

Chen Yong and Wang Yiqian

Qionghai Lake, Sichuan, China: Environmental Degradation and the Need for Multidimensional Management

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Mountain lakes, an important mountain resource in China, are increasingly faced with degradation through pollution, eutrophication, and sedimentation. This article reviews the environmental situation of Qionghai

Lake in Sichuan Province, China, and presents an analysis of the causes of its degradation. Regulations have been adopted for ecological restoration of Qionghai Lake, and a management bureau has been established. Although some positive results have been achieved, institutional and technical weaknesses and gaps remain. Degradation of mountain lakes is closely linked to degradation of their watersheds. Management of a mountain lake may extend beyond the body of water to overall improvement of its watershed, including livelihood improvement and development for all stakeholders along the lake or in upstream mountain areas. Environmental protection programs need to be integrated within development programs and involve active collaboration among various government agencies. Participatory planning and implementation of programs to restore degraded mountain lakes are also desirable. A multidimensional approach may help provide an in-depth, comprehensive understanding of the environmental problems of mountain lakes.

Keywords: Environmental degradation; mountain lake management; sedimentation; environmental dynamics; Qionghai Lake; China.

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Mountain lake management in China

Sustainable development is a common objective for both developed and developing countries. Multidimensional approaches can be important for managing mountain resources and environments to achieve this objective. Mountain lakes have increasingly faced the pressures of rapid population growth and economic development, which lead to environmental degradation. China now has 2300 lakes that are more than 1 km² in area, most of which are facing the challenge of degradation. A survey of 20 representative lakes conducted in the late 1980s in China showed that there are 13 eutrophic lakes, 4 lakes in an intermediate nutritious state, and 3 in an oligotrophic state (Zhu and Wen 1992). During the 1990s, more lakes suffered from sedi-

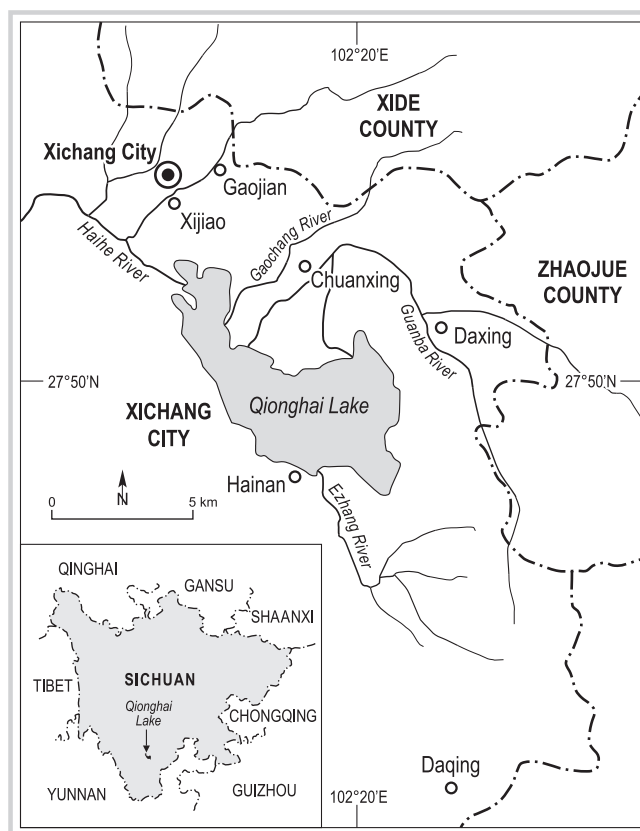


FIGURE 1 Location of Qionghai Lake in Sichuan Province, China. (Map by Andreas Brodbeck)

mentation, eutrophication, and diminishing water surface (Cui 2000; Yuan 2000) as a result of physical and human factors. As the second largest lake in Sichuan Province, Qionghai Lake has also faced these problems. In the absence of good planning and management, environmental degradation in Qionghai Lake may become irreversible. This article takes a multidimensional approach in discussing the environmental problems of Qionghai Lake, the implications for management of the lake, and further action.

