1990s. Some low-lying land and rice terraces have been excavated or modified for use as fish ponds for aquaculture.

Table 1.24 Water consumption and wastewater discharge of 20 industries in Wuxi city (1997) (data of 770 industrial enterprises)

Industry	Wastewater (10^4 t)	COD (10^4 t)	Water consumption (10^4 t)	Wastewater/10^4 yuan production (t/10^4 yuan)	COD discharge/10^4 yuan production (t/10^4 yuan)
Mining	30	144	23	24.8	0.012
Food, tobacco	1,923	5,220	3,421	86.5	0.024
Textile	4,645	25,782	15,927	37.3	0.021
Leather, pelage, down	110	1,135	123	350.7	0.15
Papermaking	1,826	7,790	2,820	350.7	0.15
Printing and media	0.87		1.93	2.9	
Oil and petrochemical	266	1,755	3,953	35.5	0.023
Chemical industry	4,457	12,946	20,160	65.7	0.019
Pharmacy	176	908	2,364	25.4	0.013
Chemical fiber manufacture	135	85	4,882	10.6	0.001
Rubber industry	116	170	427	12.1	0.002
Plastic industry	36	76	184	5	0.001
Non-metal manufacture	313	219	706	17.3	0.001
Ferrous metal metallurgy	4,499	2,219	8,116	10.9	0.001
Rare metal metallurgy	291	17	298	83.8	0.004
Metal product manufacture	494	409	875	39.5	
Mechanical and electrical manufacture	1,555	1,645	9,726	18.2	0.002
Electricity, gas, and water production	5,081	848	64,852	12.1	0.001
Other industries	297	919	666	416.2	0.007

Table 1.25 Correlation coefficients of output value and waste water discharge of different industries in Wuxi city (1996–1999)

Industry	Coefficient of wastewater production
Mining	0.0868
Food, tobacco	0.9081
Textile	0.7924
Leather, pelage and down	0.8915
Papermaking	0.9207
Printing and media production	−0.7758
Oil and petrochemistry	0.9200
Chemical industry	0.942
Pharmacy	0.7605
Chemical fiber manufacture	0.3139
Rubber industry	0.7324
Plastic industry	0.7211
Non-metal manufacture	0.7752
Ferrous metal metallurgy	0.9481
Rare metal metallurgy	0.7840
Metal product manufacture	0.7221
Mechanical and electrical manufacture	−0.1679
Electricity, gas and water production	0.9985
Other industries	0.7552

During the conversion of agricultural land to nonagricultural use, some rivers have been filled in while others became separated from the main river system, thus losing or changing their original ecological functions, influencing nutrient circulation between rivers, reducing absorption and dilution of pollutants, and indirectly causing deteriorating water quality.

Changes in agricultural technology have also influenced the aquatic environment. The main arable production in the Lake Taihu basin is two varieties of rice and wheat (or rice and rape). Because of the development of rural township enterprises, the comparative economic benefit from agriculture has been low, and labor productivity has largely turned to secondary and tertiary industries. In addition, some traditional techniques such as crop rotation and use of domestic organic fertilizer were gradually abandoned, which in turn indirectly affects the water quality of the lake. The traditional technique of using sediments from rivers, ponds, or lakes as a fertilizer no longer exists. This change has caused river and lake deposits to increase significantly, soil fertility has decreased, nutrient return and consumption are unbalanced, and chemical fertilizers have to be used, with their consumption increasing yearly. The proportion of organic to chemical fertilizer has changed from 3:7 in the mid-1980s to 1:9 in the mid-1990s. The amount of chemical fertilizer used (N, P, K) was 25 kg/ha in the 1980s and increased to 45 kg/ha in the 1990s. Nitrogen application now exceeds 30 kg/ha, accounting for more than 70% of chemical fertilizers. Because the utilization ratio of the chemical fertilizer is currently relatively low, fertilizer loss is serious. Similar problems also exist with extensive pesticide use. The increased use of chemical fertilizers and chemicals in agriculture has been accompanied by increased content of nitrogen, phosphorus, and potassium in the water bodies in or adjacent to farmland. Fertilizers and chemicals flow into rivers directly with surface runoff, thus causing not only nutrient loss, but also water pollution. The extensive, dispersive, seasonal, and flow characteristics of the chemical fertilizers and agricultural chemicals make them a significant source of eutrophication.

Since the mid-1990s, new cropping systems and agricultural structures have been introduced, namely grain farming, developing fruit orchards and poultry culture, innovative cultivation techniques, and concomitant use of fertilizer technology. Fertilizer loss and impact on the environment has, however, been reduced through cropping rotation, changing the base manure and application method of fringe fertilizer, cultivation using water-saving methods, fertilizing the land, and improving the utilization ratio of chemical fertilizer. At the same time, with the internal agricultural structural adjustment, the consumption of chemical fertilizer and agriculture chemicals has been reduced (Table 1.26). These developments have had new influences on the aquatic environment. For example, with the development of extensive feeding, numerous centralized poultry breeding facilities have been built around Lake Taihu, and the direct discharge of untreated waste became one of the major pollution sources of the basin. A further significant concern is the large amount of unconsumed fish food in aquaculture facilities, which settles on the lake bottom, increasing the organic content in water and sediment.

Nitrogen pollution, from grain and oil crop production, has a great impact on the aquatic environment. Some nitrogen (about 25%) is absorbed by crops, some is absorbed by the soil, and some enters the air (thus contributing to "greenhouse effects"), while another part enters the water with farmland runoff. In 1996, the nutrient content of rice seedling beds, fields, and irrigation canals and ditches was determined, and the mean total nitrogen content of 33 samples was 8.26 mg/L, which is 69% higher than the content of total nitrogen in rivers around the lake. The nitrogen loss with surface runoff per mu (15 mu = 1 ha) paddy field per year is 2.7–3.4 kg, which accounts for 12–17% of the total nitrogen applied. Taking Wuxi as an example, with 133,000 ha of grain fields, more than 5,400–6,800 t nitrogen enters the water body every year.

(3) Increasingly serious impacts of the fishery on the lake environment. Net enclosure fish production is concentrated in a small area in the east of Lake Taihu, with a production area of $5,400\,\mathrm{hm}^2$. The development of closed net breeding has had many adverse effects on the aquatic environment, including reduced the purifying ability of the lake and contributing to eutrophication. Such aquaculture requires the input of a large quantity of feed, the amount of which is closely correlated with

Table 1.26 Chemical fertilizer use in Wuxi city (1993–1997)

		1993	1994	1995	1996	1997
Total sales	Carbonic ammonia (10^4 t)	13.59	14.61	8.99	9.92	8.42
	Carbamide (10^4 t)	9.27	8.39	8.22	9.10	7.75
Usage/hectare	Carbonic ammonia (kg)	532.2	590.7	362.55	398.55	338.55
	Carbamide (kg)	362.55	338.4	331.35	365.55	311.7

increases in nitrogen and phosphorus load in the water body. For the per mu yield of 7,500–10, 125 kg/hm^2 from intense fish breeding, each 1 t fish produced adds 141.5 kg nitrogen and 14. 4 kg phosphorus into the lake. For example, below a 2-year-old enclosed fish-pen-culture net area, the organic matter, organic carbon, total nitrogen, and organic nitrogen in the top layer of the sediment are 190.7%, 141.4%, 87.5%, and 86.2% higher, respectively, than before (Fig. 1.4). From calculating the mean data in the 1990s, in the enclosed net area of east Lake Taihu, the nitrogen from aquaculture accounted for 2.8% of the total amount in Lake Taihu, and the phosphorus for 10.1%, thus demonstrating that fish breeding contributes significantly to the eutrophication of Lake Taihu. The increased nutrient content in the water body has resulted in nearly doubling the amount of algae, compared with the preaquaculture levels; increased diversity and biomass of protozoa; a three- to fourfold increase in aerobic bacteria and colon bacilli; and increases in aquatic plants, mollusks, and aquatic insect larvae.

(4) Insufficient wastewater treatment. Currently the wastewater treatment capacity in the Lake Taihu basin area is insufficient. The handling of industrial effluent still relies mainly on treatment in the factory. Urban sewage treatment needs massive investment, and the operating cost is high. According to the investment and operation cost of the urban sewage treatment plants that have already been built, to build a plant with capacity of 10,000 t/d needs about 5 million yuan (US $660,000), and to operate such a plant, about 520,000 yuan per year (US $70,000) is needed. For reasons of these great expenses, urban sewage treatment has developed slowly; for example, the municipal sewage handling rate of the urban area in Wuxi City is only 44% (1998 data), and if the suburbs are included, the rate was only 28%.

(5) The current water management system is unsuitable. Under the current system, the environmental protection bureaus, which have supervisory and management authority, are within the water environmental protection agency. This management system has effectively imposed the waste discharge fee and a fine for failing

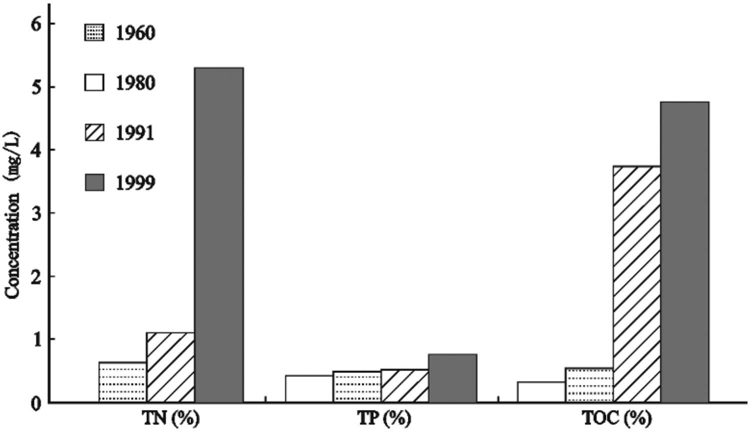

Fig. 1.4 Temporal changes in TN, TP, and TOC in surface sediment in East Lake Taihu, 1960–1999

to meet standards. However, the management system failed to manage the municipal sewage effectively and also failed to manage the rivers that bear and receive the sewage discharge. A large amount of municipal sewage has entered the rivers directly. Although river management lies with the water administration authorities, there is no legal basis from which the water administration authorities could manage the water environment and prevent water pollution. Water administration authorities cannot order enterprises to process waste within a defined time period, cannot collect the waste discharge fee from enterprises, and cannot invest in building the sewage treatment plants; thus, the water management authorities can only allow the rivers to bear and receive sewage.

If considering non-point source pollution, land resource management is closely related to water resource management. Thus, the current situation of no unified management of water quality and the water resource is hindering the process of aquatic environmental improvement and protection.

1.4 Swamping of Eastern Taihu Bay

Wenchao Li

Eutrophication of Lake Taihu, while manifesting as blue-green algal blooms in west and north Taihu, is manifest as swamping, or macrophyte-dominated eutrophication, in east Taihu, with plants covering more than 50% of the lake surface. Between the 1960s and 1990s, the biomass of aquatic plants has increased by one order of magnitude (Yang & Li, 1996b), corresponding with increasing nutrients in the surface sediment. Eastern Taihu Bay is of considerable economic importance for the region because it plays a key role in flood prevention and alleviation, supplies water for Shanghai and the east Zhejiang Province, and is one of the most developed areas of aquaculture production in China. Lying in the southeast of Lake Taihu, this bay is 27.5 km long and up to 9.0 km wide, and over its 131.25 km^2 area the water is now less than 1 m deep on average (see Fig. 1.2).

Swamping is the process of deposition within a lake, causing it to become shallower and finally to develop into a marsh. During this process, large amounts of plant material accumulate on the lake bed, rapidly choking the lake basin, blocking rivers, hindering shipping, diminishing storage capacity, and impeding flood drainage and water supply. In addition, decomposition of the plants releases organic pollutants and noxious substances that compromise water quality, further influencing the water supply and fishery (Li, 1997a).

The apparent cause of lake swamping is simply overgrowth of the aquatic plants, such that they progressively cover the lake surface. However, the actual cause is deposition, causing the lake basin to become shallower, combined with increased nutrient levels; both of which may originate beyond the lake itself. Only when these conditions occur can there be overgrowth of macrophytes.

Some human activities, such as nutrient loading and inappropriate dredging and water level management, can accelerate lake swamping (Yang et al., 1995; Yang & Li, 1996a). Conversely, proper measures such as control of nutrient sources, removal of silt, increasing the water level, and cutting and utilizing the aquatic plants can prevent or delay lake swamping (Li, 1998).

Aquaculture has both delayed and accelerated swamping in Eastern Taihu Bay (Li, 1998). From the first aquaculture along the lakeside in the 1970s, to the extensive production from 3,300 hm^2 in the 1990s, aquatic plants from Eastern Taihu Bay, principally *Zizania latifolia* Turcz, were used as the main feed source, with a harvest of 600,000 t in the 1990s. This intensive harvesting eliminated *Z. latifolia* from the entire northwest bank and from most of the southeast bank, thus initially delaying swamping. However, aquaculture now occupies almost all of eastern Taihu, making it impossible to harvest and use the aquatic plants. Furthermore,

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net enclosures block water flow during the flood season, and the stagnant conditions encourage growth of floating-leaf plants. In addition, excessive planting of *Z. latifolia* has accelerated swamping in some lake regions. Thus, aquaculture has recently accelerated swamping.

1.4.1 Current Status of Swamping

More than 50% of Eastern Taihu Bay is swampy, with plants and plant debris floating on the surface and depositing on the bottom, and the lake bed is now elevated by more than 2 m (Li, 1997a). The most seriously swamped region is Dongjiaozui, where a 2-m-high beach formed from deposits now reaches towards the opposite bank, leaving only a 1-km-wide channel open, seriously impeding the sluicing function of Eastern Taihu Bay. The largest swamped area, along the southeast bank of the lake, blocks the mouths of more than 20 rivers, including the Taipu, rendering water supply insufficient.

1.4.1.1 The Topography and Depositional State of the Lake Bed

(1) Lake bed topography

Lake bed topography was measured in Eastern Taihu Bay in 1991, and again in 1998 between the mouth of the Taipu River and Dongjiaozui (a 50 km^2 area with active deposition) (Fig. 1.5). The comparatively simple lakebed is 1.24–3.24 m a.s.l., with a shoal in the Dongjiaozui lake area. Only 10% of the lake bed is more than 2.00 m a.s.l., including a small beach more than 2.50 m high at the mouth of the Taipu river, the *Z. latifolia* growing area of the southeast bank, which is 2.0–2.5 m high, and a large shallow beach in the reeded area in the west of the Lujiagang River mouth where about 7 km^2 is more than 2.50 m a.s.l. Part of the lake bed is less than 2.00 m a.s.l., including the north of Eastern Taihu Bay center area where some 12 km^2 lies at 1.50–1.70 m a.s.l., a deep trough in the west of the Miaogang River mouth at 1.24 m, and the narrow deep-water zone less than 1.8 m a.s.l. that joins the deep-water region in the north of the bay center and west Taihu, forming the main passage for the entry and exit of water in Eastern Taihu Bay.

Southeast winds usually prevail, and long-term erosion by the wind-induced waves has resulted in the special topography of the deep-water zone in the lake centre near the northwest bank. West or northwest winds, which prevail in winter, generate storm waves leading to strong erosion near the southeast bank at Eastern Taihu Bay mouth and forming a deep trough in the lake bottom. The constant extension of Dongjiaozui results in the shrinking of the mouth of the Eastern Taihu Bay, limiting the sluicing capacity of Eastern Taihu Bay.

(2) Depositional state

Sediment deposition in Eastern Taihu Bay is very serious (Figs. 1.6, 1.7), with nearly 1 m (0.96 m) of soft deposits (hardness $< 5\,\mathrm{kgf/cm^2}$), and about 15×10^7 t being deposited each year, more than 98% of which is inorganic matter (silt) originating from outside the lake (Li, 1997b). Deposition is most serious in the

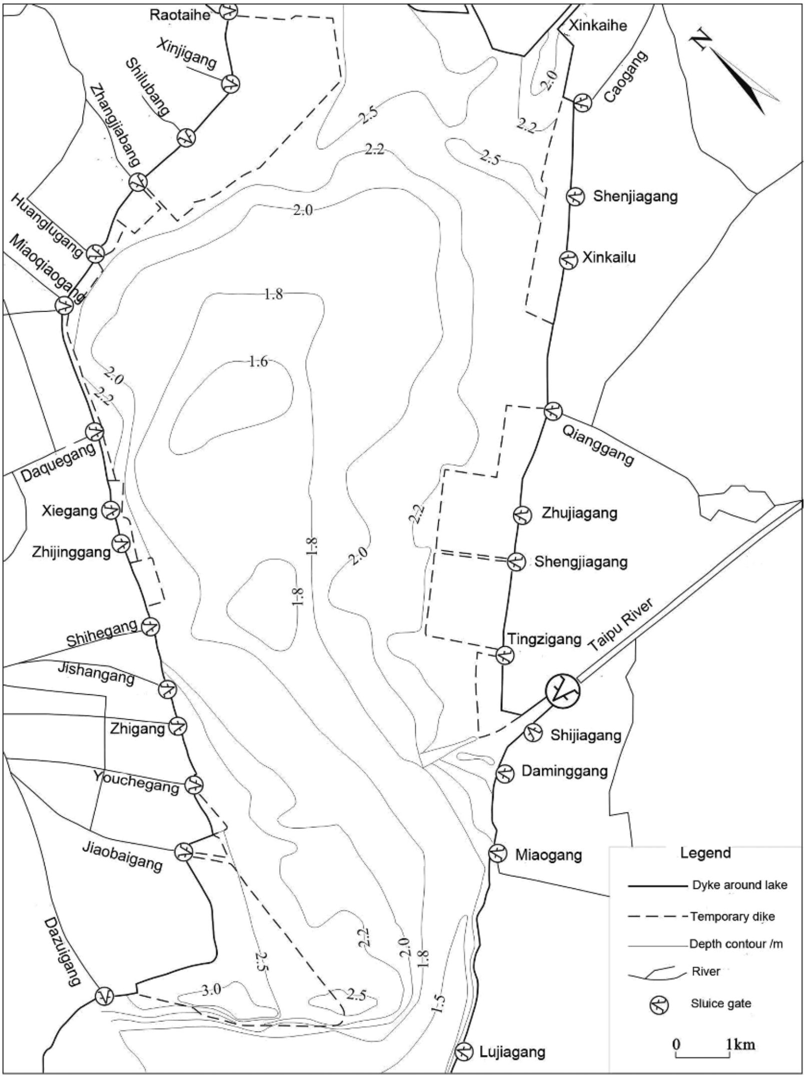

Fig. 1.5 Underwater topography of Eastern Taihu Bay in the 1990s

Z. latifolia cultivation area along the southeast bank, at the mouth of the Taipu River, and at Dongjiaozui, where some deposits are more than 2.0 m deep. In contrast, in open lake regions, deposits are less than 1.0 m deep, and at the centre and mouth of Eastern Taihu Bay deposits are less than 0.5 m deep (Fig. 1.6). This deposition pattern indicates that the silt comes principally from west Lake Taihu and is mainly transported by the inflow and outflow.