Qionghai Lake and its geographical setting

Located at 102°17'E–102°22'E, 27°47'N–27°53'N, Qionghai Lake is situated in the southeast suburbs of Xichang, the capital of Liangshan Yi Ethnic Autonomous Prefecture of Sichuan Province, at an altitude of 1507–1509 m (Figure 1). Formed by neotectonic movements in the early Pleistocene and Holocene, Qionghai Lake is a structural lake, about 11.5 km long and 5.5 km wide, with a water storage capacity of 320 million m³. Its total area is about 26.8 km² when the water level is at a maximum and 24.3 km² in the dry season. The annual volume of water exchanged is 140 mil-

TABLE 1 Water body oxygen consumption in Qionghai Lake in milligrams per liter. (Source: Tang et al 1993)

	1986	1987	1988	1989	1990	1991
BOD₅	0.5	0.5	0.5	0.5	0.4	0.5
COD_{Mn}	1.6	1.7	1.6	1.6	1.5	1.6

lion m³, whereas the detention period of the lake water is about 834 days. The Qionghai Lake catchment area is 309 km². The Gaochang, Guanba, and Ezhang rivers flow into the catchment, whereas the Haihe River is an outlet flowing into the Anning River, a tributary of the Yangtze River. The maximum comparative altitude of Qionghai Lake catchment is 1760 m; 45% of its total area has a slope gradient of over 20°. Situated in the subtropical monsoon zone, the surrounding area of Qionghai Lake has an annual average temperature of 17°C, with 9°C in January and 23°C in July and 270 frost-free days.

The surrounding area of Qionghai Lake is one of the most suitable areas for agriculture in Xichang, with a high concentration of paddy fields. There are 5 townships (*xiang*)—Xijiao, Gaojian, Hainan, Daxing, and Daqing—and 1 town (*zhen*)—Chuanxing—in Qionghai Lake Basin (excluding the townships in Xide County and Zhaojue County), with a total population of about 81,000 (in 1999), of which about 77,000 (95.53%) are engaged in agriculture. About 4870 people are of Yi ethnic minority origin (mostly living in Daqing Township at a high altitude). Farmland in the lakeside area totals 2512 hectares, of which 2259 hectares are paddy fields, accounting for 90% of the total arable land. Qionghai Lake is the chief source of water supply for domestic use for two thirds of the urban area of Xichang (covering a population of about 120,000). There are about 50 fish species in Qionghai Lake, half of which were introduced from outside. The annual catch in Qionghai Lake is about 500 tons. Over 500,000 tourists visit Qionghai Lake each year.

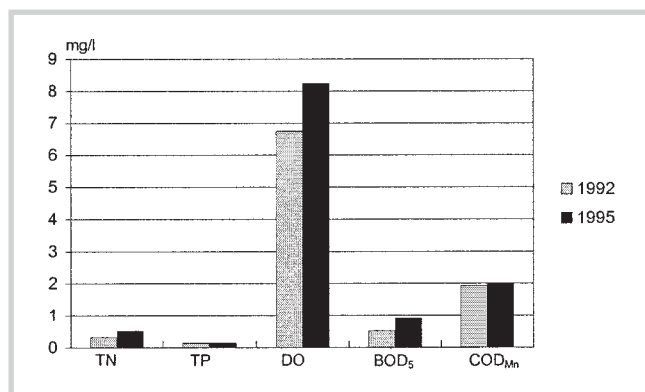


FIGURE 2 Selected water quality indicators in Qionghai Lake in 1992 and 1995. TN = total nitrogen, TP = total phosphorus; DO = dissolved oxygen; BOD₅ = biological oxygen demand; COD_{Mn} = chemical oxygen demand.