Analyzing the lake bed elevation of the Eastern Taihu Bay mouth in 1991 and 1998, it was found that deposition in this region was very active (Fig. 1.7). Except

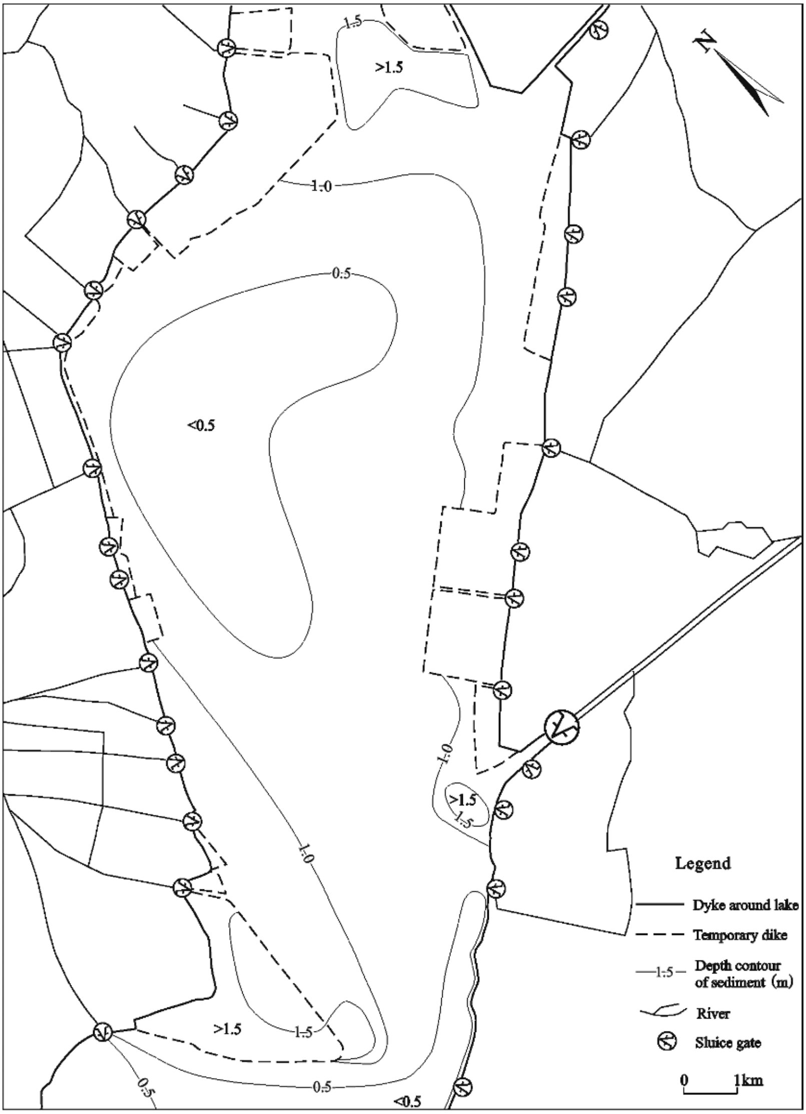

Fig. 1.6 Depth contour of soft sediment in Eastern Taihu Bay (hardness < 5 kgf/cm^2)

for slight erosion in the lake bed along the southeast, there was deposition to various degrees on all other lake bed areas. Among them there is an ox tongue-shaped deposition zone extending from east of Dongjiaozui to the Taipu river mouth, of about 6 km^2, with recently deposits more than 0.20 m deep. There is also a strip-shaped zone near Dongjiaozui, of 1 km^2, where new deposits are more than 0.30 m deep. In the *Zizania latifolia* Turcz growing area of the Taipu River mouth, new deposits are more than 0.30 m deep (Table 1.27).

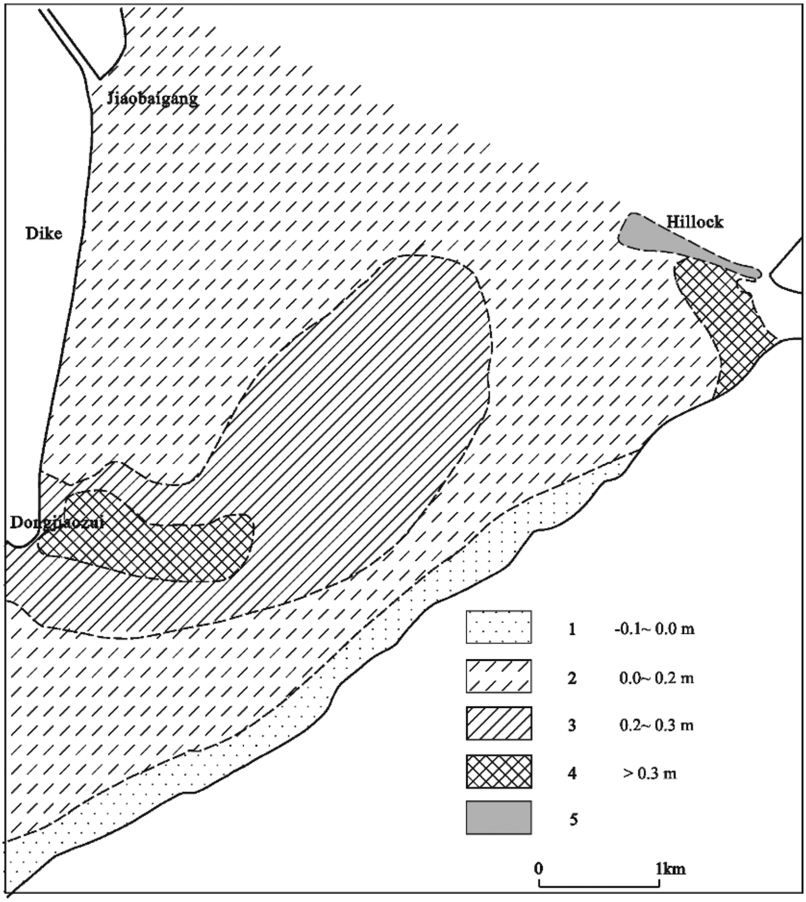

Fig. 1.7 Spatial pattern of deposition in the mouth of Eastern Taihu Bay in 1990s. 1, Slight erosion; 2, slight deposition; 3, marked deposition; 4, serious deposition; 5, hillock

1.4.1.2 Status of Aquatic Vegetation

More than 95% of the area of Eastern Taihu Bay was covered with aquatic plants, the exception being the enclosed net-pen aquaculture areas in the northeast (Fig. 1.8). The distinct vegetation was, in descending order of area: (i) in the center of the bay, *Potamogeton maackianus* A. Benn. (44% of the vegetated area); (ii) in the southeast, *Z. latifolia* (26 km^2); (iii) along the northwest bank, the community of cultured *Z. latifolia* and *Nymphoides peltatum*, *Trapa incisa*, *Hydrocharis dubia*, and some submerged plants (19 km^2); (iv) in the Dongjiaozui and southwest side of Eastern Taihu Bay, the reed growing area (8 km^2); and (v) the deep trough near Lujiagang, *Vallisneria natanus* (0.5 km^2). In addition, there was a transition zone between the *V. natanus* community and the *Potamogeton maackianus* community

Table 1.27 Characteristics of the aquatic vegetation of Eastern Taihu Bay in August 1997

Communities	Location	Coverage (km^2)	Percentage (%)	Biomass (g/m^2)	Total biomass (t)
Total	All the lake	132.38	100	3, 816	505, 200
Phragmites communis Trin.	Dongjiaozui around areas	8.25	6.2	4, 800	39, 600
Zizania latifolia Turcz	Along southeast bank	26.37	19.9	5, 600	147, 700
Zizania latifolia Turcz + *Nymphoides peltatum* + *Hydrocharis dubia*	Along northwest and northeast end	19.15	14.5	3, 500	67, 000
Nymphoides peltatum + *Trapa incisa* + *Hydrilla verticillata*	From Dongjiaozui to Zhigang, outer zone of *Zizania latifolia* Turcz growing area in the southeast area	16.07	12.1	1, 800	28, 900
Potamogeton maackianus	Center of bay	58.56	44.3	3, 590	210, 200
Potamogeton maackianus + *Vallisneria natanus*	From Miaogang to Lujiagang beach	3.31	2.5	3, 200	10, 600
Vallisneria natanus	Lujiagang	0.67	0.5	1, 760	1, 200