Review of the ecological status

Change in water quality

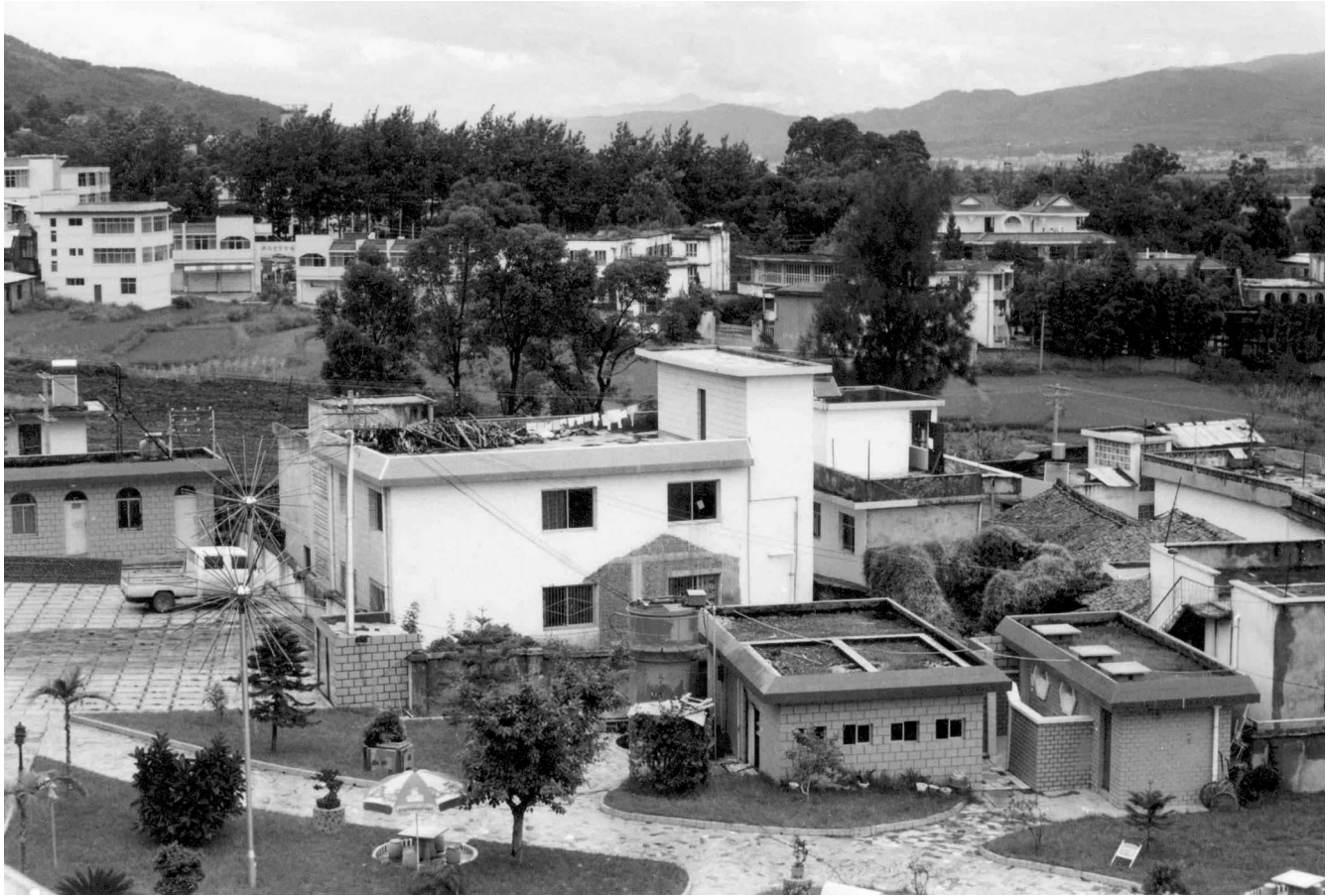
Before 1991, when there was not much pollution, water in Qionghai Lake was ecologically sound. The relatively small amount of pollution came chiefly from agricultural runoff and refuse from rural settlements in surrounding lakeside areas. There was not much humus on the lake bottom, which had the same color as the soil in the surrounding areas. Continual surveillance between 1986 and 1991, conducted by Southwest Agricultural University and Xichang Normal College, showed that pH values were 7.94–8.45, dissolved oxygen was 7.0–8.0 mg/l, chemical oxygen demand (COD_{Mn}) 1.6 mg/l, biological oxygen demand (BOD₅) 0.5 mg/l, total nitrogen (TN) 1.311 mg/l, ammonia nitrogen (NH₃-N) 0.029 mg/l, nitrogen as nitrogen oxide (NO₂-N) 0.004 mg/l, nitrate nitrogen (NO₃-N) 0.122 mg/l, and total phosphorous (TP) 0.137 mg/l. Qionghai Lake was generally oligotrophic, with little pollution (Table 1; Tang et al 1993).