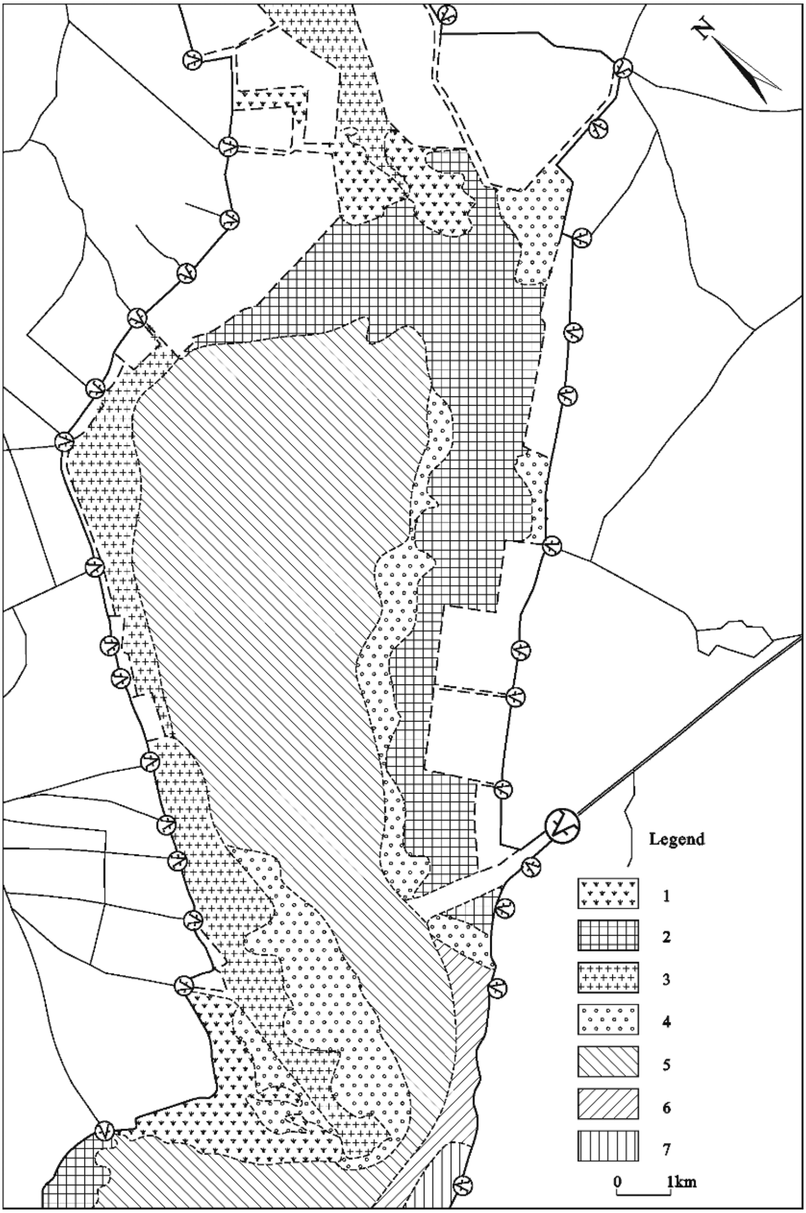

Fig. 1.8 Spatial pattern of aquatic vegetation in Eastern Taihu Bay (1997). Data derived from a 1997 survey and reference Spot-TM satellite image: 1, *Phragmites communis* Trin; 2, native *Zizania latifolia* Turcz; 3, newly cultured *Zizania latifolia* Turcz; 4, floating-leaved vegetation; 5, *Potamogeton maackianus*; 6, *Potamogeton malaianus*; 7, *Vallisneria natanus*

(3 km^2). Between Dongjiaozui on the northwest bank and Daquegang, *Spirogyra* was abundant, with biomass reaching 3 kg/m^2.

The abundant biomass of aquatic vegetation in Eastern Taihu Bay was estimated at 500,000 t in the 1990s. For most communities, biomass was 2–5 kg/m^2, whereas that of *Z. latifolia* reached 5.6 kg/m^2, and that of the floating-leaf plants and the *V. natanus* community was lower. Among the aquatic plant communities, the *P. maackianus* community had the highest proportion of total coverage (42%), followed by the *Z. latifolia* community (29.5%); the *V. natanus* community had the lowest proportion of coverage (0.2%).

1.4.1.3 Water Quality Status

Eastern Taihu Bay has the characteristics of a macrophyte-dominated shallow lake, namely, water clarity that is so deep as to see the bottom, midrange TP and Chl a, and high TN and COD (Table 1.28). The poorest water quality is found where wastewater enters at the northwest bank of the mouth of the bay.

The sources of pollution for Eastern Taihu Bay are as follows:

(1) The wind-driven flow and flood water discharge from west Lake Taihu mainly carry organic pollutants and nutrients and often form a muddy flow in the mouth of Eastern Taihu Bay. In addition, northwest winds can blow blue-green algae from west Lake Taihu into eastern Taihu Bay in the surface flow from the north or the west.

(2) The rivers from the east mountain peninsula mainly carry organic pollutants and nutrients, which usually form a fan-shaped contaminated area in the river mouth and influence the water quality along the bank. In addition, input of sewage, especially in the Daquegang area with high water flow, can cause decreased transparency of the lake water over a large area.

(3) Production of aquatic plants reaches some 1 million t/a, and most decompose as "*Zizania latifolia* Turcz yellow water," releasing nitrogen and phosphorus. The main areas so affected are between the southeast bank and the Dongjiaozui-Jishangang zone, particularly during low water in summer.

Table 1.28 Mean water quality status of Eastern Taihu Bay in 1997

Location	TN (mg/L)	NH_4^+– N(mg/L)	TP (μg/L)	COD_{Mn} (mg/L)	BOD_5 (mg/L)	Chl a (μg/L)
Mouth of Eastern Taihu	1.31	0.12	31	4.81	–	4.38
Estuary along northeast bank	1.94	0.50	182	5.16	3.18	14.12
Aquaculture area in northwest beach	1.48	0.22	33	5.93	–	3.92
Center of bay	1.38	0.24	35	6.04	–	5.15
Southeast	1.24	0.15	24	4.97	–	3.25
Outlets of southeast area	1.22	0.16	24	5.28	–	3.42

(4) Aquaculture releases fish excrement and uneaten food containing abundant organic matter and nutrients. This pollution is mainly distributed along the northwest bank of the lake, and when mixed with sewage and decomposing aquatic plants, forms a contaminated zone along the lake bank.

1.4.1.4 Division of Areas According to the Degree of Swamping

(1) Quantification of degree of swamping

Lacustrine bogs are defined according to the type of aquatic vegetation: those with emergent plants are bogs, those with submerged plants are natural ponds, and those with no large-scale growth of aquatic plants are lakes. Water depth is only a reference point, although the type of vegetation does reflect water depth.

In contrast, the degree of swamping of different areas of a specific water body has not yet been classified. However, Eastern Taihu Bay provides an opportunity to develop a classification system. Here, the aquatic vegetation is well developed and naturally distributed, and there are marked differences within the lake in the rates of decomposition and accumulation of different species of aquatic plants, thus representing development from potential to actual swamping. Therefore, the degree of swamping can be expressed by the structure of the aquatic vegetation, combined with the lake bed deposit factor. *ZZHv*, the vegetation index of the degree of swamping, is divided into four grades according to type of vegetation (Table 1.29); let *ZZHv* = {0, 1, 2, 3}.

ZZHs is the deposition index of the degree of swamping. The hard lake bed of Eastern Taihu Bay is rather flat, and silt accumulation is evident as differences in height of the lake bed silt. Supposing lake bed elevation range is H = [h1, h2], the deposition index of swamping degree of a location in a specific vegetation type is

$$ZZH_s = (H - h1)(h2 - h1)$$

The index of swamping degree is therefore *ZZH* = *ZZHv* + *ZZHs*. For Eastern Taihu Bay, this is a nonoverlapping index, with continuous numerical values from 1 to 4, reflecting the quantification principle used, namely, taking vegetation as the core and deposition as a supplement.

The swamping degree of the whole bay can be expressed with the area-weighted mean degree of swamping index *ZZHmean*:

$$ZZH_{mean} = \sum ZZH \cdot Pa \tag{1.10}$$

Table 1.29 Vegetation index for degree of swamping

Type of aquatic vegetation	Emergent	Floating-leaf	Submerged	No macrophytes
Swamping degree index, *ZZHv*	3	2	1	0

$ZZHmean = [1, 2]$ is the early marsh stage, $ZZHmean = [2, 3]$ is the peak marsh stage, and $ZZHmean = [3, 4]$ is the later marsh stage.