In the early 1990s, water quality in Qionghai Lake began to deteriorate (Yao et al 1996). According to a surveillance report by Xichang Environmental Protection Bureau in 1994, of 16 surveillance sites (about 20 physicochemical indicators had been monitored), 12% showed comparative cleanness, 75% a low degree of pollution, 6% moderate pollution, and 6% a high degree of pollution (Xu J and Xu K 1998; Sichuan Environmental Protection Bureau, unpublished data). In November 1995, Qionghai Lake presented a yellow color with turbid suspended particles (plankton bloom) over the entire water surface. According to analyses conducted in January 1996 by the Sichuan Environmental Protection Research Institute, the Xichang Teacher's College, and the Environmental Surveillance Station of Liangshan Prefecture (Xu J and Xu K 1998), the concentration of chlorofucine-*d* was 5 times that of 1988, whereas TN and TP remained virtually the same as in 1988. The physicochemical and biological indicators revealed that water quality in Qionghai Lake was moderately nutritious, on the verge of being eutrophic (Figure 2).

A review of sedimentation and its impacts

Qionghai Lake has become shallower with sedimentation. The sediment is chiefly sands and debris from the Ezhang and Guanba rivers. Some suspended material was also introduced into Qionghai Lake by the Haihe River in flood seasons. Water near the mouth of the Guanba River has been no more than 2 m in depth and has become a typical littoral zone, with a visible yellow color. According to fishermen in Hainan Township, water depth near the gate of Hainan Township Government was about 20.4 m in the 1960s and is now only

FIGURE 3 Hotels and restaurants built around Qionghai Lake to service the tourism industry are a source of wastewater pollution. (Photo by Fang Yiping)



about 17 m. This means an accumulation of 3.4 m on the lake floor or an average of about 9–11 cm per year. Sedimentation from soil erosion and debris flows in Ezhang and Guanba subwatersheds has caused diminishing of the water surface and a decline in storage capacity.

Shrinking of the water surface

The surface area of Qionghai Lake greatly diminished in the 20th century. Analysis of water levels at different times and recent aerial photographs show that the surface was about 41.6 km² in the 1930s, 38.8 km² in the 1960s, 29.3 km² in the 1970s, and about 26.8 km² in the 1990s. The average annual decline was 0.73%. There has been a decline of 14.78 km² in the past 60 years, which is approximately 55% of the present water surface. Sedimentation has been one of the chief causes of this decline in surface area. According to fishermen in Hainan Township, the mouth of Ezhang River was pushed forward about 80 m in 14 years, from 1984 to 1998, which means that the mouth of the Ezhang River has moved forward by nearly 6 m every year. The estuaries of the Ezhang and Guanba rivers have gradually extended toward the center of Qionghai Lake. In addition to pollution from wastewater, diminishing water surface has been caused by sedimentation, reclamation of farmland and fish ponds, as well as construction of buildings (Figure 3).

Degradation of the aquatic ecosystem

Lakes are important aquatic ecosystems. The integrity of a lake ecosystem requires the maintenance of a balanced, dynamic natural system. Introduction of an exotic species may have serious impacts on the balance and distribution of native species by altering the structure and developmental patterns of their biological communities (Mills et al 1994). With commercial use of water in Qionghai Lake, a number of exotic fish species such as *Hypophthalmichthys molitrix*, *Aristichthys nobilis*, *Cyprinus carpio*, *Carassius auratus*, *Ctenopharyngodon idellus*, and *Neosalanx tangkahkeii taihuensis* and other species such as *Macrobrachium nipponensis* and *Eriocheir sinensis* have been introduced (Yao et al 1995). *Neosalanx t. t.* (silverfish), for instance, has had impacts on the aquatic ecosystem. The short life span of silverfish means that they may die and rot if not fished out in time. Dead silverfish can thus be a cause of eutrophication. Some endemic species such as *Anabarilius liuchang* have become rare in Qionghai Lake because of the introduction of exotics. Among aquatic plants, water hyacinth (*Eichhornia crassipes*) is a typical species brought back from Yunnan Province by farmers as pig feed. It has been washed into the lake by floods in monsoon seasons. Because it reproduces rapidly, water hyacinth has been expanding outward and sometimes even to the center of the lake, which can accelerate degradation.

FIGURE 4 The bank at the mouth of Ezhang River was destroyed by debris flows; such sources of sediment have been responsible for shrinkage in the surface area of Qionghai Lake. (Photo by Wang Yiqian)



It is difficult for an aquatic ecosystem to be restored to health once it becomes degraded (Nakamura 1997).

Causes of environmental dynamics

Sedimentation

Sedimentation, which results from physical as well as human factors, has been responsible for decline in water surface, reduction of water retention capacity, and turbidity.

Physical factors: Qionghai Lake is surrounded by mountains on 3 sides, and its ecosystem is characterized by fragility. Located in the active neotectonic zone, the mountains in the Qionghai Lake catchment area are prone to rockfall and soil erosion. Because rains are often concentrated in the monsoon seasons and forest cover is only about 29%, landslides, debris flows, and soil erosion often occur during heavy rains (Figure 4). Soil erosion in the Qionghai Lake catchment ranges from 1800 to 3000 tons/km²/y. In the early 1990s, the magnitude of debris and sand transported into Qionghai Lake amounted to 860,000 tons annually, whereas the volume of suspended load transported out of the lake by the Haihe River was 556,000 tons. Hence, about 224,000 tons of debris and sand were deposited in Qionghai Lake annually (Tang et al 1993). Our surveys

indicate that sedimentation may be even more serious in the late 1990s.

Human factors: The upstream areas of the rivers flowing into Qionghai Lake have been inhabited by large numbers of people including the Yi people, a major ethnic minority group in the southwest of Sichuan Province (Figure 5). Many people in such areas still live from subsistence agriculture. Hillslope cropping (without conservation) is a common practice. Forestland and pastureland have frequently been reclaimed for cultivation of crops. Moreover, people living near forested areas often go into forests to collect fuelwood. Where there is little underbrush or leaf litter below the canopy due to local collecting, the ground cover may be poor. The “splash” effect of large raindrops formed on leaf surfaces during intense rainstorms can cause serious soil erosion and greatly reduce the effect of forests in preventing soil degradation (Zhou et al 1999).

Water pollution

The main cause of water pollution has been an increase in sources of pollution and more pollutant discharge.

Fish cage culture: In 1995 there were 631 fish cages in Qionghai Lake, with each cage occupying an area of 25 m². Because about 50% of the fish feed fell unused

to the lake bottom, along with a considerable amount of fish excreta, TN increased.

Domestic sewage discharge: Numerous hotels and restaurants have been built around the lake because it is an important tourist site in Xichang (Figure 3). Whereas they previously had no treatment facilities, domestic sewage that contains compound detergents is now a major source of increased phosphorus in the lake.

Pollution of chemical fertilizers and pesticides: As the main agricultural zone in Xichang, the area surrounding Qionghai Lake has an abundance of paddy fields. When chemical fertilizers and pesticides are overused, runoff in the paddy fields, as a nonpoint pollution source, brings residues of chemical fertilizers and pesticides into Qionghai Lake.