(2) Division of Eastern Taihu Bay according to degree of swamping

Taking the swamping index *ZZH* in ranks of 0.5 increments, we can divide Eastern Taihu Bay into six zones representing habitats ranging from extensive marsh to no swamping (Table 1.30, Fig. 1.9):

ⓐ Extensive marsh: there are two such zones, at the Dongjiaozui and at the southeast of Eastern Taihu Bay, together accounting for less than 10% of the area of Eastern Taihu Bay. The aquatic vegetation here is mainly a reed community, with decomposing *Phragmites communis* forming a layer more than 0.5 m thick. The poor water quality known as "yellow water due to *Z. latifolia*" is the most serious in this zone, and few fish and shrimps survive. The lake bed elevation is greater than 2.5 m, and during the low water season, the lake bed appears as a beach.

ⓑ Limited marsh: this area accounts for 35% of the bay area. The aquatic vegetation is dense *Z. latifolia* or a mixed community of sparse *Z. latifolia*, with *N. peltatum*, *T. incisa*, *H. verticillata*, *H. dubia*, and *Myriophyllum*; the layer of decomposing plants is some 0.1–0.5 m thick. In summer, water quality often deteriorates at low water levels because of "yellow water caused by *Z. latifolia*," killing numerous fish. Lake bed elevations are 1.9–2.5 m, and the lake bed near the bank is exposed at extremely low water levels.

ⓒ Severe swamping: this is present in the Xinkaihe River and outside Qianggang River, accounting for approximately 2% of the area of Eastern Taihu Bay. This zone is characterized by small floating-leaf plants. Lake bed elevation is 2–3 m, and a beach is often visible in low water seasons.

ⓓ Moderate swamping: this floating-leaf plant zone occupies some 10% of the bay. Lying outside the *Z. latifolia* area, this community comprises *N. peltatum*, *T. incisa*, *H. verticillata*, *H. dubia*, and *Myriophyllum*. Because the lake surface is covered with vegetation, ship passage is impossible, and lack of oxygen often kills fish and shrimps. Lake bed elevation is 2.0–2.5 m.

ⓔ Slight swamping: the peripheral area of submerged aquatic plants occupies nearly 30–40% of the bay area and comprises the *Potamogeton maackianus* community. Water quality is good, the layer of decomposing plant material on the lake bed is less than 0.1 m deep, and fish and shrimp grow well. Some tall submerged aquatic plants, such as *Myriophyllum*, begin to invade, a sign of early swamping. Because the surface of the water is unobstructed, small ships can pass at times of high water level. The lake bed elevation is 1.7–2.2 m.

ⓕ No swamping: the submerged aquatic vegetation zone in the bay center and near west Lake Taihu accounts for 17.7% of the total bay area. Vegetation is the *P. maackianus* community, the *Vallisneria natanus* community, or a transitional community lying between the two; there is no decomposing material on the lake bed, oxygen is sufficient, and fish and shrimp grow well. The water quality is good, water flows well, and small ships can usually pass. The lake bed elevation is less than 1.7 m.

Table 1.30 Degrees of swamping in Eastern Taihu Bay

Degree of swamping	*ZZH*	Area (km^2)	Percentage (%)	Dominant plant communities	Bottom elevation (m)
Marsh					
Extensive	(3.5, 4.0]	10.60	7.8	Dense *Phragmites communis* Trin	2.5–3.1
Limited	(3.0, 3.5]	47.38	35.0	Sparse *Zizania latifolia* Turcz	1.9–2.5
Swamping					
Severe	(2.5, 3.0]	2.38	1.8	*Nymphoides peltatum* + *Trapa incisa* Sieb et Zucc var. *quadricaudata* Glukc	2.5–3.0
Moderate	(2.0, 2.5]	12.46	9.2	Sparse *N. peltatum*, *Trapa incisa* Sieb et Zucc var. *quadricaudata* Glukc	2.0–2.5
Slight	(1.5, 2.0]	38.51	28.5	*Potamogeton maackianus* A. Benn.	1.7–2.2
No swamping	[1.0, 1.5]	23.90	17.7	*Potamogeton maackianus* A. Benn. community + *Vallisneria natanus* (Lour.) Hara	1.2–1.7

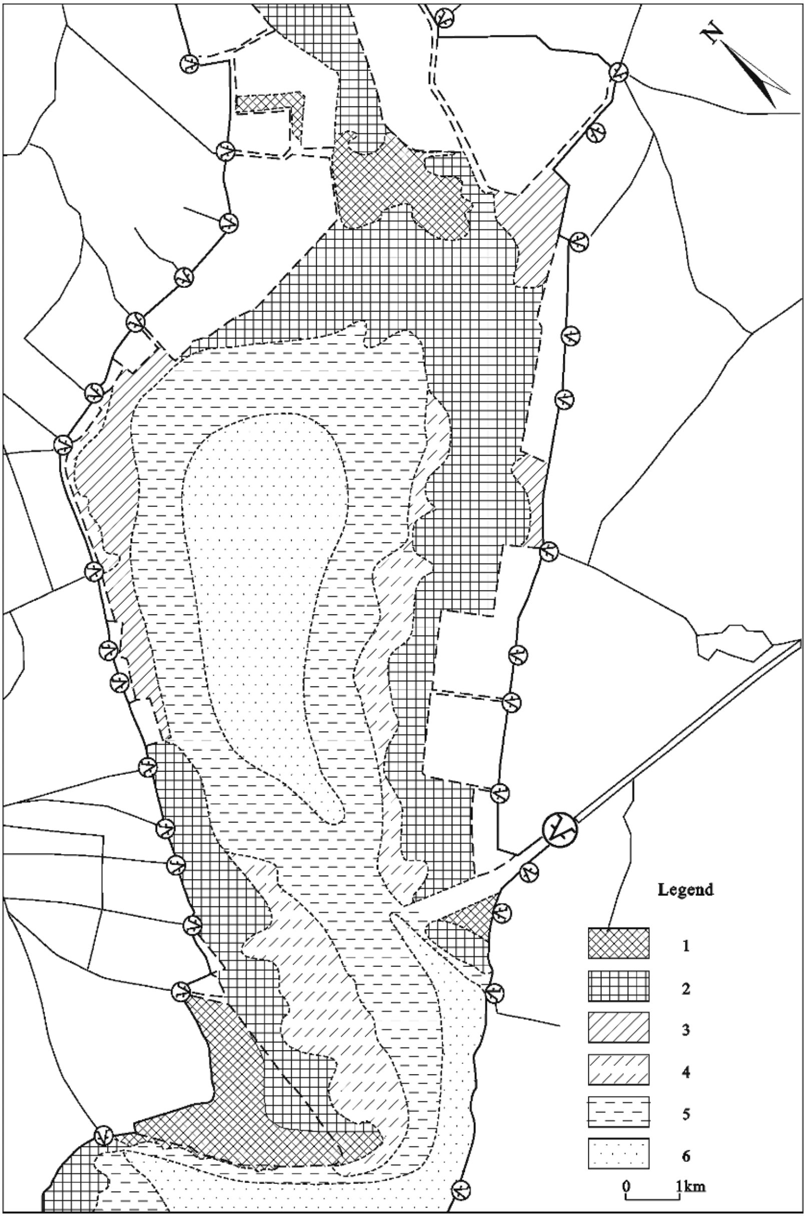

Fig. 1.9 Degree of swamping in Eastern Taihu Bay: 1, extensive marsh; 2, limited marsh; 3, severe swamping; 4, moderate swamping; 5, slight swamping; 6, no swamping

1.4.2 The Development of Swamping in Eastern Taihu Bay and Its Driving Forces

The swamping of Eastern Taihu Bay is rapidly accelerating. Both inside and outside the bay, human activity has intensified, and although some of these activities can delay the swamping process, most of them accelerate swamp development. A comparison of the conditions in 1997 and the 1960s illustrates this. In 1997, 42.8% of Eastern Taihu Bay was covered with aquatic plants such as reeds (7.8%) and *Z. latifolia* (35%) and had developed into a marsh. A further 11% was dominated by floating-leaf plants and had entered the late swamping stage (severe and moderate), which was a markedly expanding trend. Some 30% had submerged vegetation, representing an earlier swamping stage. The mean swamping index of the whole bay in 1997 was 2.41, representing active swamping.

1.4.2.1 Development of the Marsh Vegetation

Changes in the aquatic vegetation indicate the direction and speed of marsh formation.

(1) The types of aquatic vegetation and changes in their distribution

The earliest investigation is the "Aquatic Biological Survey Report in Eastern Taihu" published in 1959 by the biological department of East China Normal University (ECNU) (ECNU, 1959). At that time, *P. communis* and *Z. latifolia* formed a narrow strip along the bank of the bay, and only a sparse submerged plant community of *P. malaianus* and *V. natanus* was present on the open lake surface, reaching a mean density of biomass of $504\,\mathrm{g/m^2}$ in summer. The lake bed could not be seen, and water transparency was 0.3–0.8 m. This kind of vegetation and environmental state is similar to that which now exists (2006) in west Lake Taihu near Xishan Island.