Oil pollution from motorized boats: Because Xichang is a tourist site, the lake is a training place for water sports in Sichuan Province, with many motorized boats for tourism, recreation, and sport use. Fueled by gasoline and diesel, the boats are a source of air pollution.

Human and animal wastes: Because no water treatment facilities were installed in newly constructed buildings, nearly all the wastewater from such buildings flows into Qionghai Lake. During flooding, animal wastes from livestock feedlots near the lake are also washed into the lake.

Industrial effluent: The main industrial pollutant comes from a battery plant located in Hainan Township. Fortunately, Liangshan Prefecture Battery Plant has been renovated, with new environmentally sound treatment facilities installed. Wastewater discharge from the plant, however, requires constant monitoring.

Measures for tackling environmental problems

Given environmental deterioration in Liangshan Prefecture, particularly in Qionghai Lake in the early 1990s, the Prefecture Environmental Protection Office, set up in 1977, was elevated to full bureau status in 1997, with 2 environmental monitoring stations given prefecture-wide responsibility. Xichang's Environmental Protection Office was established as an independent bureau within the city government. Establishment of the Qionghai Lake Management Bureau (QLMB) was accompanied by successive rounds of legislative action by the Liangshan Autonomous Prefecture People's Representative Congress, culminating in the issuing of the Qionghai Lake Protection Regulations in 1997. According to these regulations, the Xichang City Government and the governments of Xide County and Zhaojue



FIGURE 5 A Yi ethnic minority family in the upstream area of the Ezhang River. (Photo by Wang Yiqian)

County are responsible for environmental protection and conservation of Qionghai Lake. Because Qionghai Lake Watershed falls mostly within Xichang City, the Xichang City Government approved detailed rules for implementing the regulations designed to protect Qionghai Lake in 1998. On this basis, QLMB was assigned overall responsibility for environmental protection of Qionghai Lake, including:

- The water.
- Lakeside areas within 200 m of the water.
- The Ezhang subwatershed (falling entirely within Xichang).
- The portions of Guanba subwatershed and Gaochang subwatershed that fall within Xichang (the portions in Zhaojue County and Xide County are the responsibilities of the 2 governments).

Within the protected zone in Xichang City, the QLMB has control over fisheries and tourism activities, construction, water resource quality, and protection of wildlife, aquatic plants, and trees. Measures instituted since the QLMB was established include:

1. Banning of fish cage culture in the lake, licensing of fishing boats, line fishing, and shrimp fishing (licenses have been issued to individuals in 7 villages, who have depended on the lake as their chief source of income, with a 2-month open season for fishing boats to prevent overharvesting).

Indicators	1992	1995	1997	1998	1999	2000	2001
Total nitrogen (mg/l)	0.322	0.520	0.221	0.198	0.408	0.108	0.597
Total phosphorus (mg/l)	0.142	0.154	0.016	0.020	0.112	0.025	0.027
DO (mg/l)	6.750	8.230	6.950	6.880	6.840	6.830	7.040
BOD ₅ (mg/l)	0.520	0.910	0.680	1.030	0.850	0.810	0.890
COD _{Mn} (mg/l)	1.930	1.980	2.400	2.490	1.810	2.110	1.220
Coliform (No./l)	2300	2300	162	16,700	9600	2300	4900

TABLE 2 Selected water quality indicators for Qionghai Lake. DO, dissolved oxygen; BOD₅, biological oxygen demand; COD_{Mn}, chemical oxygen demand. The values show an increase from 1992 to 1995, followed by a slight decrease by 1997 and further fluctuations in the second half of the decade. (Source: Liangshan Prefecture Environmental Monitoring Station, Xichang)

2. Strict control of lakeside development, including compulsory relocation of “over the water” restaurants inland and closure of restaurants that violate this measure.
3. Mandatory installation of water treatment for the battery factory.
4. Tree planting along the 200-m-wide strip of shoreline.
5. Restrictions on motorized boat traffic, with all tourist boats now being battery or manually operated.
6. A Xichang City Government regulation stating that an area within a 500-m radius from the second drinking water plant in Xichang is strictly protected as a drinking water source to ensure the safety of drinking water for urban residents in Xichang.