By 1980, the structure of the vegetation, its species composition, and the biomass had greatly changed (Fig. 1.10). The emergent plant community, principally *Z. latifolia*, had expanded and occupied the whole bank, covering 29.1% of the bay. The submerged plant community of *P. malaianus*, *H. verticillata*, and *V. natanus*, although still occupying 33.3% of the lake area, had doubled its peak biomass to $1,088\,\mathrm{g/m^2}$. The *V. natanus* community in the southwest center of the bay and the *P. maackianus* community in the northeast occupied 21% and 4.6% of the surface, respectively. The mean density of biomass of aquatic plants in the whole bay was $891\,\mathrm{g/m^2}$ in summer, an increase of 51% compared with 1959. The water transparency had markedly improved in 1980 compared to 1959, the lake bed could be seen in more than two-thirds of the lake area, and the transparency in the center of the lake was 0.2–0.8 m.

In 1986, the *P. maackianus* community around the *Z. latifolia* community occupied 31.4% of lake surface, and the *P. malaianus* community area had shrunk. The mean density of biomass of aquatic plants had increased markedly to $2,722\,\mathrm{g/m^2}$ in summer. In more than 90% of the bay area, the lake water was clear and the lake bed could be seen (Li, 1993).

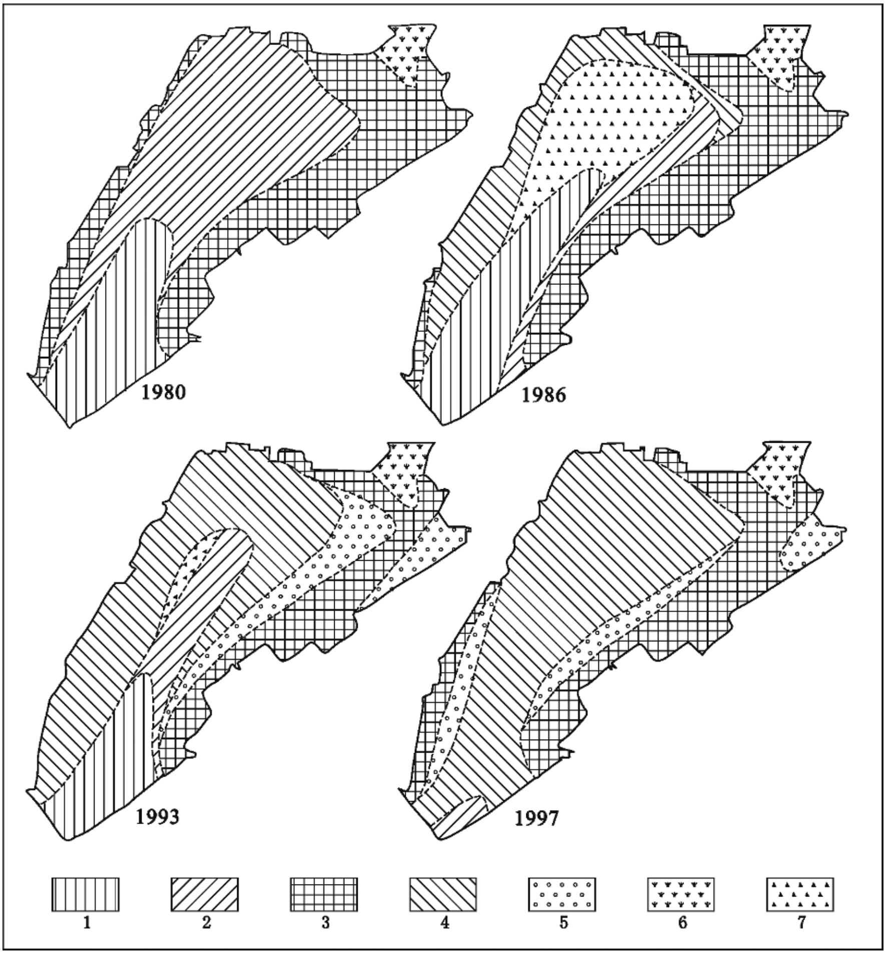

Fig. 1.10 Changes in the distribution of dominant macrophyte species in Eastern Taihu Bay between 1980 and 1997. 1, *Vallisneria natanus*; 2, *Potamogeton malaianus*; 3, *Zizania latifolia* Turcz; 4, *Potamogeton maackianus*; 5, floating-leaf macrophyte; 6, *Phragmites communis* Trin; 7, *Eleocharis palustris*

In 1993, the mean biomass of aquatic plants had further increased to 4, 990 g/m^2 in summer, and the transparency of the lake water had further improved. The *Z. latifolia* community along the northwest bank had disappeared as a result of intensive harvesting and an unusually high water level in 1991, and the *P. maackianus* community had expanded to occupy 42.9% of the lake surface. The *Z. latifolia* community in the southeast of the lake shrank about 0.5 km, and a floating-leaf plant zone developed, made up of *N. peltatum* and *T. incise*, occupying 8.7% of the bay surface. The *P. malaianus* community was reduced to a narrow strip, and the *V. natanus* community occupied only half the area it did in 1997.

Between 1993 and 1997, succession of the aquatic vegetation in Lake Taihu has comprised a 1-km-wide secondary vegetation zone forming along the northwest bank, composed of *Z. latifolia*, floating-leaf plants, and floating plants; a large area of floating leaf plants forming outside the *Z. latifolia* region between Dongjiaozui and Zhigang; and disappearance of the *V. natanus* and *P. malaianus* communities, with their replacement by the *P. maackianus* community.

(2) Succession of vegetation

Succession of the main kinds of vegetation in Eastern Taihu Bay, using area as a key indicator, is shown in Table 1.31. The *P. malaianus* and *V. natanus* communities were replaced by *P. maackianus* and, in turn, *P. maackianus* was replaced by *Z. latifolia* and floating-leaf plants. These changes represent accelerating swamping in Eastern Taihu Bay, especially since the 1990s, when emergent plants and floating-leaf plants have developed very rapidly.

Because leaves of emergent plants and floating leaf plants are exposed to air, they derive sufficient illumination and CO_2 from the atmosphere for photosynthesis and have higher productivity than submerged macrophytes. However, the harvest-utilization ratios of these emergent and floating leaf plants are lower than that of the submerged plants, and great quantities of the former decompose in the lake, often causing the serious “yellow water due to *Z. latifolia*” in summer. When the plant fragments that are difficult to decompose (20% of the dry weight of the plants) sink to the bottom, this accelerates deposition on the lake bed. In 1993, even though some 600,000 t aquatic plants was harvested, 520,000 t remained in the lake, about 56% of which were emergent plants and floating-leaf plants. The enclosed net-pen aquaculture is an obstacle to efficient harvest of the aquatic plants, and thus the amount remaining in the lake increases; it is estimated that this residuum may reach 1 million t/year.

(3) Increasing human activity and impact on the aquatic vegetation

In the 1950s, *Z. latifolia* grew naturally in the Dongjiaozui region and the neighbouring area in Eastern Taihu Bay. By the 1960s, it had extended on a large scale, and by the 1970s it occupied the whole lakeshore and had begun spreading towards the centre of the bay. In the early 1980s, it was harvested and used as food for carp breeding in the enclosed reclamation area and enclosed-net fish breeding areas, suppressing its development and reducing the area of *Z. latifolia* grass along the northwest bank. By 1991, *Z. latifolia* had disappeared from the northwestern bank area. It has been estimated that the enclosed net-pen fish breeding area was responsible for shrinking the area of *Z. latifolia* by about one-third between the 1980s and the 1990s.

After 1993, *Z. latifolia* was planted along the northwest bank to provide feed for fish culturing. The plants flourished and spread rapidly as a result of the high levels of nutrients in the wastewater from adjacent aquaculture and from rivers entering the lake, increasing the fertility of the sediment. Within 4 years, a dense zone of *Z. latifolia* was formed, which severely restricted the net-baffled water flow and wind waves, formed a stagnant environment, and limited access for harvesting aquatic plants in the fish-pen culture area. Around the edge of the *Z. latifolia* zone, a mixed zone of floating-leaf plants and floating plants formed, and this developed to the centre of the bay with the rapid expansion of enclosed net-pen aquaculture.