It has been decided that all water hyacinths should be cleared out of the water. (Urban wastewater in Xichang has flowed into the Anning River from 2 other small rivers and the Haihe River. This has little impact on water quality in Qionghai Lake unless there is major flooding.) The measures have been effective in reducing discharge of pollutants into Qionghai Lake. Table 2 shows that the main pollution indicators increased from 1992 to 1995 and declined from 1995 to 1997. Although BOD₅ declined after it reached a maximum value in 1995, the value of BOD₅ in 1997 was 0.68 mg/l, which was still higher than that in any 1 year in the 1980s or early 1990s. COD_{Mn} remained high in the 1990s, although some measures were taken. Hence, there is room for improvement of the ecological situation.

According to the Master Plan for Ecological and Environmental Construction in Liangshan Prefecture, over 200,000 people living in difficult, fragile environments in the high mountains will gradually migrate and be resettled in more hospitable environments at lower altitudes within about 10 years. Thus, poverty-stricken Yi people living in the middle and upstream areas of the Ezhang River may be resettled in a better physical environment with support from the central and local governments. In relation to China's development strategy for western China, Liangshan Prefecture, like other mountain areas in western China, may be eligible for

special funding for ecological construction—including resettlement of people living in harsh environments—because of its significant ecological role in the upper reaches of the Yangtze River. Previous experience shows that many Yi people would volunteer to settle at lower altitudes if they could have a piece of land and live a better life.

Heavy forest cover in the Qionghai Lake catchment is vital for soil conservation and reduction of sedimentation in Qionghai Lake. Since the 1980s, afforestation programs have been implemented in the surrounding mountain areas of Qionghai Lake as part of the national project of constructing protection forest belts in the upper reaches of the Yangtze River. The overall vegetation coverage rate has been increased and is higher than those in other parts of Xichang City, but soil erosion is still serious. Plans have been made by the city government to boost afforestation in all upstream areas in the Qionghai Lake Watershed and dredge sediment in Qionghai Lake. These plans have not been fully implemented because of lack of funds. Private persons are also being encouraged to undertake afforestation on barren land, but enthusiasm is not great because the quota for timber harvesting set by the government is low.

Implications for further policy and actions

The above actions and measures show that the prefecture and city governments have attached great importance to natural resource management and the environment. However, there are still a number gaps and weaknesses of an institutional and technical nature, indicating a need for additional policies and actions (Lai et al 1998).

Institutional factors

Current approaches to protect Qionghai Lake rely to a large extent on control and enforcement procedures. Although these and the necessary legislative provisions are essential in any system of ecological restoration, their long-term efficacy also depends on a number of other factors:

- Adequacy of resources (financial and human) and capacity (especially tactical and project-planning capabilities) commensurate with the range of responsibilities accorded.
- Appropriate levels of jurisdiction and planning, for example, the QLMB in relation to other Xichang government agencies, such as the Forestry Bureau and the Soil and Water Conservation Office, as well as the neighboring counties of Zhaojue and Xide (part of which are within the Qionghai catchment area).
- The active collaboration of various sectoral government agencies (including those in Zhaojue and Xide Counties) and the participation of primary stakeholders (including private organizations and individuals) in planning, accepting, funding, and implementing environmentally beneficial practices.
- The Haihe River is Qionghai Lake's main outlet to the Anning River and also the conduit (from the Xihe River) for the bulk of Xichang City's urban wastewater, which is discharged untreated into the Anning River. Backflow into Qionghai Lake occurs sporadically during flood season, leading to deterioration of lake water quality and sedimentation in the lake. Technical innovations to prevent the backflow of water into Qionghai Lake are needed.
- In communities such as those in the upper reaches of the Ezhang subwatershed, there is an apparent gap between the needs of farm households (for fuel, animal feed, green manure to maintain soil fertility, and vegetation to stabilize gullies and hillslopes) and the ready availability of suitable tree, shrub, and other vegetative species.

Technical factors

Environmental protection of Qionghai Lake and its catchment area would benefit from a sharper technical focus. In particular, the integrity of the ecosystem of Qionghai Lake and the causal relationships between sedimentation and human activities in the overall lake catchment area (including Gaochang, Guanba, and Ezhang subwatersheds and other surrounding hills) require closer examination:

- There appears to be little official information on current trends affecting aquatic species in Qionghai Lake, particularly with regard to the population dynamics of endemic fish species. Given the present policy of permitting commercial operators to introduce, stock, and harvest exotic species in the lake, it is imperative to undertake adequate studies about the lake's aquatic ecosystem and to carefully monitor the impact of such policies on biodiversity.
- Available data suggest that the average soil erosion rate for Xichang as a whole (around 4350 tons/km²/y in the late 1980s) may in fact be higher than that in Guanba and Ezhang subwatersheds (estimated at below 3000 tons/km²/y in the early 1990s). This raises the question of the technical feasibility of enhancing soil conservation activities within these subwatersheds to a level more effective than that existing elsewhere in Xichang.
- The technical approaches being used in erosion control also bear further examination. In the past, emphasis was given largely to planting (often air seeded) of rapidly growing timber species (especially Yunnan pine or *Pinus yunnanensis*) as protective forests. But this overlooks the fact that trees and other vegetative species stand a better chance of survival and regeneration when they also serve the economic and social needs of the communities where they are planted.

Conclusions and recommendations

In many cases, degradation of lakes is closely linked to degradation of their watersheds. Unplanned and exploitative use of the land around lakes and the rivers and streams that feed into them often has a negative impact on water quality and evolution. This has been particularly true in fragile mountain environments, where hazards such as debris flows, soil erosion, and torrents are prone to occur. Qionghai Lake, as a typical mountain lake in a fragile environment, has suffered from sedimentation, eutrophication, and the threat of loss of biodiversity. To promote sustainable use of the lake as a valuable resource in Xichang and Liangshan Prefectures, further work and actions are required to address the range of institutional and technical issues raised.

There appears to be a need for clearer division of the responsibilities of relevant governmental departments in planning, funding, and implementation of environmental protection measures (including the QLMB, the land bureau, the hydrological bureau, the forestry bureau, and the soil conservation office). Although a prefecture-level and city-level coordination committee has been set up with an office in the QLMB, work seems ineffective. Thus, for example, the office does not seem capable of controlling discharge of wastewater into the lake from the booming "country clubs" and private hotels on the west bank (Luo 2001, 2002). There is also a need to review and interpret more carefully existing technical information relating to soil erosion and sedimentation issues and to find appropriate technological solutions to practical problems.

At the same time, there is a need to develop a comprehensive approach integrating environmental conservation objectives with improvement of household food security, land productivity, fuel supplies, and the meet-

ing of other sociocultural obligations. All stakeholders, both in upstream and downstream areas, need to be considered and analyzed in policy formulation and implementation. This means that environmental protection programs need to be integrated with development programs, particularly programs of poverty alleviation, in the upstream areas of Qionghai Lake Basin. This should involve a critical examination of the feasi-

bility of improving existing land use practices through better use of farm resources, including trees, shrubs, grasses, and other vegetative species. Qionghai Lake is a typical mountain lake under great pressure from a large population and rapid economic development. Exploration of the management of such lakes could have significance for the management of other mountain resources in similar situations.

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AUTHORS

Chen Yong

Chengdu Institute of Mountain Hazards and Environment (IMHE), Chinese Academy of Sciences (CAS), Chengdu, PO Box 417, Sichuan, 610041, and Institute of Environmental Science and Engineering, Sichuan University, Chengdu 610064, Sichuan, People's Republic of China.
yongchenscu@19.com.cn

Wang Yiqian

Development Research Center, Sichuan University, Chengdu 610065, Sichuan, People's Republic of China
Wang_Yiqian@hotmail.com

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