Table 1.31 Temporal changes in area, density, and biomass of aquatic vegetation in Eastern Taihu Bay (1959–1997)

Year	Type of communities	Distribution area		Mean density of biomass	Biomass	
		Area (hm^2)	Percentage (%)	(g/m^2)	Biomass (t)	Percentage (%)
1959	*Potamogeton malaianus*	14, 500	90.0	504	81, 194	– –
1980	Total	14,600	100.0	891	443,000	100.0
	Phragmites communis Trin	800	5.5	5,625	45,000	10.1
	Zizania latifolia Turcz	4,667	32.0	6,724	310,000	70.0
	Potamogeton maackianus	733	5.0	2,046	14,000	3.2
	Potamogeton malaianus	5,333	36.5	1,088	58,000	13.1
	Vallisneria natanus	3,067	21.0	522	16,000	3.6
1986	Total	12,967	100.0	2,722	353,000	100.0
	Phragmites communis Trin	567	4.4	3,750	21,000	6.0
	Vallisneria natanus	3,400	26.2	5,241	178,000	50.4
	Potamogeton maackianus	4,067	31.4	2,149	87,400	24.7
	Eleocharis palustris	1,133	8.7	840	9,500	2.7
	Potamogeton malaianus	733	5.6	1,410	10,300	2.9
	Vallisneria natanus	3,067	23.7	1,527	46,800	13.3
1993	Total	12,807	100.0	4,990	641,650	100.0
	Phragmites communis Trin	726	5.7	5,610	40,700	6.3
	Zizania latifolia Turcz	2,822	22.0	7,632	215,300	33.6

Table 1.31 (continued)

Year	Type of communities	Distribution area		Mean density of biomass	Biomass	
		Area (hm^2)	Percentage (%)	(g/m^2)	Biomass (t)	Percentage (%)
	Nymphoides peltatum and *Trapa incisa*	1,113	8.7	6,517	72,600	11.3
	Potamogeton maackianus	5,489	42.9	4,683	257,100	40.1
	Eleocharis palustris	140	1.1	3,000	4,200	0.7
	Potamogeton malaianus	1,145	8.9	3,904	44,700	7.0
	Vallisneria natanus	1,372	10.1	514	7,050	1.1
1997	Total	13,238	100.0	3,816	505,200	100.0
	Phragmites communis Trin	825	6.2	4,800	39,600	7.8
	Zizania latifolia Turcz	2,637	19.9	5,600	147,700	29.2
	Zizania latifolia Turcz + *N. peltatum* + *Hydrocharis dubia*	1,915	14.5	3,500	67,000	13.3
	N. peltatum + *Trapa incise* + *Hydrilla verticillata*	1,607	12.1	1,800	28,900	5.7
	Potamogeton maackianus	5,856	44.3	3,590	210,200	41.7
	Potamogeton maackianus + *Vallisneria natanus*	331	2.5	3,200	10,600	2.1
	Vallisneria natanus	67	0.5	1,760	1,200	0.2

P. malaianus and *V. natanus* both have the characteristics of mud tolerance and resistance to stormy waves, preferring water flow, whereas *P. maackianus* needs limpid water; the enclosed fish-pen net in the bay centre has weakened the disturbance of the lake bed and has reduced bottom mud resuspension, improving the transparency of the lake water. This is the main reason that *P. maackianus* can replace *P. malaianus* and *V. natanus*. The secondary vegetation zone between Dongjiaozui and Jishangang, made up of *Z. latifolia* and floating-leaf plants, has developed rapidly, reaching to the opposite bank, and has almost closed the Taipu river mouth. These plants can seriously block the water flow and promote deposition, thus threatening the sluice activities of the Taipu River.

(4) Aquatic vegetation succession and swamping

The main natural factors promoting development of the aquatic vegetation in Eastern Taihu Bay are deposition and accumulation of nutrients. Human activities such as reclamation, planting and harvesting of macrophytes, and aquaculture can change the direction and speed of aquatic vegetation development. Harvesting results in the residual amount of emergent plants and floating-leaf plants greatly exceeding that of the submerged plants. For example, in the large harvest in 1993, the dry residue of Z. *latifolia* and floating-leaf plants reached $1,774\,\mathrm{g/m^2}$ and $2,119\,\mathrm{g/m^2}$, respectively, which was four to five times that of the submerged plants ($418\,\mathrm{g/m^2}$).

Aquatic vegetation can be beneficial because there is accelerated deposition of debris and improved clarification of the water, and rivers flowing out from the lake are not blocked. However, aquatic vegetation can be disadvantageous, because deposition of fragments of aquatic plants can increase lake silting, accelerating the swamping process. Since *Z. latifolia* developed, deposition of plant material has markedly increased in Eastern Taihu Bay, as evident in the changes in total organic carbon (TOC) in the sediment at different depths (Fig. 1.11). The *Z. latifolia* residue can be distinguished in the top 30 cm of the sediment, where the TOC content reaches 5.6–17.3%, representing 10–30% of the organic matter.

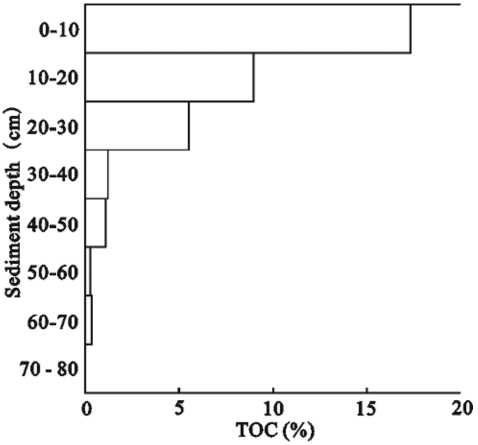

Fig. 1.11 Changes in the total organic carbon (*TOC*) content in different depths of sediment in *Zizania latifolia* Turcz growing area in Eastern Taihu Bay

The rapid expansion of the area of emergent plants and floating-leaf plants is the main characteristic of aquatic vegetation succession in Eastern Taihu Bay; this increases deposition of biological material, accelerating the swamping process.

1.4.2.2 Change in Hydrology and Swamping in Eastern Taihu Bay

Eastern Taihu Bay was originally a shallow lake bay, with a hard lake bed at an elevation of about 1 m above sea level (a.s.l.). The bay served as the flushing passage of flood water for Lake Taihu, with the Guajingkou River to the north being the main river mouth exiting the lake. Silty flood waters from west Lake Taihu enter Eastern Taihu Bay, causing extensive deposition nearly 1 m deep of soft deposits. Silt accounts for 98.46% of the content and organic matter only 1.54%, thus demonstrating that the external silt source is the main cause of deposition in Eastern Taihu Bay.

Before the Taipu river water conservancy construction was built in the 1990s, the lake water flushing through the river along the southeast bank of the bay formed a relatively even deposition zone of incoming and outgoing flow between Miaogang and Guajinggang. According to data from 1954, the silt deposited in Eastern Taihu Bay was about 143,650 t/a, the mean amount per unit area was 1.1 kg/m^2, and the rate of deposition was less than 0.1 cm/a. After the Taipu River water conservancy construction was built, silty lake water entered Eastern Taihu Bay, then flowed via the Taipu River to the East China Sea. The amount of silt entering the lake north of the Taipu River decreased, and the rate of deposition was also reduced. However, the region from the mouth of the Taipu River to Dongjiaozui became the main deposition location and deposition markedly accelerated here; between January 1991 and February 1998, there was 20–30 cm of new deposits, with 3–5 cm being deposited each year. Such rapid deposition created conditions for expansion of *Z. latifolia* and provided nutrition for the extensive growth of floating-leaf plants and submerged plants, thus promoting further silt deposition and acceleration of swamping. The development of the aquatic plants further promoted silt deposition, thus accelerating the swamping process in the bay region, and seriously jeopardized the function of the Taipu River water supply and floodwater discharge.

1.4.2.3 Reclamation of the Beach and Swamping

Between 1949 and the late 1970s, the area of enclosed reclaimed beach in Eastern Taihu Bay reached 112 km^2, which was approximately 0.85 times that of the existing water surfaces and larger than the natural beach area. Within the embankment north of Lujiagang, the reclaimed area is nearly 182 km^2; within the embankment encircling the bay there are ten dykes within a reclaimed area of 51 km^2, and the remaining area of bay surface is only 131 km^2. The remaining reclaimed area is in the northeast bay where the water surface is only 1 km wide, and the swamping problem is very serious, with reeds and *Z. latifolia* covering the bay surface.

The enclosed reclamation areas reduce the lake area and accelerate deposition. Development of marsh in Eastern Taihu Bay is accompanied by reduced wind fetch and wave action, which in turn promotes growth of aquatic plants and accelerates swamping.

1.4.2.4 Aquaculture Development and Swamping

Eastern Taihu Bay is one of the most developed areas of intensive aquaculture in the region, with three kinds of production: enclosed reclaimed areas with ponds for fish breeding, large lake surface net-pen culturing, and natural catch in enclosures. As yield from the wild catch fishery has fallen sharply, aquaculture has developed rapidly. In the 1990s, the total production area (including the reclaimed ponds) was already 6, 600 hm^2 in the 1990s, yielding an annual production of 28,000 t, with a value of 0.2700 billion yuan.

(1) Fisheries in reclaimed areas

The main development of the reclaimed pond area in Eastern Taihu Bay took place in the 1970s and was stabilized by the 1990s, with an area of 3, 300 hm^2, annual production of 24,000 t (Figs. 1.12, 1.13), and a value of 0.1500 billion yuan. The principal species were grass carp and bream, which were fed plants collected from Eastern Taihu Bay. The maximum harvest, in 1993, was 600,000 t, representing more than half the total for Eastern Taihu Bay.

This form of aquaculture is efficient at reducing secondary pollution and delaying swamping. By harvesting the aquatic plants, some 2,000 t nitrogen and 300 t phosphorus were removed from Eastern Taihu Bay every year, equivalent to 28% and 57% of the external load, respectively, thus delaying eutrophication. Thus, providing food for the herbivorous fish in the enclosed reclamation area has had a positive impact on the environment in Eastern Taihu, and this activity should be protected and supported. However, in recent years, most of the lake surface has been enclosed with nets, obstructing plant harvest and limiting the positive impacts just described. Further work is needed to achieve sustainable development of aquaculture in Eastern Taihu and to protect its environment.

(2) Enclosed net-pens

When enclosed net-pens began in 1984, they were limited to the Jiaobaigang and Jishangan regions along the northwest bank of the bay and concentrated on production of grass carp and bream. In the next decade of development, the net-pens was found irregularly around the bank of the bay, occupying less than 660 hm^2, and yielding a total output of nearly 3,000 t valued at 0.024 billion yuan in 1993. There was a diversification of species, with the addition of crabs, which accounted

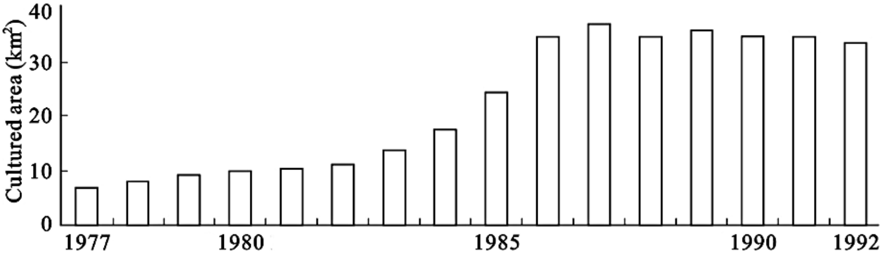

Fig. 1.12 Growth of the area for cultured aquatic products in the reclaimed pond area in Eastern Taihu Bay, 1977–1992

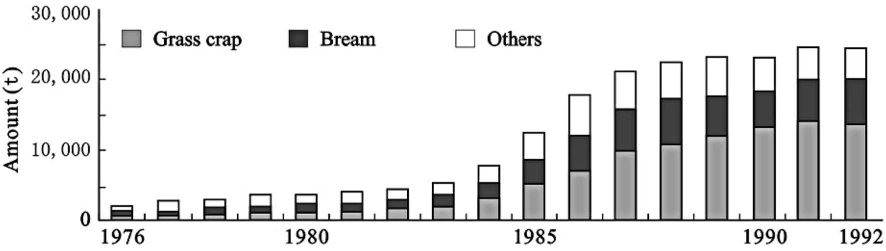

Fig. 1.13 Growth of annual aquaculture production in the reclaimed pond area in Eastern Taihu Bay, 1977–1992

for nearly 40% of the area. After 1993, there was extensive development of the net-pens, and by 1997 they had spread over the lake, covering an area of 3, 200 hm^2 (24% of Eastern Taihu Bay); output exceeded 4,000 t, which was valued at nearly 0.12 million yuan (more than that of the natural fishery harvest from all of Lake Taihu). Crab had become a very important product, representing 2, 660 hm^2 and an output value of 96.6 million yuan, more than 80% of the area and value of the net-pen aquaculture.

Enclosed net-pen aquaculture has produced significant economic and social benefits for the local fisherman, peasants, and aquaculturists around the Taihu region. However, a lack of systematic planning and management has had numerous negative consequences, as described next.

ⓐ Serious hindering of the harvest and utilization of aquatic plants has accelerated lake swamping. Taking the year 1993 as an example, the amount of the water plants growing every year was 1,120,000 t, which absorbed nitrogen at 3916 t and phosphorus at 496 t, equivalent of 58% and 95% of the outside source load in Eastern Taihu Bay separately; among them, 600,000 t water plants was reaped and utilized, mainly used as the fodder of pond breeding fish in the enclosed reclamation area, taking 1891 t nitrogen and 296 t phosphorus away from the lake, the equivalent of 28% and 57% of the outside source load in Eastern Taihu Bay separately. However, the enclosed net-pen breeding divides up most of the lake surface, hindering harvest, and thus a significant means of pollutant removal from Eastern Taihu Bay is lost. Furthermore, extensive *Z. latifolia* has been planted by some aquaculturists, and the pens that are more than 3 years old are covered by weeds such as *Spirogyra*, *T. incisa*, *N. peltatum*, and *H. dubia.* These plants block water flow and storm waves, resulting in a stagnant environment, in which plants decompose and accumulate on the lake bed, giving rise to episodes of yellow water caused by decay of *Z. latifolia*, all of which accelerates the depositing and swamping process.

ⓑ Influence on floodwater drainage and water supply. The main sluicing rivers along the southeast bank in Eastern Taihu Bay are already seriously silted. Furthermore, the nets on most of the lake hamper construction of water conservancy and environmental improvement projects, and the mouth of the Taipu, the biggest sluicing river, is surrounded by nets, which can collapse, allowing fish to escape.

ⓒ Disrupting and blocking shipping. Eastern Taihu Bay is now the main artery for agricultural shipping and small-scale cargo vessels. Originally small ships

Table 1.32 Water quality of 13 river mouths in Eastern Taihu Bay in winter, 1997

River name	TN (mg/L)	NH_4^+–N (mg/L)	TP (μg/L)	COD_{Mn} (mg/L)	BOD_5 (mg/L)	Chl a (μg/L)
Jiaobaigang	2.10	0.18	110	6.11	2.97	10.23
Youchegang	0.74	0.05	120	3.20	1.96	0.93
Zhigang	1.02	0.05	90	3.27	1.97	4.19
Jishangang	2.04	0.11	120	5.98	3.86	23.99
Shihegang	1.35	0.05	80	4.28	2.29	8.37
Zhijinggang	7.45	4.28	560	11.11	9.53	56.79
Xiegang	4.20	1.29	450	10.01	7.33	52.08
Dongdaquegang	1.55	0.05	330	4.63	1.72	7.53
Miaoqiaogang	1.66	0.19	140	4.40	1.54	13.39
Huanglugang	1.23	0.05	100	4.13	2.40	4.56
Zhangjiabang	0.70	0.14	80	3.15	1.68	0.50
Shilubang	0.61	0.08	80	3.54	2.36	0.50
Raotaihe	0.60	0.03	110	3.26	1.70	0.50
Mean	1.94 ± 1.91	0.50 ± 1.18	182 ± 157	5.16 ± 2.60	3.18 ± 2.46	14.12±19.09
Inflow from Dongjiaozui	1.31	0.12	31	4.81	–	4.38

Table 1.33 Trend of mean water quality in Eastern Taihu Bay from 1980 to 1997

Sampling number and sampling frequency	TN (mg/L)	NH_3^+–N (mg/L)	TP (μg/L)	COD_{Mn} (mg/L)	BOD_5 (mg/L)	Chl a (μg/L)	Water colour	Transparency (m)
2 sites, and 3 times 1980	0.65	0.05	30	2.87	0.98		14.7	0.53
11 sites, and 9 times 1990–1991	1.01	0.14	43	5.50	1.25	3.5	15.0	0.80
43 sites, and 4 times 1993–1994	1.04	0.20	75	5.57	1.07	4.3	–	Clear to bottom
20 sites, and 4 times 1997	1.39	0.19	31	5.51	–	4.4	–	Clear to bottom

navigated some 48 rivers along the lake; however, currently only one route between Daquegang to Qianggang and one along the south bank are navigable. The remainder have been obstructed by enclosure nets or blocked by weeds.

ⓓ Aggravated water pollution. Sewage from the Dongshan peninsula enters Eastern Taihu Bay through more than ten rivers. Before the installation of the enclosure nets, the sewage was purified by strong dilution after entering Eastern Taihu Bay. Abundant nets and weeds now render the northwest bank stagnant, and the sewage cannot be diluted. In addition, the lack of oxygen in the water and mud means that organic pollutants cannot be oxidized, and a 1-km-wide zone of contamination has developed. The "yellow water" caused by *Z. latifolia* along the northwest bank has negatively impacted the fishery, with disappearance of shrimp along the northwest bank, spread of epidemics affecting fish and crab in nets, increased mortality, and decreased growth rate and quality. Expansion of the enclosed nets towards the lake centre is accompanied by expansion of the contaminated zone along the northwest bank towards the lake center, directly jeopardizing the supply water quality from Taipu River to Shanghai.

1.4.2.5 Outside Pollution and Swamping

Thirteen rivers entering the lake between the Jiaobaigang and Yaotai Rivers along the northwest bank have been polluted with domestic sewage, village and urban industrial sewage, and farmland and fish pond drainage water (Table 1.32). After entering the bay these river waters pollute the river mouths and adjacent banks. Phosphorus is the most significant pollutant, minimally 80 μg/L; the TP content of 9 rivers exceeds 100 μg/L, with that in the seriously polluted areas of Zhijinggang and Xiegang reaching 330–560 μg/L. The most serious TN and BOD_5 pollution also occurs in Zhijinggang and Xiegang.

Since the 1980s, eutrophication in Eastern Taihu Bay has been rapid (Table 1.33), with TN, TP, and COD content continuously increasing. In contrast, BOD and Chl a concentrations are steady, and transparency is increasing as a consequence of numerous water plants and improved water quality protection. Swamping of Eastern Taihu Bay is accelerating, driven by excessive economic activity with associated pollution, land reclamation, and fishery development. The swamping of Eastern Taihu Bay and eutrophication of north Taihu have now become two of the biggest simultaneous environmental problems affecting the lake.

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